BE 436 - Biomechanics of Human Movement

Lab #1: Analyzing Biomechanics of Gait

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Group Monday - B2

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Introduction:

Throughout this lab, our group became familiar with the use of Bonner Hall's motion capture lab in order to evaluate the biomechanics of human gait, including walking, jogging, and skipping movements. We assigned one team member to be the motion capture subject, one team member to be the video recorder, one team member to take pictures and help suit up the motion capture subject, and two team members to work at the computer and ensure data was collected properly.

For this lab, we utilized a fitted motion capture suit and multiple motion capture markers attached to the suit with velcro. Each ball corresponds to a specific part of the body in order to calculate reaction forces in three dimensions for analysis. Vicon Motion Capture software tracks these bodysuit markers using an array of cameras, measuring velocity and acceleration over time for each discrete body part or muscle group's marker.

Using the motion capture suit and Vicon Motion Capture software, we were able to collect data points for analysis of each gait experiment. We aimed to collect the most accurate data possible through proper setup of the motion capture suit as well as defining the hard boundaries of the motion capture system's viewing area.

There are a few potential sources of error when recording experimental data for this experiment. When recording gait, motion capture markers on parts of the suit that are not as adhesive as other areas of the body may move around when experiencing sudden movement, like when jumping or hitting the floor. This may create large reaction force data spikes, seen as outliers in the data. Additionally, data may be lost if a marker moves out of the visible area of the motion capture cameras. However, we were able to mitigate this by marking off the boundaries of the cameras to the best of our ability.

Materials and Methods:

1. Begin the lab by completing basic setup tasks
    a. Start the Zoom call for partner group A2
    b. Start the Vicon Motion Capture software
        i. Create a folder to collect data, which was stored under a database, then the following folders: Courses, be436, be436_sp22, Group 13, Experiment 1, Patient 1, and finally, Session 1.
    c. Assist one group member in putting on the motion capture suit
        i. Attach velcro motion trackers to the motion capture suit by following the Marker Placement Guide on UBLearns
2. Calibrate the motion capture software
    a. Allow the test subject to stand in the viewing area to confirm that the software is accurately tracking the motion of the subject, and all markers are visible
    b. Have the test subject move towards each outer bound of the viewing area until the software begins to lose sight of suit markers. Place some type of marker on

the border of each viewing area to denote where the motion capture cameras begin to lose sign of the test subject
    c. Use the Auto Initializing Labeling pipeline for the calibration
3. Begin analysis of human gait
    a. Once data collection has started, walk at a set pace along the boundaries of the viewing area three times. Stop data collection after the completion of the third lap around the viewing area
    b. Repeat the previous step to record the second set of data for the walking data
    c. Repeat steps 3A and 3B for jogging and skipping. When complete, you should have two sets of data for each motion totalling to six total datasets.
4. Process and save recorded data
    a. Once all data is collected, save and apply the Export pipeline to all six trials
    b. Upload collected data to UBBox and share with the partner group

Results:

Section 1: Ground reaction forces

In the following section, we show the graphs we have obtained for the ground reaction forces. Data plots 1.1-2.3, 3.1-4.3, and 5.1-6.3 are the results for each direction (x, y and z), in walking, jogging, and skipping gait tests respectively. For both walking and skipping datasets, we averaged the RASI and LASI markers. For the jogging dataset, we used the T10 marker as our center of gravity.

To calculate the ground reaction forces, we used the center of gravity positions we obtained from the RASI, LASI and T10 markers, and first converted those to meters. After we had that data converted, we took the difference from each data point to the next and then divided that by our time interval of 0.01 seconds. This gave us our subject's speed, which we will discuss in the following section.

$$[X\ direction\ Position\ 2\ (m)\ -\ X\ direction\ Position\ 1\ (m)\ ]\ /\ 0.01\ s$$ Equation 1.1

We did this calculation in x, y and z directions. Now that we have speed, we took the difference between two speed data points and divided that by 0.01 seconds, to get acceleration in each direction of each trial.

$$[X\ direction\ Speed\ 2\ (m)\ -\ X\ direction\ Speed\ 1\ (m)\ ]\ /\ 0.01\text{s}$$ Equation 1.2

Using the acceleration we just obtained, we then found the ground reaction forces by multiplying acceleration and the mass of our subject.

$$Ground\ Reaction\ Force\ =\ mass\ of\ subject\ (77kg)\ *\ acceleration$$ Equation 1.3

Using the LASI and RASI markers, we calculated the ground reaction forces during the walking gait trial.

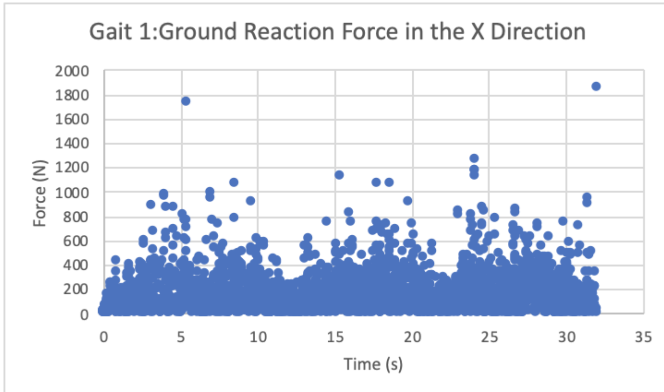


Figure 1.1 - X-directional ground reaction force during the first walking gait trials

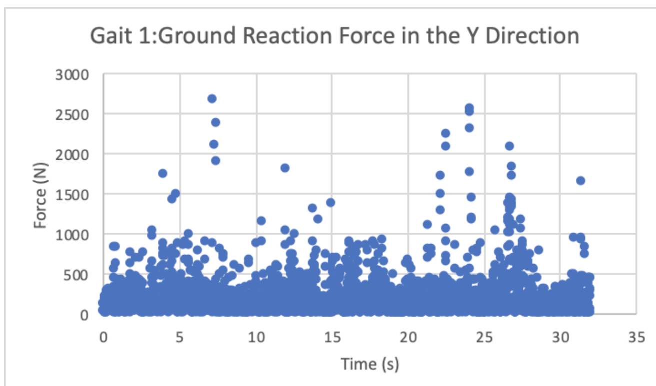


Figure 1.2 - Y-directional ground reaction force during the first walking gait trials

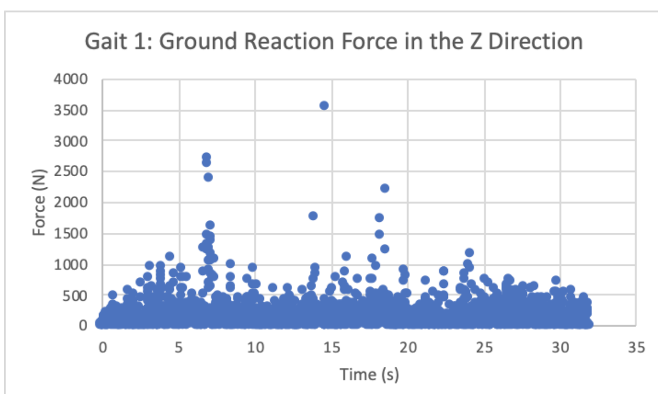


Figure 1.3 - Z-directional ground reaction force during the first walking gait trials

The maximum ground reaction forces and average ground reaction force per step are as follows.

	x	y	z
Max Ground Reaction Force (N)	1861.8	2657.9	3553.2
Average Ground Reaction Force Per Step (N)	130.23	181.89	128.91

Using the LASI and RASI markers, we calculated the ground reaction forces during Gait 2.

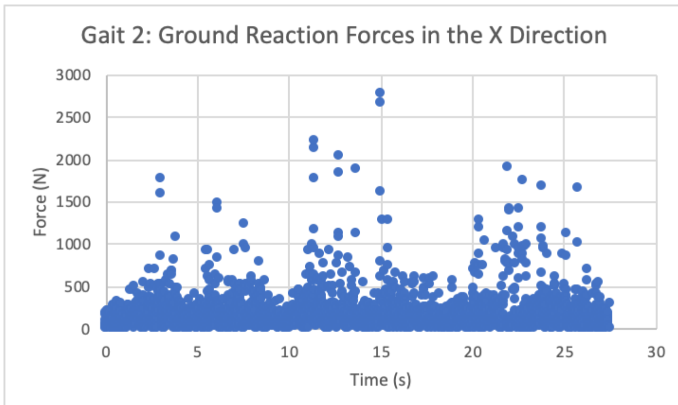


Figure 2.1 - X-directional ground reaction forces during the second walking gait trials

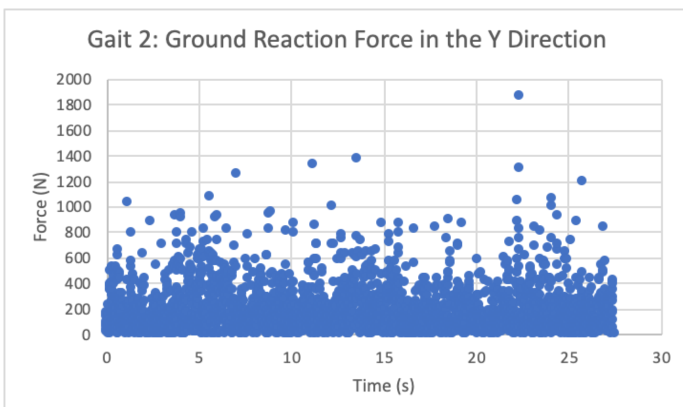


Figure 2.2 - Y-directional ground reaction forces during the second walking gait trials

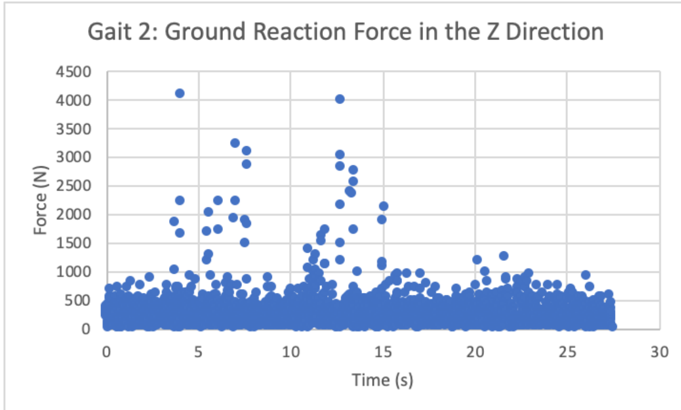


Figure 2.3 - Z-directional ground reaction forces during the second walking gait trials

The maximum ground reaction forces and average ground reaction force per step are as follows.

	x	y	z
Max Ground Reaction Force (N)	2773.1	1861.4	4084.1
Average Ground Reaction Force Per Step (N)	164.51	151.32	215.58

Using the T10 marker, we calculated the ground reaction forces during Jog 1.

