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# Dynamic Stability in Unilateral Transtibial Prosthesis Users

By Cynthia Kendell

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Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements
for the MSc Degree in Human Kinetics

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# Abstract

This study evaluated a multi-factorial, portable method of assessing dynamic-stability for unilateral transtibial prosthesis users. Twenty unilateral transtibial prosthesis users completed walking trials over various conditions (level and uneven ground, stairs, and a ramp). Plantar pressure data were collected using the F-Scan Mobile system. Six dynamic-stability parameters (relating to center of pressure motion, foot perturbations, and gait timing) were extracted from this data and dynamic-stability index values were calculated. Results showed that the parameters and index values differed between the intact and prosthetic limbs, between walking conditions, and between prosthesis users able-bodied subjects. Parameter and index values correlated poorly with stability criteria measures (Community Balance and Mobility Scale, Berg Balance Scale, Prosthetics Evaluation Questionnaire). Parameter and index calculations should be optimized for unilateral transtibial prosthesis users. Improved validation of the parameters and index is recommended, using an established, quantitative, dynamic-stability assessment method.

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# List of Abbreviations

| | |
|---|---|
| A | Able-Bodied |
| ADLs | Activities of Daily Living |
| ANOVA | Analysis of Variance |
| AP | Anterior/Posterior Pressure Position-Time Curve (test variable) |
| A/P | Anterior/Posterior |
| BBS | Berg Balance Scale |
| BoS | Base of Support |
| CBMS | Community Balance and Mobility Scale |
| CellTrig | Cell Triggering Frequency |
| C | Combined Limbs |
| CoF | Center of Force |
| CoG | Center of Gravity |
| CoM | Center of Mass |
| CoP | Center of Pressure |
| DLT | Direct Linear Transform |
| DGI | Dynamic Gait Index |
| DST | Double Support Time |
| FRT | Functional Reach Test |
| GAMA | Gait and Motion Analysis |
| GRF | Ground-Reaction Force |
| IFD | Inter-Foot Distance |
| I | Intact Limb |
| MaxLat | Maximum Lateral Placement of Force |
| ML | Medial/Lateral Pressure Position-Time Curve (test variable) |
| M/L | Medial/Lateral |
| P | Prosthetic Limb |
| PEQ | Prosthetics Evaluation Questionnaire |
| POMA | Performance Oriented Mobility Assessment |
| PPA | Prosthetic Profile of the Amputee |
| ROM | Range of Motion |
| SD | Standard Deviation |
| SPSS | Statistical Package for the Social Sciences |
| SRT | Sharpened Romberg Test |
| ST | Stride Time |
| TOHRC | The Ottawa Hospital Rehabilitation Center |
| TUG | Timed Up-and-Go |

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# Chapter 1. Introduction

Falling is a major concern for people with lower-limb amputations. A previous study revealed that 82% of polled individuals with lower-limb amputations had fallen within the previous year, with 49% of those falls occurring while the person wore their prosthesis [1]. Another study, focusing on individuals with unilateral amputations, found that 54% had fallen within the previous year, with 75% of those people reporting more than one fall [2]. Falls were attributed to intrinsic factors (psychological issues, age, disease, instability, vision issues, medication), environmental factors, and prosthetic factors (i.e., socket fit) [1,2]. To understand why falls are occurring so frequently in this population, quantitative information is needed on how lower-limb amputations affect gait and influence stability over various conditions.

Stability is "the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition"[3]. For individuals who have had a lower-limb amputation, stability is usually assessed during the rehabilitation process using clinical tests. These tests are observational or measure the activities of daily living (ADLs) and are designed to be time efficient; therefore, a minimum number of tasks are used in the stability evaluation. Other assessment methods are restricted to a laboratory setting. However, assessment of walking for various conditions is not possible in such a setting, and data can be time consuming to process and interpret. An ideal dynamic stability assessment method is one that could be used in different environments and conditions, use a multi-factorial approach for dynamic stability, and provide clinically meaningful output.

The purpose of this study was to evaluate a new method of assessing dynamic stability for people who use a transtibial prosthesis. Lemaire et al. [4] identified six parameters related to dynamic stability and developed a dynamic-stability index based on these parameters [5]. The research reported in this thesis evaluated the appropriateness of the six stability parameters and the dynamic-stability index for stability assessment in individuals with unilateral transtibial amputations. Subjects performed six mobility tasks:

level ground walking, uneven ground walking, stair ascent and descent, as well as ramp ascent and descent.

To evaluate the dynamic-stability measures, differences in stability parameter and index values between the intact and prosthetic limbs were investigated, as well as differences between conditions. Stability parameters and index values were also compared to able-bodied data for level ground walking, and to three stability criteria measures: the Prosthetics Evaluation Questionnaire (PEQ), the Berg Balance Scale (BBS), and the Community Balance and Mobility Scale (CBMS).

## 1.1 Rationale

Individuals with lower-limb amputations are vulnerable to instability, as evidenced by the high occurrence of falls in this population [1,2]. To prevent activity avoidance and promote confident gait, it is extremely important to determine the gait characteristics of people with amputations that contribute to instability. Currently, there is limited information available on the gait of individuals with amputations, and the issue of instability cannot be thoroughly addressed due to the lack of appropriate dynamic-stability assessment tools.

A dynamic-stability index has been developed [5] and found useful in assessing dynamic stability in able-bodied subjects. Further testing is required to determine whether the selected stability parameters are appropriate for calculating the dynamic-stability index in a population with transtibial amputations, and whether the index is sensitive to change across varying levels of stability. Different levels of stability may be associated with different environmental conditions such as level ground, uneven ground, ramps, and stairs. This study will expand on previous research by comparing the stability parameters and index values to other commonly used stability criteria measures (clinical balance tests and self-reports).

From clinical observations, it is evident that an individual's dynamic stability varies when walking over different surfaces and obstacles. The ability to quantitatively assess dynamic stability over a range of walking conditions helps ensure that an individual using a prosthesis can safely ambulate outside of the prosthetic clinic.

The development of a stability assessment tool that is sensitive to stability changes in individuals with unilateral transtibial amputations has the potential to benefit several parties. Researchers will have the ability to assess stability in the community, and compare performance over a range of walking conditions. Prosthetists and physicians could use the information generated from the dynamic-stability index to evaluate a client's stability on multiple devices, correct prosthetic fitting issues (i.e., optimize alignment), and make the appropriate device prescription. The information might also be valuable to health insurance companies and funding agencies when determining whether to cover the cost of a prosthetic device. Clinicians could use the stability index output to monitor changes in stability over time and evaluate the success of rehabilitation programs or interventions. Most importantly, with the implementation of the dynamic-stability index into rehabilitation protocols and device prescription, individuals with amputations will benefit directly from an improved level of care.

## 1.2 Objectives

The objectives of this research were to:

1. determine if the six parameters identified by Lemaire et al. [4] are valid stability measures for individuals with unilateral transtibial amputations;
2. evaluate whether the dynamic-stability index [5] is a valid method of assessing the stability of individuals with unilateral transtibial amputations;
3. examine stability parameter and index differences between the intact and prosthetic limbs in unilateral transtibial prosthesis users;
4. compare differences in stability parameters and index values between level ground, uneven ground, stair, and ramp conditions in unilateral transtibial prosthesis users;
5. determine whether stability parameter and index values for prosthesis users walking over various conditions, differ from able-bodied level ground walking;

6. establish whether a relationship exists between each of the stability parameters and index values, and scores on the Berg Balance Scale, Community Balance and Mobility Scale, and Prosthetics Evaluation Questionnaire.

## 1.3 Hypotheses

1. The stability parameters and index values will show that the intact limb is more stable.
2. The stability parameters and index values will differ between conditions.
3. The stability parameters and index values for each condition will differ from able-bodied level ground walking.
4. The six stability parameters and stability index values will be negatively correlated with the Berg Balance Scale, Community Balance and Mobility Scale, and Prosthetics Evaluation Questionnaire, for each condition.

## 1.4 Limitations

Gym mats were used to simulate walking on an uneven surface; however, these mats did not have a variable consistency and may not have produced data representative of walking on outdoor uneven ground. For some subjects, areas of high pressure existed between the foot and the shoe when the foot was not contacting the ground. This made it impossible for the current dynamic-stability index software to automatically identify gait events. For trials where this occurred, the research assistant manually identified gait events, which may have lead to small inaccuracies in the stance phase timing.

This study relied on centre of pressure (CoP) data to calculate several of the stability parameters, and subsequently the index values. When using plantar pressure measurement systems, CoP is based on normal forces; therefore, shear forces were not used for stability parameter calculations or the dynamic-stability index. Ideally, the resultant of normal and shear forces would be used to determine CoP.

Calculation of the maximum lateral placement of force (MaxLat) was based on the width of the unmodified sensor. Because sensors were cut to fit each subject's shoe, the number of sensor columns that were intact during data collection is unknown. This could affect the validity of the MaxLat variable and between-subject comparisons, since MaxLat represents the distance from the CoP to the sensor edge.

Finally, although commonly used methods of assessing dynamic stability and functional level were used as stability criteria measures, each has limitations. The CBMS and BBS were not designed for individuals with transtibial amputations and the PEQ, which uses a visual analog scale, is a subjective measure.

### 1.5 Delimitations

This study focused on individuals with unilateral transtibial amputations who were high-level community ambulators. Findings should not be generalized to individuals with other types of lower-limb amputations.

### 1.6 Overview of Thesis

Chapter 2 provides an overview of able-bodied gait parameters for walking on level ground, ramps, and stairs; discusses plantar pressure during gait; and summarizes the literature on gait for individuals with transtibial amputations. The literature review also presents current methods used to evaluate balance and stability. Chapter 3 describes the design of the study, including subjects, methods, and data analysis. Results are presented in Chapter 4 and discussed in Chapter 5.

# Chapter 2. Review of the Literature

## 2.1 Able-bodied Gait

Normative data for able-bodied individuals are well established and documented in the literature. While this literature is primarily on level ground walking, substantial investigation has recently covered other surfaces and terrains. By comparing an individual's gait to established baselines, pathological gait patterns can be identified. For the purposes of this thesis, able-bodied gait will refer to the mean pattern of a group of individuals who did not have a pathology that may have affected their locomotion [6].

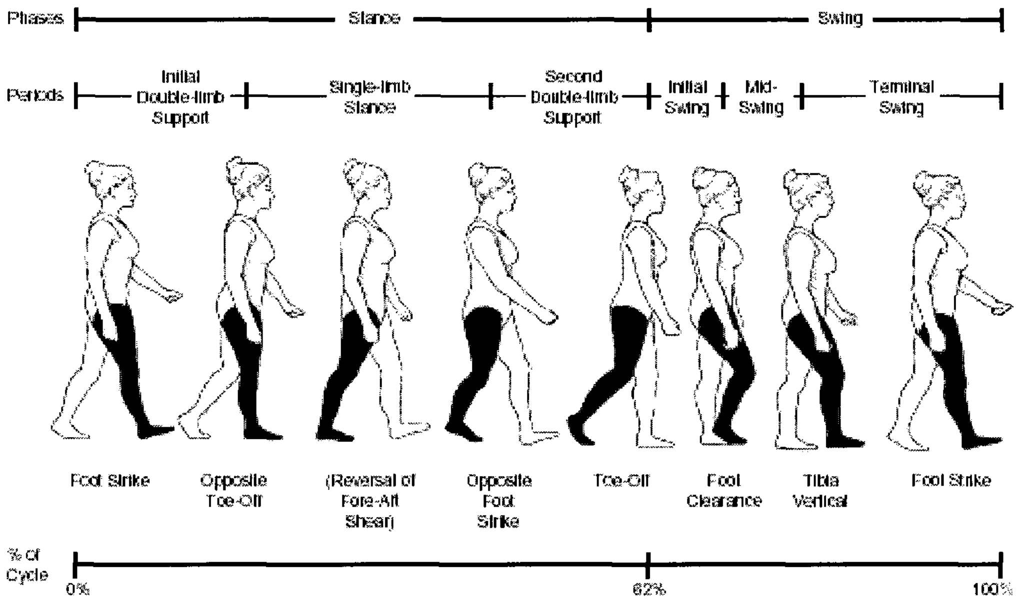


**Figure 1:** Gait cycle normalized by time [7].

### 2.1.1 Level Walking

A gait cycle can be defined as the movement from one-foot strike to the successive foot strike on the same side [7] and consists of two phases: stance and swing. Stance phase is the longest phase, approximately 60 % of the gait cycle, while swing phase comprises the remaining 40% [7,8]. The entire cycle is approximately one second in duration [9].

### 2.1.1.1 Temporal-Spatial Parameters

Temporal-spatial parameters are measures of time and distance and typically include cadence (steps/min), velocity (cm/s or m/min), stride length, stride time, and step length. These measures, including the time an individual spends in each phase of the gait cycle, provide valuable information on stability and symmetry of movement [9].

Cadence varies depending on the speed of walking and step length. Men often have a lower cadence than women, which is linked to height differences between men and women and the resultant differences in leg length [8]. For adults, Chambers and Sutherland [7] reported that able-bodied cadence is 114 steps/min, similar to findings by Winter [8] who reported a range of 101-122 steps/min. Able-bodied walking velocity for an adult is approximately 1.23 m/s [7]. These values are close to those reported by Nadeau et al. [10] who reported on several additional temporal-spatial parameters, as summarized in Table 1.

| Variables | Level Walking |
|---|---|
| Speed (m/s) | 1.16 (0.10) |
| Cadence (step/min) | 105.4 (8.20) |
| Cycle Duration (s) | 1.145 (0.09) |
| Stride Length (m) | 1.32 (0.05) |
| Stance Phase (%) | 63.0 (1.00) |
| Swing Phase (%) | 37.0 (1.00) |
| Initial Double Support Phase (%) | 13.2 (1.20) |
| Terminal Double Support Phase (%) | 12.9 (1.10) |
| Total Double Support Phase (%) | 26.1 (2.00) |

**Table 1:** Mean and standard deviation (SD) of temporal-spatial parameters for level walking [10].

### 2.1.1.2 Kinematics

Kinematics is the branch of mechanics that describes characteristics of motion without explaining the underlying causes. According to Winter [8], the number of kinematic variables required to describe a single gait cycle is high since nine variables are required to describe the movement of a single segment in two-dimensions: vertical and horizontal positions, velocities, and accelerations; angle; angular velocity; and angular acceleration. Due to high processing and reporting requirements, researchers report only what is relevant to their research objectives. Joint angles are commonly reported since clinicians visually observe these angles and normative values are well established.

According to Perry [11], the ankle rapidly plantarflexes to 10° during loading response and then the ankle dorsiflexes as the tibia rotates forward over the foot. The ankle plantarflexes 20° during pre-swing and, after toe-off, dorsiflexes until a neutral position is reached in mid-swing. The knee begins to flex immediately following foot strike, reaches a maximum flexion angle of about 18°, and then extends to 5° flexion. The knee flexes during pre-swing, this time reaching a maximum flexion angle of 60° by mid-swing. From mid-swing to terminal swing, the knee extends completely. The hip gradually extends during the stance phase and reaches 10° hyperextension in terminal stance. During pre-swing, the hip begins to flex until 35° of flexion is reached. This position is maintained throughout terminal swing and loading response. The pelvis remains very stable during gait, experiencing only 5° of flexion and extension for a total range of motion (ROM) of 10°. The head and trunk display a similar range of movement corresponding to a shift in support during gait.

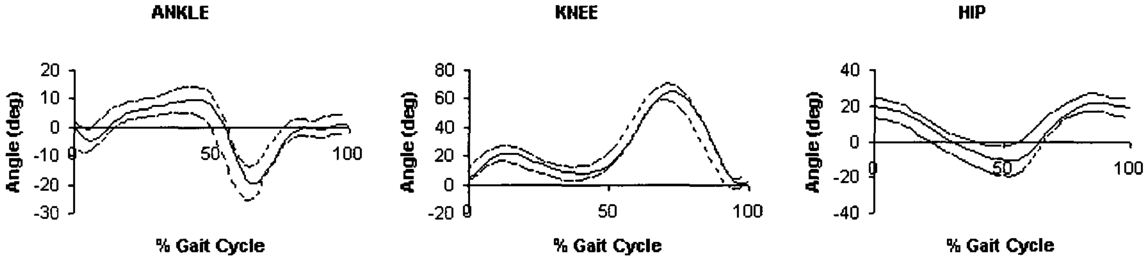


**Figure 2:** Normative joint angles (solid) and SD (dashed) of the ankle, knee, and hip in the sagittal plane [8].

Nadeau [10] described frontal plane movement at each joint of the lower extremity. The ankle slightly abducts in early stance but the joint immediately begins to adduct and continues to do so until peak adduction (9°) is reached at 40% of the gait cycle. In late stance, the ankle begins to abduct once again and reaches peak abduction at toe-off. By mid-swing, the ankle is at a neutral position but then abducts slightly in terminal swing. The knee displays very little movement in the frontal plane during level gait, exhibiting a total range of movement of no more than 5-7°. The knee remains in a neutral position throughout stance and abducts slightly at toe-off, with this abduction accounting for the majority of the total range of motion. The hip is in neutral position at the beginning of stance but immediately begins to adduct and remains adducted for the remainder of the stance phase, reaching peak adduction at approximately 50% of the gait cycle. Just prior to toe-off, the hip rapidly abducts and reaches peak abduction of 5° just after toe-off, subsequently returning to a neutral position for the remainder of the gait cycle.

In the transverse plane, the ankle is externally rotated for the duration of the stance phase (Figure 3). In initial swing, the ankle internally rotates slightly for a short period. The knee is also externally rotated for the majority of the gait cycle with peak external rotation occurring at heel strike and toe-off. Knee angle in the transverse plane is very sensitive to marker placement and this curve is rarely used for clinical interpretation [12]. The hip rotates only a few degrees (internally during stance and externally during swing) but, as with the knee, there is a substantial range of variation (± 10°).

The pelvis is normally tilted approximately 8° anteriorly in the sagittal plane. In the frontal plane, each side of the pelvis rises when the corresponding leg is weight-bearing (i.e., stance) and drops 4° when the leg is unloaded (i.e., swing). This phenomenon is known as physiological Trendelenberg. In the transverse plane, the pelvis rotates inward on the side of the advancing leg and simultaneously rotates externally on the contralateral side. Internally rotating the pelvis lengthens the "reach" of the advancing leg. Excessive pelvic rotation indicates an attempt to increase reach and may reflect hip or knee problems [12].

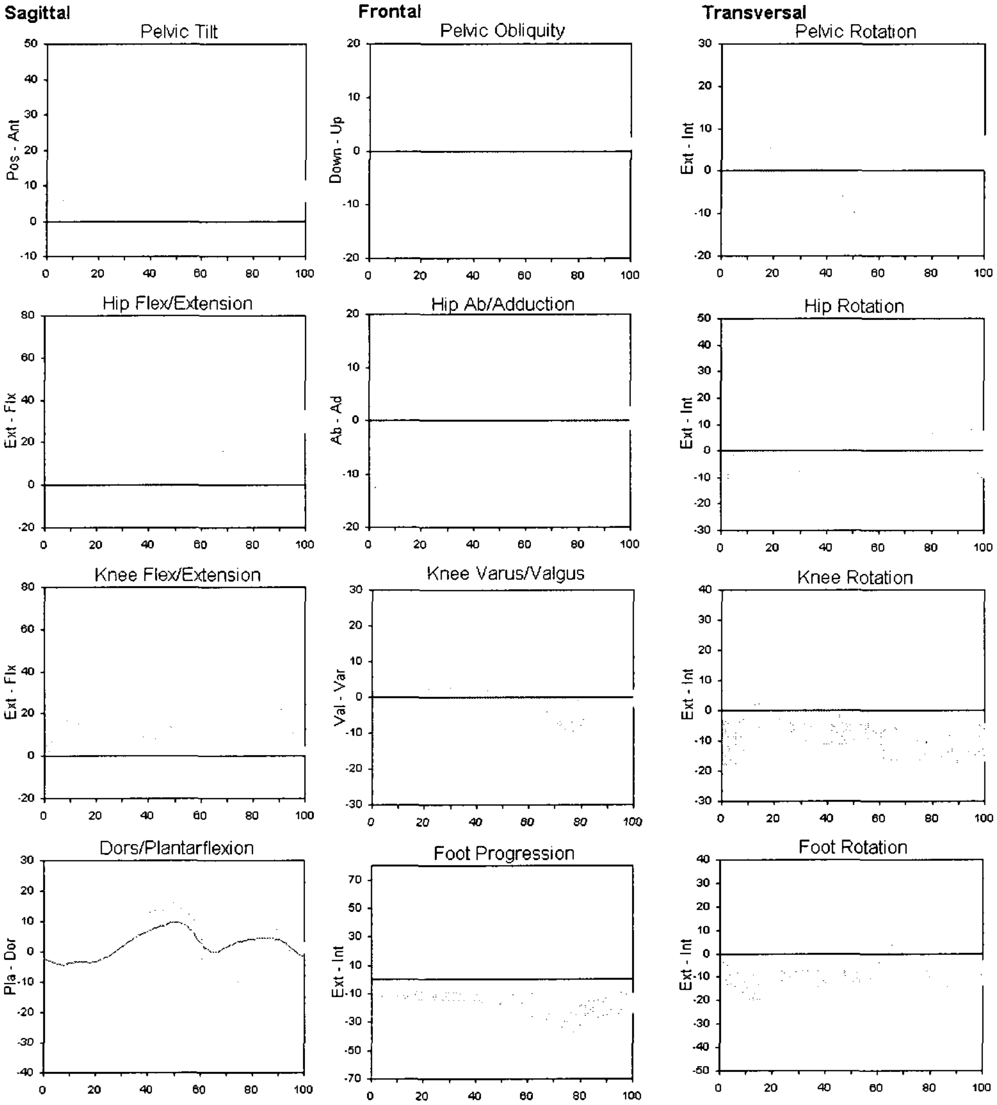


**Figure 3**: Able-bodied joint angles in three planes during level ground walking [12].

## 2.1.2 Inclined Walking

Few studies exist on inclined walking biomechanics; however, the studies that have been done provide information on the changes that occur when walking up and down sloped surfaces.

### 2.1.2.1 Temporal-spatial Parameters

Research findings regarding temporal-spatial parameters have been confounding. Redfern and DiPasquale [13] reported that, for inclines with an angle of 0-10°, stride length did not change but stride period increased. Leroux et al. [14] also found changes in temporal-spatial parameters, observing increased stride length and stride duration when walking uphill and decreased stride length and stride duration when walking downhill. In contrast, Lay et al. [15] found no significant differences in stride length or duration across inclines or conditions (i.e., level vs. inclined).

#### 2.1.2.2 Kinematics

Lay et al. [15] reported that, during up-slope walking, angular motion changed at the ankle, hip, and knee. Ankle angles resembled level walking in early swing but the ankle remained dorsiflexed for most of stance phase, due to the incline. The knee displayed increased flexion at heel strike followed by knee extension in mid-stance, which assisted in lifting the body up the incline. The hip was more flexed during up-slope walking than level walking. These findings were in agreement with the earlier work of Leroux et al. [14] who found that during up-slope walking the hip was flexed, the ankle was dorsiflexed, and the trunk and pelvis were tilted forward. Increases in ankle, hip, and knee flexion assisted in lifting the leg for toe clearance. The body's forward tilt was an adaptation that placed the center of gravity (CoG) ahead of the base of support (BoS) to assist with forward propulsion [14].

In down-slope walking, the ankle movement pattern was very similar to walking on a level surface but the ankle was less dorsiflexed. Knee flexion was notably increased during stance phase and early swing. The hip was more flexed during mid to late swing and early stance but hip flexion decreased during mid-stance, compared to level walking. Leroux [14] also noted a backward tilt of the trunk and pelvis when walking down-slope. An earlier study by Redfern and DiPasquale [13] also investigated the biomechanics of walking down a slope. The findings were similar to those previously discussed in that increased knee flexion during stance was identified and little variation was found between hip and ankle trajectories for the level and inclined conditions.

Overall, kinematic changes were conducive to toe clearance and balance maintenance during uphill walking and to controlling the descent of the body when downhill walking.

### 2.1.3 Stair Ascent and Descent

Laboratory research on stair-climbing gait dates back over 20 years [10]. McFayden and Winter [16] conducted one of the earliest studies on this topic. The authors identified and described the phases of the gait cycle for stair ascent and descent.

In stair ascent, stance phase was broken into three sub-phases. *Weight acceptance* starts when the middle to front portion of the foot contacts the step and continues until the body is moved into position to be pulled up to the next step. The *pull-up* phase occurs from the beginning of single leg support to mid-swing of the contralateral leg (32% of stride). *Forward continuance* occurs from mid-swing of the contralateral leg to the end of ipsilateral stance. This phase is characterized by lifting and forward translation of the body to place the center of mass (CoM) over the contralateral limb on the next step. The swing phase consists of foot clearance and foot placement. During *foot clearance,* the ankle is dorsiflexed and the leg is pulled back through flexion at the knee to lift the leg and clear the intermediate step. *Foot placement* onto the step is controlled by the hip extensors and foot dorsiflexors.

Stair descent has different sub phases than stair climbing. Stance phase begins with *weight acceptance* on the lateral side of the striking foot and continues until toe-off. When the limb is in single support, the knee extends to lift the body slightly and move the body forward (termed *forward continuance*). *Controlled lowering* of the limb from one step to the next occurs from midstance to the beginning of swing. Swing phase consists of leg pull-through and preparation for foot placement. In *leg pull-through*, the leg is moved forward and off the step. This action involves less knee flexion than in stair ascent since intermediate step clearance is less of an obstacle. In *preparation for limb placement*, the knee and hip begin to extend during mid swing as the ankle plantarflexes. With all three joints extended, the lower extremity is prepared for weight acceptance.

