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Lab 3: Gait Analysis

## Introduction

Human gait is the locomotion of the body through the movement of the limbs. Moreover, the bipedal gait cycle is defined as the sequence between when a certain foot contacts the ground and when that same foot next enters that position. This cycle has two phases:

- Stance phase: When the foot is in contact with the ground
- Swing phase: when the foot is not in contact with the ground

Gait can be measured though several spatio-temporal parameters including:

- Step Length: the distance between successive heel contacts with the ground
- Gait Speed: the step length per unit time
- Cadence: the number of steps per unit time

Additionally, a more involved analysis of human gait can be conducted though plots of joint angles and moments over the course of a person's stance phase. The three joints most important to understanding human gait are the ankle, knee, and hip joints. Through this method one can determine whether a subject's limb is in flexion or extension: bending movements that decrease and increase the angles between body parts respectively. Finding these joint moments can be achieved through inverse dynamics. In this process, kinetics is utilized in order to determine the kinematics of movement. In biomechanics applications, joint moments can be determined through a combination of kinetics and ground force reactions.

The goal of this lab was to analyze the human bipedal gait cycle using a link-segment model: where the body is simplified to a set of points and connecting lines representing joints and segments respectively. Following, we aimed to quantify the stance phase portion of the subject's gait through parameters such as step length, gait speed, and cadence. Finally, we hoped to plot the joint angle, angular velocity, and moment of the ankle, knee, and hip in effort to describe the flexion and extension undertaken in their stance phase. This data was used to compare these characteristics of gait when the subject was walking at comfort pace and walking quickly.

## Methods

In order to adequately measure human gait with a link segment model, measurements were taken both with a force plate and motion capture. The force plate utilized was an AMTI Accu-Gait. This device, recording at 1000 Hz, takes six measurements at the point in contact: three forces and three moments in the x, y, z directions. For the motion capture this lab used Nexus Software. 13 reflecting markers were placed on the subject in the following locations:

- Left and right acromion
- Left and right trochanter
- Left and right lateral epicondyle
- Left and right lateral malleolus
- Left and right toe
- Left and right heel
- Center back

When running the analysis, these markers provide the x and z coordinates at 100 Hz for each of these critical locations.

This trial was performed by a 63 Kg male student. The subject walked down a straight path with the markers set correctly on his body. 12 VICON cameras actively recorded his movement for the motion capture. The subject's starting position was selected so that his right foot would land on the force plate. This first step on the force plate marked the start for the gait analyzed in this lab.

In addition to these measurements, the weight, center of masse (COM), and radius of gyration of the foot, lower leg, and upper leg were needed to perform the inverse dynamics analysis. These values were obtained from Leva (1996), which provided the mass percent, the longitude COM, and radius of gyration for each body part in male college students.

In the analysis the equations of motion depicted below were utilized.

$$\sum F = ma$$

$$\sum M = I\alpha$$

Figure 1. Equations of Motion

Specifically, the sum of forces in the x and z axes as well as the sum of moments in the y axis were crucial to find the net muscle moments. Since the ground reaction force and center of pressure was known through the force plate, the analysis began with the foot. The markers in combination with the data from Leva (1995) provided the location of each force, and thus the equations of motion were used to calculate the joint reaction forces as well as the moment at the subject's ankle throughout his stance phase. Following, the same methodology and equations could then be used to calculate the reactions and moments at the knee and hip respectively. This approach was applied to both walking speeds.

## Results

| Parameter | Normal Walk | Fast Walk |
|---|---|---|
| Step Length (m) | 0.6337 | 0.8102 |
| Gait Speed (m/s) | 0.8746 | 1.5770 |
| Cadence (steps/min) | 33.2508 | 76.66 |

Figure 2. Step length, gait speed, and cadence of the subject for normal and fast walking condition

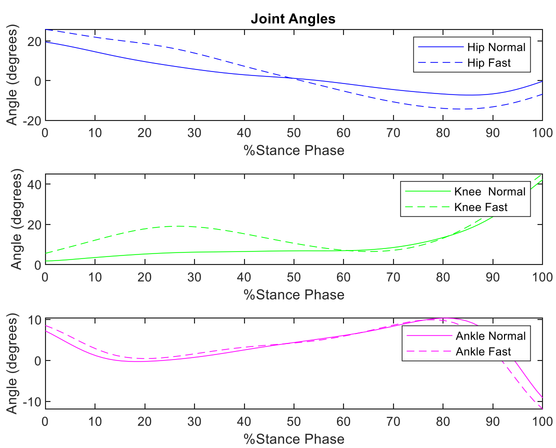


Figure 3. Joint angles of the subject's hip, right knee, and right ankle over the course of the stance phase for normal and fast walking