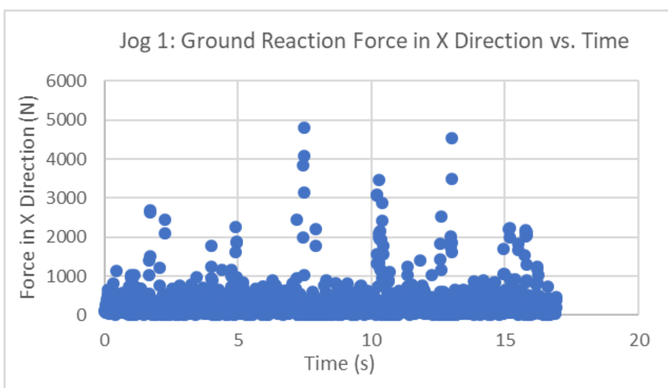


Figure 3.1 - X-directional ground reaction forces during the first jogging gait trials

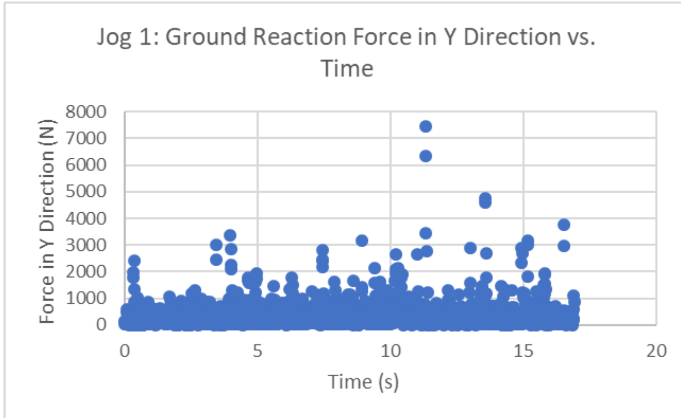


Figure 3.2 - Y-directional ground reaction forces during the first jogging gait trials

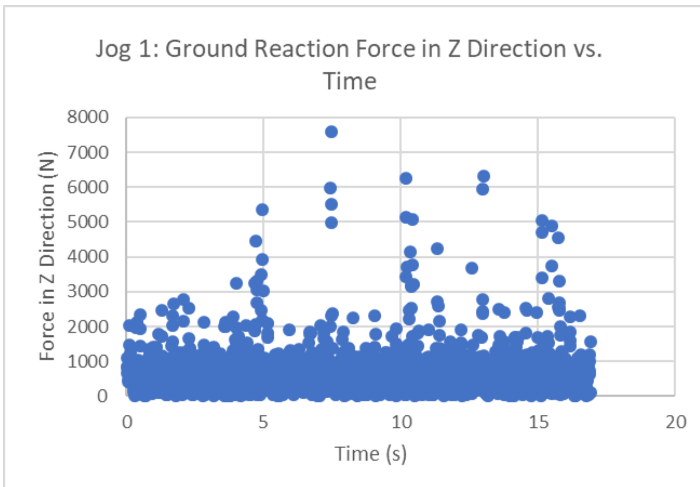


Figure 3.3 - Z-directional ground reaction forces during the first jogging gait trials

For Jog 1, we found the following maximum and the average ground reaction force per step.

	x	y	z
Max Ground Reaction Force (N)	4803.8	7451.7	7584.3
Average Ground Reaction Force Per Step (N)	317.43	278.78	668.89

Using the T10 marker, we calculated the ground reaction forces during Jog 2.

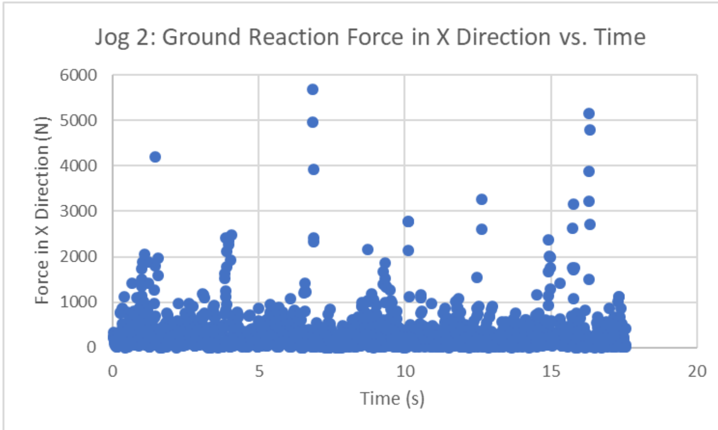


Figure 4.1 - X-directional ground reaction forces during the second jogging gait trials

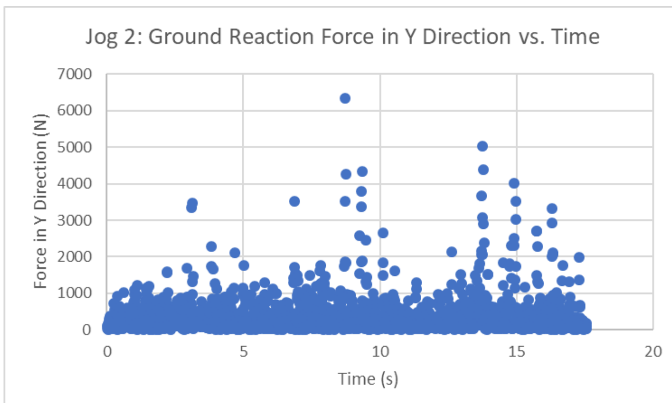


Figure 4.2 - Y-directional ground reaction forces during the second jogging gait trials

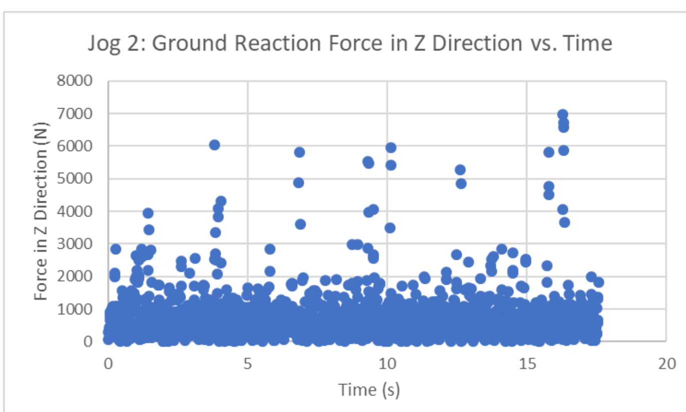


Figure 4.3 - Z-directional ground reaction forces during the second jogging gait trials

For Jog 2, we found the following maximums and average ground reaction force per step.

	x	y	z
Max Ground Reaction Force (N)	5680.8	6342.4	6961.7
Average Ground Reaction Force Per Step (N)	347.71	394.77	786.85

Using the LASI and RASI markers, we calculated the ground reaction forces during Skip 1.

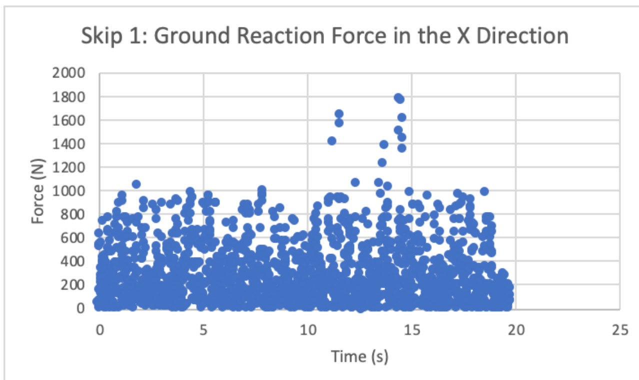


Figure 5.1 - X-directional ground reaction forces during the first skipping gait trials

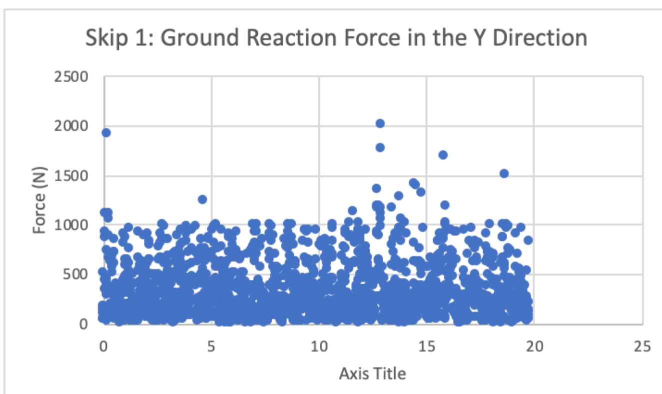


Figure 5.2 - Y-directional ground reaction forces during the first skipping gait trials