### 2.1.3.1 Temporal-spatial Parameters

Nadeau et al. [10] found that, when compared to level ground walking, stair climbing was associated with a slower cadence, shorter stance phase, and longer cycle duration. The temporal-spatial parameters recorded by Nadeau et al. [10] are summarized in Table 2. A study by Mian et al. [17] focused on age related aspects of stair descent but, in the process, collected normative data (Table 3). This data provides general temporal-spatial characteristics of stair descent; however, this data may not be generalizable since it was collected from young men (age 26.6 ± 3.1).

| **Temporal-spatial Parameters<br>Stair Ascent** | |
|---|---|
| Speed (m/s) | 0.46 (0.07)* |
| Cadence (step/min) | 93.6 (12.80)* |
| Cycle Duration (ms) | 1304 (183)* |
| Stride Length (m) | 0.66 (0.09)* |
| Stance Phase (%) | 60.3 (1.10)* |
| Swing Phase (%) | 39.7 (1.10)* |
| Initial Double Support (%) | 11.8 (0.90) |
| Terminal Double Support (%) | 12.3 (1.03) |
| Total double Support (%) | 24.9 (2.10) |

**Table 2:** Mean and standard deviation (SD) for temporal-spatial parameters for stair ascent. An asterisk (*) denotes values that are significantly different ($p<0.05$) in comparison to level ground walking [10].

| **Temporal-spatial Parameters<br>Stair Descent** | |
|---|---|
| Descent Time (s) | 2.09(.026) |
| Stride Time (s) | 0.96(0.12) |
| Single Support (s) | 0.72(0.08) |
| Double Support | 0.25(0.06) |
| Stance (% Stride) | 62.9(2.50) |
| Step Width | 20.7(3.10) |
| Left TOE$_{CL}$ (cm) | 11.2(1.60) |
| Left HEEL$_{CL}$ (cm) | 8.5(1.50) |
| Right TOEL$_{CL}$ (cm) | 10.9(1.10) |
| Right HEEL $_{CL}$ (cm) | 8.7(1.60) |

**Table 3:** Mean and standard deviation (SD) for temporal-spatial parameters during stair descent. TOE$_{CL}$ (toe clearance) and HEEL$_{CL}$ (heel clearance) were defined as the distance of the toe or heel above the front edge of the step during swing [17].

### 2.1.3.2 Kinematics

Nadeau et al. [10] compared lower extremity kinematics in the frontal and sagittal planes during stair climbing to level ground walking (Figure 4). In the frontal plane, the ankle was adducted in early stance but gradually abducted to reach a maximum of 14.3° during single support phase. After reaching maximum abduction, the ankle immediately began to adduct, reaching maximum adduction (10°) in mid-swing. The knee remained in a neutral position for the majority of the gait cycle but adducted slightly during late swing and early stance, displaying a total ROM of approximately 10°. The hip was slightly adducted in early stance and gradually abducted until maximum abduction (5°) was reached just after toe-off. After toe-off, the hip began to adduct and continued adducting into early stance.

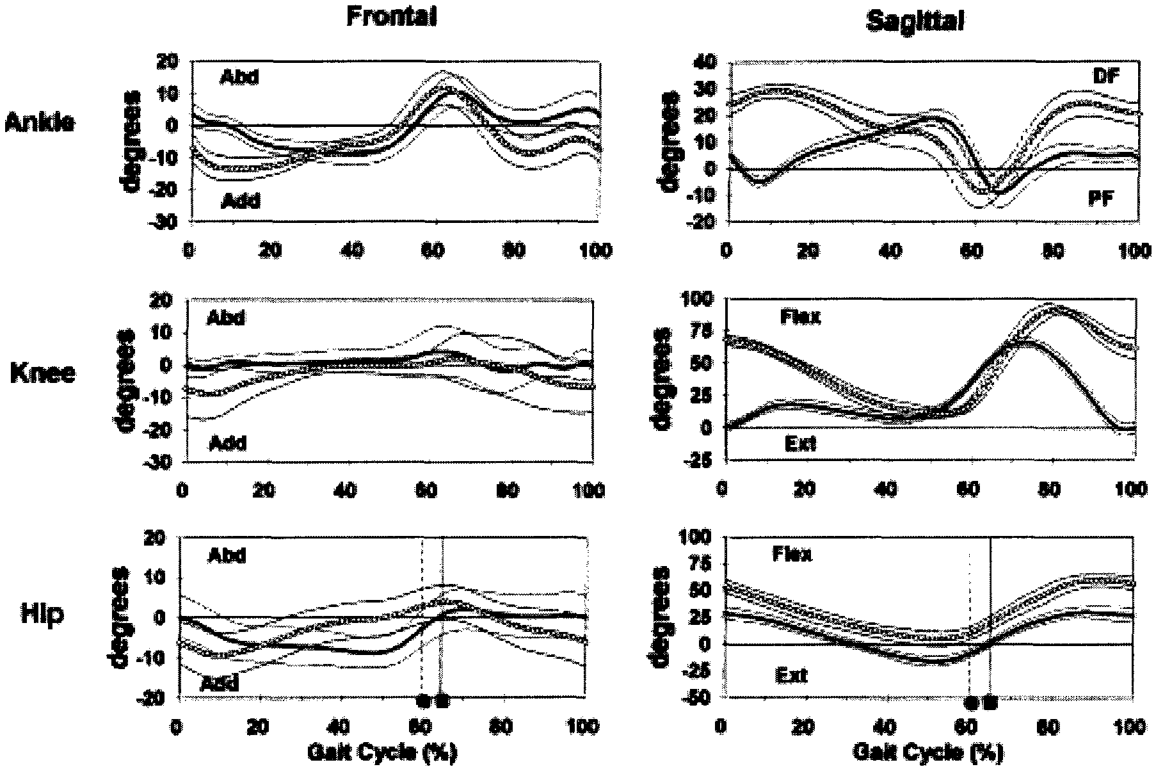


**Figure 4:** Frontal and sagittal profiles of the ankle, knee, and hip during level walking (black line) and stair climbing (grey line) shown with standard deviation (thin lines) [10] (Abd - Abduction, Add - Adduction, Flex - Flexion, Ext - Extension).

Mian et al. [17] collected 3D joint angle data during stair descent. A summary of the normative kinematic data are presented in Table 4.

| | | Max (deg) | Min (deg) | Range |
|---|---|---|---|---|
| Sagittal Plane | Pelvis (anterior/posterior tilt) | 3.8 (2.9) | -1.2 (3.7) | 5.0 (1.7) |
| | Hip (flexion/extension) | 32.0 (5.0) | 1.5 (5.1) | 30.4 (3.6) |
| | Knee (flexion/extension) | 92.6 (3.7) | 6.5 (4.3) | 86.1 (5.4) |
| | Ankle (plantar/dorsiflexion) | 32.1 (4.5) | -23.8 (5.2) | 55.9 (6.6) |
| Frontal Plane | Pelvis (up/down obliquity) | 2.9 (1.9) | -3.7 (2.2) | 6.6 (2.5) |
| | Hip (adduction/abduction) | 4.7 (2.2) | -5.4 (2.8) | 10.1 (2.2) |
| Transverse Plane | Pelvis (internal/external rotation) | 5.0 (3.5) | -2.7 (3.0) | 7.8 (2.5) |
| | Hip (internal/external rotation) | -0.9 (6.5) | -18.0(18.1) | 17.1 (5.4) |

**Table 4**: Mean and standard deviation (SD) for maximum, minimum, and range of joint and pelvic angles during stair ascent [17].

### 2.1.4 Plantar Pressure

Plantar pressure analysis is extremely useful in understanding the mechanics of walking since this measure provides detailed information about how the feet interact with the ground. In Figure 5, plantar pressure curves for able-bodied gait are presented alongside an example of pathological gait for comparison. For able-bodied gait, it is clear that the heel contacts the ground before the toe. In addition, upon heel contact, the plantar pressure to body weight ratio increases very rapidly to 1.0, indicating that the heel is supporting the entire weight of the body. In contrast, individuals with ataxic gait contact the ground with the heel and toe simultaneously (as evidenced by the overlap of plantar pressure curves) and body weight is distributed over the sole of the foot.

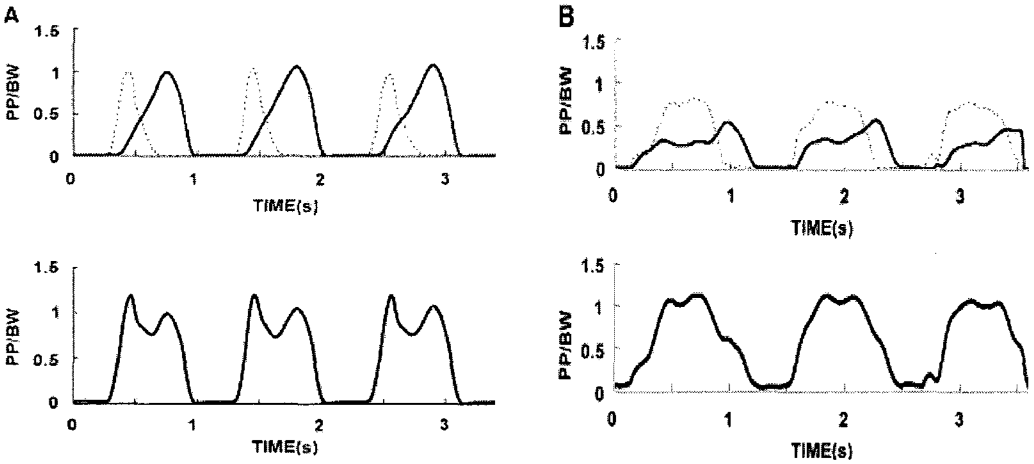


**Figure 5**: Example of plantar pressures for (A) able-bodied gait and (B) severely ataxic gait. The top graphs show separate toe (solid lines) and heel (dotted lines) curves. The bottom graphs show summation of toe and heel pressures. All plantar pressures are normalized by weight (PP/BW)[18].

In terms of CoP trajectory, a study by Rai and Aggarwal [19] noted a distinct rollover pattern in 58 able-bodied subjects in which the posterolateral aspect of the heel contacted the ground, followed by the midfoot, metatarsal regions, and then the toe. This transition from the hindfoot to forefoot should be stable [20]. In addition, CoP trajectory for able-bodied individuals is characterized as shifting from the medial to the lateral aspect of the foot during the transition from double to single support, and a shift from the lateral to the medial aspect of the foot during the transition from single to double support [20]. Additional shifts in the medial/lateral (M/L) or anterior/posterior (A/P) trajectories are indicative of abnormal shifts in weight and reflective of instability. Figure 6 presents an able-bodied M/L trajectory.

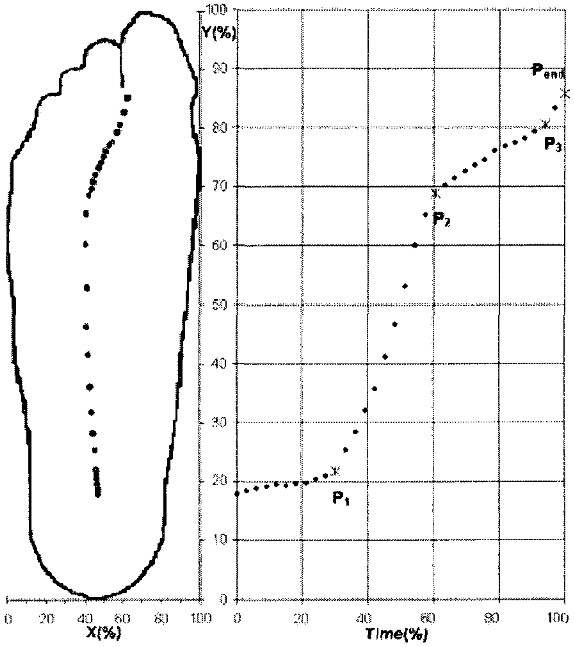


**Figure 6:** CoP trajectory of left foot normalized with respect to foot dimensions. $P_1$= point of maximum acceleration in the rear foot, $P_2$= point of maximum deceleration of the forefoot, $P_3$= point of maximum acceleration under the hallux (not always observed), $P_{end}$= end of CoP displacement/stance phase. Note the shift in CoP trajectory from the medial to lateral aspect of the foot [20].

## 2.2 Amputee Gait

Gait varies greatly among people with transtibial amputations, with some relying on walkers, crutches, and canes, and others appearing to have able-bodied gait. While rehabilitation focuses on achieving an able-bodied gait pattern, the majority of individuals with transtibial amputations use compensatory movements while walking. These compensations are "necessary to fulfill the role of the lost ankle muscles" [21]. This section outlines gait deviations that commonly occur with a transtibial amputation.

### 2.2.1 Temporal-Spatial Parameters

A 1997 study compared the gait of able-bodied individuals to those with transtibial amputations [22]. For those with amputations, the intact (i.e., non-amputated) limb was analyzed separately from the prosthetic limb. In comparison to normative data, stance time on the amputated limb was significantly shorter and swing time was significantly longer. When comparing intact and prosthetic limbs for people with transtibial amputations, stance time on the amputated limb was significantly shorter and swing time was significantly longer. The temporal-spatial data are presented in Table 5. These findings are supported by Bateni and Olney [23] who reported that, for people with transtibial amputations, stance phase on the intact limb comprised a larger percentage of the total gait cycle in comparison to the prosthetic limb (64.4 ± 2.8 % vs. 60.2 ± 2.4 %). The authors suggested that a person with an amputation may not completely trust the prosthetic limb and therefore transfers weight to the intact limb after a shorter period. Table 5 shows that stance time on the intact limb is greater than stance time on the prosthetic limb, as well as greater than that of able-bodied subjects.

| **Speed/Limb** | **Stance Time** | | **Swing Time** | |
|---|---|---|---|---|
| | **Absolute (s)** | **Relative (%)** | **Absolute (s)** | **Relative (%)** |
| **1.2 m/s** | | | | |
| Able-bodied | 0.778<br>(± 0.055) | 65.7<br>(±1.2) | 0.407<br>(± 0.032) | 34.3<br>(± 1.2) |
| Amputee-Intact | 0.798<br>(± 0.051) | 65.3<br>(± 2.6) | 0.427<br>(± 0.065) | 34.7<br>(± 2.6) |
| Amputee-Prosthetic | 0.758<br>(± 0.061) | 61.8<br>(± 0.9) | 0.468<br>(± 0.047) | 38.2<br>(± 0.9) |
| **1.6 m/s** | | | | |
| Able-bodied | 0.659<br>(± 0.033) | 62.9<br>(± 1.1) | 0.388<br>(± 0.019) | 37.1<br>(± 1.0) |
| Amputee-Intact | 0.667<br>(± 30.06) | 62.9<br>(± 2.6) | 0.394<br>(± 0.048) | 37.1<br>(± 2.6) |
| Amputee-Prosthetic | 0.624<br>(± 0.051) | 60.3<br>(± 0.9) | 0.410<br>(± 0.034) | 39.7<br>(± 0.9) |

**Table 5:** Mean absolute and relative stance and swing times (± SD) for able-bodied subjects and subjects with transtibial amputations. Modified from [22].

### 2.2.2 Kinematics

Previous studies have shown that the joint angle profiles for the hip, knee, and ankle, are similar in shape for people with and without amputations [22,23]. For the prosthetic limb, Bateni and Olney [23] noted an increased range of knee flexion on the prosthetic limb by approximately 10 degrees, increased knee flexion on the contralateral limb, and increased hip flexion (Figure 7). Increased knee flexion on the intact limb during early stance could assist in forward propulsion while increased hip flexion brings the body forward and over the foot (i.e., moves the CoG within the BoS). The greatest differences in joint angle profiles occurred at the ankle, with a much smaller range of motion for the prosthetic limb than for the intact limb [22,23]. Many movements can be attributed to the type of prosthetic foot used by the individual and the material properties, which may compress to simulate limited plantar flexion and dorsiflexion.

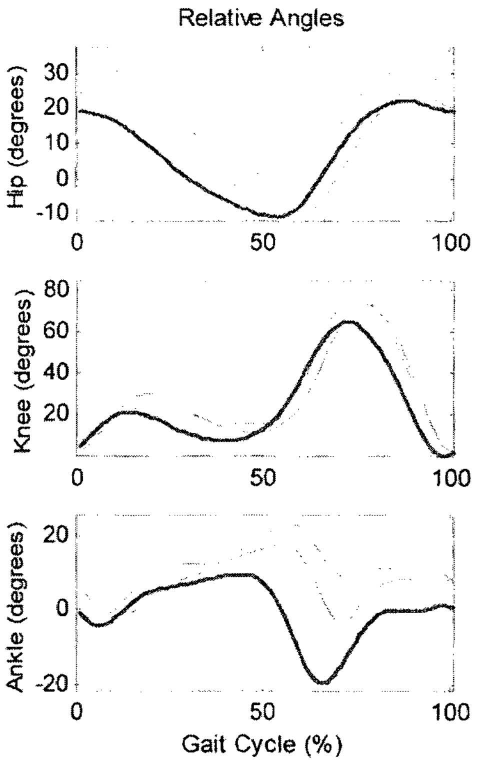


**Figure 7**: Joint angles for one subject (grey dashed=prosthetic limb, grey solid=intact limb, black solid=mean able-bodied value) [23].

Common gait deviations among people with transtibial amputations can be also be related to prosthetic fit and function. Berger [24] detailed common gait compensations that relate to prosthetic devices. Excessive knee flexion on the prosthetic side during heel strike to midstance (i.e., greater than 15-20°) may be due to excessive dorsiflexion, anterior tilt of the prosthetic socket, or a stiff heel cushion (knee flexion increases to provide shock absorption). Decreased or absent knee flexion during this period may be related to excessive plantar flexion, a soft heel cushion, pain associated with increased pressure between the socket and the residual limb during weight-bearing knee flexion, or insufficient quadriceps strength (i.e., the knee is forced into extension to reduce quadriceps activity). From midstance to toe-off, knee flexion timing differs from able-bodied gait. Early knee flexion may be related to excessive dorsiflexion of the prosthetic foot, anterior tilt of the socket, or anterior displacement of the socket over the foot. By contrast, late onset knee flexion may be related to plantar flexion, posterior socket tilt, or posterior socket displacement over the foot.

## 2.3 Stability Assessment Instruments/Tools

This section will review the clinical tests, lab-based equipment, and in-shoe pressure measurement systems currently used to assess balance and stability.

### 2.3.1 Clinical Tests for Balance and Stability

#### 2.3.1.1 Berg Balance Scale

The Berg Balance Scale (BBS) was developed as a means of evaluating balance in the elderly [25]. The scale consists of 14 different tasks. Points are awarded based on an individual's ability to complete the task or reach a specific goal (i.e., time or distance). A maximum of four points can be awarded for each task, with a maximum possible total of 56 points. A higher score is correlated with better balance. This test can be completed in approximately 20 minutes and only requires a chair, stopwatch, and ruler. The tasks are completed from a standing or seated position; therefore, the BBS may be of limited use for assessing dynamic stability.

A study by Bogel Thorbahn and Newton [26] found the BBS to be sensitive in predicting assistive device use, but not in differentiating fallers from non-fallers. In contrast, Shumway-Cook et al. [27] found that declining BBS scores were associated with an increased risk of falls, although the relationship was not linear (Figure 8). More recently, Lajoie and Gallagher [28] reported poor performance on the BBS as a predictor of falling in an elderly population. There has also been debate about the recommended cut-off BBS value to predict falls, with studies recommending cut-off values 45, 46, 49 [29,28,27].

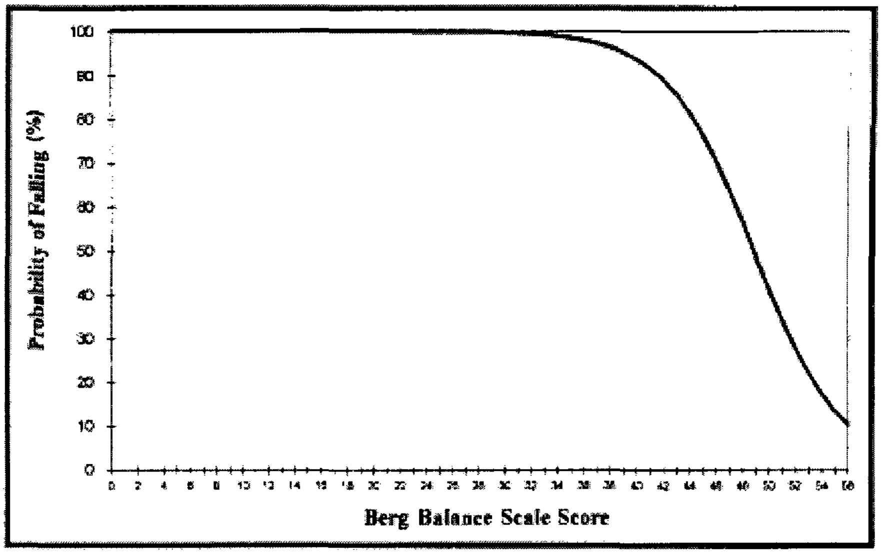


**Figure 8**: Predicted probability for falls as a function BBS scores [27].

### 2.3.1.2 Timed Up and Go

The Timed Up and Go (TUG) test was developed to test balance in an elderly population [30]. In the TUG, the subject is timed while rising from a chair, walking three meters, turning around, walking back to the chair, and sitting down again [31]. The subject walks at a self-selected pace. The test is over when the subject's buttocks contact the chair.

An appropriate cut-off value of the TUG score to predict falls has been disputed. The TUG was found to be useful in predicting falls in a community dwelling elderly population, with a time of 14 seconds or more indicating a high risk of falls [27]. Bischoff et al. [32] recommended a cut-off of 12 seconds for community dwelling women aged 65-85. In individuals with vestibular dysfunction, a time of greater than 11.1 seconds was correlated with an increased risk of falls [33]. These time variations may be due to differences in the populations involved in each study and could also be due to protocol differences since chair height and type (arms/no arms) are not standardized [34].

### 2.3.1.3 Community Balance and Mobility

The Community Balance and Mobility Scale (CBMS) was designed to evaluate balance and mobility in a population that is "ambulatory and functioning at a high level, yet who have persistent balance problems" [35]. The scale consists of 13 tasks, six of which are done on both the right and left limbs, for a total of 19 tasks. The scale was designed to represent motor skills necessary for function within the community by including tasks that incorporated multitasking, sequencing and movement components, and complex motor skills [36]. Subjects are required to perform a variety of activities while moving along an eight meter track. A scoring guide accompanies the questionnaire with detailed scoring information for each task. In general, the subject receives a score of zero if they cannot complete the task, and a score between one and five depending on task performance. The maximum possible score is 96, with a higher score indicating increased balance and mobility.

CBMS has been a useful functional measure for studies involving individuals with traumatic brain injury. Howe et al. [36] found positive correlations between CBMS and physical therapist global balance ratings. Individuals who scored above or below 50 on the CBMS had significantly different scores on the Community Integration Questionnaire. Inness et al. [37] also found a significant correlation between CBMS and the Community Integration Questionnaire, suggesting that, in individuals with traumatic brain injuries, better balance skills correspond to greater community integration. Because the CBMS was developed for evaluating those with traumatic brain injury, and its reliability and validity were established for this population, CBMS's validity for other populations requires additional research.

### 2.3.1.4 *Functional Reach Test*

Duncan et al. [38] developed the functional reach test (FRT) to measure dynamic balance. The test uses a yardstick that is secured to a wall at acromion height and oriented parallel to the floor. For evaluation, the patient stands at the end of the yardstick in a relaxed, comfortable position. They are asked to make a fist and raise their arm parallel to the floor. At this time, the placement of the third metacarpal bone along the yardstick is noted. The patient is then instructed to reach forward as far as possible, without losing balance or taking a step, and the position of the third metacarpal is measured again. The distance between the two positions is calculated and averaged over three trials. The averaged value is considered "functional reach". When compared to force plate date data, the FRT had a positive correlation to the excursion of the CoP (Pearson r= 0.69).

Several studies have used the FRT but report confounding results. When used at four-week intervals over the course of a rehabilitation program for veterans, FRT values changed over time, reflecting improved balance with rehabilitation [39]. In contrast, other studies reported no significant differences in the distance reached by healthy individuals and those with documented balance disorders [40,41].

While the FRT is fast and easy to administer, the reaching task may not be related to dynamic stability since the subject stands without moving their feet during evaluation. The developers of the instrument also acknowledge that the FRT is limited to A/P instability measurement [38].

#### 2.3.1.5 Romberg / Sharpened Romberg Test

Many variations of the Romberg test are reported in the literature. In the original Romberg Test, a patient was instructed to stand with feet together and arms hanging at the sides. The time that the patient maintained this posture was measured. The test was conducted with the patient's eyes open and again with the eyes closed [42,43].

The Sharpened Romberg Test (SRT) is similar but the width of the BoS is reduced. Subjects are instructed to stand erect on a hard surface with the feet aligned heel-to-toe (i.e., in tandem) and arms folded across the chest [44]. Once stable, the subject is instructed to close their eyes. The length of time that the subject is able to maintain a stable posture is measured to the nearest second. Timing is stopped once the subject opens their eyes or moves their arms or feet.

#### 2.3.1.6 Dynamic Gait Index

Shumway-Cook and Woollacott [45] developed the Dynamic Gait Index (DGI) to assess dynamic postural control in older adults. The DGI involves eight tasks; including, walking at self-selected speed, changing speeds, walking while looking side to side, walking while looking up and down, pivoting, walking over and around obstacles, and climbing stairs. Performance is rated on an ordinal scale, with zero representing severe impairment and three representing able-bodied performance, for a maximum score of 24. A study by Whitney et al. [46] found that a score of 19 or less was associated with an increased risk of falling. More specifically, individuals with a score of 19 were 2.58 times more likely to have a reported fall in the previous six months compared to those who scored above 19.

The DGI was found to be valid when compared to other commonly used balance assessment tools, such as BBS and the timed walk test [47,48], and was reliable across raters and trials [48,49].

#### 2.3.1.7 Performance Oriented Mobility Assessment

The Performance Oriented Mobility Assessment (POMA) was developed by Tinetti [50]. The test is comprised of two sections, one for balance and one for gait [51]. The balance section contains nine items with a maximum total score of 16. Subjects are asked to perform several activities; for example, sit on an armless chair and stand. Scoring is based on how the task is performed. The gait section has eight items and a maximum score of 12. For this section, several aspects of walking (i.e., foot swing, gait symmetry, walking time, etc.) are evaluated. Scoring is done on a three point ordinal scale from 0-2, such that a higher score corresponds to better performance.

This instrument is quick and easy to use and requires limited equipment. The assessment is different from the other clinical tests in that it addresses the need for separate testing for static and dynamic stability.

### 2.3.2 Instrumentation for Balance and Stability Measurement

#### 2.3.2.1 Camera-Based Systems

Camera-based systems are used to capture 3D coordinate data. The most commonly used systems rely on passive reflective markers. These markers are attached to the body and reflect light onto the camera lens. Markers are placed at specific anatomical locations, although the number of markers used and their locations vary depending on the application and the marker set selected. An example of a full-body marker set is shown in Figure 9.