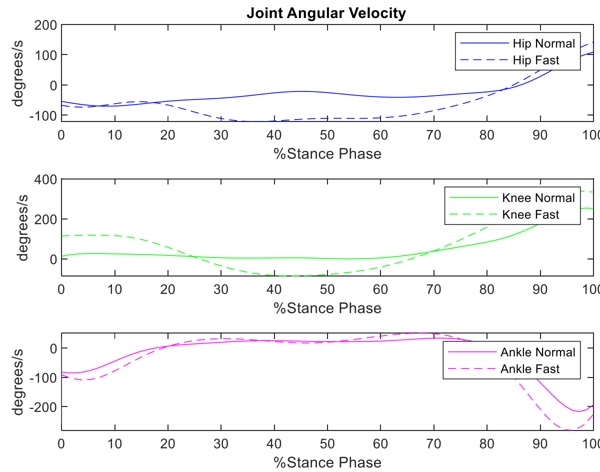


Figure 4. Joint angular velocities of the subject's hip, right knee, and right ankle over the course of the stance phase for normal and fast walking

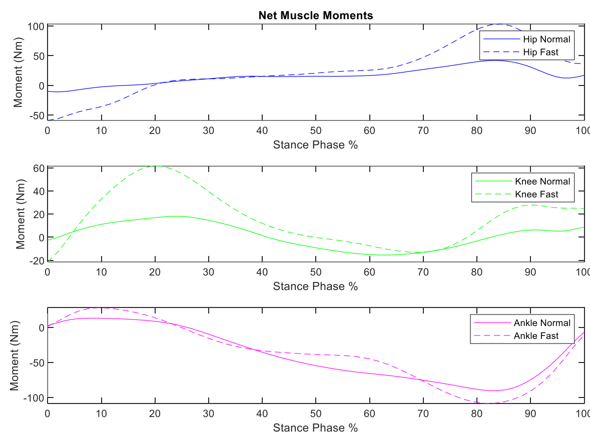


Figure 5. Net joint moments of the subject's hip, right knee, and right ankle over the course of the stance phase for normal and fast walking

## Conclusion

The gait parameters of figure 2. all appear within reason given the subjects size and age. Both Bohannon et al. 2011 and Tudor-Lock et al. 2019 found slightly higher average gait speeds and cadences for people of the subject's age walking at their comfort speed. While the subject of this lab would still fit within their normal distribution of measurements, it is possible the slightly slower values could be a result of the subject walking slower than comfort level due to being in an experimental setting. Compared to the normal walk, the subject displayed a higher value in all three parameters when walking at a fast pace.

The three joints analyzed in figure 3. all exhibit roughly the same pattern of movement between the normal and fast walking paces. However, the angles of the joints appear to be more extreme for the fast-paced walking. Moreover, the both the minimum and the maximums are of greater magnitude. Particularly for the knee and hip joints, the biggest deviation between the two paces occurs roughly during the foot-flat part of the stance phase, between 20% and 30%. Given that this portion of the stance phase is when the user begins to adjust their balance and carry over their secondary foot, it's likely that more dramatic rotation of these joints is needed at higher walking speeds. Similar observations can be made about the joint angular velocities in figure 4. While the shape of the curves at the different speeds resemble each other, the angular velocities of the fast-paced walking reach more dramatic values.

The joint moments in figure 5. depict the torque exerted on the joints during the stance phase. The magnitude of these moments is determined both by the magnitude of the loads acting on the joints as well as the angle of the segments. Moreover, the segment angle will determine how close the joint reaction forces are, both vertically and horizontally, to the center of mass. Looking specifically at the ankle moment, it consistently acts in the clockwise direction to varying degrees across the entire stance phase after 20%. This can be explained by the center of pressure moving from the heel, slightly left of the ankle, to the tip, far right from the ankle. Meanwhile, the hip and knee maintain a moment within a small range of 0 Nm throughout the stance phase during normal walking. The data in this figure also exhibits that a greater moment is exerted on the joints when moving at a faster speed. This is especially apparent in the knee, where there is a large disparity between the normal and fast paced moments at around 20% of the stance phase. The moments are bigger at a faster pace due to the greater ground reaction force they require, which leads to higher joint reaction forces, as well as the more dramatic segment angles created.

A potential source of error in this lab could be the simplifications made to the body. The link segment model transforms a three-dimensional body into a two-dimensional figure. Moreover, any depth the segments had are now reduced to an infinitesimally thin line. This depiction will not yield entirely accurate results, as the actual limbs do not have an even weight distribution. For example, in the standing straight position, the center of mass location utilized would provide the correct location along the z axis, but the incorrect coordinate along the x and y axes. Moreover, a further simplification was made on the foot, where the center of mass was placed along the vector connecting the heel and tip. This center of mass should be in a triangulated location between the tip, heel, and ankle. All these assumptions would artificially alter the location of the center of mass relative to the joint and ground reaction forces and would consequently alter the calculated joint moment.

**References**

Bohannon, Richard & Andrews, Addison. (2011). Normal walking speed: A descriptive meta-analysis. Physiotherapy. 97. 182-9. 10.1016/j.physio.2010.12.004.

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