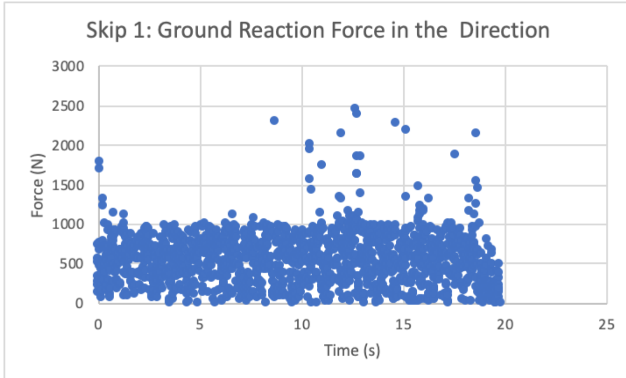


Figure 5.3 - Z-directional ground reaction forces during the first skipping gait trials

For Skip 1, we found these maximums and average ground reaction force per step

	x	y	z
Max Ground Reaction Force (N)	1687.1	1992.9	2457.2
Average Ground Reaction Force Per Step (N)	266.34	266.71	562.06

Using the LASI and RASI markers, we calculated the ground reaction forces during Skip 2.

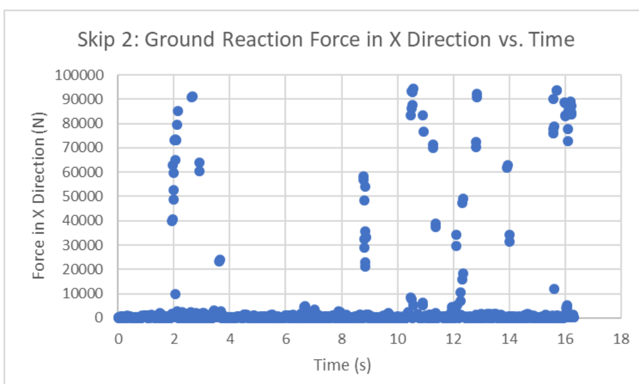


Figure 6.1 - X-directional ground reaction forces during the second skipping gait trials

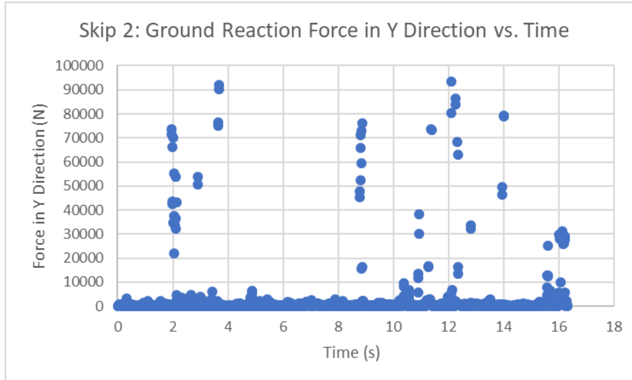


Figure 6.2 - Y-directional ground reaction forces during the second skipping gait trials

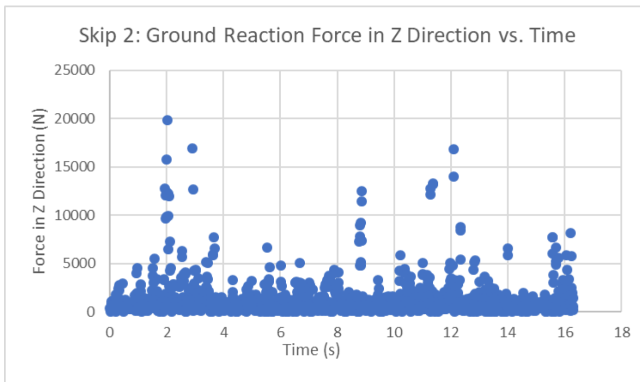


Figure 6.3 - Z-directional ground reaction forces during the second skipping gait trials

For Skip 2, we have found the following maxes and average ground reaction force per step .

	x	y	z
Max Ground Reaction Force (N)	94194.9	93363.4	19864.2
Average Ground Reaction Force Per Step (N)	7148.60	6817.62	2336.85

Section 2 - Linear speed of test subject

In this section, we have found the linear speed of our subject during each of the six trials. We used the same four markers as we did with the ground reaction forces. LASI, RASI and T10. Figures 7.1-8.3, 9.1-10.3, and 11.1-12.3 show the linear speed in the x, y, and z directions for walking, jogging, and skipping gaits respectively.

Using the LASI and RASI markers, we calculated the linear speed of Connor during Gait 1.

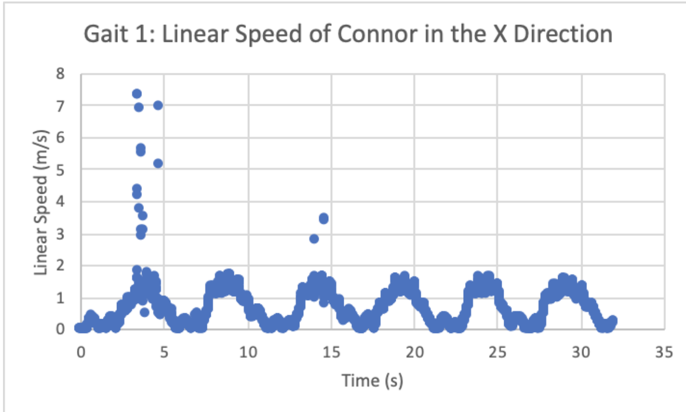


Figure 7.1 - X-directional linear speed during the first walking gait trials

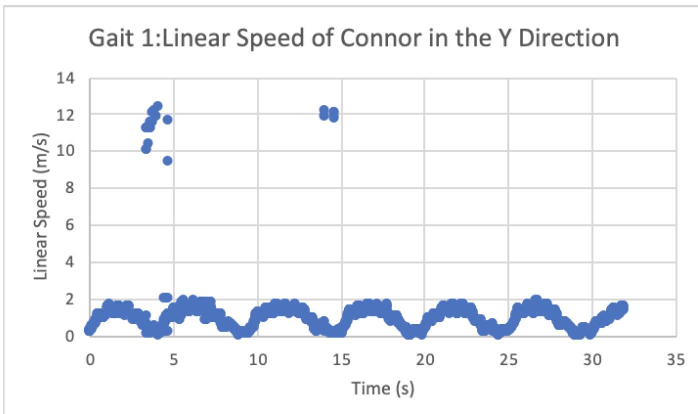


Figure 7.2 - Y-directional linear speed during the first walking gait trials

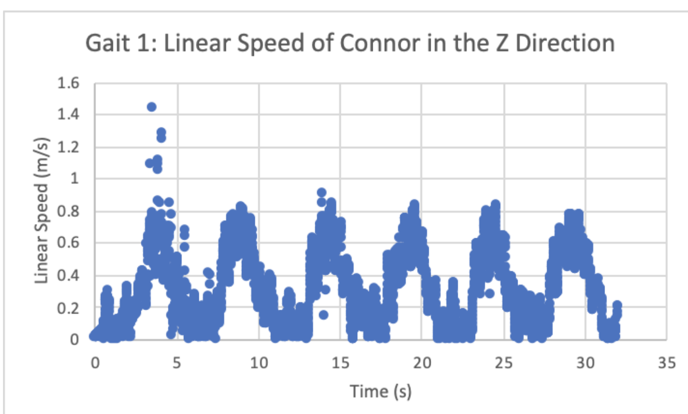


Figure 7.3 - Z-directional linear speed during the first walking gait trials

For normal gait 1, we found the maximum linear speeds and Average Linear Speed Per Step (m/s).

	x	y	z
Max Linear Speed (m/s)	7.351	12.372	1.437
Average Linear Speed per Step (m/s)	0.302	0.683	0.148

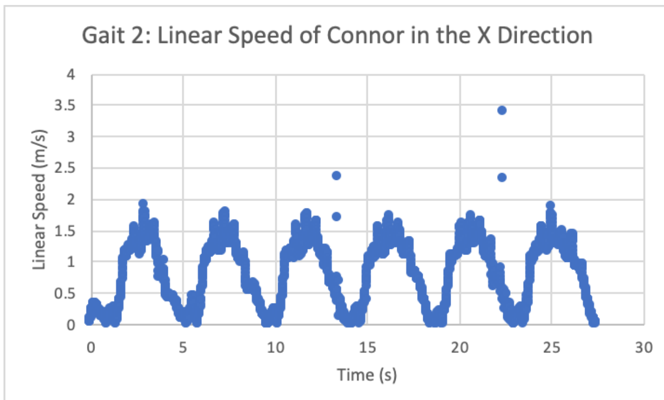


Figure 8.1 - X-directional linear speed during the second walking gait trials

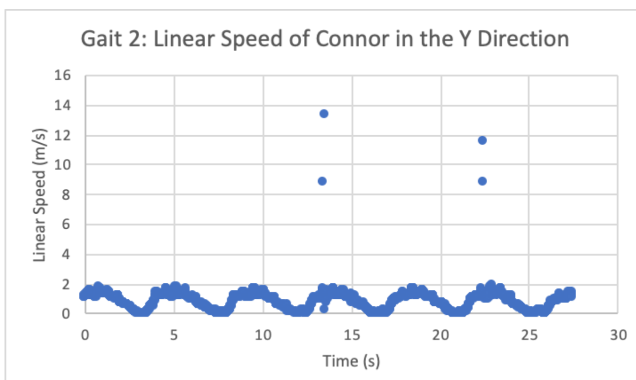


Figure 8.2 - Y-directional linear speed during the second walking gait trials

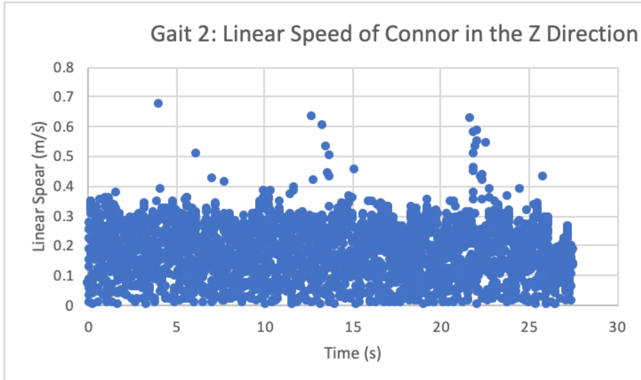


Figure 8.3 - Z-directional linear speed during the second walking gait trials

The maximum linear speeds and Average Linear Speed Per Step (m/s) are:

	x	y	z
Max Linear Speed (m/s)	3.400	12.372	0.671
Average Linear Speed per Step (m/s)	1.805	0.6934	0.4451

Using the T10 marker, we calculated the linear speed of Connor during Jog 1.

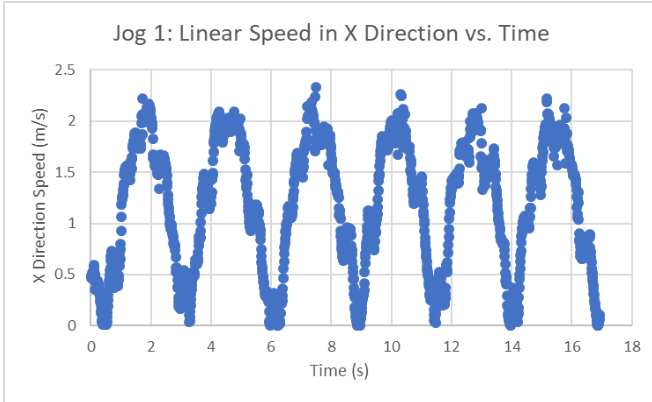


Figure 9.1 - X-directional linear speed during the first jogging gait trials

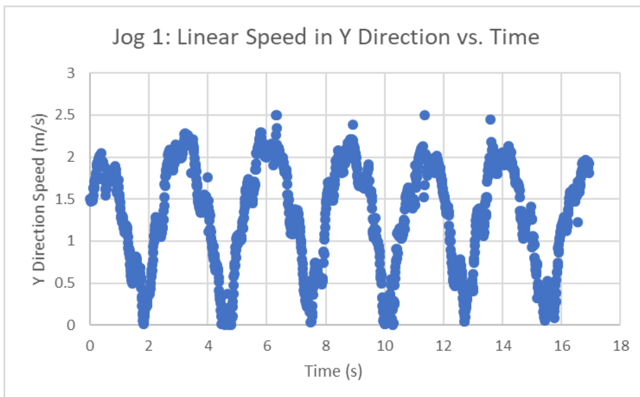


Figure 9.2 - Y-directional linear speed during the first jogging gait trials

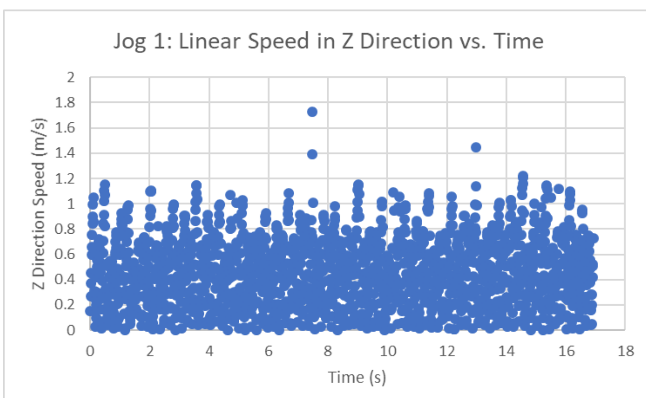


Figure 9.3 - Z-directional linear speed during the first jogging gait trials

For Jog 1, we found the following maximums and Average Linear Speed Per Step (m/s).

	x	y	z
Max Linear Speed (m/s)	2.328	2.499	1.723
Average Linear Speed per Step (m/s)	1.229	1.229	0.4843

Using the T10 marker, we calculated the linear speed of Connor during Jog 2.

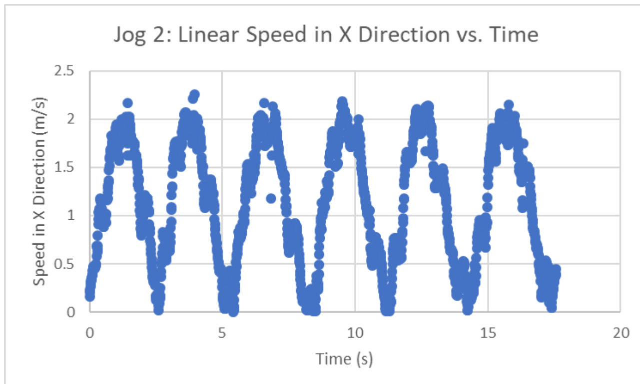


Figure 10.1 - X-directional linear speed during the second jogging gait trials

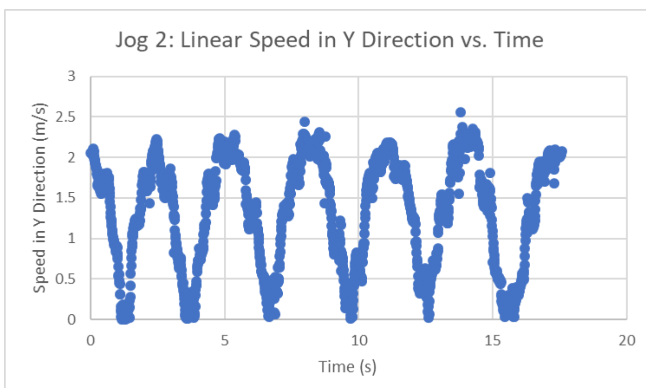


Figure 10.2 - Y-directional linear speed during the second jogging gait trials

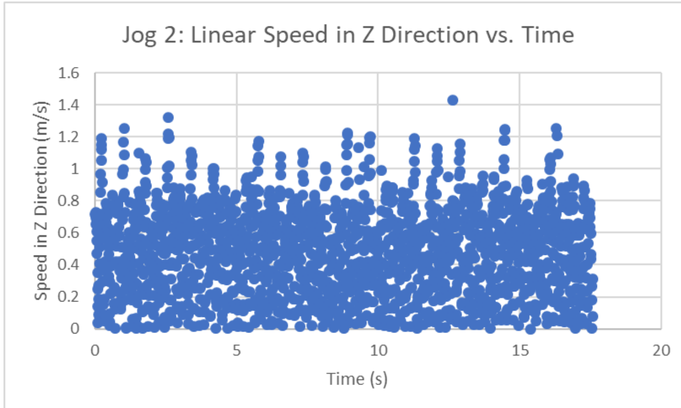


Figure 10.3 - Z-directional linear speed during the second jogging gait trials

For Jog 2, we found the following maximums and Average Linear Speed Per Step (m/s).

	x	y	z
Max Linear Speed (m/s)	2.254	2.556	1.428
Average Linear Speed per Step (m/s)	1.229	1.229	0.4843

Using the LASI and RASI markers, we calculated the linear speed of Connor during Skip 1.

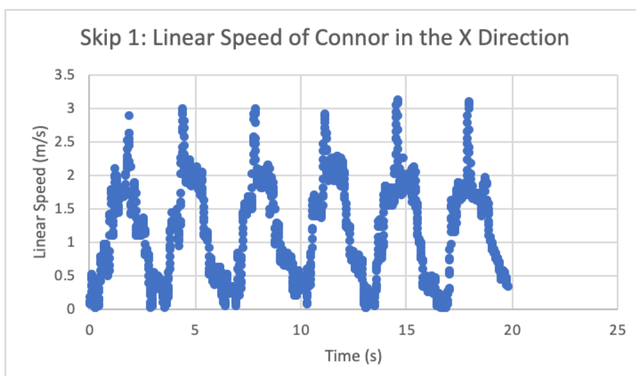


Figure 11.1 - X-directional linear speed during the first skipping gait trials

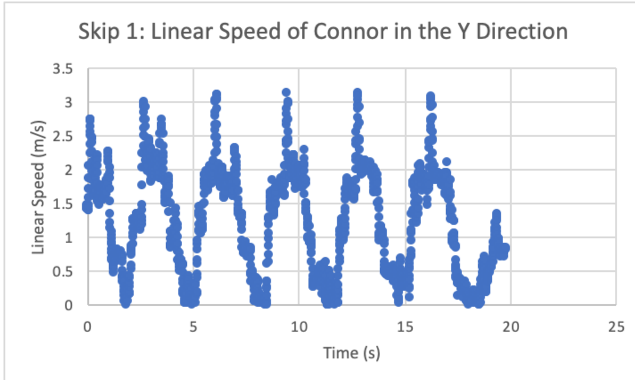


Figure 11.2 - Y-directional linear speed during the first skipping gait trials

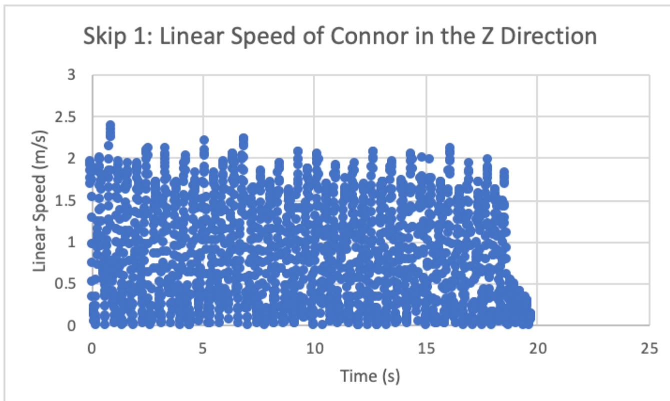


Figure 11.3 - Z-directional linear speed during the first skipping gait trials

For Skip 1, we found the following maximum speeds and Average Linear Speed Per Step (m/s).

	x	y	z
Max Linear Speed (m/s)	3.101	3.143	2.401
Average Linear Speed per Step (m/s)	1.6451	0.72065	0.84644

Using the LASI and RASI markers, we calculated the linear speed of Connor during Skip 2.