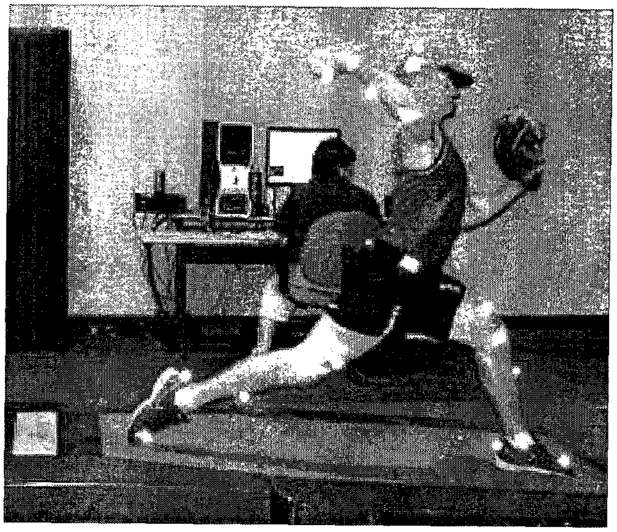


**Figure 9:** Motion capture using reflective markers and a full-body marker set.

Camera calibration is required to obtain scaled data. As explained in Robertson et al. [52], a calibration object is positioned in the field of view of the cameras. The calibration object has a set of points that have known locations in 3D space. All cameras capture a 2D image of the calibration object and the information is used to calculate the mathematical relationship between the 2D images and the 3D position of each point on the calibration object. This calibration process has commonly used the direct linear transform (DLT) [6]. Once the camera system is calibrated, the DLT equations are applied to a marker set to determine the location of each marker and enable a 3D model to be created.

#### 2.3.2.2 Force Plates

Force plates are large force transducers used to measure the sum of the forces applied to the plate, or the ground-reaction force (GRF) [52]. Several models of force plates are available; Bertec (Bertec Corp., Columbus, OH, USA), Kistler (Kistler Instrumente AG, Winterthur, Switzerland), and AMTI (Advanced Mechanical Technology, Inc., Watertown, MA, USA).

A limiting factor when using force plates in dynamic stability analysis is that force plate output provides the sum of forces in each plane. As a result, gait analysis only works when only one foot is contacting the force plate. Force plates may cause subjects to walk in an unnatural manner because, if the force plates are visible, subjects may alter their gait in an effort to contact the plate (i.e., targeting). If force plates are concealed in the laboratory floor, many additional trials may be needed since the subject may not always contact the force plate. Force plates are typically restricted to laboratory settings so findings may not be applicable to other conditions.

#### 2.3.2.3 Accelerometers

Accelerometers are commonly used to measure linear and angular acceleration. Commercially available accelerometers can use different technologies (strain gauge, piezoelectric, or piezoresistive) and can be uniaxial or triaxial [52]. Accelerometers are cost effective, small, and portable but provide only limited information. Accelerometers are often most helpful when combined with other gait analysis equipment. In addition, only linear acceleration is measured accurately.

#### 2.3.2.4 Plantar Pressure Measurement Systems

Plantar pressure measurement systems are useful because they provide information about how the foot is contacting the ground and what is happening at the foot/ground interface. Depending on the application, there are several options for measuring plantar pressure.

In-shoe plantar pressure measurement systems typically consist of a pair of insoles and a data logger/receiver unit. The insoles are instrumented with pressure sensors; the type and number of sensors is dependent on the system being used. When the foot contacts the ground, the sensors produce an electrical resistance proportional to the pressure applied. Figure 10 shows three commonly used in-shoe plantar pressure measurement systems; the F-Scan Mobile (Tekscan Inc., Boston, USA), Pedar-X (Novel, St. Paul, MN, USA), and Parotec (Paromed, Medizintechnik, GmbH, Munich, Germany). These systems appear similar but have different capabilities based on the number and type of sensors (Table 6). In-shoe pressure measurement with wearable data logging or wireless data transfer permits gait analysis over a variety of activities and conditions [53,54,55].

**Figure 10:** F-Scan Mobile, Pedar-X, Parotec (l-r)[53,54,55].

| Device | Type of Sensor | # Sensors | Weight of Data Logger |
|---|---|---|---|
| **F-Scan** | Force-sensing resistors (FSR) | 960/insole ($4/in^2$) | 1.8 kg |
| **Pedar-X** | Capacitance transducer | 99/insole | 400g |
| **Parotec** | Hydrocell | 24/insole | 586g |

**Table 6:** Comparison of three commonly used in-shoe plantar pressure measurement systems [53,54,55].

Plantar pressure walkways and platforms use similar technologies as in-shoe pressure measurement systems in that the sensors produce an electrical voltage proportional to the force applied (Figure 11-Figure 12). The major advantage of walkway or platform systems is that no equipment has to be worn by the subject, allowing for more natural gait. When using plantar pressure platforms, as with force platforms, targeting is a concern.

The major limitation of plantar pressure measurement systems is that only normal forces are recorded (force perpendicular to the sensor surface). These systems cannot measure A/P or M/L shear forces [57,58,59].

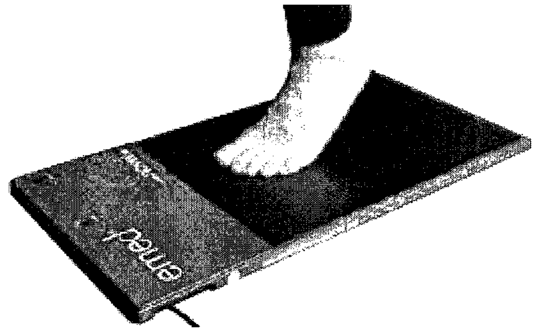


**Figure 11:** Emed-m platform [54].

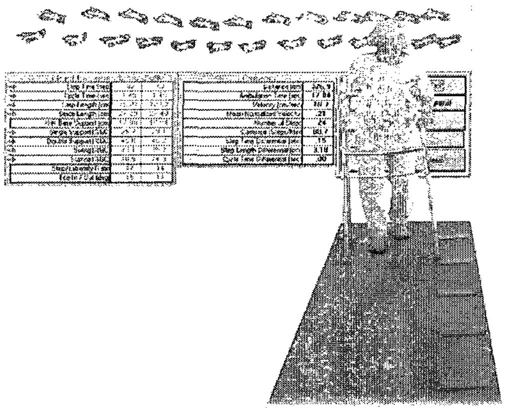


**Figure 12:** GAITRite walkway [56].

## 2.4 Self-Report Instruments

Self-report instruments are beneficial because they are time and cost efficient and can be administered over the phone (depending on the type of questionnaire) or by mail. Patient input provided through self-report is useful for evaluating patient care and providing context for quantitative analysis. This section outlines two commonly used self-report instruments that provide insight into the use of lower-limb prostheses.

### 2.4.1 Prosthetics Evaluation Questionnaire

Legro et al. [60] developed the Prosthetics Evaluation Questionnaire (PEQ) to evaluate both the prosthesis and quality of life with a prosthesis. The PEQ consists of nine subscales; ambulation, appearance, frustration, perceived response, residual limb health, social burden, sounds, utility, and well being [61]. The scales are independent, so specific scales can be selected to answer the research question. The PEQ uses a visual analog scale (Figure 13). For each question, the respondent marks a 100 mm line, measured from the left (0-100). A positive response is associated with a higher number. For each scale, a single score is calculated by dividing the sum of responses by the number of questions answered. All questions focus on the previous four weeks. The PEQ as a whole was found valid and reliable [60]. In addition, Miller et al. [62] evaluated sections of the PEQ that pertained to mobility and found these sections to be reliable and valid.

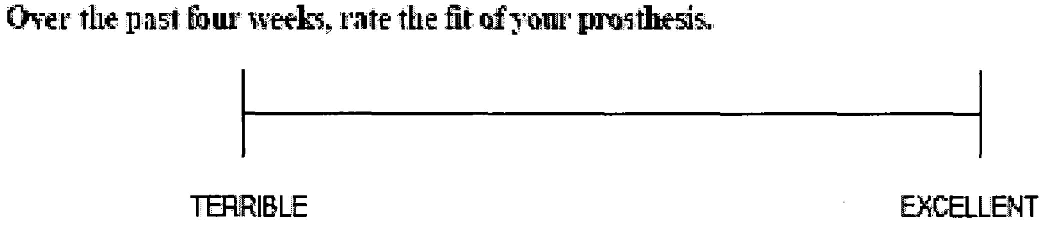

Over the past four weeks, rate the fit of your prosthesis.

**Figure 13:** Example of a question using a visual analog scale in the PEQ [63].

### 2.4.2 Prosthetic Profile of the Amputee

Grisé et al. [64] developed The Prosthetic Profile of the Amputee (PPA) in 1993. This questionnaire is administered to individuals with lower limb amputations after discharge from rehabilitation and is intended to evaluate factors related to prosthetic use, specifically factors contributing to use or non-use of a prosthesis [65]. The questionnaire can be administered over the phone or in person.

The 44 PPA questions are grouped into six categories: physical condition, prosthesis, prosthetic capabilities, environment, leisure activities, and demographic characteristics [65]. The questions use a variety of measurement scales (i.e., qualitative, nominal, ordinal scales, and ratio).

A limitation of this instrument is that a composite score cannot be computed for the PPA or for the six categories. The authors recommended that associations between the outcome variable and various factors (i.e., specific questions) could be done using appropriate statistical analyses, such as regression analysis [65]. The PPA is reliable and valid [62,66].

## 2.5 Dynamic Stability Factors

Instability is associated with a risk of falls. While many factors contribute to instability (age, chronic disease, medication effects, altered metal status) [2], this section will focus only on the biomechanical factors.

In terms of temporal-spatial parameters, several studies have investigated the relationship between walking speed, acceleration, and stability [18,64,67,68]. Generally, decreased walking velocity/speed is related to decreased stability [18,64]. Menz et al. [64] explained this decrease as an attempt to maintain trunk stability. Similarly, increased double support time (DST) is related to decreased stability [18], due to a compensatory strategy that increases time with a larger base of support.

Kinematically, joint angles decrease in individuals with vestibulopathy [18], effectively creating a more rigid walking pattern with shorter steps and a decreased walking velocity. A walking pattern characterized by prolonged double support, decreased joint angles, and decreased velocity has been called a "protective gait pattern" by Conrad et al. [70].

Since all strides are similar during able-bodied walking [71], stride-parameter variability has been associated with decreased stability. Specifically, stride-time (ST) variability and joint-angle variability have been related to instability [71,72,73], with the variability of lower limb joint angles increasing as walking velocity increased [71].

The BoS has also been identified as a measure of stability, such that the width of the BoS increases with decreased stability [69,74], while the length of the BoS (i.e., A/P distance between CoG and CoP, step length) decreases with decreased stability [75,76,69]. Krebes et al. [74] found that the width of the BoS, as measured by inter-foot distance (IFD), was dependent on walking speed. During paced gait, individuals with vestibulopathy had a greater IFD than able-bodied subjects. When walking at a self-selected speed, there was no difference in IFD; however, those with vestibulopathy decreased walking speed, presumably to decrease forward CoG velocity.

CoP is a reasonable measure for dynamic stability since it is related to changes in GRFs, total body CoM [77], and net ankle moments [78]. As previously discussed, the CoP trajectory should have a smooth A/P transition from heel to toe. In the M/L plane, the CoP should move from the center of the heel, to the lateral border of the foot, and back to medial foot. Any additional fluctuations in CoP trajectory suggest abnormal weight shifting and instability (i.e., movement at the ankle to adjust the body CoM). Ienaga [18] noted that, in addition to an irregular CoP trajectory, instability could be indicated by an increased foot contact area.

Since many factors affect stability and many of these factors are related, a multi-factorial approach is required to accurately evaluate stability. Recently, a "dynamic gait stability index" was developed [4,5]. The index used six gait parameter values, derived from plantar pressure data, to calculate a single index value between zero and one, with a higher index value representing greater dynamic instability [4,5]. The factors that were found to be good indicators of stability included A/P CoP motion, M/L CoP motion, maximal lateral position, cell triggering frequency, DST, and ST. These parameters changed with various conditions of stability. The usefulness of these six parameters and the index for evaluating dynamic stability was only investigated for able-bodied subjects, requiring additional testing and validation with other populations.

## 2.6 Gaps in the Literature

As illustrated by the brevity of the section pertaining to the gait of individuals with amputations, few studies have focussed on stability in this population. More specifically, there is a complete absence of literature on the plantar pressure characteristics of people with transtibial amputations. Schmid et al. [20] described plantar pressure characteristics of people with transfemoral amputations; however, no similar study has been conducted on those with transtibial amputations. This study addresses gaps in the existing literature by providing data on temporal-spatial and plantar pressure characteristics of a population with transtibial amputations.

# Chapter 3. Methods

This study protocol was approved by ethics review boards at The Ottawa Hospital Rehabilitation Center and The University of Ottawa (Appendix A).

## 3.1 Subjects

Potential subjects were identified from patient files at The Ottawa Hospital Rehabilitation Center (TOHRC). The project research assistant and physiatrist reviewed patient files and selected potential participants on a case-by-case basis.

The sample population consisted of 20 individuals (15 males, five females) with unilateral transtibial amputations who were community ambulators (i.e., able to ambulate independently and navigate environmental barriers). Their mean age and mass were 61±14 years, and 79±16 kg, respectively. The use of a single point cane was acceptable. Exclusion criteria included bilateral lower extremity amputations and the use of either a knee-ankle-foot orthosis or an ankle-foot orthosis on the contralateral limb. Individuals were also excluded from the study if the physiatrist determined that the individual had ongoing health issues that may have prevented them from safely participating in the study. Activity level and physical condition varied greatly between subjects.

If an individual was deemed appropriate for participation, a subject letter (Appendix B) and information sheet (Appendix C) were mailed to the home address. If the individual decided to participate, they contacted the research assistant via phone or e-mail. The research assistant provided an overview of the study, ensured that the individual could complete all required tasks, and set an appointment. During this appointment, the subject read and signed a consent form (Appendix D) and completed the testing protocol. Subjects were informed that they could refuse to attempt or complete a task at any time.

No able-bodied participants were recruited for this study. The researchers had access to previously collected data from 15 able-bodied individuals (nine males, six females) walking on level ground [4]. Their mean age and mass were 34±12 years and 69±12 kg, respectively.

## 3.2 Equipment

The F-Scan mobile was used to collect plantar pressure data at 120 Hz. For stair trials, subjects walked in a stairwell at TOHRC (12 stairs: rise=19 cm, run=27.5 cm). For ramp trials, subjects navigated a ramp with a 7° incline. The stairs and ramp were equipped with handrails and coated with a slip-resistant material.

## 3.3 Testing Protocol

All data were collected at TOHRC. Once the subject signed the consent form, a prosthetist examined the subject's residual limb and prosthetic device to ensure limb health and device functionality. Once a subject's ability to participate was confirmed, they completed balance testing, walking trials, and a questionnaire.

### 3.3.1 Balance Testing

A physiotherapist from the physiotherapy department at TOHRC administered the BBS [25] and the CBMS [35] tests to all subjects. The same physiotherapist administered both tests for all subjects.

### 3.3.2 Gait Analysis

In preparation for gait analysis, F-Scan insoles were trimmed to the appropriate size and inserted into the subject's own shoes. Subjects wore the F-Scan Mobile throughout all walking trials. All cables were secured to the subject's legs to ensure that a natural gait pattern was achieved. For all trials, subjects walked at self-selected speeds and were given sufficient practice time to become comfortable with each condition prior to data collection. For safety purposes, a spotter walked beside the subject at all times. A trial was considered successful if the subject walked without stumbling or falling and if the device functioned properly. Walking trials were conducted as follows:

- **Level Ground** – Data were recorded as each subject walked along a 10 m level walkway. When the subject reached the end of the walkway, they were instructed to stop and turn around. A new trial was recorded as the subject walked in the opposite direction. Five successful trials were recorded.
- **Uneven Ground** – Data were recorded as each subject walked over a row of foam mats (8 m x 1 m). When the subject stepped off the mats and onto the floor, they were instructed to stop and turn around. A new trial was recorded as the subject walked in the opposite direction. Five successful trials were recorded.
- **Ramp** – Data were recorded as each subject walked on a ramp in the TOHRC Gait and Motion Analysis (GAMA) Laboratory. Once the subject reached the top of the ramp, they were asked to stop and turn around. A new trial was recorded as the subject walked down the ramp. Ten trials were completed (five ascending and five descending).
- **Stairs** – Data were recorded as each subject navigated a 12-step stairwell at TOHRC. Once the subject reached the top of the stairs, they were asked to stop and turn around. A new trial was collected as the subject walked down the stairs. Four trials were collected (two ascending and two descending).

### 3.3.3 Questionnaire

All subjects completed the function and mobility scales (ambulation, appearance, residual limb health, sounds, and utility) of the PEQ [60]. The research assistant administered the PEQ to all subjects.

## 3.4 Data Analysis

Twelve variables were examined, as shown in Table 7.

| Equipment / Tool | Variables |
|---|---|
| F-Scan | A/P CoP trajectory (AP)<br>M/L CoP trajectory (ML)<br>Maximum lateral placement of force (MaxLat)<br>Cell triggering frequency (CellTrig)<br>Double Support Time (DST)<br>Stride Time (ST) |
| Dynamic-stability index | Index value for intact limb<br>Index value for prosthetic limb<br>Index value across both limbs (average) |
| PEQ | Score on ambulation scale |
| BBS | Score |
| CBMS | Score |

**Table 7:** Summary of variables.

### 3.4.1 Data Processing

For each subject, F-Scan frame data for each trial were exported as an ASCII file and processed using custom software. A median filter was applied to the data to remove plantar pressure outliers. The following six stability parameters were extracted for each stride and each foot:

1. **AP**: When A/P position of the CoP trajectory is plotted as row number versus time, pressure should move from high to low row number, resulting in a negative slope. Any shifts to a positive slope represent A/P perturbations while walking. The value for AP was previously calculated by counting the number of positive deviations in slope [4,5]. During preliminary analyses for the current study, it became evident that when climbing stairs initial-contact is made with the forefoot, then with the heel, and ultimately push-off with the forefoot. To distinguish changes in slope direction caused by this toe-heel motion from changes caused by instability, the first derivative of the raw A/P CoP trajectory was calculated (A/P CoP velocity) and a dual threshold was implemented (Figure 14). The AP value is the number of velocity crossings outside a dual threshold of 0.5 mm/frame.

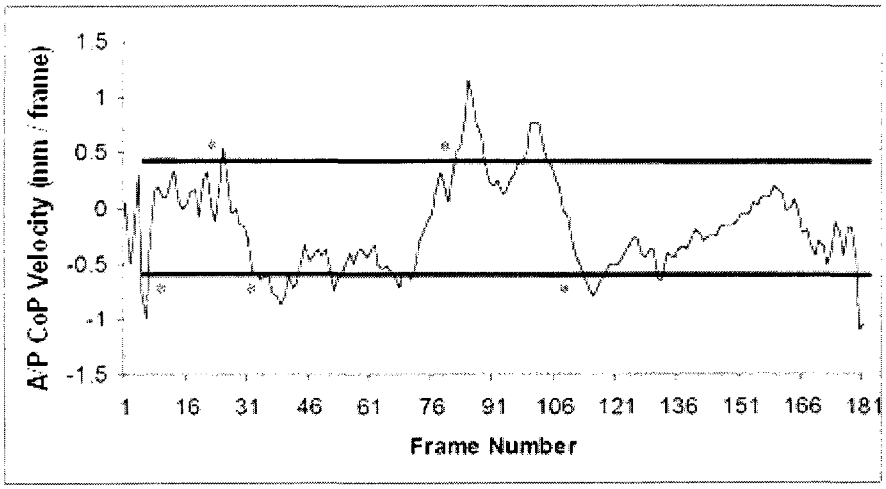


**Figure 14:** Calculating shifts in A/P CoP velocity using a dual threshold. An asterisk (*) indicates the counting of a shift. Velocity must cross both thresholds for a shift to be counted. Modified from [4].

2. **ML**: When the M/L position of the CoP is plotted as column numbers versus time, the M/L CoP trajectory begins medially, moves laterally, and ends medially. To distinguish M/L shifts resulting from instability, a threshold is required. As with AP, the first derivative of M/L CoP position is calculated and a dual threshold is implemented (0.5 mm/frame). ML is the number of shifts in the M/L CoP velocity, outside of the established dual threshold.
3. **MaxLat**: For MaxLat the column number of the most laterally activated cell of the CoP trajectory is identified and subtracted from the total number of columns in a sensor. A smaller difference represents activation of a cell that is closer to the edge of the sensor (i.e., more unstable). This difference is then expressed as a percentage of the overall sensor width, such that a higher value corresponds to increased instability.
4. **CellTrig**: Ideally, the foot should smoothly transition from heel to toe, without side-to-side perturbations. When a smooth transition occurs, each sensor should only be activated once. CellTrig is the maximum number of times a sensor ("cell") is turned on ("triggered"), normalized by number of frames in a stride.
5. **ST**: The time from foot-strike to foot-strike on the same foot.
6. **DST**: The time spent with both feet contacting the ground.

To exclude gait initiation and termination strides, the output for several middle strides (three upramp, three downramp; five for all other conditions) were extracted for each foot. For each subject and condition, an average value for each stability parameter was calculated over the total number of strides extracted (# strides extracted per trial × # trials per condition) for the prosthetic and intact limb.

Parameter data for each subject were arranged into a text file for input into MatLab. Using a fuzzy logic controller (Matlab$^{\copyright}$ Fuzzy Logic Toolbax), the stability parameters were used to calculate the dynamic-stability index [5]. The dynamic stability model was created using triangular membership functions (i.e., Good, Medium-Good, Medium-Poor, Poor). Stability input ranges for each parameter were established using able-bodied data (AP, ML, CellTrig and MaxLat) and stroke patient data (ST and DST). Based on these ranges, each parameter was classified into one of the four membership functions. Using the centriod method for defuzzification, a single dynamic stability index value was generated for each stride (0=more stable; 1=least stable). For each condition, an average index value was calculated for each limb (intact and prosthetic). The average values for each limb were then averaged to generate a combined index value.

For the BBS and CMBS, the physiotherapist scored the results for each subject. The research assistant scored the ambulation scale of the PEQ.

### 3.4.2 Statistical Analysis

The data for all parameters were imported into Statistical Package for the Social Sciences (SPSS) version 15.0 for Windows. Paired t-tests ($p<0.05$) were used to examine differences between the intact and prosthetic limbs for each variable and condition.

A one-way Analysis of Variance (ANOVA) was used to determine whether stability parameters differed between conditions. Similarly, a one-way ANOVA was used to evaluate whether the dynamic-stability index values (intact, prosthetic, and combined) differed between conditions. If a difference was found, a post-hoc Bonferroni test was used to find conditions that differed significantly ($p<0.05$).

For each condition and limb, stability parameter and dynamic-stability index values were compared to values for able-bodied level ground walking using an independent-samples t-test ($p<0.05$).

Pearson correlations ($p<0.05$) were used to test for linear relationships between each of the six stability parameters and each of the stability criteria measures (BBS, CMBS, and PEQ), for each condition. Pearson correlations ($p<0.05$) were also used to test for relationships between each of the three dynamic-stability index values (intact, prosthetic, and combined) and each of the stability criteria measures, for each condition.

# Chapter 4. Results

This chapter highlights the differences in stability parameters and dynamic-stability index values between limbs and conditions, and between prosthesis users and able-bodied individuals. In addition, stability parameters and the dynamic-stability index are compared to data collected using commonly used stability assessment instruments (i.e., the stability criteria measures). Figure 15 shows an example of F-Scan output for subject 2 over each condition. Figure 16 summarizes the average values obtained for each stability parameter and the dynamic-stability index.

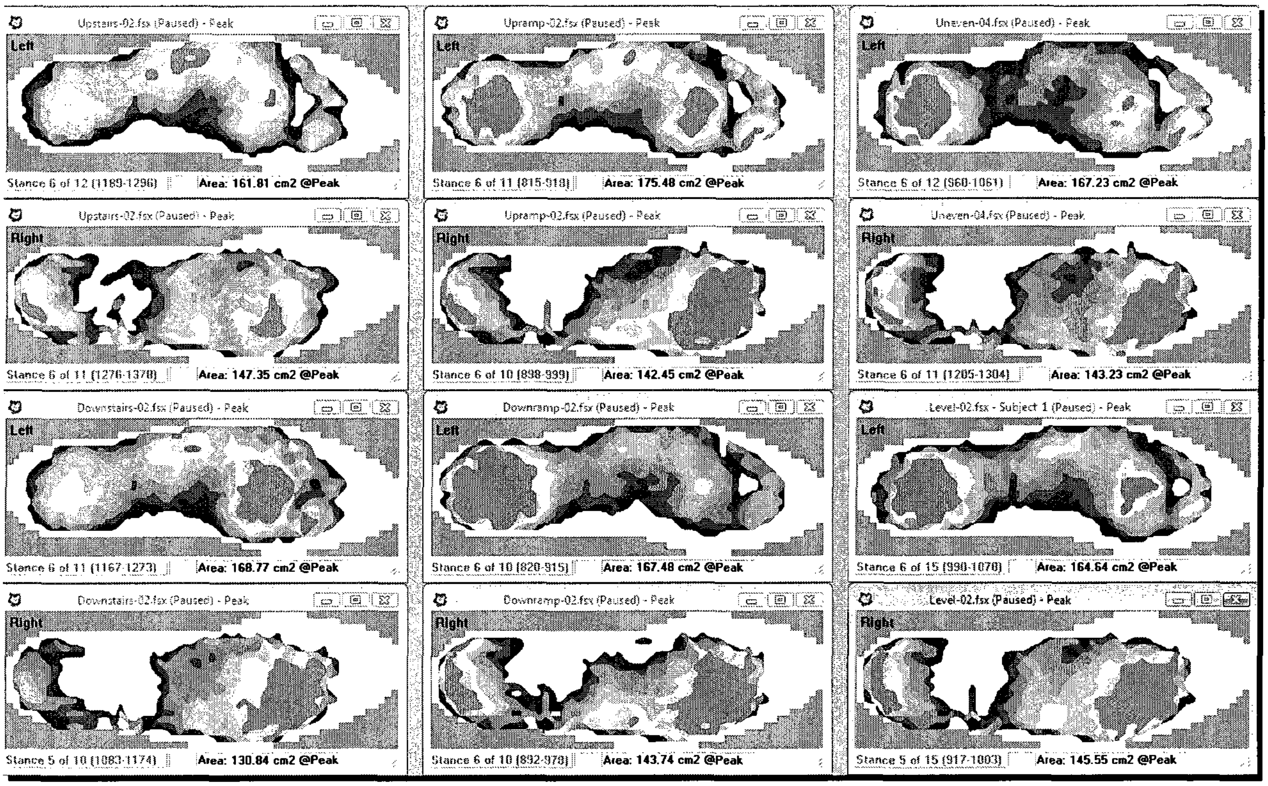
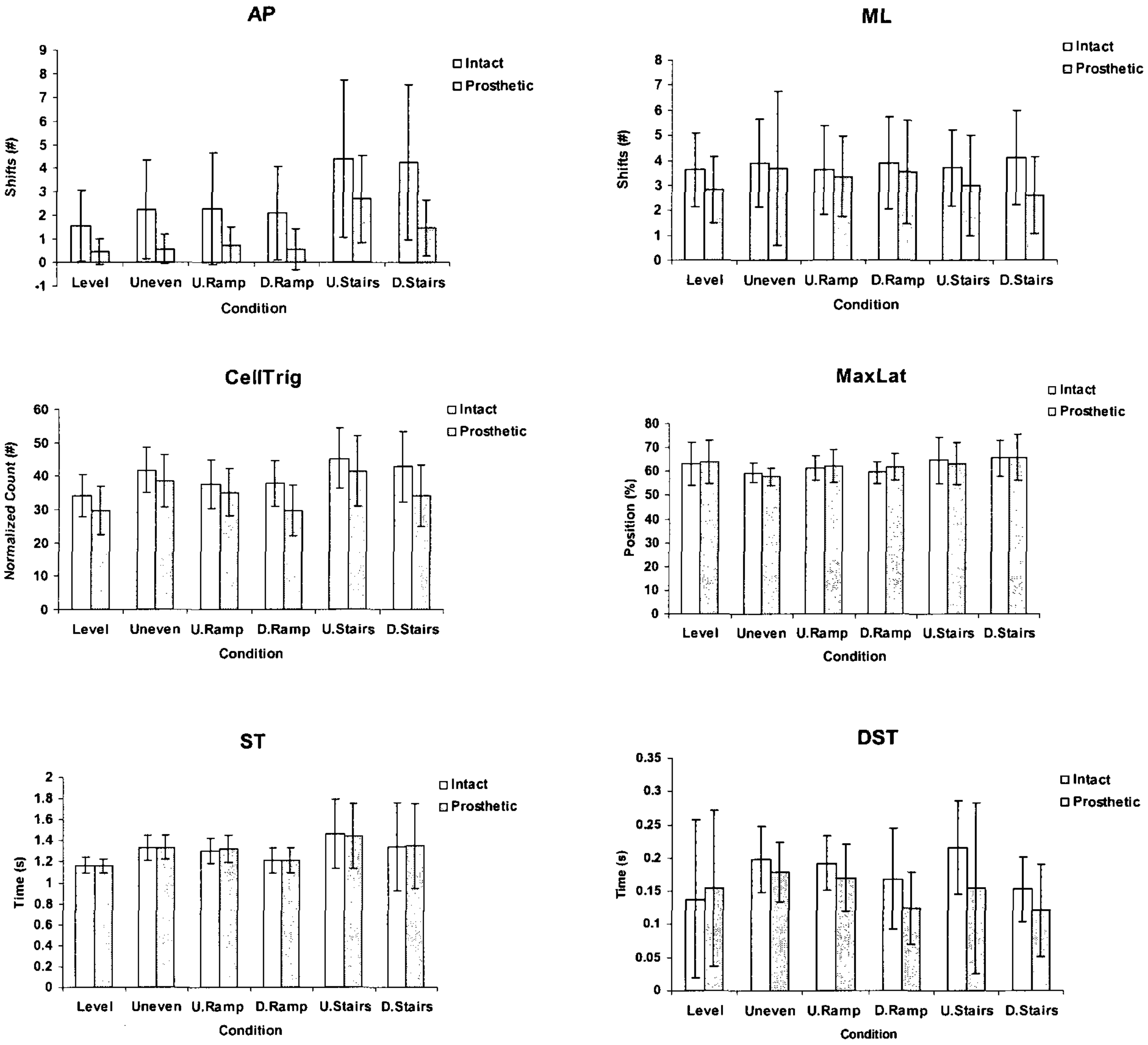


**Figure 15:** An example of F-Scan output. Images represent peak stance-phase plantar pressures for each condition. Top two rows (left to right): upstairs, upramp, and uneven ground. Bottom two rows (left to right): downstairs, downramp, level ground.



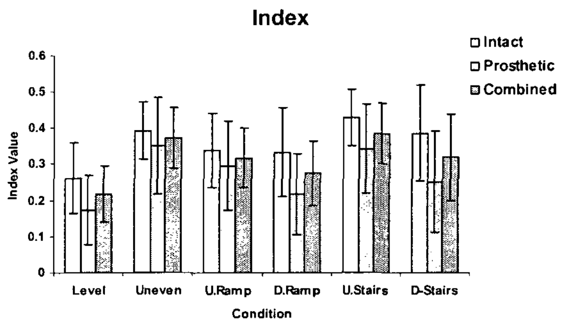


**Figure 16:** Mean and standard deviation (error bars) for each stability parameter and the dynamic-stability index for all conditions (level walking, uneven ground, upramp, downramp, upstairs, downstairs).

## 4.1 Differences Between Limbs

Paired sample t-tests were used to assess differences between the intact and prosthetic limbs for each stability parameter and the dynamic-stability index ($p<0.05$). Results are summarized in Table 8.

| **Variable** | | **Condition** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Level** | **Uneven** | **Upramp** | **Downramp** | **Upstairs** | **Downstairs** |
| **AP (#)** | Difference | 1.091 | 1.678 | 1.530 | 1.515 | 1.699 | 2.792 |
| | SD | 1.703 | 2.07 | 2.606 | 2.345 | 3.496 | 3.936 |
| | p-value | **0.010*** | **0.002*** | **0.017*** | **0.009*** | **0.043*** | **0.005*** |
| **ML (#)** | Difference | 0.785 | 0.218 | 0.271 | 0.346 | 0.690 | 1.492 |
| | SD | 1.670 | 2.926 | 1.851 | 2.018 | 2.221 | 2.239 |
| | p-value | **0.049*** | 0.742 | 0.521 | 0.452 | 0.181 | **0.008*** |
| **CellTrig (#)** | Difference | 4.251 | 3.308 | 2.450 | 8.152 | 3.762 | 8.761 |
| | SD | 9.286 | 9.161 | 10.340 | 7.931 | 9.230 | 8.527 |
| | p-value | 0.055 | 0.123 | 0.303 | **0.000*** | 0.084 | **0.000*** |
| **MaxLat (%)** | Difference | -0.798 | 1.607 | -0.926 | -2.405 | 1.521 | -0.253 |
| | SD | 7.662 | 5.727 | 9.421 | 7.592 | 13.817 | 13.793 |
| | p-value | 0.647 | 0.225 | 0.665 | 0.173 | 0.628 | 0.935 |
| **ST (s)** | Difference | 0.006 | 0.000 | -0.016 | 0.001 | 0.022 | -0.008 |
| | SD | 0.020 | 0.027 | 0.086 | 0.017 | 0.057 | 0.035 |
| | p-value | 0.165 | 0.960 | 0.401 | 0.823 | 0.102 | 0.346 |
| **DST (s)** | Difference | -0.017 | 0.019 | 0.023 | 0.043 | 0.062 | 0.032 |
| | SD | 0.226 | 0.051 | 0.038 | 0.102 | 0.129 | 0.049 |
| | p-value | 0.743 | 0.112 | **0.014*** | 0.074 | **0.046*** | **0.009*** |
| **Index** | Difference | 0.087 | 0.041 | 0.042 | 0.116 | 0.086 | 0.135 |
| | SD | 0.115 | 0.140 | 0.155 | 0.154 | 0.122 | 0.131 |
| | p-value | **0.003*** | 0.202 | 0.242 | **0.003*** | **0.005*** | **0.000*** |

**Table 8:** Mean differences and standard deviations (SD) between limbs (Intact-Prosthetic). P-values in bold and marked with an asterisk (*) represent significant differences between limbs ($p<0.05$).

### 4.1.1 AP

Average AP values for the intact limb were greater than the prosthetic limb for all conditions (Table 8). The greatest difference between limbs occurred for downstairs. Differences in AP between the intact and prosthetic limbs were significant for all conditions. The standard deviations were also much higher on the intact limb for all conditions (Figure 16).

### 4.1.2 ML

Average ML values for the intact limb were greater than the prosthetic limb for all conditions (Table 8). The greatest difference between limbs occurred for downstairs. The difference in ML between intact and prosthetic limbs was significant for level ground and downstairs. Figure 16 shows that, for most conditions, the standard deviations were similar for intact and prosthetic limbs, but for uneven ground, the standard deviation was much greater on the prosthetic side in comparison to the intact limb.

### 4.1.3 CellTrig

For CellTrig, the average values were greater for the intact limb for all conditions (Table 8). The differences between the intact and prosthetic limb were only significant for downramp and downstairs.

### 4.1.4 MaxLat

For MaxLat, average values were greater on the intact side for two conditions (uneven and upstairs) and greater on the prosthetic side for four conditions (level, upramp, downramp, and downstairs) (Table 8). There were no significant differences between limbs.

### 4.1.5 ST

Average ST values for intact and prosthetic limbs were very similar (Table 8). In fact, no differences between intact and prosthetic limbs were statistically significant.

### 4.1.6 DST

Average DST was greater on the intact limb for all conditions except level ground (Table 8). The difference in average DST between limbs was significant for upramp, upstairs, and downstairs.

### 4.1.7 Index

The average value for the dynamic-stability index was consistently greater on the intact limb than the prosthetic limb (Table 8). The difference between limbs was significant for level ground, downramp, upstairs, and downstairs.

### 4.1.8 Summary

For all variables except MaxLat and ST, a significant difference existed between limbs for at least one walking condition. For AP, ML, CellTrig and the index, all intact limb outcomes were greater than the prosthetic limb. There were cases where the outcomes for the prosthetic limb were greater than the intact limb; however, these differences were not significant. Significant differences between limbs occurred most often for AP (all six conditions). The stability index was significantly different between limbs for four of six conditions. When all variables were considered, significant differences between limbs mainly occurred for downstairs (five of seven variables).

## 4.2 Differences Between Conditions

One-way ANOVAs were used to compare stability parameter and dynamic-stability index values over conditions (p<0.05). Results are summarized in Table 9.

| Variable | Limb | ANOVA p-values | Significantly Different Conditions | Bonferroni p-values |
|---|---|---|---|---|
| **AP(#)** | Intact | 0.001 | Upstairs > Level | 0.008 |
| | | | Downstairs > Level | 0.015 |
| | Prosthetic | 0.000 | Upstairs > Level | 0.000 |
| | | | Upstairs > Uneven | 0.000 |
| | | | Upstairs > Upramp | 0.000 |
| | | | Upstairs > Downramp | 0.000 |
| | | | Upstairs > Downstairs | 0.006 |
| **ML (#)** | Intact | 0.936 | | |
| | Prosthetic | 0.519 | | |
| **CellTrig (#)** | Intact | 0.000 | Uneven > Level | 0.033 |
| | | | Upstairs > Level | 0.000 |
| | | | Downstairs > Level | 0.008 |
| | | | Upstairs > Upramp | 0.044 |
| | Prosthetic | 0.000 | Upstairs > Level | 0.000 |
| | | | Upstairs > Downramp | 0.000 |
| | | | Uneven > Level | 0.017 |
| | | | Uneven > Downramp | 0.015 |
| **MaxLat (%)** | Intact | 0.021 | | |
| | Prosthetic | 0.036 | Downstairs > Uneven | 0.018 |
| **ST (s)** | Intact | 0.003 | Upstairs > Level | 0.002 |
| | | | Upstairs > Downramp | 0.019 |
| | Prosthetic | 0.002 | Upstairs > Level | 0.002 |
| | | | Upstairs > Downramp | 0.030 |
| **DST (s)** | Intact | 0.007 | Upstairs > Level | 0.014 |
| | Prosthetic | 0.180 | | |
| **Index** | Intact | 0.000 | Uneven > Level | 0.002 |
| | | | Upstairs > Level | 0.000 |
| | | | Downstairs > Level | 0.003 |
| | Prosthetic | 0.000 | Uneven > Level | 0.000 |
| | | | Upramp > Level | 0.029 |
| | | | Upstairs > Level | 0.000 |
| | | | Uneven > Downramp | 0.011 |
| | | | Upstairs > Downramp | 0.023 |
| | Combined Limbs | 0.000 | Uneven > Level | 0.000 |
| | | | Upramp > Level | 0.101 |
| | | | Upstairs > Level | 0.000 |
| | | | Downstairs > Level | 0.008 |
| | | | Uneven > Downramp | 0.015 |
| | | | Upstairs > Downramp | 0.003 |

**Table 9:** Significant differences between conditions, according to post-hoc Bonferroni tests (p<0.05).

### 4.2.1 AP

For AP, condition had a significant effect on the intact limb (F (5,114) = 4.571, p=0.001) and the prosthetic limb (F (5,114) =13.264, p=0.000). For the intact limb, AP was significantly greater for upstairs and downstairs when compared to level ground. On the prosthetic side, AP was greater for upstairs than for all other conditions.

### 4.2.2 ML

Condition did not have an effect on ML for the intact limb (F (5,114) =0.256, p=0.936) or the prosthetic limb (F (5,114) =0.848, p=0.519). There were no significant differences between any conditions for either foot.

### 4.2.3 CellTrig

CellTrig was affected by walking condition for the intact limb (F (5,114) =5.480, p=0.000) and the prosthetic limb (F (5,114) =6.452, p=0.000). For the intact limb, CellTrig for uneven ground, upstairs, and downstairs, was significantly greater than level ground. In addition, upstairs was significantly greater than upramp. On the prosthetic side, CellTrig was significantly greater for upstairs than level ground and downramp. CellTrig was also significantly greater for uneven ground than level ground and downramp.

### 4.2.4 MaxLat

MaxLat was affected by walking condition for the intact limb (F (5,114) = 2.783, p=0.021), however, post-hoc analysis did not indicate differences between any conditions. For the prosthetic limb, walking condition affected MaxLat (F (5,114) = 2.478, p=0.036) such that MaxLat was significantly greater downstairs than for uneven ground.

### 4.2.5 ST

For ST, condition had an effect for the intact limb (F (5,114) = 3.902, p=0.003) and the prosthetic limb (F (5,114) = 3.992, p=0.002). For both legs, upstairs was significantly greater than level ground and downramp.

### 4.2.6 DST

DST was affected by walking condition for the intact limb (F (5,114) =3.356, p=0.007) but not for the prosthetic limb (F (5,114) =1.549, p=0.180). For the intact limb, DST was greater for upstairs than level ground walking.

### 4.2.7 Index

Condition had an effect on the dynamic-stability index for the intact limb (F (5,114) =6.448, p=0.000), the prosthetic limb (F (5,114) =6.690, p=0.000), and the combined value for both limbs (F (5,114) =9.502, p=0.000). For the intact limb, the index values for uneven ground, upstairs, and downstairs were significantly greater than for level ground. For the prosthetic limb, the index values for uneven ground, upramp, and upstairs were significantly greater than for level ground. In addition, uneven and upstairs were greater than downramp. The combined index values for uneven ground, upramp, upstairs, and downstairs were all significantly greater than for level ground. In addition, the combined index value was significantly greater for uneven and upstairs than for downramp.

### 4.2.8 Summary

Condition had an effect on every stability parameter with the exception of ML, for at least one limb. CellTrig had more significant differences between conditions than any other parameter (four for intact, four for prosthetic). The condition that was most often significantly different from other conditions was upstairs (six times for intact, nine times for prosthetic).

For the dynamic-stability index there were a greater number of significant differences between conditions for the combined index (six significant differences) than the index for each individual limb (three for intact and five for prosthetic). The condition that was most often significant from other conditions was level ground (ten significant differences).

## 4.3 Comparison to Able-Bodied Data

Independent samples t-tests were used to compare data collected from unilateral transtibial prosthesis users for six walking conditions to previously collected data from able-bodied individuals walking on level ground [4,5].

### 4.3.1 AP

For both limbs, AP was less than able-bodied for level ground, uneven ground, upramp, and downramp (Table 10). For upstairs, AP for both limbs was greater than able-bodied. For downstairs, AP was greater than able-bodied on the intact limb, but less than able-bodied on the prosthetic limb. In terms of significant differences, AP on the intact limb was significantly greater than able-bodied for upstairs and downstairs. For the prosthetic limb, AP was significantly less than able-bodied for all conditions, with the exception of upstairs.

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 2.496 | | | | | |
| | SD | 1.175 | | | | | |
| I | Mean | 1.548 | 2.235 | 2.282 | 2.086 | 4.379 | 4.247 |
| | SD | 1.497 | 2.085 | 2.372 | 1.991 | 3.336 | 3.28 |
| | p-value | 0.051 | 0.666 | 0.728 | 0.451 | **0.028*** | **0.037*** |
| P | Mean | 0.456 | 0.556 | 0.752 | 0.571 | 2.680 | 1.455 |
| | SD | 0.535 | 0.614 | 0.748 | 0.865 | 1.835 | 1.187 |
| | p-value | **0.000*** | **0.000*** | **0.000*** | **0.000*** | 0.737 | **0.015*** |

**Table 10:** AP means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking ($p<0.05$).

### 4.3.2 ML

ML was less than able-bodied for all conditions, for both limbs (Table 11). For the intact limb, ML was significantly less than able-bodied for level ground, upramp, and upstairs. On the prosthetic limb, ML was significantly less than able-bodied for all conditions except uneven ground.

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 4.967 | | | | | |
| | SD | 1.334 | | | | | |
| I | Mean | 3.622 | 3.897 | 3.618 | 3.888 | 3.703 | 4.114 |
| | SD | 1.486 | 1.765 | 1.78 | 1.851 | 1.526 | 1.883 |
| | p-value | **0.009*** | 0.058 | **0.020*** | 0.065 | **0.015*** | 0.145 |
| P | Mean | 2.838 | 3.680 | 3.347 | 3.542 | 3.013 | 2.622 |
| | SD | 1.320 | 3.085 | 1.597 | 2.068 | 2.014 | 1.534 |
| | p-value | **0.000*** | 0.141 | **0.003*** | **0.026*** | **0.003*** | **0.000*** |

**Table 11:** ML means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking (p<0.05).

### 4.3.3 CellTrig

CellTrig was greater than able-bodied for both limbs for all conditions (Table 12). On the intact limb, CellTrig was significantly greater than able-bodied for all conditions. On the prosthetic limb CellTrig was significantly greater than able-bodied for all conditions except level ground and downramp.

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 29.075 | | | | | |
| | SD | (4.568) | | | | | |
| I | Mean | 33.960 | 41.824 | 37.634 | 37.741 | 45.260 | 42.867 |
| | SD | 6.305 | 6.754 | 7.318 | 6.746 | 9.041 | 10.577 |
| | p-value | **0.016*** | **0.000*** | **0.000*** | **0.000*** | **0.000*** | **0.000*** |
| P | Mean | 29.709 | 38.516 | 35.184 | 29.589 | 41.498 | 34.106 |
| | SD | 7.318 | 7.835 | 7.087 | 7.629 | 10.547 | 9.132 |
| | p-value | 0.770 | **0.000*** | **0.006*** | 0.806 | **0.000*** | **0.041*** |

**Table 12:** CellTrig means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking (p<0.05).

### 4.3.4 MaxLat

MaxLat was greater than able-bodied for level ground, upstairs, and downstairs for both limbs (Table 13). Overall, the values for intact and prosthetic limbs were very close to able-bodied. The only significant difference was between able-bodied and the prosthetic limb for uneven ground (P<A).

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 62.372 | | | | | |
| | SD | 6.480 | | | | | |
| I | Mean | 63.183 | 59.397 | 61.262 | 59.536 | 64.746 | 65.575 |
| | SD | 9.137 | 4.149 | 5.159 | 4.504 | 9.649 | 7.610 |
| | p-value | 0.772 | 0.108 | 0.576 | 0.136 | 0.417 | 0.199 |
| P | Mean | 63.981 | 57.790 | 62.188 | 61.942 | 63.225 | 65.828 |
| | SD | 9.153 | 3.793 | 7.024 | 5.541 | 8.841 | 9.803 |
| | p-value | 0.566 | **0.013*** | 0.937 | 0.834 | 0.755 | 0.245 |

**Table 13:** MaxLat means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking (p<0.05).

### 4.3.5 ST

ST was significantly greater than able-bodied all conditions, for both limbs for (Table 14).

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 1.065 | | | | | |
| | SD | 0.090 | | | | | |
| I | Mean | 1.166 | 1.335 | 1.304 | 1.217 | 1.462 | 1.342 |
| | SD | 0.073 | 0.114 | 0.123 | 0.121 | 0.332 | 0.417 |
| | p-value | **0.001*** | **0.000*** | **0.000*** | **0.000*** | **0.000*** | **0.009*** |
| P | Mean | 1.160 | 1.335 | 1.320 | 1.216 | 1.441 | 1.350 |
| | SD | 0.068 | 0.116 | 0.130 | 0.118 | 0.306 | 0.401 |
| | p-value | **0.001*** | **0.000*** | **0.000*** | **0.000*** | **0.000*** | **0.006*** |

**Table 14:** ST means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking (p<0.05).

### 4.3.6 DST

DST was greater than able-bodied for all conditions except for downramp and downstairs on the prosthetic side (Table 15). DST on the intact limb was significantly greater than able-bodied for uneven ground, upramp and upstairs. On the prosthetic side, double support time was significantly greater than able-bodied for uneven ground.

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 0.130 | | | | | |
| | SD | 0.093 | | | | | |
| I | Mean | 0.138 | 0.198 | 0.192 | 0.168 | 0.216 | 0.153 |
| | SD | 0.119 | 0.050 | 0.041 | 0.076 | 0.071 | 0.049 |
| | p-value | 0.833 | **0.009*** | **0.011*** | 0.191 | **0.004*** | 0.359 |
| P | Mean | 0.155 | 0.179 | 0.170 | 0.125 | 0.154 | 0.121 |
| | SD | 0.118 | 0.045 | 0.050 | 0.054 | 0.128 | 0.070 |
| | p-value | 0.507 | **0.047*** | 0.116 | 0.843 | 0.537 | 0.738 |

**Table 15:** DST means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking ($p<0.05$).

### 4.3.7 Index values

Index values for prosthesis users were greater than able-bodied for all conditions, except for level ground on the prosthetic limb (Table 16). Index values for the intact limb and combined limbs were significantly greater than able-bodied for all conditions except level ground. For the prosthetic limb, the index value for uneven, upramp, and upstairs, were significantly greater than able-bodied.

| Limb | | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|---|
| A | Mean | 0.213 | | | | | |
| | SD | 0.071 | | | | | |
| I | Mean | 0.261 | 0.393 | 0.339 | 0.334 | 0.429 | 0.387 |
| | SD | 0.980 | 0.079 | 0.103 | 0.123 | 0.078 | 0.132 |
| | p-value | 0.115 | **0.000*** | **0.000*** | **0.001*** | **0.000*** | **0.000*** |
| P | Mean | 0.175 | 0.352 | 0.297 | 0.218 | 0.343 | 0.252 |
| | SD | 0.097 | 0.133 | 0.123 | 0.111 | 0.123 | 0.140 |
| | p-value | 0.205 | **0.000*** | **0.016*** | 0.876 | **0.000*** | 0.292 |
| C | Mean | 0.218 | 0.372 | 0.318 | 0.276 | 0.386 | 0.319 |
| | SD | 0.079 | 0.085 | 0.082 | 0.088 | 0.083 | 0.119 |
| | p-value | 0.847 | **0.000*** | **0.000*** | **0.030*** | **0.000*** | **0.004** |

**Table 16:** Index means and standard deviations (SD) for able-bodied (A) and prosthesis users (I=Intact Limb; P=Prosthetic Limb; C=Combined Limbs). P-values in bold and marked with an asterisk (*) denote a significant difference from able-bodied level-ground walking ($p<0.05$).

### 4.3.8 Summary

In the majority of cases (55 out of 90), there was a significant difference ($p<0.05$) between variables when prosthesis user data and able-bodied data were compared. Of all parameters, ST was most frequently significantly different from able-bodied (12 out of 12 cases). MaxLat was the variable that was significantly different from able-bodied for the least number of cases (one out of 12).