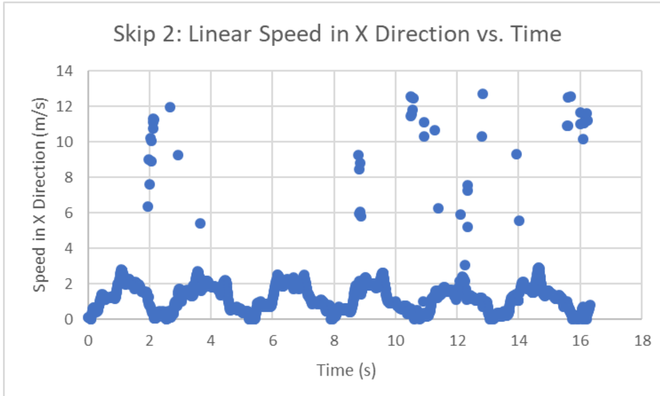


Figure 12.1 - X-directional linear speed during the second skipping gait trials

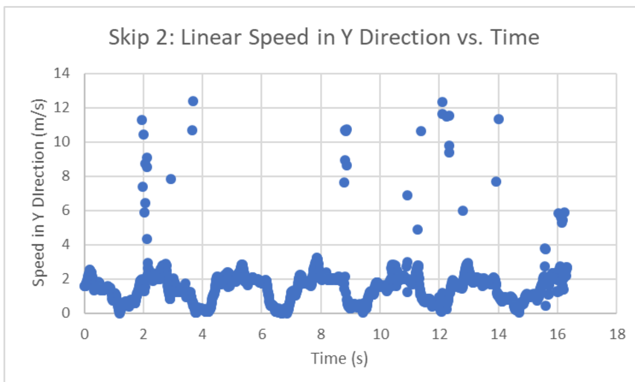


Figure 12.2 - Y-directional linear speed during the second skipping gait trials

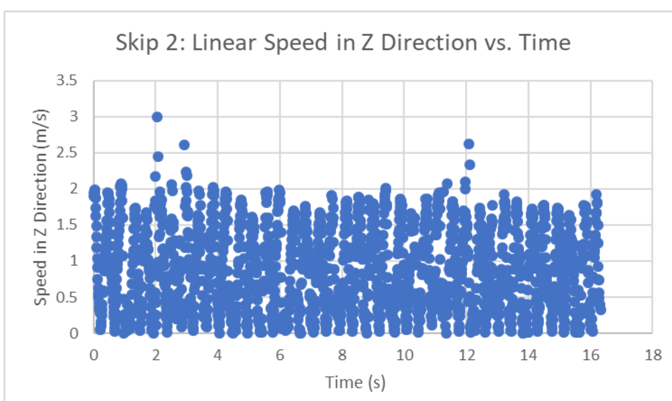


Figure 12.3 - Z-directional linear speed during the second skipping gait trials

For Skip 2, we found the following maximum and Average Linear Speed Per Step (m/s).

	x	y	z
Max Linear Speed (m/s)	12.708	12.386	3.003
Average Linear Speed per Step (m/s)	1.9148	1.9825	0.91078

Section 3 - Trajectory of test subject

In this section you can find the trajectory of our subject throughout all six of the trials. Figures 13.1-13.2, 13.3-13.4, and 13.5-13.6 show the trajectory in the x-y plane for the two walking, jogging, and skipping trials respectively. To calculate the trajectory of our subject in the gait and skipping trials, we took the average of the RASI and LASI markers of the x and y positions. For the jogging trials, we calculated the trajectory using the x and y positions of the T10 marker.

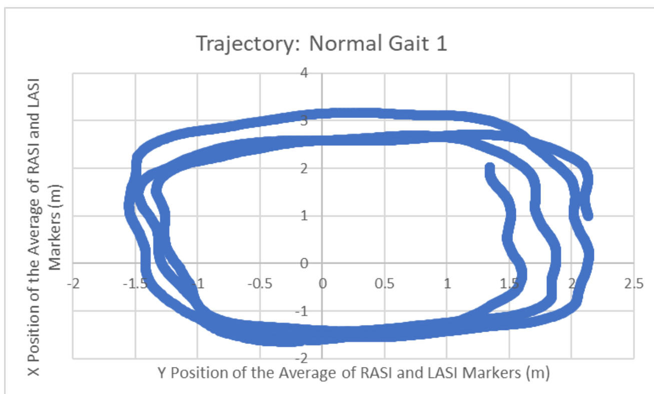


Figure 13.1 - Trajectory plot of x vs. y position for the first walking gait trial

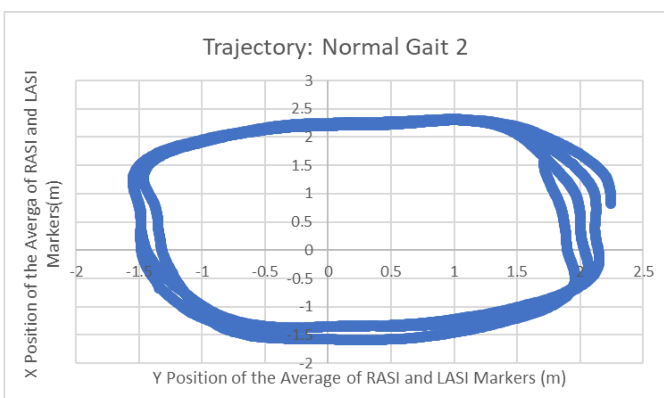


Figure 13.2 - Trajectory plot of x vs. y position for the second walking gait trial

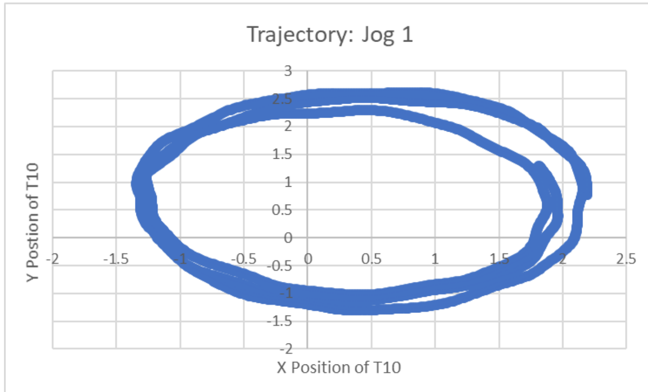


Figure 13.3 - Trajectory plot of x vs. y position for the first jogging gait trial

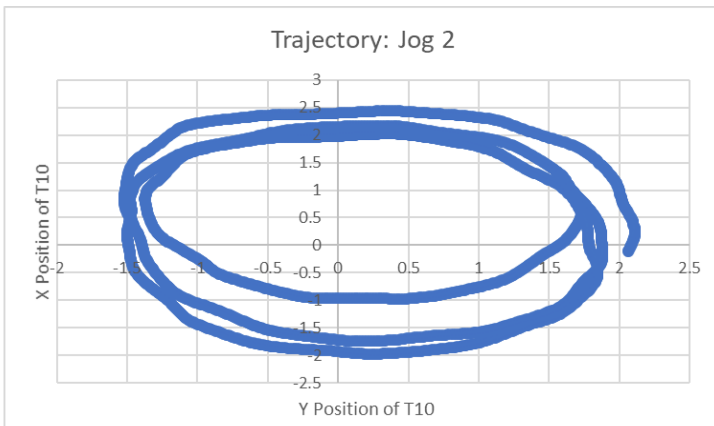


Figure 13.4 - Trajectory plot of x vs. y position for the second jogging gait trial

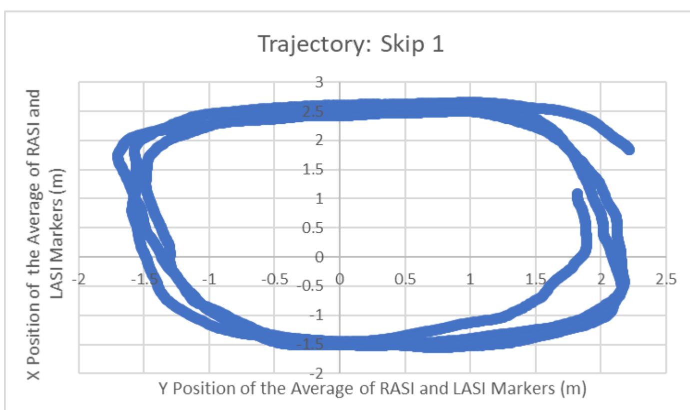


Figure 13.5 - Trajectory plot of x vs. y position for the first skipping gait trial