## 4.4 Relationship to Stability Criteria Measures

Table 17 contains stability criteria scores for all subjects. Pearson correlations were used to evaluate relationships between each stability parameter and index value for each condition, and each of three stability criteria measures (PEQ, BBS, CBMS).

| Subject | PEQ | BBS | CBMS |
|---|---|---|---|
| 1 | 94.01 | 55 | 71 |
| 2 | 52.08 | 53 | 33 |
| 3 | 59.11 | 47 | 34 |
| 4 | 81.77 | 47 | 41 |
| 5 | 83.46 | 56 | 67 |
| 6 | 72.53 | 39 | 25 |
| 7 | 39.97 | 41 | 16 |
| 8 | 84.38 | 52 | 66 |
| 9 | 81.77 | 49 | 61 |
| 10 | 43.36 | 47 | 39 |
| 11 | 68.49 | 56 | 76 |
| 12 | 77.34 | 52 | 52 |
| 13 | 87.76 | 56 | 41 |
| 14 | 59.24 | 56 | 59 |
| 15 | 79.43 | 55 | 64 |
| 16 | 79.95 | 52 | 40 |
| 17 | 78.13 | 56 | 74 |
| 18 | 81.51 | 53 | 74 |
| 19 | 88.02 | 53 | 58 |
| 20 | 75.39 | 43 | 18 |
| Mean | 73.39 | 50.90 | 50.45 |
| SD | 14.66 | 5.16 | 18.72 |

**Table 17:** Stability criteria measure scores for each subject.

### 4.4.1 PEQ

Pearson correlation results for the PEQ are summarized in Table 18. For the PEQ ambulation score, only three of a possible 90 (3.3%) correlations were significant. For the intact limb, $ST_{\text{upstairs}}$ was negatively correlated with PEQ scores. For the prosthetic limb, $ML_{\text{upramp}}$ and $DST_{\text{upstairs}}$ were negatively correlated with the PEQ. There were no statistically significant correlations between the dynamic-stability index and the PEQ ambulation scale. There were no strong correlations $(-0.6 \leq r \leq 0.6)$.

| | Condition | | | | | |
|---|---|---|---|---|---|---|
| | **Level** | **Uneven** | **Upramp** | **Downramp** | **Upstairs** | **Downstairs** |
| **Parameter** | Intact | | | | | |
| AP (#) | -0.067 | -0.342 | -0.025 | -0.165 | -0.330 | -0.247 |
| ML (#) | -0.132 | -0.200 | -0.193 | -0.044 | -0.033 | 0.204 |
| CellTrig (#) | 0.011 | 0.020 | 0.075 | -0.007 | 0.002 | -0.023 |
| MaxLat (%) | -0.405 | -0.320 | -0.243 | -0.375 | -0.347 | -0.109 |
| ST (s) | -0.168 | -0.277 | -0.368 | -0.202 | **-0.445*** | -0.337 |
| DST (s) | -0.017 | -0.176 | -0.232 | -0.240 | -0.257 | -0.363 |
| **Parameter** | Prosthetic | | | | | |
| AP (#) | 0.288 | -0.069 | 0.087 | -0.337 | -0.339 | -0.069 |
| ML (#) | -0.335 | -0.317 | **-0.570**** | -0.309 | -0.147 | -0.284 |
| CellTrig (#) | 0.261 | 0.262 | 0.177 | 0.237 | -0.089 | 0.045 |
| MaxLat (%) | -0.248 | -0.237 | -0.115 | -0.139 | 0.101 | 0.024 |
| ST (s) | -0.231 | -0.328 | -0.322 | -0.189 | -0.432 | -0.309 |
| DST (s) | -0.074 | -0.196 | -0.300 | -0.127 | **-0.522*** | -0.241 |
| **Index** | | | | | | |
| Intact | -0.363 | -0.057 | -0.163 | -0.246 | 0.270 | -0.200 |
| Prosthetic | -0.129 | 0.174 | -0.072 | -0.099 | -0.071 | -0.108 |
| Combined | -0.305 | 0.110 | -0.155 | -0.234 | 0.074 | -0.174 |

**Table 18:** Pearson correlations between the PEQ ambulation scale scores and each condition+variable. Pearson's *r* values are presented for each variable and condition. Significant differences are in bold and marked with an asterisk (* = $p<0.05$; ** = $p< 0.01$).

### 4.4.2 BBS

Pearson correlation results for the BBS are summarized in Table 19. For the BBS, 37 out of 90 (41.1 %) correlations were significant. For the stability parameters, there were more significant correlations for the prosthetic side than the intact side (19 vs. 11). All significant correlations were negative. There were five strong correlations for the intact limb ($AP_{downramp}$, $ST_{upramp}$, $ST_{downramp}$, $ST_{upstairs}$, $ST_{downstairs}$) and eight strong correlations for the prosthetic limb ($ML_{level}$, $ML_{uneven}$, $ML_{upstairs}$, $ML_{downstairs}$, $ST_{downramp}$, $ST_{upstairs}$, $ST_{downstairs}$, $DST_{level}$). For the dynamic-stability index, there was one significant correlation for the intact limb (level ground), three for the prosthetic limb (upramp, upstairs, and downstairs), and three for the combined limbs (level, upramp, and downstairs). There were no strong correlations for the dynamic-stability index. When examining condition, the greatest number of significant correlations occurred for upstairs.

| | **Condition** | | | | | |
|---|---|---|---|---|---|---|
| | **Level** | **Uneven** | **Upramp** | **Downramp** | **Upstairs** | **Downstairs** |
| **Parameter** | Intact | | | | | |
| AP (#) | -0.309 | **-0.556*** | -0.354 | **-0.624**** | **-0.477*** | **-0.491*** |
| ML (#) | 0.137 | 0.044 | -0.023 | -0.134 | -0.021 | 0.048 |
| CellTrig (#) | -0.065 | -0.084 | -0.071 | 0.031 | -0.301 | -0.315 |
| MaxLat (%) | 0.074 | 0.020 | -0.052 | -0.175 | 0.181 | -0.108 |
| ST (s) | -0.406 | -0.435 | **-0.609**** | **-0.680**** | **-0.752**** | **-0.609**** |
| DST (s) | 0.342 | -0.280 | **-0.581**** | **-0.537*** | **-0.531*** | -0.285 |
| **Parameter** | Prosthetic | | | | | |
| AP (#) | 0.382 | -0.169 | 0.220 | 0.073 | **-0.518*** | 0.097 |
| ML (#) | **-0.625**** | **-0.710**** | **-0.563**** | **-0.500*** | **-0.705**** | **-0.785**** |
| CellTrig (#) | -0.034 | -0.224 | -0.327 | -0.108 | **-0.528*** | -0.441 |
| MaxLat (%) | 0.168 | -0.334 | **-0.515*** | -0.271 | 0.021 | -0.166 |
| ST (s) | **-0.461*** | **-0.473*** | **-0.585**** | **-0.658**** | **-0.689**** | **-0.606**** |
| DST (s) | **-0.613**** | **-0.516*** | **-0.565**** | -0.208 | **-0.460*** | -0.299 |
| **Index** | | | | | | |
| Intact | **-0.476*** | -0.224 | -0.239 | -0.154 | -0.175 | -0.396 |
| Prosthetic | -0.368 | -0.216 | **-0.527*** | -0.442 | **-0.463*** | **-0.530*** |
| Combined | **-0.523*** | -0.275 | **-0.543*** | -0.386 | -0.425 | **-0.531*** |

**Table 19:** Pearson correlations between the BBS scores each condition+variable. Pearson's *r* values are presented for each variable and condition. Significant differences are in bold and marked with an asterisk (* = p<0.05; ** = p< 0.01).

### 4.4.3 CBMS

The CBMS had 31 significant correlations out of a possible 90 (34%), all of which were negative, except $AP_{level}$ (Table 20). For the stability parameters, there were 14 significant correlations for the intact limb and 15 for the prosthetic limb. There were four strong correlations for the intact limb ($ST_{upstairs}$, $ST_{downstairs}$, $DST_{upramp}$, $DST_{downramp}$), and three for the prosthetic limb ($ML_{downstairs}$, $ST_{upstairs}$, $ST_{downstairs}$). For the stability index there were two significant correlations; however, neither of these were strong correlations. There were no significant correlations between CBMS and CellTrig or MaxLat for either limb, for any condition.

| | **Condition** | | | | | |
|---|---|---|---|---|---|---|
| | **Level** | **Uneven** | **Upramp** | **Downramp** | **Upstairs** | **Downstairs** |
| **Parameter** | Intact | | | | | |
| AP (#) | -0.408 | **-0.598**** | -0.401 | **-0.572**** | **-0.526*** | **-0.563**** |
| ML (#) | 0.041 | 0.126 | 0.056 | 0.054 | 0.048 | -0.009 |
| CellTrig (#) | -0.019 | -0.136 | -0.050 | 0.124 | -0.170 | -0.281 |
| MaxLat (%) | -0.235 | 0.024 | -0.158 | -0.291 | 0.088 | 0.095 |
| ST (s) | -0.398 | **-0.500*** | **-0.574**** | **-0.496*** | **-0.826**** | **-0.669**** |
| DST (s) | 0.110 | **-0.539*** | **-0.688**** | **-0.606**** | **-0.593**** | **-0.496*** |
| **Parameter** | Prosthetic | | | | | |
| AP (#) | **0.502*** | 0.113 | 0.410 | 0.104 | **-0.581**** | 0.236 |
| ML (#) | **-0.451*** | **-0.526*** | **-0.505*** | -0.424 | **-0.567**** | **-0.668**** |
| CellTrig (#) | 0.150 | 0.110 | 0.033 | 0.190 | -0.394 | -0.223 |
| MaxLat (%) | -0.144 | -0.316 | -0.350 | -0.207 | 0.173 | -0.017 |
| ST (s) | **-0.522*** | **-0.578**** | -0.438 | **-.464*** | **-0.822**** | **-0.657**** |
| DST (s) | -0.409 | **-0.524*** | **-0.596**** | -0.212 | **-0.476*** | -0.381 |
| **Index** | | | | | | |
| Intact | **-0.489*** | -0.144 | -0.178 | -0.117 | 0.090 | -0.320 |
| Prosthetic | -0.383 | 0.040 | -0.367 | -0.272 | -0.276 | -0.287 |
| Combined | **-0.540*** | -0.036 | -0.385 | -0.253 | -0.162 | -0.346 |

**Table 20:** Pearson correlations between the CBMS scores and each condition+variable. Pearson's *r* values are presented for each variable and condition. Significant differences are in bold and marked with an asterisk (* = $p<0.05$; ** = $p< 0.01$).

# Chapter 5. Discussion

The stability parameters and dynamic-stability index seem promising in their usefulness for assessing stability in individuals with transtibial amputations. Stability parameter and index values for the test population differed between limbs, between conditions, and in comparison to normative data. There were few strong linear correlations between stability parameters and criteria measures, and even fewer between index values and criteria measures.

## 5.1 Differences Between Limbs

Although it was hypothesized that the intact limb would be more stable than the prosthetic limb, comparisons between limbs indicated decreased dynamic stability on the intact limb, as evidenced by higher stability parameter and index values, with few exceptions. As shown in Table 8, MaxLat values were higher on the prosthetic side for four conditions, ST values are greater on the prosthetic limb for two conditions, and DST values were greater on the prosthetic limb for one condition; however, for these three parameters, values for intact and prosthetic limbs were very close and the differences negligible (i.e., thousandths of a second for ST).

The observed differences between limbs were not often statistically significant. AP was significantly different between limbs for all six conditions, and the dynamic-stability index was significantly different between limbs for four conditions, while the remainder of variables were significantly different between limbs for three conditions or less. The lack of significant differences between the two limbs, especially for ST, may be related to a rehabilitation approach that focuses on producing a gait that appears able-bodied (i.e., symmetrical). More likely, however, is that the lack of significant differences was due to a small study sample with high inter-subject variability. This was evidenced by high standard deviations that were nearly double the mean in some cases (i.e., $AP_{upramp}$, $DST_{level}$). High variability is expected when working with individuals with physical disabilities since it is difficult to obtain a homogenous study sample. For example, several individuals in this study were former Paralympic athletes, while others suffered from diabetes related neuropathy, and even partial vision loss.

For all variables, where significant differences existed between limbs, values for the intact limb were greater than the prosthetic limb. Although greater numbers indicated decreased dynamic stability, the argument that the intact limb was less stable than the prosthetic limb is not straightforward. According to the definition used in this study, dynamic stability is, "the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition" [3]. This definition implies that the ability to adapt to disturbances is an integral aspect of dynamic stability. It can be argued that the intact limb carries the majority of the responsibility for adapting to and correcting for changes in body equilibrium during walking. The foot and ankle on the intact side are capable of a greater range of 3D motion and have the musculature and neurological capacity to actively control 3D movement. In contrast, the prosthetic limb is typically fabricated out of stiffer materials to provide safety and a sense of security and designed to allow passive control with some energy storage and return during walking. Individuals with amputations also have reduced proprioception in the prosthetic limb that would that would hinder their ability to correct for changes in walking surface.

By compensating on the intact limb, use of the prosthetic limb may be optimized to promote smooth transition over the prosthetic side, maximize energy storage and return, and facilitate forward progression. Adapting on the intact limb can improve a person's overall dynamic stability.

## 5.2 Differences Between Conditions

When examining variables for each condition, there were significant differences between some variables, for some conditions. In addition, stability parameters and index values were affected differently for each foot.

In previous research on the dynamic-stability index [4,5], subjects were tested over conditions of increasing instability. In this study, tasks did not increase in difficulty; however, it was believed that subjects would be most stable on level ground and least stable for upstairs. At the very least, stability parameter and index values for level ground should be more stable in comparison to other conditions, given that level ground is the least challenging and most commonly encountered condition. When examining the stability parameters, upstairs differed most often from other conditions, and most often from level ground. In addition, when all three dynamic-stability indices were considered (intact, prosthetic, combined limbs), values for level ground were significantly less than other conditions most often. These two findings indicated that the stability parameters, and the dynamic-stability index, were sensitive to differences between conditions of highest and lowest dynamic stability.

Differences between intact and prosthetic limbs were also evident when comparing each variable across conditions. For all parameters except ML and ST, for which similar results occurred for each limb, significant differences between conditions for the intact limb were not the same conditions that were significantly different for the prosthetic limb. This showed that both limb and condition affected the values obtained for each stability parameter and the dynamic-stability index. Condition did not affect ML for either limb. ML may not be a good indicator of stability in this population, or perhaps the threshold used to identify abnormal perturbations (established using able-bodied individuals) may need to be adjusted. Another possible explanation could be that individuals who use a prosthesis develop a gait pattern that has less side-to-side motion, resulting in lower ML values and less variability across conditions (i.e., optimized for forward progression).

When examining stability parameters, upstairs differed from other conditions most frequently (six times for intact and nine times prosthetic), emphasizing the importance of examining stability for this condition. When all parameters are considered, CellTrig was affected by condition most often (four times for each limb). For the dynamic-stability index, condition affected the combined-limb value more frequently than values for each individual limb. In this case, taking an average value of the intact and prosthetic limbs increased the differences between several conditions to the point that they became statistically significant, indicating that a combined index value was more sensitive at detecting differences between conditions.

## 5.3 Comparison to Able-Bodied Data

When variables for individuals with transtibial amputations were compared to able-bodied data, 61% of the differences were significant. Where significant differences existed between able-bodied and test data, several trends were evident. For AP, able-bodied data was significantly greater than prosthesis-user data for all conditions except for upstairs and downstairs on the intact limb. For ML, able-bodied values were also significantly greater than values for the intact and prosthetic limb for all conditions. Since increased stability is associated with fewer shifts in CoP trajectory, it was surprising that level ground AP and ML values for able-bodied individuals were greater than values for individuals with amputations for the more demanding conditions (i.e., uneven ground, ramps ). One explanation is that prosthetic gait is less active, resulting in fewer A/P and M/L adjustments, while in able-bodied gait both limbs are actively adjusting.

Although values for AP and ML were higher for able-bodied individuals in comparison to test data for the majority of cases, CellTrig values were lower. AP, ML, and CellTrig are all indicative of foot perturbations. Small, fast perturbations may cause high CellTrig but low AP and ML since the perturbations may not be large enough to exceed established thresholds for AP and ML. Low CellTrig and high AP and ML can occur when the foot maintains contact with the ground (i.e., no cells are turned on or off) but there is a shift in body weight that causes pressure changes under the foot, which affect the CoP and result in increased values for AP and ML. The latter scenario is difficult to achieve.

ST for test subjects was significantly greater than for the able-bodied group for all conditions. This shows that individuals with transtibial amputations walk slower than able-bodied.

For DST, differences between able-bodied and prosthesis users were only significant in four cases. On the intact limb, DST was significantly greater than able-bodied for uneven, upramp and upstairs. For the prosthetic limb, DST was significantly greater than able-bodied for uneven ground. During upramp and upstairs, increased DST on the intact limb was related to the increased need for weight bearing on the intact limb as the individual attempted to advance the prosthetic leg. For uneven ground, DST was greater than able-bodied for both limbs. Since the foam mats were not consistently dense throughout, prolonged DST may be related to a protective gait pattern [70], whereby prosthesis users took the time to ensure that their foot was safely positioned before moving into single support. In addition, increased DST on the prosthetic limb may have been greater than able-bodied DST because, unlike walking on hard surfaces, walking on a foam mat does not promote rollover on the prosthetic foot. Without an ankle to assist in forward propulsion, shifting body weight completely onto the contralateral limb is hindered, increasing the amount of time spent in double support.

In terms of the dynamic-stability index, there was a significant difference between able-bodied and prosthesis users for five of six conditions on the intact limb, three of six conditions on the prosthetic limb, and five of six conditions for the combined dynamic-stability index value. As expected, for all cases where there was a significant difference, values for the prosthesis users were greater than able-bodied. The intact limb differed from able-bodied more often than the prosthetic limb, indicating that the intact limb was more unstable over more conditions than the prosthetic limb. Although the limb was more unstable, it was also better able to cope with instability by making the necessary compensations required to continue walking.

## 5.4 Relationship to Stability Criteria Measures

As with evaluating any new tool, stability parameters and index values were compared to several stability criteria instruments. For all variables, negative correlations were expected since lower values for these variables indicate improved dynamic stability, while higher scores for the criteria measures indicate improved stability.

The researchers hypothesized that the stability parameters and index values would correlate with the stability criteria measures; however, this did not occur. The BBS had more significant correlations than the CBMS and the PEQ. For the BBS, almost half of all correlations were significant, with most of these occurring on the prosthetic limb. Even when correlations were significant, most correlations were not strong ($-0.6 \leq r \leq 0.6$).

The low number of strong and statistically significant correlations was likely due to the "stability criteria instruments". The BBS and CMBS were not designed specifically for individuals with amputations [25,35], so the low number of strong, negative correlations may indicate that these tests are not valid dynamic stability measures for the study population. For the CBMS, several individuals could not even attempt certain tasks, such as hopping forward on one foot, crouching and walking, and running. The PEQ was designed for individuals with amputations, but the limitations of this instrument became evident over the course of the study. Specifically, several people expressed difficulty understanding questions and the researcher observed many people having trouble comprehending the concept of the visual analog scale. Participants did not seem to understand that their mark on the scale was going to be measured. Instead, they marked in the general vicinity of the beginning or the end of the scale. In short, the PEQ was highly dependent to the subject's interpretation of the instructions.

## 5.5 Summary

This study highlighted the asymmetry present in the gait of individuals with transtibial amputations. Overall, the values obtained for each limb indicated that the intact limb was less stable than the prosthetic limb; however, this may be less accurate than describing the intact limb as more adaptable, therefore having an increased capacity for stability. Similarly, describing the prosthetic limb as more stable may not be as accurate as describing it as having a reduced capacity to adapt to disturbances, in comparison to the intact limb.

This study was the first to attempt to quantify stability in individuals with transtibial amputations. Since there was no baseline data for the test conditions, a gold standard did not exist for ranking conditions in terms of dynamic stability. The assumption that subjects would be most stable when walking on level ground, and least stable when ascending stairs, was supported in this study. The stability parameters and the dynamic-stability index were able to distinguish between conditions of greatest (upstairs) and least (level ground) instability, but the sensitivity of these measures was not sufficient to consistently identify differences between the other conditions.

In comparison to able-bodied data, prosthesis users were typically less stable (i.e., parameter and index values were greater than able-bodied). Unexpectedly, AP and ML were significantly greater for able-bodied subjects for several cases, although it is unclear whether this occurred because the prosthetic gait pattern is optimized for forward progression, with accommodation by walking slower, or due to the use of an inappropriate dual threshold for parameter calculation in the population.

The stability parameters and the dynamic-stability index correlated poorly with all three criteria measures. As previously discussed, the thresholds used to calculate AP and ML may not have been appropriate for this population. When the dynamic-stability index was originally created, the upper limits for AP, ML, CellTrig, and MaxLat parameters were determined from able-bodied individuals walking on level ground, and the ST and DST upper limits were based on values obtained for stroke patients with severe mobility impairment. The upper limits for ST and DST should be lowered in the index model to reflect prosthetic gait.

In addition, there may have been issues with the criteria measures. The BBS and CBMS were not specifically designed for the test population so their use as criteria measures is limited. However, given the variety of tasks examined by each scale, and the other options available, these two tools were the best choice. The PEQ was specifically designed for individuals with amputations but it was clear that many subjects had issues relating to both using a visual analog scale and interpreting the questions.

As with the majority of scientific research, this study focussed on statistically significant differences. One problem with addressing only significant differences in the data is that statistical significance does not necessarily translate into clinical significance. Differences between limbs, conditions, and subject groups (i.e., able-bodied versus prosthesis users) that are not statistically significant, may still have a substantial effect on the gait, and stability, of the individual.

## 5.6 Conclusion

This study attempted to determine whether the selected dynamic-stability parameters and dynamic-stability index were valid measures of stability for unilateral transtibial amputees. Validity was assessed by examining the ability of the parameters and index to identify stability differences between limbs, walking conditions, and groups, and by correlating parameter and index values to subject scores on several clinical measures that could relate to stability and balance.

Overall, the parameters and index indicated stability differences between limbs, conditions, and groups, although the number of significant differences were relatively low. This may have been due to a small, non-homogeneous population and differences between individual mobility strategies. Sample size could not have been increased due to the relatively small population of prosthesis users, but inter-subject variability could be addressed by analyzing subgroups of subjects, divided by activity or ability levels. This would reduce variability between subjects and make differences clearer. In addition, by calculating parameter and index values, based on population-specific data (as opposed to normative able-bodied values), definitive results might be obtained. The following changes may improve the performance of the dynamic-stability index for the current population:

- adjust the dynamic-stability index so that it calculates index values based on ranges specific to people with transtibial amputations
- establish new AP and ML thresholds for people with transtibial amputations

- recalculate MaxLat based on the number of columns remaining once the sensor has been cut, as opposed the total number of columns in the uncut sensor
- investigate different variable combinations to determine which combination of variables is best suited to individuals with transtibial amputations
- weight the index values for each limb before calculating an overall index value

The parameter and index values did not correlate well to the clinical measures. Since there were issues with the criteria measures selected for use in this study, validation using a more established method, such a video motion analysis, would be valuable. Another possibility, which may be easier to implement, is to have each subject rank the test conditions in terms of difficulty. This would provide context for subject performance, help make a link between functional level and dynamic stability, and provide an alternate set of validation data.

Based on this study, the stability parameters and dynamic stability index are promising for assessing stability in unilateral prosthesis users; however, further investigation is required to evaluate the stability parameters and the stability index as a valid means of assessing dynamic stability in unilateral transtibial prosthesis users. Calculation of the stability parameters and the dynamic-stability index must be optimized for individuals with transtibial amputations. The data collected in this study provides a large data set that may be useful in establishing appropriate variable thresholds and ranges for future research.

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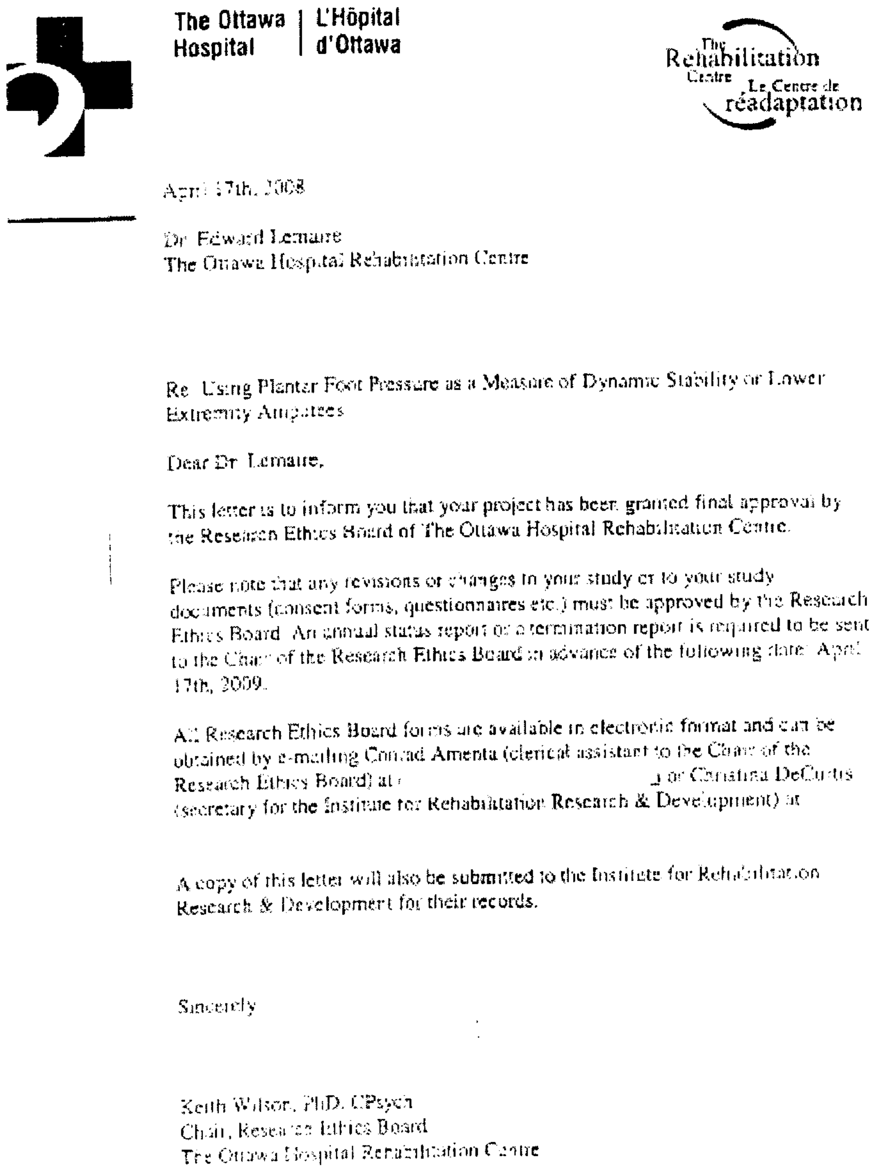
# Appendix A: Ethical Approval



The Ottawa Hospital | L'Hôpital d'Ottawa

The Rehabilitation Centre
Le Centre de réadaptation

April 17th, 2008

Dr Edward Lemaire
The Ottawa Hospital Rehabilitation Centre

Re Using Plantar Foot Pressure as a Measure of Dynamic Stability in Lower Extremity Amputees

Dear Dr Lemaire,

This letter is to inform you that your project has been granted final approval by the Research Ethics Board of The Ottawa Hospital Rehabilitation Centre.

Please note that any revisions or changes to your study or to your study documents (consent forms, questionnaires etc.) must be approved by the Research Ethics Board. An annual status report or a termination report is required to be sent to the Chair of the Research Ethics Board in advance of the following date: April 17th, 2009.

All Research Ethics Board forms are available in electronic format and can be obtained by e-mailing Conrad Amenta (clerical assistant to the Chair of the Research Ethics Board) at or Christina DeCurtis (secretary for the Institute for Rehabilitation Research & Development) at

A copy of this letter will also be submitted to the Institute for Rehabilitation Research & Development for their records.

Sincerely

Keith Wilson, PhD, CPsych
Chair, Research Ethics Board
The Ottawa Hospital Rehabilitation Centre

Please note that the University of Ottawa accepted ethical approval of this study by the Ottawa Hospital Research Ethics Board, however, no additional certificate was issued.

# Appendix B: Subject Letter

The Ottawa Hospital | L'Hôpital d'Ottawa

**Request for Participation in a Research Study**
**"A Measure of Dynamic Stability for a Lower Extremity Amputee Population"**

Dear Mr. /Mrs. /Ms. __________,

Please consider this request to volunteer as a participant for the project "A Measure of Dynamic Stability for a Lower Extremity Amputee Population". Dynamic stability defines how stable you are when moving. This project will help us understand how the pressure patterns under your feet relate to dynamic stability. We can then take this information and build a new tool for stability measurement. This dynamic stability analysis tool will help with research, prosthetic decision making, and could help to improve safety for people with unstable walking patterns. Information on the project is listed in the attached Information Sheet.

To participate in this study you must have a unilateral (one leg) transtibial or transfemoral amputation and be able to use a prosthesis to walk in the community, cross most environmental barriers, and perhaps use the prosthesis for other activities beyond simple walking.

Since participation is on a volunteer basis, you are not obligated to participate. If you decide to participate, you would be free to withdraw from the study at any time without suffering any negative consequences and without it affecting any of your present or future relationships with your health care providers or The Ottawa Hospital Rehabilitation Centre. Your parking costs would be reimbursed.

Please contact Cynthia Kendell, Project Assistant to either indicate your interest as a participant for this research project or to tell us that you do not want to be contacted further about this project:

You will be contacted by telephone within the next four weeks if we do not receive a reply from you. You can also contact Edward Lemaire, PhD, Project Primary

if you have

Thank you for considering this request.

Dr. Nancy Dudek, MD, MEd

Dr. Edward Lemaire, PhD

The Ottawa Hospital | L'Hôpital d'Ottawa

**Lettre de participation pour l'étude : « Une mesure de stabilité dynamique pour une population d'amputés d'un membre inférieur »**

Cher Monsieur __________

Vous êtes invité à participer à une étude: « une mesure de stabilité dynamique pour une population d'amputés d'un membre inférieur ». La stabilité dynamique définit à quel point vous êtes stable lorsque vous êtes en mouvement. Ce projet nous aidera à comprendre comment les patrons de pression sous vos pieds influencent la stabilité dynamique. Nous pourrons alors prendre cette information et construire un nouvel outil pour mesurer la stabilité. Cet outil d'analyse de la stabilité sera utile en recherche, à la prise de décision pour les prothèses, et pourrait même contribuer à améliorer la sécurité des personnes ayant des patrons de marche instables. Les informations à propos de cette étude sont décrites dans la fiche d'information.

Pour participer à cette étude vous devez avoir une amputation unilatérale (une jambe) transtibiale ou transfémorale et être en mesure d'utiliser une prothèse pour marcher dans la communauté, traverser la plupart des obstacles environnementaux, et peut-être utiliser la prothèse pour d'autres activités.

Étant donné que la participation à cette étude est sur une base volontaire, vous n'êtes pas obligé d'y participer. Si vous décidez de participer, vous êtes libre de vous retirer à tout moment, sans subir aucune conséquence négative et sans que cela affecte vos relations présentes ou futures avec vos fournisseurs de soins de santé ou le Centre de réadaptation de l'Hôpital d'Ottawa. Vos frais de stationnement seront remboursés.

S'il vous plaît, contacter Cynthia Kendell, assistante de projet, pour lui indiquer que vous désirez participer à ce projet de recherche ou que vous ne voulez pas être contacté de nouveau au sujet de cette étude:

Vous serez contacté par téléphone dans les quatre prochaines semaines, si nous ne recevons pas une réponse de votre part. Vous pouvez également communiquer avec Edward Lemaire, PhD, chercheur principal du projet, (

si vous avez des questions a propos de cette etude.

Merci de bien vouloir considérer cette demande.

Dr. Nancy Dudek, MD, MEd　　　　Dr. Edward Lemaire, PhD

The Ottawa Hospital | L'Hôpital d'Ottawa

**Lettre de participation pour l'étude : « Une mesure de stabilité dynamique pour une population d'amputés d'un membre inférieur »**

Chère Madame __________,

Vous êtes invitée à participer à une étude: « une mesure de stabilité dynamique pour une population d'amputés d'un membre inférieur ». La stabilité dynamique définit à quel point vous êtes stable lorsque vous êtes en mouvement. Ce projet nous aidera à comprendre comment les patrons de pression sous vos pieds influencent la stabilité dynamique. Nous pourrons alors prendre cette information et construire un nouvel outil pour mesurer la stabilité. Cet outil d'analyse de la stabilité sera utile en recherche, à la prise de décision pour les prothèses, et pourrait même contribuer à améliorer la sécurité des personnes ayant des patrons de marche instables. Les informations à propos de cette étude sont décrites dans la fiche d'information.

Pour participer à cette étude vous devez avoir une amputation unilatérale (une jambe) transtibiale ou transfémorale et être en mesure d'utiliser une prothèse pour marcher dans la communauté, traverser la plupart des obstacles environnementaux, et peut-être utiliser la prothèse pour d'autres activités.

Étant donné que la participation à cette étude est sur une base volontaire, vous n'êtes pas obligée d'y participer. Si vous décidez de participer, vous êtes libre de vous retirer à tout moment, sans subir aucune conséquence négative et sans que cela affecte vos relations présentes ou futures avec vos fournisseurs de soins de santé ou le Centre de réadaptation de l'Hôpital d'Ottawa. Vos frais de stationnement seront remboursés.

S'il vous plaît, contacter Cynthia Kendell, assistante de projet, pour lui indiquer que vous désirez participer à ce projet de recherche ou que vous ne voulez pas être contactée de nouveau au sujet de cette étude:

Vous serez contactée par téléphone dans les quatre prochaines semaines, si nous ne recevons pas une réponse de votre part. Vous pouvez également communiquer avec Edward Lemaire, PhD, chercheur principal du projet, si vous avez des questions à propos de cette étude.

Merci de bien vouloir considérer cette demande.

Dr. Nancy Dudek, MD, MEd Dr. Edward Lemaire, PhD

# Appendix C: Information Sheet

The Ottawa Hospital | L'Hôpital d'Ottawa

**Information Sheet – A Measure of Dynamic Stability for a Lower Extremity Amputee Population**

Researchers at the Ottawa Hospital Rehabilitation Centre are evaluating a new way of measuring how stable you are while walking, using measurements of the pressures between your shoe and foot. This project will verify whether this new approach works well with lower limb prosthesis consumers. When completed, this research may help your health care team understand a person's stability level.

After you arrive at The Ottawa Hospital Rehabilitation Centre, a prosthetist and physiotherapist will examine your residual limb and prosthesis to ensure that the prosthesis is functioning properly. Your foot will also be examined to ensure that the skin is intact. You will be asked to complete a prosthesis evaluation questionnaire and to complete balance testing. A research assistant will help you to put on a waist belt that will hold two boxes, one for collecting foot pressure information (F-Scan) and the other to collect acceleration sensor information (XSens). Plastic shoe insoles will be fitted into your shoes, connected to a box strapped to your ankle, and then connected by a wire to the F-Scan box on the waist belt. XSens sensors will be attached using tape to your lower back and upper back. The sensors will be connected by wires to the XSens box on the waist belt. All trials will be video taped and use of a walking aid (i.e., cane, crutch, etc.) will be noted. The equipment weighs approximately 800 grams.

*You will be asked to complete the following tasks while data are collected:*

- **Level ground walking**: Walk at your normal pace along a 16 m, level area while data are collected. Repeat 5 times.
- **Stairs**: Walking up a set of 12 stairs at your normal pace. Stop at the top platform, turn, and then walk down the 12 stairs. You may rest at the top and bottom of the stairs. Repeat two times.
- **Ramp / Incline**: Walking at your normal pace along level ground, stepping onto a 4 m ramp, walk up the ramp, stop on a platform at the top of the ramp, turning, walk down the ramp, and back onto level ground. Repeat five times.
- **Uneven Ground**: Walk at your normal pace over an 8m area covered with foam. Repeat five times.

All walking surfaces will be slip resistant and the ramp will be equipped with a handrail. At least one person will walk near you during all walking trials. Since participation is on a volunteer basis, you are not obligated to participate. If you decide to participate, you will be free to withdraw from the study at any time without suffering any negative consequences and without it affecting any of your present or future relationships with your health care providers or The Ottawa Hospital Rehabilitation Centre. Your parking costs will be reimbursed.

If you have any questions or would like more information to assist in making your decision, please feel free to contact a member of our research team: Dr. Edward Lemaire of The Ottawa *Hospital Rehabilitation Centre* at 6

The Ottawa Hospital
L'Hôpital d'Ottawa

## Lettre d'information pour les participants à l'étude : «Une mesure de stabilité dynamique pour une population d'amputés d'un membre inférieur. »

Les chercheurs du Centre de réadaptation de l'Hôpital d'Ottawa évaluent une nouvelle manière de mesurer votre stabilité lors de la marche. Des mesures de pression captées entre votre chaussure et votre pied sont utilisées pour produire un nombre qui représente votre stabilité. Dans ce projet, vos données seront employées pour vérifier si cette nouvelle approche fonctionne bien avec les utilisateurs de prothèse du membre inférieur. Lorsque terminée, cette mesure de stabilité aidera votre équipe de soins de santé à comprendre le niveau de stabilité d'une personne.

A votre arrivée au Centre de réadaptation de l'Hôpital d'Ottawa, un prothésiste et un physiothérapeute examineront votre membre résiduel et votre prothèse afin de s'assurer que tout fonctionne correctement. On examinera votre pied afin de s'assurer qu'il n'y ait pas de plaie ou blessure. Nous allons aussi vous demander de répondre à un questionnaire d'évaluation de votre prothèse et de faire des évaluations d'équilibre. Un aide de recherche vous aidera à mettre une ceinture de taille qui tient deux boîtes, une pour recueillir l'information de la pression des pieds (F-Scan) et l'autre pour recueillir l'information de la sonde d'accélération (XSens). Des semelles en plastique adaptées à l'intérieur de vos chaussures seront reliées à une boîte attachée à votre cheville. Celle-ci sera alors reliée par un fil à la boîte F-Scan sur la ceinture de taille. Des sondes de XSens seront fixées à l'aide d'un ruban adhésif au haut et au bas de votre dos. Les sondes seront reliées par des fils dans la boîte de XSens sur la ceinture de taille. Toutes les épreuves seront filmées et l'utilisation d'un aide à la marche (canne, béquille, etc.) sera notée. L'équipement pèse environ 800 grammes.

Vous serez invité à accomplir les tâches suivantes tandis que des données sont recueillies:

- **Marche sur terrain plat** : Marcher à un rythme normal sur une distance de 16 m sur un terrain plat tandis que des données sont recueillies. Répéter 5 fois.
- **Escaliers** : Monter 12 marches d'escalier à un rythme normal. Un arrêt sur la plateforme supérieure pour ensuite redescendre les 12 marches. Vous pouvez vous reposer en haut et en bas des escaliers. Répéter 2 fois.
- **Rampe/pente** : Marcher sur terrain plat puis monter vers le haut sur une rampe de 4 m de longueur à votre rythme normal. Un arrêt sur la plateforme du haut pour ensuite redescendre la rampe, jusqu'au terrain plat. Répéter 5 fois.
- **Terrain inégal** : Marcher à un rythme normal sur un caoutchouc mousse d'une longueur de 8m. Répéter 5 fois.

Votre sécurité est notre priorité. Au minimum une personne marchera près de vous pendant les épreuves de marche. Aucune surface de marche ne sera glissante et une main courante sera en place aux escaliers et sur la rampe. La session d'essai prendra environ 90 minutes. Vos frais de stationnement seront remboursés.

Votre participation étant strictement volontaire, vous n'êtes pas obligée de participer. Bien entendu, si vous décidez de participer, vous pourrez vous retirer à n'importe quelle moment sans aucune conséquence ultérieure avec le Centre de réadaptation de l'Hôpital d' Ottawa.

Si vous avez des questions ou vous voulez plus d'information avant de prendre votre décision, n'hésitez pas à contacter un membre de notre équipe de recherche :

- Dr Edward Lemaire au Centre de réadaptation à l'Hôpital d'Ottawa au numéro suivant (

# Appendix D: Consent Form

The Ottawa Hospital | L'Hôpital d'Ottawa

**Consent for Study "A Measure of Dynamic Stability for a Lower Extremity Amputee Population"**

Principal Researcher: Dr. Edward Lemaire,
The Ottawa Hospital Rehabilitation Centre

I,__________________________, consent to participate in this project to develop a new measurement tool for stability during movement.

I have had the project explained to me and I have been given a chance to ask questions about the study. The study has been explained to me as follows:

After I arrive at The Ottawa Hospital Rehabilitation Centre, a prosthetist and physiotherapist will examine my residual limb and prosthesis to ensure that my prosthesis is functioning properly. My foot will also be examined to ensure that the skin is intact. I will be asked to complete a prosthesis evaluation questionnaire. A research assistant will help me to put on a waist belt that will hold two boxes, one for collecting foot pressure information (F-Scan) and the other to collect acceleration sensor information (XSens). Plastic shoe insoles will be fitted into my shoes, connected to a box strapped to my ankle, and then connected by a wire to the F-Scan box on the waist belt. XSens sensors will be attached using tape to my lower back and upper back. The sensors will be connected by wires to the XSens box on the waist belt. All trials will be video taped and use of a walking aid (i.e., cane, crutch, etc.) will be noted.

I will be asked to complete the following tasks while data are collected:

**Level ground walking:** Walk at my normal pace along a 16 m, level area while data are collected. Repeat 5 times.

**Stairs:** Walking up a set of 12 stairs at my normal pace. Stop at the top platform, turn, and then walk down the 12 stairs. I may rest at the top and bottom of the stairs. Repeat two times.

**Ramp / Incline:** Walking at my normal pace along level ground, stepping onto a 4 m ramp, walk up the ramp, stop on a platform at the top of the ramp, turning, walk down the ramp, and back onto level ground. Repeat five times.

**Uneven Ground:** Walk at my normal pace over an 8m area covered with foam. Repeat five times.

Initials ________________

A minimum of one person will walk near me during the walking trials. All walking surfaces will be slip resistant and a safety rail will be in place on the ramp. The testing session will take about 90 minutes. My parking costs will be reimbursed.

I understand that:

1. I will perform 4 different walking tasks and complete each task 2-5 times.
2. My safety will be ensured at all times with a minimum of one person walking along beside me during the walking trials.
3. All personal information obtained throughout the study will be kept confidential.
4. Participation is on a volunteer basis.
5. Gathered data will be destroyed/deleted after 10 years.

**I understand the purpose of this study. By signing below, I agree to take part. This is assuming that**

- **Information will be collected and used for research purposes only.**
- **This information will be kept private.**
- **There is no pressure on me to take part.**
- **Even if I do choose to take part now, I am still free to leave the study at any time and for any reason. I can to this by simply telling Dr. Lemaire or his research assistant Cynthia Kendell.**
- **My decision – either to take part in the study or to leave the study – will have no effect on my treatment at the Ottawa Hospital Rehabilitation Centre, now or in the future.**
- **After signing, I will get a copy of this consent form and the information sheet for my records.**

My confidentiality will be maintained at all times, and only the researcher team will keep a record of my name. The data will be stored in a locked filing cabinet at The Ottawa Hospital Rehabilitation Centre for 10 years after which it will be destroyed. My information will be accessed by the research team (investigators and research assistants from The Ottawa Hospital Rehabilitation Centre and University of Waterloo). The research team will not disclose the contents of my study records to any party other than the research funding agency (identifying information will not be shared). The results of the study may also be used for medical and scientific publications but my identity will not be disclosed.

I will be advised of any new information that arises during the study that may have a bearing on my participation.

Initials _______________

I acknowledge that I have had the study and the contents of this consent form explained to me, that I understand this information and that I have received a copy of the consent form for my records.

I consent to having a **photograph** taken of me and having it published or presented for research and scientific purposes. yes____no_____ (please initial one)

I consent to having the **video** taken of me published or presented for research and scientific purposes. yes_____no_____ (please initial one)

I consent to the use of images that show my head and/or face. yes_____no_____ (please initial one)

Participant: ________________________________ Date: ____________________

Researcher: ________________________________ Date: ____________________

The Ottawa Hospital | L'Hôpital d'Ottawa

**Formulaire de consentement pour l'étude “ Une mesure de stabilité dynamique pour une population d'amputés d'un membre inférieur ”**

Chercheur principal : Dr Edward Lemaire,
Le Centre de réadaptation de l'Hôpital d'Ottawa.

Je, ____________________, accepte de participer au projet de recherche qui consiste à développer un nouvel outil pour mesurer la stabilité pendant le mouvement. Le projet m'a clairement été expliqué et j'ai eu l'occasion de poser des questions sur l'étude.

A mon arrivée au Centre de réadaptation de l'Hôpital d'Ottawa, un prothésiste et un physiothérapeute examineront mon membre résiduel et ma prothèse afin de s'assurer que tout fonctionne correctement. On examinera mon pied afin de s'assurer qu'il n'y ait pas de plaie ou blessure. Je vais aussi répondre à un questionnaire d'évaluation de ma prothèse. Un aide de recherche m'aidera à mettre une ceinture de taille qui tient deux boîtes, une pour recueillir l'information de la pression des pieds (F-Scan) et l'autre pour recueillir l'information de la sonde d'accélération (XSens). Des semelles en plastique adaptées à l'intérieur de mes chaussures seront reliées à une boîte attachée à ma cheville. Celle-ci sera alors reliée par un fil à la boîte F-Scan sur la ceinture de taille. Des sondes de XSens seront fixées à l'aide d'un ruban adhésif au haut et au bas de mon dos. Les sondes seront reliées par des fils dans la boîte de XSens sur la ceinture de taille. Toutes les épreuves seront filmées et l'utilisation d'un aide à la marche (canne, béquille, etc.) sera notée.

Je serai invité à accomplir les tâches suivantes tandis que des données sont recueillies:

- **Marche sur terrain plat** : Marcher à un rythme normal sur une distance de 16 m sur un terrain plat tandis que des données sont recueillies. Répéter 5 fois.
- **Escaliers** : Monter 12 marches d'escalier à un rythme normal. Un arrêt sur la plateforme supérieure pour ensuite redescendre les 12 marches. Vous pouvez vous reposer en haut et en bas des escaliers. Répéter 2 fois.
- **Rampe/pente** : Marcher sur terrain plat puis monter vers le haut sur une rampe de 4 m de longueur à votre rythme normal. Un arrêt sur la plateforme du haut pour ensuite redescendre la rampe, jusqu'au terrain plat. Répéter 5 fois.
- **Terrain inégal** : Marcher à un rythme normal sur un caoutchouc mousse d'une longueur de 8m. Répéter 5 fois.

Au minimum une personne marchera près de moi pendant les épreuves de marche. Aucune surface de marche ne sera glissante et une main courante sera en place aux escaliers et sur la rampe. La session d'essai prendra environ 90 minutes. Mes frais de stationnement seront remboursés.

Initiales ______________

Je comprends que :

1) Je vais faire 4 épreuves de marche différentes. Chaque épreuve sera répétée 2-5 fois.
2) Ma sécurité sera assurée par au moins une (1) personne qui sera à mes côtés pendant les épreuves de marche.
3) Toutes les informations personnelles seront gardées de façon confidentielle.
4) Ma participation à cette étude se fait de façon volontaire.
5) Toutes les informations recueillies seront détruites après dix ans.

**Je comprends l'objectif de l'étude. En signant ci-dessous, je consens à y participer. Il est entendu que :**

- **les renseignements recueillis seront utilisés à des fins de recherche uniquement;**
- **les renseignements demeureront confidentiels;**
- **personne n'a exercé de pressions pour m'inciter à participer à l'étude;**
- **même si je choisis de participer, je peux décider de me retirer de l'étude en tout temps sans raison particulière. J'aurai simplement à appeler Dr. Lemaire ou son adjointe de recherche, Cynthia Kendell, pour l'informer de ma décision;**
- **ma décision de participer à l'étude ou de m'en retirer n'aura aucun effet sur mon traitement au Centre de réadaptation de L'Hôpital d'Ottawa maintenant ou dans l'avenir;**
- **je recevrai une copie du formulaire de consentement après l'avoir signé ainsi qu'une copie de la feuille de renseignements pour mes dossiers.**

Toutes les informations seront confidentielles et seulement l'équipe de recherche gardera en archive mon nom. Les données seront gardées dans un classeur verrouillé au Centre de réadaptation de l'Hôpital d'Ottawa pour une période de dix ans, après quoi elles seront détruites. L'équipe de recherche (les chercheurs et les aides de recherche du Centre de réadaptation de l'Hôpital d'Ottawa et de l'Université de Waterloo) pourra avoir accès à mes informations. Les membres de l'équipe de recherche ne divulgueront les informations de cette étude à quiconque sauf aux agences qui subventionnent la recherche. Toutefois l'information pouvant m'identifier ne sera pas divulguée. Les résultats de l'étude pourront être utilisés pour fin de publications médicales ou scientifiques de façon anonyme.

Pendant le projet, je serai avisé de toutes nouvelles informations liées à ma participation du projet.

Le projet de recherche m'a été expliqué et je comprends l'information qui m'a été donnée. Je reconnais avoir reçu une copie du présent formulaire de consentement.

Initiales _______________

Je consens qu'on prenne des photos durant la session pour utiliser dans des publications et des présentations à des fins de recherches scientifiques. oui_____non_____(veuillez mettre vos initiales)

Je consens que la session vidéo puisse être utilisée dans des publications et des présentations à des fins de recherches scientifiques. oui_____non_____(veuillez mettre vos initiales)

Je consens à l'utilisation d'images montrant ma tête ou mon visage. oui_____non_____ (veuillez mettre vos initiales)

Participant(e): ________________________ Date : ________________________

Chercheur : ________________________ Date : ________________________

# Appendix E: Subject Data

| Subject | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 3.52 | 4.33 | 3.76 | 1.56 | 40.24 | 8.56 | 57.81 | 4.36 | 1.09 | 0.02 | 0.13 | 0.02 |
| 2 | 1.72 | 1.62 | 3.48 | 0.96 | 20.52 | 2.58 | 96.49 | 0.43 | 1.26 | 0.05 | 0.21 | 0.01 |
| 3 | 5.44 | 2.79 | 8.60 | 3.19 | 35.48 | 3.96 | 68.51 | 8.32 | 1.14 | 0.04 | 0.15 | 0.01 |
| 4 | 1.20 | 0.82 | 2.36 | 1.41 | 24.56 | 3.42 | 60.98 | 7.48 | 1.18 | 0.02 | 0.18 | 0.01 |
| 5 | 0.00 | 0.00 | 3.92 | 1.58 | 26.16 | 4.00 | 56.42 | 1.16 | 1.05 | 0.02 | 0.11 | 0.01 |
| 6 | 3.64 | 2.74 | 3.32 | 2.41 | 33.24 | 5.11 | 64.17 | 3.27 | 1.25 | 0.05 | -0.32 | 0.63 |
| 7 | 1.24 | 0.66 | 2.80 | 1.41 | 38.00 | 3.07 | 58.94 | 1.37 | 1.19 | 0.03 | 0.20 | 0.02 |
| 8 | 0.28 | 0.89 | 4.00 | 2.20 | 36.36 | 18.78 | 57.55 | 5.83 | 1.32 | 0.46 | 0.31 | 0.42 |
| 9 | 2.24 | 3.77 | 3.52 | 1.90 | 33.92 | 4.15 | 49.12 | 5.11 | 1.13 | 0.09 | 0.10 | 0.02 |
| 10 | 0.00 | 0.00 | 3.08 | 1.15 | 46.52 | 5.92 | 62.78 | 4.42 | 1.21 | 0.03 | 0.14 | 0.01 |
| 11 | 0.00 | 0.00 | 2.00 | 0.79 | 29.05 | 5.09 | 67.63 | 6.02 | 1.15 | 0.07 | 0.14 | 0.03 |
| 12 | 0.96 | 0.93 | 3.52 | 1.33 | 34.52 | 4.33 | 64.06 | 5.13 | 1.15 | 0.03 | 0.23 | 0.22 |
| 13 | 2.60 | 1.50 | 4.32 | 1.60 | 44.36 | 7.30 | 62.19 | 3.94 | 1.23 | 0.05 | 0.19 | 0.02 |
| 14 | 2.92 | 1.68 | 5.84 | 2.01 | 30.68 | 5.00 | 59.96 | 4.85 | 1.11 | 0.03 | 0.11 | 0.01 |
| 15 | 1.24 | 0.88 | 2.52 | 1.33 | 36.80 | 5.94 | 59.10 | 2.61 | 1.11 | 0.04 | 0.13 | 0.01 |
| 16 | 1.52 | 1.05 | 3.08 | 1.12 | 36.84 | 5.22 | 63.55 | 9.46 | 1.07 | 0.09 | 0.13 | 0.02 |
| 17 | 0.08 | 0.28 | 3.77 | 1.54 | 30.15 | 4.63 | 69.65 | 6.51 | 1.05 | 0.03 | 0.10 | 0.01 |
| 18 | 0.12 | 0.33 | 3.72 | 1.99 | 37.48 | 8.01 | 64.32 | 2.07 | 1.19 | 0.05 | 0.14 | 0.02 |
| 19 | 0.20 | 0.41 | 3.36 | 1.04 | 34.44 | 2.57 | 57.84 | 5.85 | 1.23 | 0.03 | 0.14 | 0.01 |
| 20 | 2.04 | 1.17 | 1.48 | 0.96 | 29.88 | 4.75 | 62.59 | 2.24 | 1.22 | 0.05 | 0.22 | 0.02 |