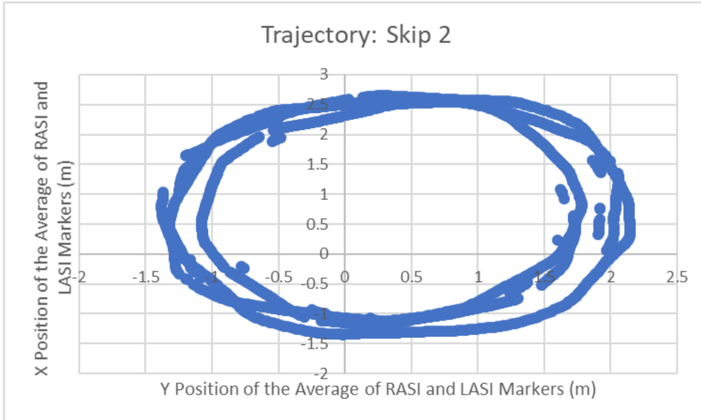


Figure 13.6 - Trajectory plot of x vs. y position for the second skipping gait trial

Section 4 - Step distance and cadence

To calculate step distance and cadence, we first graphed the Z position of the left heel, LHEE. We then marked all the local maxima greater than 0.2 meters on this graph. The data below 0.2 meters is more noisy, so this process gives us a more accurate representation of the peaks. The resultant graphs can be seen below in figures 14.1 -14.6. Due to data loss, the right heel, RHEE, was used during the Skip tests, but the same procedure was followed.

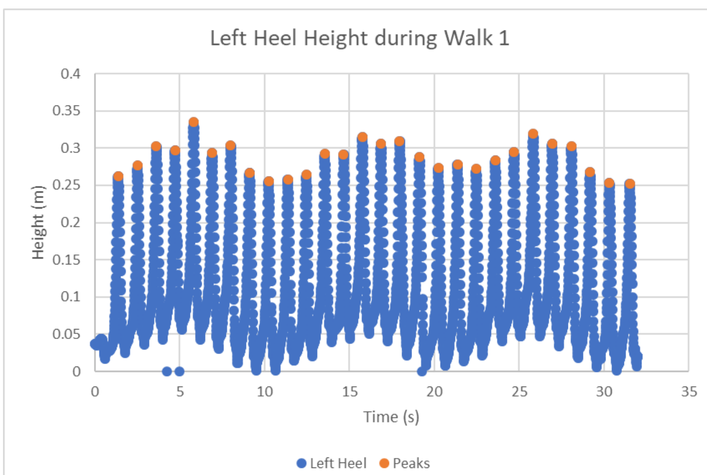


Figure 14.1 - Left heel height for the first walking gait trial

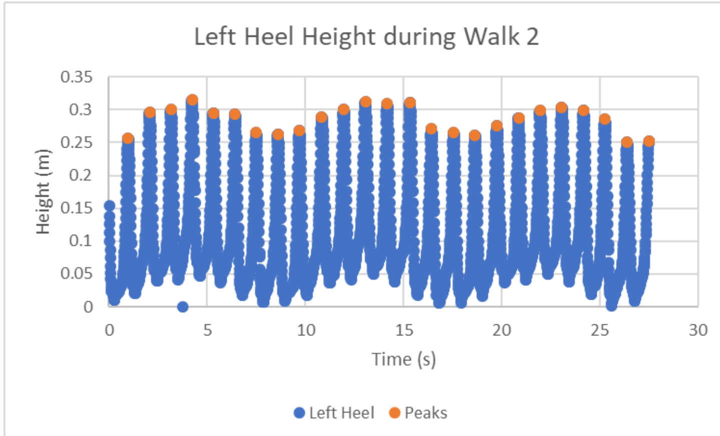


Figure 14.2 - Left heel height for the second walking gait trial

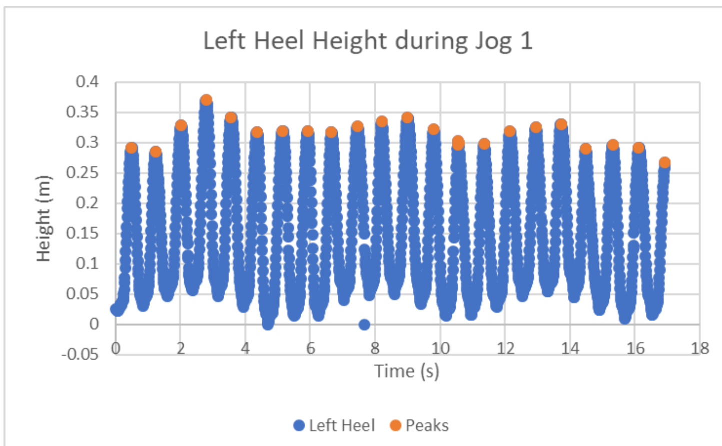


Figure 14.3 - Left heel height for the first jogging gait trial

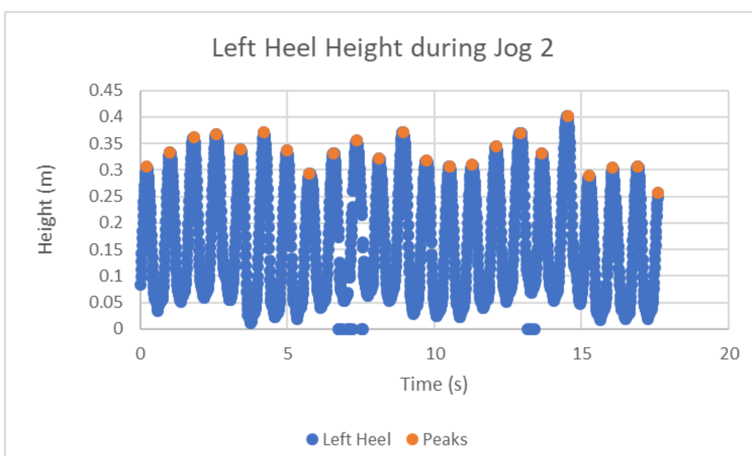


Figure 14.4 - Left heel height for the second jogging gait trial

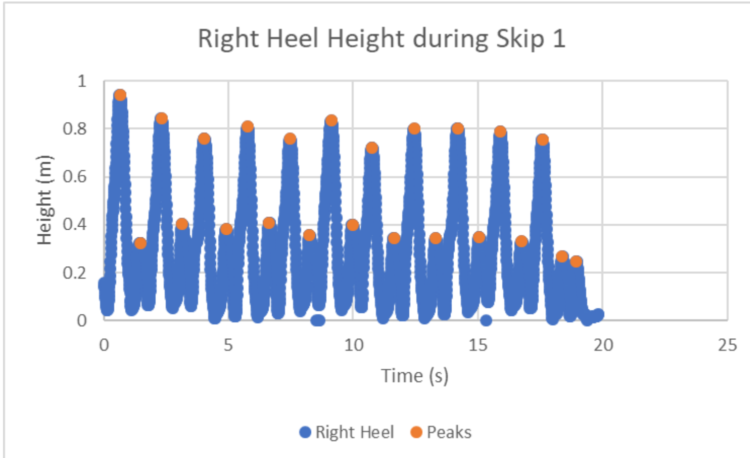


Figure 14.5 - Right heel height for the first skipping gait trial

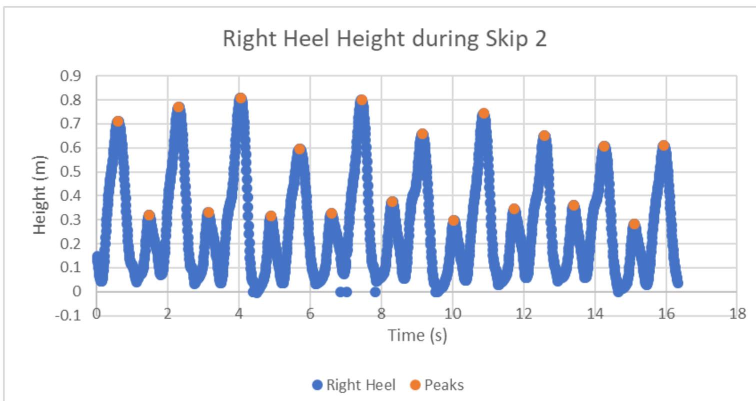


Figure 14.5 - Right heel height for the second skipping gait trial

The corresponding X and Y positions for each peak, and the following formula, were then used to determine the step distance.

$$distance = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad \text{Equation 4.1}$$

However, since these peaks are only for one foot, this calculated distance needs to be divided in half to get the actual step distance. The calculated maximum and average step distance for each gait can be seen below.

Gait Trail	Average Step Distance (m)	Maximum Step Distance (m)
Walk 1	0.733	0.800
Walk 2	0.747	0.796
Jog 1	0.882	0.947

Jog 2	0.881	1.031
Skip 1	0.777	0.989
Skip 2	0.902	1.080

Additionally, the times that each peak occurred at is used in other sections to divide the dataset into distinct cycles to get an average per cycle.

In order to calculate cadence, we first counted the total number of peaks, then doubled that number to account for the steps taken with both feet. We then used the following relationship to determine the steps per minute.

$$\frac{Recorded\ Steps}{Recorded\ Time} = \frac{x}{60\ seconds} \quad \text{Equation 4.2}$$

Where x is the steps per minute, or cadence.

The calculated cadence for each gait can be seen below.