**Table 21:** Level ground stability parameters for the intact limb.

| | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.88 | 0.33 | 2.52 | 0.51 | 33.88 | 6.36 | 72.56 | 8.80 | 1.09 | 0.02 | 0.12 | 0.01 |
| 2 | 0.00 | 0.00 | 1.76 | 1.20 | 18.36 | 1.08 | 95.32 | 0.05 | 1.25 | 0.04 | 0.17 | 0.01 |
| 3 | 0.28 | 0.54 | 5.96 | 2.73 | 38.84 | 4.68 | 63.24 | 1.43 | 1.14 | 0.08 | 0.14 | 0.01 |
| 4 | 0.00 | 0.00 | 3.28 | 0.68 | 26.08 | 2.20 | 63.44 | 2.74 | 1.18 | 0.03 | 0.12 | 0.01 |
| 5 | 0.00 | 0.00 | 1.16 | 0.55 | 17.80 | 1.50 | 67.77 | 7.79 | 1.05 | 0.02 | 0.09 | 0.01 |
| 6 | 0.00 | 0.00 | 4.56 | 2.06 | 31.92 | 3.41 | 54.79 | 4.38 | 1.26 | 0.05 | 0.64 | 0.63 |
| 7 | 0.00 | 0.00 | 4.64 | 1.35 | 22.60 | 2.43 | 70.92 | 2.78 | 1.19 | 0.03 | 0.16 | 0.01 |
| 8 | 1.52 | 1.58 | 1.56 | 1.12 | 30.96 | 13.33 | 65.99 | 3.36 | 1.24 | 0.50 | 0.16 | 0.09 |
| 9 | 0.40 | 0.65 | 3.80 | 1.08 | 30.16 | 2.21 | 57.00 | 1.77 | 1.11 | 0.03 | 0.15 | 0.01 |
| 10 | 0.32 | 0.48 | 4.00 | 0.50 | 21.88 | 1.20 | 57.01 | 2.71 | 1.20 | 0.03 | 0.14 | 0.01 |
| 11 | 1.30 | 1.26 | 2.00 | 0.00 | 31.35 | 1.90 | 70.23 | 2.09 | 1.14 | 0.08 | 0.12 | 0.06 |
| 12 | 1.40 | 1.00 | 0.84 | 1.25 | 45.36 | 10.16 | 53.88 | 4.29 | 1.14 | 0.03 | 0.13 | 0.01 |
| 13 | 0.72 | 1.21 | 3.28 | 1.21 | 26.44 | 1.80 | 65.82 | 2.77 | 1.25 | 0.06 | 0.15 | 0.01 |
| 14 | 0.08 | 0.28 | 1.40 | 0.76 | 34.16 | 5.25 | 60.32 | 4.91 | 1.11 | 0.03 | 0.08 | 0.01 |
| 15 | 0.36 | 0.49 | 2.76 | 0.93 | 25.52 | 2.99 | 59.27 | 5.09 | 1.09 | 0.09 | 0.12 | 0.02 |
| 16 | 0.00 | 0.00 | 1.48 | 0.51 | 20.24 | 2.18 | 63.91 | 4.58 | 1.06 | 0.05 | 0.12 | 0.01 |
| 17 | 1.31 | 0.75 | 3.15 | 0.80 | 34.15 | 3.02 | 55.24 | 1.59 | 1.07 | 0.05 | 0.10 | 0.02 |
| 18 | 0.24 | 0.44 | 2.80 | 0.96 | 30.32 | 5.69 | 60.76 | 3.06 | 1.17 | 0.03 | 0.13 | 0.01 |
| 19 | 0.00 | 0.00 | 3.04 | 1.02 | 37.44 | 4.38 | 59.91 | 1.77 | 1.22 | 0.03 | 0.12 | 0.01 |
| 20 | 0.32 | 0.63 | 2.76 | 1.27 | 36.72 | 4.93 | 62.23 | 3.68 | 1.22 | 0.04 | 0.14 | 0.01 |

**Table 22:** Level ground stability parameters for the prosthetic limb.

|  | AP (#) |  | ML (#) |  | CellTrig (#) |  | MaxLat (%) |  | ST (s) |  | DST (S) |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Subject** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** |
| 1 | 1.88 | 1.54 | 3.00 | 1.35 | 46.08 | 6.87 | 57.26 | 3.53 | 1.21 | 0.05 | 0.16 | 0.04 |
| 2 | 3.00 | 1.32 | 3.36 | 0.95 | 33.88 | 6.55 | 59.17 | 2.69 | 1.57 | 0.07 | 0.25 | 0.03 |
| 3 | 7.00 | 2.29 | 6.52 | 2.50 | 45.28 | 6.26 | 63.98 | 10.17 | 1.55 | 0.13 | 0.25 | 0.03 |
| 4 | 1.92 | 1.93 | 2.48 | 2.28 | 34.48 | 3.74 | 57.30 | 5.94 | 1.37 | 0.15 | 0.24 | 0.02 |
| 5 | 0.12 | 0.44 | 3.20 | 1.08 | 37.88 | 4.95 | 56.68 | 3.45 | 1.26 | 0.09 | 0.17 | 0.04 |
| 6 | 7.36 | 5.99 | 6.16 | 3.89 | 41.20 | 7.27 | 64.39 | 2.84 | 1.53 | 0.17 | 0.15 | 0.20 |
| 7 | 3.64 | 2.40 | 2.80 | 1.35 | 43.64 | 10.74 | 56.30 | 5.62 | 1.34 | 0.11 | 0.27 | 0.07 |
| 8 | 0.28 | 1.21 | 5.00 | 1.53 | 39.36 | 16.46 | 56.81 | 5.28 | 1.38 | 0.43 | 0.24 | 0.46 |
| 9 | 1.77 | 1.28 | 2.77 | 0.90 | 50.40 | 7.57 | 49.86 | 4.06 | 1.32 | 0.13 | 0.14 | 0.24 |
| 10 | 0.60 | 1.08 | 3.68 | 1.31 | 54.08 | 9.15 | 65.60 | 6.62 | 1.29 | 0.16 | 0.17 | 0.03 |
| 11 | 0.12 | 0.44 | 2.48 | 1.33 | 33.24 | 4.84 | 63.87 | 8.26 | 1.32 | 0.06 | 0.16 | 0.02 |
| 12 | 2.88 | 1.42 | 3.76 | 1.13 | 47.44 | 8.51 | 62.18 | 5.05 | 1.26 | 0.04 | 0.22 | 0.02 |
| 13 | 1.96 | 1.34 | 1.72 | 0.84 | 57.40 | 7.15 | 60.78 | 3.67 | 1.41 | 0.07 | 0.28 | 0.04 |
| 14 | 4.36 | 1.60 | 8.08 | 3.35 | 36.08 | 6.71 | 60.50 | 3.87 | 1.24 | 0.08 | 0.16 | 0.02 |
| 15 | 2.21 | 1.38 | 6.67 | 2.62 | 37.54 | 6.03 | 55.49 | 6.05 | 1.16 | 0.07 | 0.13 | 0.02 |
| 16 | 1.32 | 0.75 | 2.56 | 1.16 | 42.76 | 7.13 | 57.00 | 7.88 | 1.20 | 0.17 | 0.15 | 0.02 |
| 17 | 0.00 | 0.00 | 4.88 | 1.80 | 36.82 | 5.80 | 64.74 | 6.05 | 1.21 | 0.06 | 0.15 | 0.02 |
| 18 | 0.20 | 0.41 | 3.04 | 1.54 | 41.72 | 5.50 | 63.61 | 4.77 | 1.33 | 0.07 | 0.19 | 0.03 |
| 19 | 1.80 | 1.61 | 4.00 | 1.35 | 42.12 | 6.81 | 56.65 | 9.36 | 1.41 | 0.23 | 0.22 | 0.03 |
| 20 | 2.28 | 1.28 | 1.80 | 0.91 | 35.08 | 4.15 | 55.77 | 1.61 | 1.33 | 0.05 | 0.26 | 0.03 |

**Table 23:** Uneven ground stability parameters for the intact limb.

| Subject | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.72 | 0.54 | 1.80 | 1.32 | 52.60 | 5.87 | 60.78 | 8.62 | 1.22 | 0.08 | 0.15 | 0.01 |
| 2 | 0.24 | 0.66 | 0.56 | 0.77 | 21.32 | 2.51 | 55.03 | 0.31 | 1.57 | 0.07 | 0.23 | 0.03 |
| 3 | 0.64 | 1.32 | 9.68 | 2.91 | 48.00 | 4.29 | 58.54 | 1.58 | 1.53 | 0.09 | 0.23 | 0.03 |
| 4 | 0.24 | 0.44 | 3.12 | 0.33 | 31.72 | 3.63 | 61.25 | 2.36 | 1.38 | 0.09 | 0.18 | 0.10 |
| 5 | 0.16 | 0.55 | 2.24 | 1.27 | 32.44 | 4.23 | 59.79 | 3.84 | 1.26 | 0.08 | 0.16 | 0.02 |
| 6 | 1.84 | 4.01 | 13.40 | 6.79 | 42.44 | 6.19 | 62.13 | 4.26 | 1.56 | 0.17 | 0.21 | 0.04 |
| 7 | 0.48 | 0.87 | 6.04 | 1.74 | 42.56 | 10.59 | 66.15 | 5.88 | 1.34 | 0.14 | 0.26 | 0.10 |
| 8 | 0.12 | 0.33 | 1.20 | 0.50 | 35.96 | 3.30 | 58.45 | 6.05 | 1.29 | 0.07 | 0.15 | 0.01 |
| 9 | 0.53 | 1.14 | 2.40 | 1.85 | 46.87 | 11.26 | 54.20 | 3.30 | 1.30 | 0.39 | 0.26 | 0.14 |
| 10 | 0.72 | 1.67 | 3.68 | 1.93 | 30.68 | 4.24 | 58.07 | 3.47 | 1.32 | 0.09 | 0.16 | 0.03 |
| 11 | 0.96 | 0.54 | 2.60 | 0.96 | 40.16 | 4.02 | 61.42 | 3.09 | 1.32 | 0.09 | 0.13 | 0.04 |
| 12 | 1.36 | 1.44 | 1.48 | 2.06 | 43.84 | 6.01 | 52.97 | 2.76 | 1.29 | 0.09 | 0.16 | 0.01 |
| 13 | 0.00 | 0.00 | 2.84 | 0.85 | 35.36 | 3.55 | 60.33 | 1.38 | 1.42 | 0.10 | 0.20 | 0.03 |
| 14 | 0.00 | 0.00 | 4.56 | 1.71 | 33.96 | 5.48 | 56.38 | 5.90 | 1.23 | 0.12 | 0.10 | 0.01 |
| 15 | 0.42 | 0.58 | 2.38 | 0.97 | 34.50 | 3.80 | 58.71 | 5.04 | 1.15 | 0.04 | 0.12 | 0.02 |
| 16 | 0.00 | 0.00 | 2.56 | 1.23 | 26.28 | 2.48 | 58.71 | 2.31 | 1.23 | 0.07 | 0.17 | 0.10 |
| 17 | 2.18 | 1.01 | 2.18 | 0.64 | 42.47 | 3.34 | 50.90 | 0.59 | 1.25 | 0.09 | 0.15 | 0.01 |
| 18 | 0.40 | 0.91 | 4.36 | 2.04 | 39.20 | 4.80 | 54.50 | 4.40 | 1.30 | 0.06 | 0.16 | 0.03 |
| 19 | 0.00 | 0.00 | 1.28 | 0.61 | 43.88 | 4.08 | 53.26 | 4.34 | 1.38 | 0.08 | 0.23 | 0.17 |
| 20 | 0.12 | 0.44 | 5.24 | 1.88 | 46.08 | 5.89 | 54.22 | 3.48 | 1.33 | 0.05 | 0.17 | 0.02 |

**Table 24:** Uneven ground stability parameters for the prosthetic limb.

|  | AP (#) |  | ML (#) |  | CellTrig (#) |  | MaxLat (%) |  | ST (s) |  | DST (S) |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 6.60 | 4.01 | 4.53 | 4.02 | 34.73 | 4.99 | 55.49 | 9.51 | 1.15 | 0.23 | 0.13 | 0.02 |
| 2 | 3.07 | 1.03 | 3.27 | 1.10 | 22.07 | 1.98 | 65.23 | 3.51 | 1.40 | 0.05 | 0.21 | 0.01 |
| 3 | 8.60 | 5.11 | 9.60 | 3.04 | 30.60 | 3.14 | 75.63 | 6.46 | 1.37 | 0.14 | 0.18 | 0.02 |
| 4 | 1.07 | 0.88 | 2.73 | 1.10 | 29.27 | 2.40 | 61.59 | 3.56 | 1.31 | 0.07 | 0.22 | 0.02 |
| 5 | 0.00 | 0.00 | 2.47 | 0.52 | 34.80 | 8.89 | 56.51 | 4.12 | 1.20 | 0.04 | 0.16 | 0.01 |
| 6 | 4.53 | 3.85 | 4.13 | 1.92 | 37.47 | 5.85 | 66.72 | 3.82 | 1.56 | 0.09 | 0.23 | 0.04 |
| 7 | 1.93 | 1.28 | 2.00 | 0.93 | 47.93 | 4.51 | 55.44 | 1.90 | 1.45 | 0.08 | 0.27 | 0.02 |
| 8 | 0.33 | 0.90 | 5.07 | 2.05 | 37.07 | 19.17 | 59.61 | 7.50 | 1.38 | 0.30 | 0.21 | 0.20 |
| 9 | 3.93 | 2.58 | 2.47 | 1.41 | 41.53 | 7.39 | 52.85 | 6.41 | 1.25 | 0.13 | 0.17 | 0.02 |
| 10 | 0.33 | 0.77 | 4.22 | 1.96 | 44.28 | 6.58 | 61.45 | 3.81 | 1.44 | 0.10 | 0.17 | 0.06 |
| 11 | 0.00 | 0.00 | 2.33 | 1.45 | 34.07 | 11.19 | 63.17 | 9.34 | 1.15 | 0.28 | 0.16 | 0.05 |
| 12 | 1.40 | 1.12 | 3.27 | 0.88 | 44.93 | 7.85 | 62.17 | 6.34 | 1.35 | 0.03 | 0.25 | 0.02 |
| 13 | 3.40 | 1.88 | 1.93 | 1.49 | 52.07 | 9.23 | 63.48 | 5.89 | 1.30 | 0.08 | 0.24 | 0.03 |
| 14 | 1.93 | 1.03 | 5.73 | 1.98 | 33.93 | 4.91 | 60.62 | 6.19 | 1.18 | 0.06 | 0.16 | 0.01 |
| 15 | 1.07 | 0.26 | 2.60 | 1.88 | 41.53 | 6.24 | 58.16 | 4.11 | 1.09 | 0.03 | 0.14 | 0.02 |
| 16 | 1.07 | 1.49 | 2.33 | 0.62 | 40.67 | 7.85 | 61.48 | 10.54 | 1.30 | 0.08 | 0.17 | 0.03 |
| 17 | 0.31 | 0.75 | 4.46 | 1.71 | 28.54 | 5.78 | 67.54 | 6.95 | 1.25 | 0.09 | 0.13 | 0.02 |
| 18 | 0.47 | 0.64 | 3.60 | 1.64 | 43.33 | 4.95 | 63.05 | 7.12 | 1.26 | 0.05 | 0.18 | 0.04 |
| 19 | 0.87 | 1.19 | 3.67 | 0.72 | 41.67 | 5.11 | 57.54 | 6.25 | 1.46 | 0.12 | 0.21 | 0.03 |
| 20 | 4.73 | 2.69 | 1.93 | 1.10 | 32.20 | 4.36 | 57.48 | 2.78 | 1.21 | 0.03 | 0.23 | 0.02 |

**Table 25:** Upramp stability parameters for the intact limb.

| Subject | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.67 | 0.82 | 2.40 | 1.18 | 41.27 | 8.33 | 61.07 | 3.04 | 1.16 | 0.05 | 0.19 | 0.14 |
| 2 | 0.73 | 0.59 | 2.67 | 0.98 | 19.60 | 2.72 | 54.72 | 1.22 | 1.41 | 0.05 | 0.24 | 0.02 |
| 3 | 0.47 | 0.74 | 7.40 | 3.38 | 46.07 | 4.42 | 65.34 | 2.77 | 1.34 | 0.06 | 0.17 | 0.02 |
| 4 | 0.87 | 0.99 | 3.00 | 0.38 | 33.87 | 4.79 | 70.74 | 5.42 | 1.31 | 0.07 | 0.17 | 0.02 |
| 5 | 0.13 | 0.52 | 2.40 | 0.83 | 35.00 | 3.05 | 56.24 | 1.84 | 1.19 | 0.05 | 0.11 | 0.01 |
| 6 | 0.47 | 1.13 | 6.20 | 2.54 | 38.87 | 5.37 | 61.51 | 4.59 | 1.56 | 0.11 | 0.21 | 0.02 |
| 7 | 0.40 | 0.83 | 5.53 | 1.68 | 36.67 | 3.48 | 71.18 | 4.67 | 1.45 | 0.08 | 0.31 | 0.05 |
| 8 | 0.00 | 0.00 | 1.13 | 0.52 | 31.60 | 3.00 | 70.28 | 3.27 | 1.31 | 0.07 | 0.20 | 0.13 |
| 9 | 1.73 | 4.53 | 2.67 | 1.35 | 44.47 | 14.23 | 62.04 | 5.74 | 1.61 | 1.17 | 0.19 | 0.04 |
| 10 | 0.72 | 0.89 | 4.44 | 0.78 | 30.17 | 5.64 | 58.96 | 6.28 | 1.42 | 0.10 | 0.16 | 0.02 |
| 11 | 1.20 | 0.41 | 3.73 | 1.10 | 32.93 | 4.20 | 69.83 | 8.92 | 1.21 | 0.12 | 0.08 | 0.13 |
| 12 | 1.73 | 1.10 | 1.53 | 1.36 | 43.93 | 5.56 | 51.53 | 4.70 | 1.34 | 0.04 | 0.19 | 0.01 |
| 13 | 0.40 | 0.91 | 2.93 | 1.98 | 25.47 | 13.51 | 54.13 | 28.26 | 1.29 | 0.06 | 0.19 | 0.03 |
| 14 | 0.00 | 0.00 | 3.07 | 0.70 | 31.47 | 4.88 | 60.79 | 4.40 | 1.22 | 0.07 | 0.09 | 0.02 |
| 15 | 1.33 | 1.05 | 3.27 | 0.96 | 31.80 | 3.28 | 56.30 | 4.09 | 1.09 | 0.10 | 0.15 | 0.02 |
| 16 | 0.00 | 0.00 | 3.53 | 1.46 | 25.87 | 4.72 | 67.42 | 4.70 | 1.31 | 0.07 | 0.16 | 0.02 |
| 17 | 2.92 | 2.56 | 4.15 | 2.41 | 41.85 | 4.45 | 53.30 | 1.28 | 1.29 | 0.09 | 0.13 | 0.04 |
| 18 | 1.07 | 1.03 | 2.60 | 1.18 | 31.93 | 5.54 | 59.87 | 5.55 | 1.24 | 0.04 | 0.15 | 0.02 |
| 19 | 0.13 | 0.35 | 1.07 | 0.59 | 37.60 | 4.60 | 61.51 | 5.45 | 1.41 | 0.09 | 0.16 | 0.02 |
| 20 | 0.07 | 0.26 | 3.20 | 1.57 | 43.27 | 5.28 | 77.00 | 12.37 | 1.21 | 0.04 | 0.15 | 0.01 |

**Table 26:** Upramp stability parameters for the prosthetic limb.

| | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 5.87 | 2.42 | 4.07 | 1.49 | 37.33 | 6.22 | 52.14 | 10.32 | 1.16 | 0.09 | 0.10 | 0.01 |
| 2 | 1.73 | 0.70 | 2.87 | 1.36 | 21.67 | 4.03 | 60.89 | 1.50 | 1.06 | 0.09 | 0.21 | 0.04 |
| 3 | 5.47 | 4.00 | 9.33 | 4.50 | 40.00 | 3.95 | 69.95 | 9.11 | 1.19 | 0.04 | 0.14 | 0.02 |
| 4 | 3.93 | 2.89 | 4.87 | 4.61 | 37.07 | 7.42 | 57.79 | 6.08 | 1.35 | 0.12 | 0.32 | 0.09 |
| 5 | 0.00 | 0.00 | 4.13 | 1.92 | 28.73 | 3.24 | 56.97 | 1.59 | 1.08 | 0.03 | 0.12 | 0.01 |
| 6 | 5.47 | 1.64 | 5.40 | 1.88 | 33.67 | 4.97 | 61.95 | 2.04 | 1.40 | 0.27 | 0.18 | 0.03 |
| 7 | 4.60 | 1.72 | 2.07 | 1.49 | 44.00 | 4.00 | 55.77 | 2.38 | 1.42 | 0.06 | 0.29 | 0.04 |
| 8 | 0.00 | 0.00 | 6.80 | 2.73 | 34.93 | 6.28 | 57.86 | 6.01 | 1.20 | 0.06 | 0.12 | 0.02 |
| 9 | 2.20 | 1.61 | 4.00 | 1.81 | 43.73 | 9.42 | 49.69 | 6.01 | 1.15 | 0.08 | 0.17 | 0.14 |
| 10 | 1.11 | 1.71 | 5.17 | 1.29 | 40.61 | 5.61 | 64.45 | 2.87 | 1.39 | 0.16 | 0.15 | 0.03 |
| 11 | 0.07 | 0.26 | 2.00 | 0.85 | 32.07 | 5.60 | 62.79 | 5.91 | 1.12 | 0.11 | 0.13 | 0.03 |
| 12 | 1.40 | 1.50 | 2.73 | 1.49 | 46.53 | 8.72 | 63.24 | 6.18 | 1.27 | 0.04 | 0.25 | 0.03 |
| 13 | 2.07 | 0.80 | 2.93 | 0.96 | 44.73 | 9.46 | 60.45 | 2.62 | 1.21 | 0.03 | 0.20 | 0.03 |
| 14 | 1.67 | 0.98 | 3.60 | 1.18 | 46.00 | 11.17 | 57.70 | 2.20 | 1.07 | 0.05 | 0.14 | 0.02 |
| 15 | 1.27 | 0.70 | 3.93 | 2.15 | 46.00 | 6.16 | 56.93 | 3.16 | 1.11 | 0.03 | -0.03 | 0.30 |
| 16 | 0.87 | 0.52 | 2.33 | 0.49 | 29.40 | 4.81 | 59.78 | 3.08 | 1.13 | 0.04 | 0.13 | 0.02 |
| 17 | 0.13 | 0.35 | 4.07 | 1.53 | 40.67 | 7.17 | 61.00 | 3.02 | 1.23 | 0.08 | 0.13 | 0.02 |
| 18 | 0.00 | 0.00 | 3.40 | 1.24 | 37.40 | 5.54 | 62.61 | 4.02 | 1.14 | 0.04 | 0.14 | 0.01 |
| 19 | 0.60 | 1.40 | 3.07 | 1.22 | 38.67 | 10.64 | 56.24 | 3.33 | 1.41 | 0.04 | 0.19 | 0.02 |
| 20 | 3.27 | 1.49 | 1.00 | 0.00 | 31.60 | 3.85 | 62.52 | 2.29 | 1.26 | 0.07 | 0.26 | 0.03 |

**Table 27:** Downramp stability parameters for the intact limb.

| Subject | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.00 | 0.00 | 3.67 | 1.54 | 28.07 | 3.65 | 60.06 | 5.31 | 1.18 | 0.11 | 0.10 | 0.02 |
| 2 | 0.93 | 0.70 | 2.93 | 1.49 | 18.20 | 2.21 | 56.01 | 1.25 | 1.06 | 0.10 | 0.15 | 0.02 |
| 3 | 0.80 | 1.21 | 8.87 | 4.16 | 30.20 | 3.28 | 63.31 | 2.03 | 1.18 | 0.03 | 0.11 | 0.01 |
| 4 | 0.80 | 0.77 | 2.53 | 0.99 | 36.73 | 4.80 | 70.46 | 7.02 | 1.35 | 0.10 | 0.10 | 0.02 |
| 5 | 0.13 | 0.52 | 1.53 | 0.64 | 18.00 | 1.20 | 66.40 | 6.35 | 1.07 | 0.03 | 0.07 | 0.01 |
| 6 | 0.20 | 0.56 | 6.73 | 3.41 | 30.53 | 3.68 | 61.64 | 2.38 | 1.37 | 0.09 | 0.14 | 0.14 |
| 7 | 0.00 | 0.00 | 4.67 | 1.05 | 22.93 | 3.51 | 73.65 | 1.98 | 1.41 | 0.06 | 0.18 | 0.05 |
| 8 | 0.07 | 0.26 | 1.13 | 0.52 | 24.27 | 2.46 | 66.59 | 2.98 | 1.21 | 0.06 | 0.09 | 0.01 |
| 9 | 0.07 | 0.26 | 5.13 | 5.38 | 42.53 | 13.16 | 59.63 | 4.81 | 1.17 | 0.22 | 0.15 | 0.06 |
| 10 | 2.61 | 1.79 | 4.78 | 1.17 | 23.78 | 2.41 | 59.13 | 5.69 | 1.38 | 0.16 | 0.14 | 0.09 |
| 11 | 1.00 | 0.00 | 2.00 | 0.00 | 38.80 | 3.90 | 68.82 | 1.36 | 1.15 | 0.10 | 0.08 | 0.02 |
| 12 | 1.40 | 1.06 | 0.67 | 0.98 | 37.07 | 4.17 | 53.81 | 3.56 | 1.27 | 0.03 | 0.15 | 0.01 |
| 13 | 0.00 | 0.00 | 3.47 | 1.13 | 22.93 | 2.81 | 62.56 | 3.47 | 1.21 | 0.05 | 0.12 | 0.02 |
| 14 | 0.00 | 0.00 | 2.07 | 0.96 | 30.93 | 7.85 | 59.39 | 3.31 | 1.07 | 0.06 | 0.06 | 0.01 |
| 15 | 0.33 | 0.49 | 6.53 | 7.58 | 32.73 | 11.09 | 62.64 | 6.75 | 1.05 | 0.16 | 0.31 | 0.47 |
| 16 | 0.00 | 0.00 | 3.40 | 0.91 | 17.27 | 1.28 | 66.31 | 3.33 | 1.13 | 0.05 | 0.09 | 0.02 |
| 17 | 2.93 | 1.58 | 2.73 | 1.28 | 35.07 | 5.35 | 51.75 | 1.00 | 1.25 | 0.09 | 0.10 | 0.04 |
| 18 | 0.07 | 0.26 | 2.60 | 0.91 | 26.87 | 4.36 | 60.33 | 2.26 | 1.14 | 0.03 | 0.09 | 0.02 |
| 19 | 0.00 | 0.00 | 1.87 | 1.64 | 36.00 | 3.38 | 56.83 | 1.94 | 1.40 | 0.03 | 0.14 | 0.02 |
| 20 | 0.07 | 0.26 | 3.53 | 1.64 | 38.87 | 5.37 | 59.53 | 2.14 | 1.26 | 0.06 | 0.13 | 0.01 |