Gait Trial	Cadence (steps per minute)
Walk 1	105
Walk 2	109.051
Jog 1	155.844
Jog 2	156.907
Skip 1	139.183
Skip 2	139.62

Section 5 - Work done

Using the ground reaction forces for the x, y, z components of Gait 1, we calculated the force generated by the body (F_{gen}) by considering the sum of the forces (Equation 5.1). Then, to calculate the work done for the x, y, z components, we used the force generated values and the corresponding distance per step calculated in the previous section (Equation 5.2). These values calculated for work were then plotted versus time (s) in Figures 15.1 though 15.3 This process was then repeated for Gait 2, Jog 1, Jog 2, Skip 1, and Skip 2 which was then plotted in figures 15.4 through 15.18.

$$F_{net} = F_{w} + F_{gen} \qquad \text{Equation 5.1}$$

$$W = F_{gen} + d_{step} \qquad \text{Equation 5.2}$$

From the data calculated for work done, we determined the max values in the x,y, and z directions as you can see in the chart below.

Trial	Max work in x direction (J)	Max work in y direction (J)	Max work in z direction (J)
Walk 1	36744.26	69434.79	525155.53
Walk 2	17505.73	75408.73	21727.03
Jog 1	4482.38	6617.46	6724.36
Jog 2	5672.73	6255.92	6801.71
Skip 1	4615.91	4546.07	5629.57
Skip 2	85726.88	84976.14	18616.60

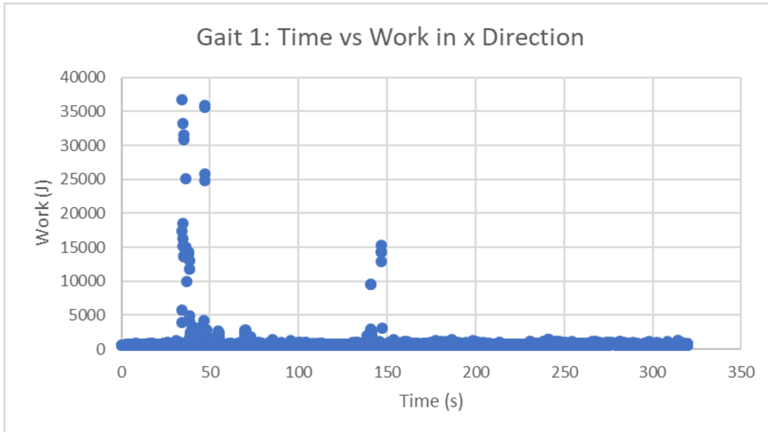


Figure 15.1 - Time vs Work in x direction for the first gait trial.

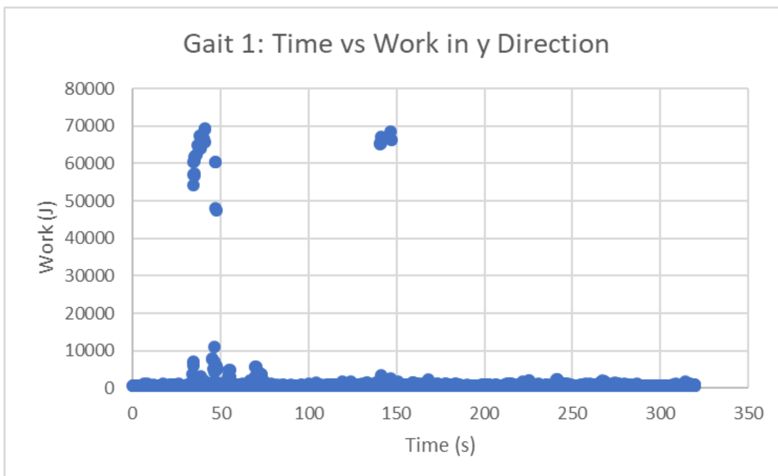


Figure 15.2 - Time vs Work in y direction for the first gait trial.

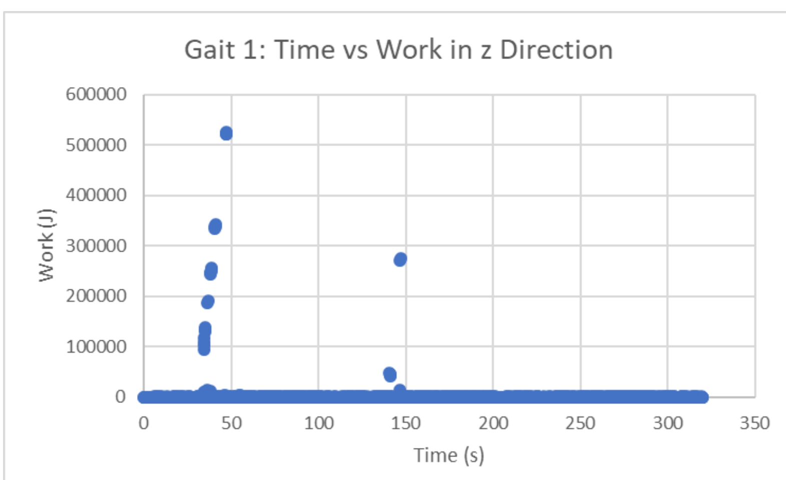


Figure 15.3 - Time vs Work in z direction for the first gait trial.

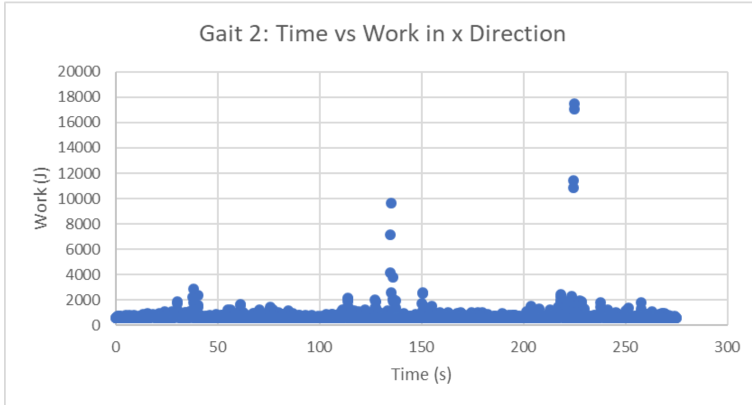


Figure 15.4 - Time vs Work in x direction for the second gait trial.

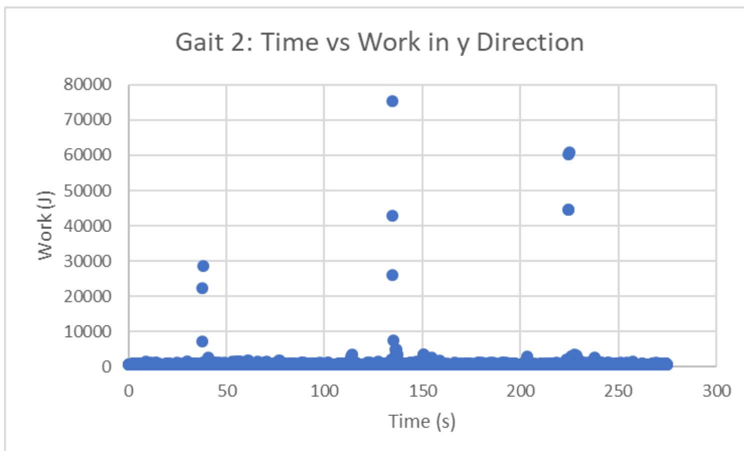


Figure 15.5 - Time vs Work in y direction for the second gait trial.

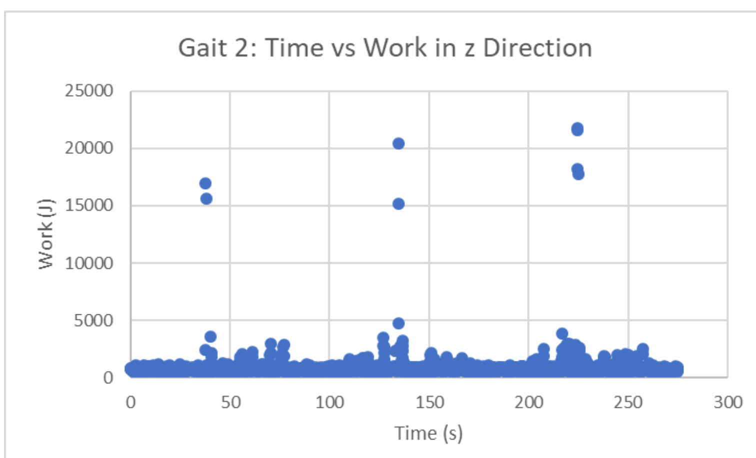


Figure 15.6 - Time vs Work in z direction for the second gait trial.

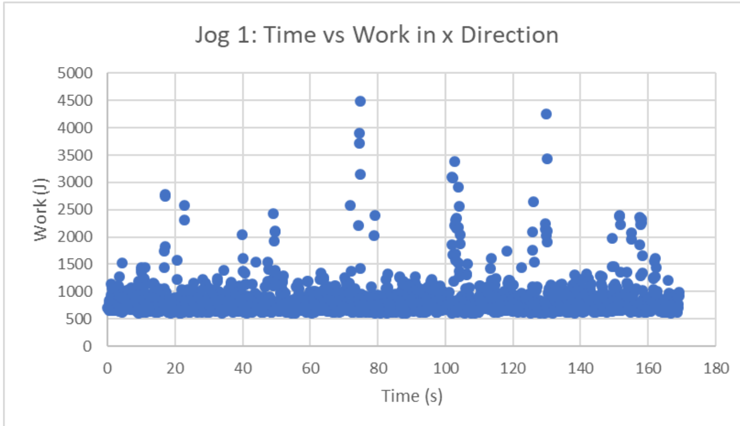


Figure 15.7 - Time vs Work in x direction for the first jog trial.