**Table 28:** Downramp stability parameters for the prosthetic limb.

|  | AP (#) |  | ML (#) |  | CellTrig (#) |  | MaxLat (%) |  | ST (s) |  | DST (S) |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 6.44 | 1.81 | 5.22 | 1.56 | 38.00 | 4.30 | 61.14 | 4.99 | 0.99 | 0.02 | 0.15 | 0.01 |
| 2 | 6.40 | 1.17 | 2.40 | 0.97 | 21.40 | 2.17 | 75.71 | 4.67 | 1.52 | 0.07 | 0.19 | 0.03 |
| 3 | 7.40 | 4.35 | 2.80 | 1.87 | 51.00 | 10.59 | 87.52 | 4.17 | 1.71 | 0.19 | 0.39 | 0.34 |
| 4 | 3.40 | 1.35 | 3.60 | 1.51 | 40.40 | 3.95 | 62.08 | 3.32 | 1.54 | 0.06 | 0.27 | 0.04 |
| 5 | 1.10 | 0.32 | 2.80 | 0.92 | 39.70 | 3.77 | 56.62 | 3.58 | 1.12 | 0.13 | 0.16 | 0.01 |
| 6 | 11.83 | 5.81 | 6.33 | 1.75 | 49.50 | 4.59 | 58.98 | 3.29 | 1.96 | 0.55 | 0.20 | 0.02 |
| 7 | 8.70 | 5.23 | 3.40 | 0.84 | 65.30 | 14.44 | 57.01 | 3.11 | 2.33 | 0.57 | 0.29 | 0.05 |
| 8 | 0.70 | 1.34 | 4.90 | 2.60 | 52.50 | 12.50 | 62.83 | 6.59 | 1.32 | 0.14 | 0.29 | 0.21 |
| 9 | 4.50 | 1.08 | 2.10 | 1.66 | 39.30 | 6.78 | 47.87 | 2.18 | 1.14 | 0.22 | 0.16 | 0.09 |
| 10 | 0.30 | 0.67 | 4.40 | 1.35 | 44.30 | 8.08 | 70.93 | 7.45 | 1.29 | 0.18 | 0.22 | 0.20 |
| 11 | 2.50 | 1.58 | 2.70 | 1.25 | 40.30 | 5.50 | 73.06 | 5.68 | 1.22 | 0.09 | 0.15 | 0.02 |
| 12 | 0.60 | 1.07 | 1.70 | 0.95 | 44.30 | 4.97 | 67.87 | 3.27 | 1.34 | 0.09 | 0.13 | 0.03 |
| 13 | 3.40 | 1.90 | 3.80 | 1.14 | 54.60 | 5.06 | 61.52 | 6.78 | 1.47 | 0.11 | 0.23 | 0.03 |
| 14 | 9.60 | 2.91 | 7.70 | 2.98 | 38.60 | 6.70 | 65.51 | 5.49 | 1.39 | 0.15 | 0.17 | 0.02 |
| 15 | 5.80 | 2.44 | 3.60 | 1.71 | 52.30 | 14.51 | 60.49 | 5.05 | 1.11 | 0.07 | 0.14 | 0.01 |
| 16 | 4.00 | 1.41 | 2.30 | 0.82 | 43.20 | 6.83 | 54.26 | 2.79 | 1.65 | 0.16 | 0.22 | 0.03 |
| 17 | 1.90 | 1.45 | 4.40 | 1.35 | 46.00 | 8.88 | 83.96 | 2.25 | 1.23 | 0.10 | 0.22 | 0.02 |
| 18 | 0.80 | 0.92 | 2.30 | 1.42 | 46.00 | 10.21 | 66.24 | 3.47 | 1.35 | 0.19 | 0.15 | 0.03 |
| 19 | 1.80 | 0.63 | 4.70 | 0.67 | 56.00 | 12.26 | 61.38 | 9.73 | 1.72 | 0.15 | 0.25 | 0.03 |
| 20 | 6.40 | 1.90 | 2.90 | 1.52 | 42.50 | 7.81 | 59.95 | 3.11 | 1.86 | 0.17 | 0.34 | 0.16 |

**Table 29:** Upstairs stability parameters for the intact limb.

|  | AP (#) |  | ML (#) |  | CellTrig (#) |  | MaxLat (%) |  | ST (s) |  | DST (S) |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 1.00 | 0.00 | 3.22 | 1.72 | 36.56 | 4.13 | 77.72 | 9.86 | 1.00 | 0.02 | 0.11 | 0.01 |
| 2 | 2.50 | 0.53 | 2.20 | 1.03 | 19.80 | 3.26 | 54.35 | 0.54 | 1.52 | 0.07 | 0.20 | 0.01 |
| 3 | 2.50 | 1.72 | 4.50 | 4.06 | 47.50 | 7.56 | 62.32 | 1.52 | 1.73 | 0.30 | 0.13 | 0.01 |
| 4 | 0.30 | 0.48 | 3.90 | 1.60 | 40.20 | 4.32 | 71.66 | 4.39 | 1.45 | 0.21 | 0.15 | 0.05 |
| 5 | 3.00 | 0.00 | 2.10 | 1.52 | 32.80 | 5.41 | 62.63 | 5.51 | 1.10 | 0.12 | 0.12 | 0.01 |
| 6 | 4.00 | 0.00 | 9.83 | 4.40 | 49.50 | 4.59 | 61.23 | 2.76 | 1.80 | 0.11 | 0.14 | 0.02 |
| 7 | 6.80 | 3.05 | 5.30 | 3.80 | 53.60 | 19.37 | 70.38 | 10.68 | 2.19 | 0.69 | 0.69 | 0.99 |
| 8 | 1.60 | 0.52 | 1.70 | 1.57 | 47.20 | 5.57 | 78.38 | 7.53 | 1.25 | 0.08 | 0.12 | 0.04 |
| 9 | 0.70 | 0.67 | 3.70 | 1.49 | 35.90 | 8.33 | 59.06 | 2.09 | 1.18 | 0.23 | 0.13 | 0.08 |
| 10 | 2.60 | 2.41 | 2.20 | 1.32 | 40.90 | 10.38 | 67.15 | 10.87 | 1.22 | 0.10 | 0.09 | 0.02 |
| 11 | 3.40 | 0.84 | 2.90 | 0.32 | 38.70 | 4.85 | 77.25 | 7.70 | 1.21 | 0.09 | 0.14 | 0.03 |
| 12 | 4.30 | 1.57 | 1.10 | 0.57 | 34.00 | 2.83 | 50.94 | 2.41 | 1.34 | 0.10 | 0.12 | 0.01 |
| 13 | 3.20 | 1.40 | 4.40 | 2.01 | 43.00 | 5.08 | 68.10 | 10.71 | 1.51 | 0.11 | 0.14 | 0.09 |
| 14 | 0.30 | 0.67 | 1.30 | 0.67 | 48.00 | 13.61 | 53.61 | 3.63 | 1.45 | 0.25 | 0.09 | 0.02 |
| 15 | 2.20 | 0.63 | 2.30 | 1.16 | 43.20 | 6.71 | 54.77 | 2.80 | 1.12 | 0.06 | 0.11 | 0.01 |
| 16 | 1.50 | 1.58 | 2.00 | 1.25 | 27.40 | 5.21 | 67.72 | 3.24 | 1.64 | 0.15 | 0.10 | 0.01 |
| 17 | 2.30 | 1.16 | 1.70 | 0.82 | 36.40 | 4.12 | 55.59 | 1.78 | 1.22 | 0.11 | 0.14 | 0.03 |
| 18 | 1.60 | 0.97 | 1.00 | 1.56 | 36.20 | 5.33 | 64.09 | 7.82 | 1.30 | 0.17 | 0.09 | 0.01 |
| 19 | 2.70 | 2.31 | 1.60 | 1.17 | 49.20 | 8.31 | 56.39 | 10.17 | 1.72 | 0.15 | 0.14 | 0.01 |
| 20 | 7.10 | 4.31 | 3.30 | 1.25 | 69.90 | 17.72 | 51.17 | 12.43 | 1.85 | 0.23 | 0.14 | 0.03 |

**Table 30:** Upstairs stability parameters for the prosthetic limb.

| | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 4.33 | 2.18 | 3.11 | 1.54 | 30.67 | 3.32 | 53.65 | 2.03 | 0.84 | 0.08 | 0.07 | 0.02 |
| 2 | 5.40 | 1.65 | 3.40 | 1.71 | 21.00 | 3.74 | 66.93 | 3.05 | 1.48 | 0.03 | 0.19 | 0.01 |
| 3 | 5.60 | 3.13 | 3.50 | 1.58 | 47.50 | 4.17 | 71.75 | 9.68 | 1.51 | 0.07 | 0.16 | 0.03 |
| 4 | 4.80 | 1.62 | 5.30 | 1.06 | 46.50 | 4.14 | 66.45 | 8.99 | 1.54 | 0.09 | 0.19 | 0.03 |
| 5 | 0.50 | 0.53 | 2.50 | 0.71 | 32.10 | 3.78 | 68.01 | 2.99 | 0.70 | 0.07 | 0.10 | 0.01 |
| 6 | 13.50 | 4.72 | 7.67 | 2.25 | 51.67 | 6.50 | 84.20 | 0.32 | 1.81 | 0.20 | 0.12 | 0.03 |
| 7 | 8.30 | 3.02 | 2.20 | 1.03 | 59.60 | 9.55 | 56.37 | 3.73 | 2.48 | 0.43 | 0.25 | 0.09 |
| 8 | 0.00 | 0.00 | 4.90 | 2.18 | 39.20 | 4.02 | 74.43 | 4.67 | 1.14 | 0.05 | 0.14 | 0.01 |
| 9 | 3.40 | 2.88 | 2.90 | 1.29 | 42.00 | 8.43 | 57.88 | 3.20 | 1.31 | 0.37 | 0.16 | 0.11 |
| 10 | 0.00 | 0.00 | 3.00 | 0.82 | 42.80 | 5.94 | 65.12 | 7.33 | 0.87 | 0.03 | 0.12 | 0.02 |
| 11 | 3.40 | 2.41 | 4.50 | 1.35 | 41.50 | 6.15 | 65.37 | 6.70 | 1.21 | 0.09 | 0.12 | 0.04 |
| 12 | 1.30 | 0.67 | 3.10 | 1.20 | 47.50 | 6.43 | 62.39 | 3.66 | 1.24 | 0.09 | 0.14 | 0.02 |
| 13 | 5.50 | 1.27 | 7.80 | 3.36 | 63.20 | 4.80 | 58.11 | 6.54 | 1.47 | 0.10 | 0.19 | 0.01 |
| 14 | 7.40 | 3.27 | 5.50 | 1.90 | 37.40 | 2.12 | 71.41 | 5.57 | 1.20 | 0.06 | 0.20 | 0.19 |
| 15 | 3.40 | 1.35 | 1.20 | 0.63 | 25.80 | 2.30 | 68.24 | 7.52 | 0.73 | 0.05 | 0.07 | 0.02 |
| 16 | 7.10 | 2.18 | 3.90 | 1.73 | 46.00 | 5.29 | 62.24 | 10.62 | 1.68 | 0.16 | 0.14 | 0.03 |
| 17 | 4.00 | 4.14 | 7.60 | 4.22 | 51.90 | 9.04 | 69.18 | 3.04 | 1.26 | 0.12 | 0.18 | 0.06 |
| 18 | 0.90 | 0.32 | 2.60 | 0.97 | 42.20 | 4.08 | 74.64 | 6.30 | 1.18 | 0.11 | 0.12 | 0.03 |
| 19 | 1.60 | 1.84 | 4.80 | 3.12 | 52.20 | 6.21 | 58.07 | 5.47 | 1.75 | 0.17 | 0.22 | 0.06 |
| 20 | 4.50 | 1.43 | 2.80 | 1.14 | 36.60 | 4.43 | 57.08 | 2.52 | 1.47 | 0.10 | 0.19 | 0.02 |

**Table 31:** Downstairs stability parameters for the intact limb.

| | AP (#) | | ML (#) | | CellTrig (#) | | MaxLat (%) | | ST (s) | | DST (S) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.00 | 0.00 | 1.67 | 1.80 | 31.22 | 5.09 | 76.98 | 8.39 | 0.84 | 0.09 | 0.02 | 0.01 |
| 2 | 1.80 | 1.03 | 2.00 | 0.82 | 18.90 | 2.42 | 55.22 | 0.59 | 1.47 | 0.03 | 0.18 | 0.01 |
| 3 | 1.50 | 0.53 | 3.00 | 1.15 | 42.50 | 4.20 | 61.13 | 5.01 | 1.51 | 0.15 | 0.18 | 0.03 |
| 4 | 2.10 | 1.10 | 3.30 | 1.16 | 35.30 | 4.69 | 75.52 | 3.15 | 1.53 | 0.08 | 0.10 | 0.02 |
| 5 | 1.50 | 1.51 | 1.90 | 0.88 | 16.80 | 1.32 | 70.78 | 8.69 | 0.73 | 0.13 | -0.04 | 0.10 |
| 6 | 0.50 | 1.22 | 7.17 | 4.54 | 41.50 | 5.72 | 62.07 | 1.98 | 1.86 | 0.22 | 0.14 | 0.01 |
| 7 | 1.80 | 0.63 | 5.40 | 2.01 | 43.60 | 8.33 | 80.55 | 3.28 | 2.38 | 0.54 | 0.20 | 0.08 |
| 8 | 2.00 | 1.05 | 1.60 | 0.97 | 31.00 | 4.47 | 82.48 | 2.12 | 1.13 | 0.06 | 0.05 | 0.01 |
| 9 | 1.50 | 3.06 | 1.50 | 0.85 | 41.70 | 13.61 | 64.41 | 3.28 | 1.38 | 0.41 | 0.17 | 0.16 |
| 10 | 2.00 | 0.00 | 2.00 | 0.94 | 25.00 | 6.51 | 71.60 | 3.63 | 0.87 | 0.05 | 0.06 | 0.02 |
| 11 | 1.70 | 1.77 | 3.40 | 1.26 | 37.90 | 6.56 | 78.18 | 6.86 | 1.20 | 0.06 | 0.07 | 0.06 |
| 12 | 3.20 | 1.03 | 1.00 | 0.00 | 31.80 | 4.05 | 49.28 | 3.71 | 1.24 | 0.10 | 0.14 | 0.02 |
| 13 | 0.20 | 0.63 | 2.60 | 1.07 | 33.70 | 4.50 | 66.89 | 4.41 | 1.48 | 0.14 | 0.12 | 0.02 |
| 14 | 0.00 | 0.00 | 1.40 | 0.84 | 31.60 | 7.00 | 54.56 | 4.50 | 1.24 | 0.33 | 0.10 | 0.13 |
| 15 | 0.70 | 0.82 | 2.40 | 0.70 | 22.00 | 2.98 | 53.44 | 1.21 | 0.75 | 0.08 | 0.06 | 0.01 |
| 16 | 0.00 | 0.00 | 2.60 | 1.17 | 28.10 | 4.72 | 70.51 | 1.86 | 1.71 | 0.16 | 0.15 | 0.03 |
| 17 | 4.10 | 4.25 | 1.00 | 0.00 | 43.40 | 8.00 | 54.71 | 1.47 | 1.27 | 0.13 | 0.24 | 0.12 |
| 18 | 1.10 | 0.74 | 2.10 | 1.20 | 30.90 | 4.82 | 59.82 | 2.59 | 1.21 | 0.05 | 0.10 | 0.08 |
| 19 | 3.40 | 2.59 | 2.00 | 1.25 | 49.70 | 8.33 | 66.46 | 17.19 | 1.76 | 0.09 | 0.21 | 0.11 |
| 20 | 0.00 | 0.00 | 4.40 | 1.71 | 45.50 | 6.28 | 61.99 | 4.55 | 1.44 | 0.09 | 0.15 | 0.03 |

**Table 32:** Downstairs stability parameters for the prosthetic limb.

| Subject | Level | | Uneven | | Upramp | | Downramp | | Upstairs | | Downstairs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.38 | 0.18 | 0.47 | 0.10 | 0.33 | 0.07 | 0.27 | 0.20 | 0.34 | 0.18 | 0.15 | 0.13 |
| 2 | 0.20 | 0.05 | 0.30 | 0.14 | 0.21 | 0.21 | 0.18 | 0.04 | 0.15 | 0.03 | 0.19 | 0.04 |
| 3 | 0.39 | 0.17 | 0.49 | 0.04 | 0.40 | 0.11 | 0.47 | 0.15 | 0.50 | 0.00 | 0.50 | 0.00 |
| 4 | 0.16 | 0.05 | 0.28 | 0.14 | 0.19 | 0.06 | 0.31 | 0.15 | 0.44 | 0.13 | 0.47 | 0.08 |
| 5 | 0.13 | 0.06 | 0.37 | 0.18 | 0.25 | 0.03 | 0.13 | 0.06 | 0.42 | 0.16 | 0.17 | 0.18 |
| 6 | 0.35 | 0.17 | 0.44 | 0.12 | 0.36 | 0.27 | 0.30 | 0.13 | 0.46 | 0.11 | 0.50 | 0.00 |
| 7 | 0.39 | 0.15 | 0.45 | 0.11 | 0.50 | 0.21 | 0.48 | 0.08 | 0.47 | 0.10 | 0.50 | 0.00 |
| 8 | 0.18 | 0.16 | 0.33 | 0.17 | 0.26 | 0.18 | 0.33 | 0.17 | 0.46 | 0.11 | 0.38 | 0.20 |
| 9 | 0.23 | 0.21 | 0.47 | 0.10 | 0.41 | 0.29 | 0.44 | 0.14 | 0.46 | 0.13 | 0.38 | 0.20 |
| 10 | 0.45 | 0.13 | 0.50 | 0.00 | 0.44 | 0.00 | 0.42 | 0.13 | 0.41 | 0.15 | 0.42 | 0.18 |
| 11 | 0.11 | 0.10 | 0.23 | 0.18 | 0.25 | 0.00 | 0.15 | 0.14 | 0.40 | 0.16 | 0.44 | 0.13 |
| 12 | 0.31 | 0.17 | 0.46 | 0.10 | 0.44 | 0.04 | 0.46 | 0.11 | 0.46 | 0.13 | 0.46 | 0.13 |
| 13 | 0.31 | 0.17 | 0.42 | 0.14 | 0.40 | 0.00 | 0.45 | 0.12 | 0.45 | 0.11 | 0.46 | 0.11 |
| 14 | 0.21 | 0.12 | 0.34 | 0.16 | 0.31 | 0.27 | 0.46 | 0.11 | 0.40 | 0.14 | 0.42 | 0.15 |
| 15 | 0.27 | 0.21 | 0.40 | 0.17 | 0.39 | 0.00 | 0.47 | 0.11 | 0.50 | 0.00 | 0.08 | 0.00 |
| 16 | 0.29 | 0.20 | 0.43 | 0.14 | 0.37 | 0.00 | 0.14 | 0.15 | 0.47 | 0.10 | 0.46 | 0.12 |
| 17 | 0.14 | 0.12 | 0.33 | 0.19 | 0.14 | 0.01 | 0.38 | 0.18 | 0.40 | 0.14 | 0.50 | 0.00 |
| 18 | 0.27 | 0.19 | 0.42 | 0.15 | 0.45 | 0.21 | 0.29 | 0.21 | 0.50 | 0.00 | 0.38 | 0.19 |
| 19 | 0.21 | 0.17 | 0.45 | 0.10 | 0.44 | 0.00 | 0.33 | 0.17 | 0.50 | 0.00 | 0.50 | 0.00 |
| 20 | 0.23 | 0.10 | 0.28 | 0.14 | 0.23 | 0.11 | 0.22 | 0.08 | 0.40 | 0.14 | 0.37 | 0.16 |

**Table 33:** Dynamic-stability index values for the intact limb.

| Subject | Level | | Uneven | | Upramp | | Downramp | | Upstairs | | Downstairs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 1 | 0.11 | 0.12 | 0.48 | 0.08 | 0.35 | 0.01 | 0.14 | 0.11 | 0.31 | 0.21 | 0.25 | 0.22 |
| 2 | 0.13 | 0.02 | 0.19 | 0.01 | 0.20 | 0.21 | 0.11 | 0.04 | 0.17 | 0.02 | 0.15 | 0.02 |
| 3 | 0.37 | 0.17 | 0.49 | 0.04 | 0.43 | 0.22 | 0.32 | 0.23 | 0.44 | 0.13 | 0.41 | 0.15 |
| 4 | 0.09 | 0.04 | 0.18 | 0.15 | 0.25 | 0.23 | 0.33 | 0.21 | 0.42 | 0.16 | 0.22 | 0.20 |
| 5 | 0.08 | 0.00 | 0.20 | 0.16 | 0.25 | 0.00 | 0.08 | 0.00 | 0.21 | 0.20 | 0.09 | 0.03 |
| 6 | 0.31 | 0.18 | 0.50 | 0.09 | 0.43 | 0.30 | 0.29 | 0.18 | 0.52 | 0.04 | 0.50 | 0.00 |
| 7 | 0.20 | 0.07 | 0.40 | 0.13 | 0.43 | 0.09 | 0.23 | 0.09 | 0.44 | 0.13 | 0.44 | 0.13 |
| 8 | 0.12 | 0.09 | 0.26 | 0.20 | 0.17 | 0.20 | 0.08 | 0.00 | 0.50 | 0.00 | 0.16 | 0.18 |
| 9 | 0.12 | 0.05 | 0.46 | 0.11 | 0.41 | 0.29 | 0.37 | 0.20 | 0.22 | 0.19 | 0.30 | 0.21 |
| 10 | 0.10 | 0.04 | 0.18 | 0.12 | 0.25 | 0.00 | 0.17 | 0.08 | 0.34 | 0.21 | 0.13 | 0.13 |
| 11 | 0.09 | 0.03 | 0.41 | 0.16 | 0.23 | 0.27 | 0.42 | 0.17 | 0.30 | 0.21 | 0.34 | 0.20 |
| 12 | 0.37 | 0.20 | 0.45 | 0.13 | 0.46 | 0.29 | 0.28 | 0.21 | 0.17 | 0.18 | 0.13 | 0.13 |
| 13 | 0.17 | 0.16 | 0.36 | 0.18 | 0.26 | 0.00 | 0.15 | 0.14 | 0.40 | 0.18 | 0.15 | 0.15 |
| 14 | 0.23 | 0.21 | 0.27 | 0.17 | 0.14 | 0.00 | 0.19 | 0.19 | 0.38 | 0.20 | 0.13 | 0.13 |
| 15 | 0.08 | 0.02 | 0.22 | 0.20 | 0.12 | 0.00 | 0.17 | 0.17 | 0.46 | 0.13 | 0.08 | 0.00 |
| 16 | 0.08 | 0.00 | 0.12 | 0.09 | 0.16 | 0.07 | 0.10 | 0.04 | 0.08 | 0.00 | 0.14 | 0.13 |
| 17 | 0.18 | 0.18 | 0.50 | 0.00 | 0.47 | 0.26 | 0.17 | 0.17 | 0.29 | 0.22 | 0.43 | 0.16 |
| 18 | 0.12 | 0.12 | 0.41 | 0.16 | 0.15 | 0.00 | 0.08 | 0.01 | 0.34 | 0.20 | 0.16 | 0.18 |
| 19 | 0.30 | 0.21 | 0.47 | 0.11 | 0.30 | 0.07 | 0.27 | 0.20 | 0.37 | 0.20 | 0.46 | 0.13 |
| 20 | 0.25 | 0.19 | 0.47 | 0.10 | 0.47 | 0.11 | 0.40 | 0.17 | 0.50 | 0.00 | 0.37 | 0.17 |

**Table 34:** Dynamic-stability index values for the prosthetic limb.

| Subject | Level | Uneven | Upramp | Downramp | Upstairs | Downstairs |
|---|---|---|---|---|---|---|
| 1 | 0.25 | 0.48 | 0.34 | 0.21 | 0.32 | 0.20 |
| 2 | 0.16 | 0.25 | 0.20 | 0.14 | 0.16 | 0.17 |
| 3 | 0.38 | 0.49 | 0.41 | 0.40 | 0.47 | 0.45 |
| 4 | 0.13 | 0.23 | 0.22 | 0.32 | 0.43 | 0.35 |
| 5 | 0.11 | 0.29 | 0.25 | 0.10 | 0.32 | 0.13 |
| 6 | 0.33 | 0.47 | 0.40 | 0.29 | 0.49 | 0.50 |
| 7 | 0.29 | 0.43 | 0.47 | 0.36 | 0.45 | 0.47 |
| 8 | 0.15 | 0.30 | 0.22 | 0.21 | 0.48 | 0.27 |
| 9 | 0.17 | 0.46 | 0.41 | 0.40 | 0.34 | 0.34 |
| 10 | 0.28 | 0.34 | 0.34 | 0.30 | 0.37 | 0.27 |
| 11 | 0.10 | 0.32 | 0.24 | 0.28 | 0.35 | 0.39 |
| 12 | 0.34 | 0.46 | 0.45 | 0.37 | 0.31 | 0.29 |
| 13 | 0.24 | 0.39 | 0.33 | 0.30 | 0.42 | 0.31 |
| 14 | 0.22 | 0.31 | 0.22 | 0.33 | 0.39 | 0.28 |
| 15 | 0.17 | 0.31 | 0.26 | 0.32 | 0.48 | 0.08 |
| 16 | 0.19 | 0.27 | 0.27 | 0.12 | 0.28 | 0.30 |
| 17 | 0.16 | 0.41 | 0.31 | 0.27 | 0.35 | 0.46 |
| 18 | 0.20 | 0.41 | 0.30 | 0.18 | 0.42 | 0.27 |
| 19 | 0.26 | 0.46 | 0.37 | 0.30 | 0.44 | 0.48 |
| 20 | 0.24 | 0.38 | 0.35 | 0.31 | 0.45 | 0.37 |

**Table 35:** Combined dynamic-stability index values.