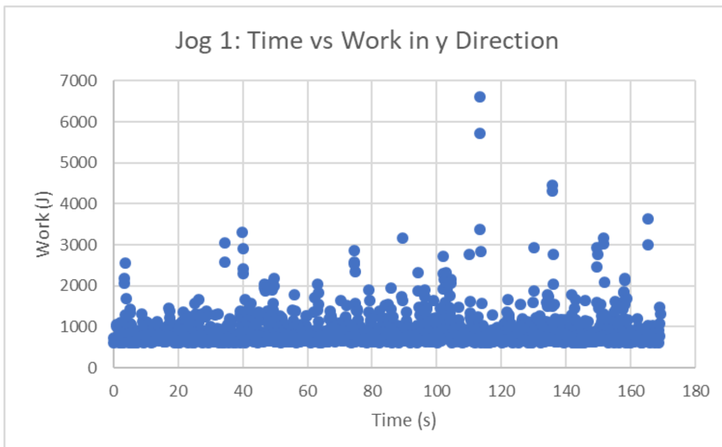


Figure 15.8 - Time vs Work in y direction for the first jog trial.

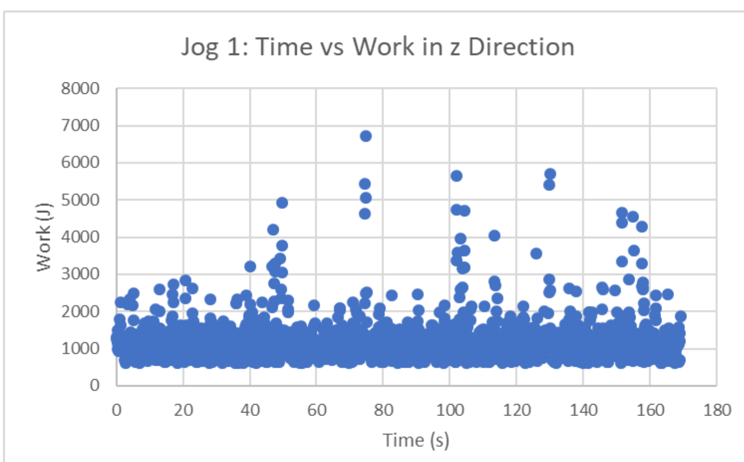


Figure 15.9 - Time vs Work in z direction for the first jog trial.

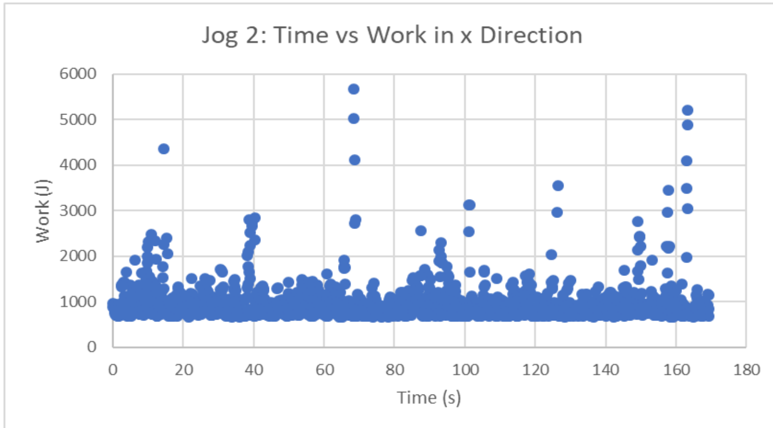


Figure 15.10 - Time vs Work in x direction for the second jog trial.

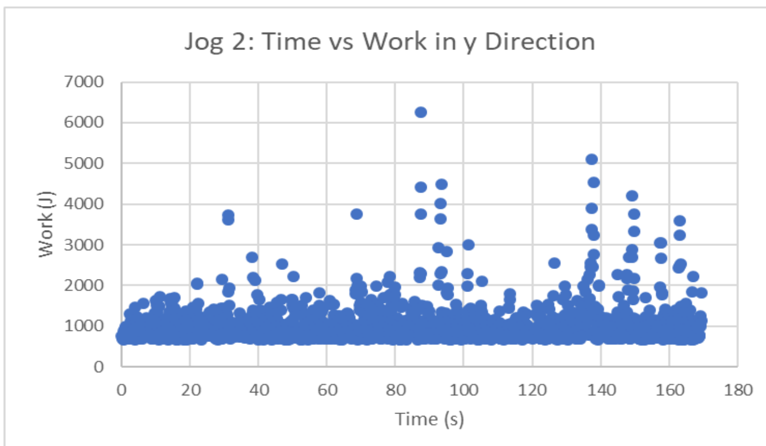


Figure 15.11 - Time vs Work in y direction for the second jog trial

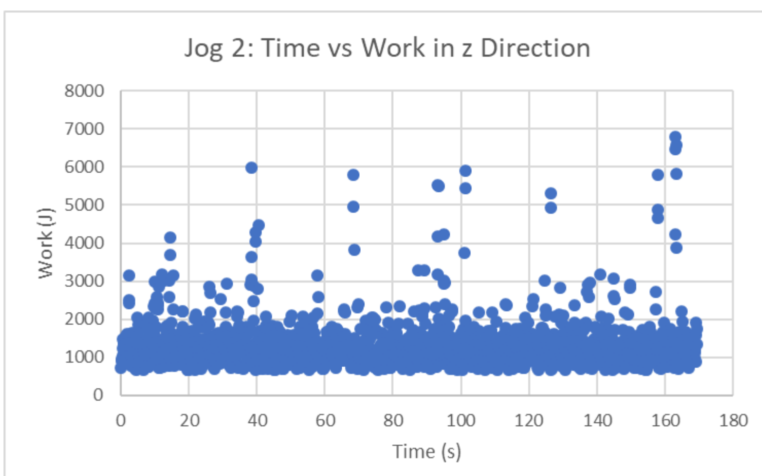


Figure 15.12 - Time vs Work in z direction for the second jog trial.

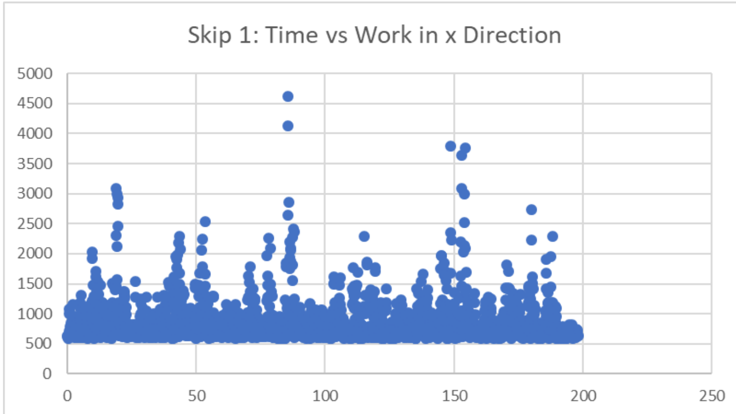


Figure 15.13 - Time vs Work in x direction for the first skip trial.

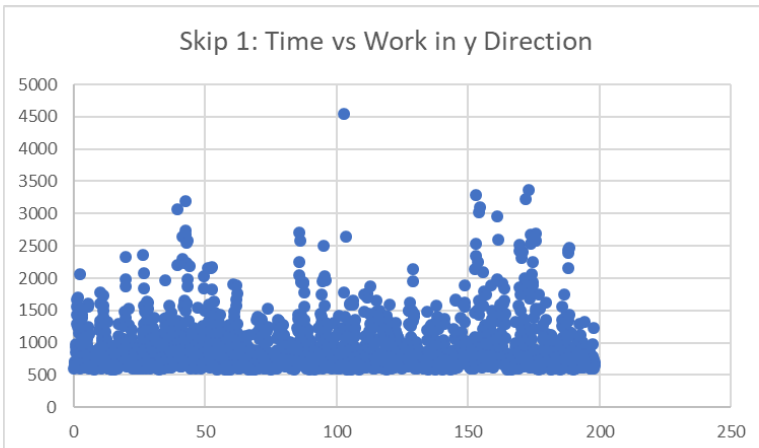


Figure 15.14 - Time vs Work in y direction for the first skip trial.

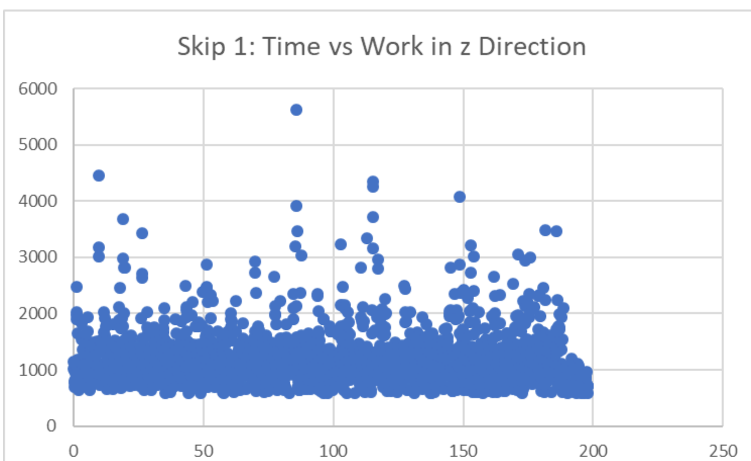


Figure 15.15 - Time vs Work in z direction for the first skip trial.

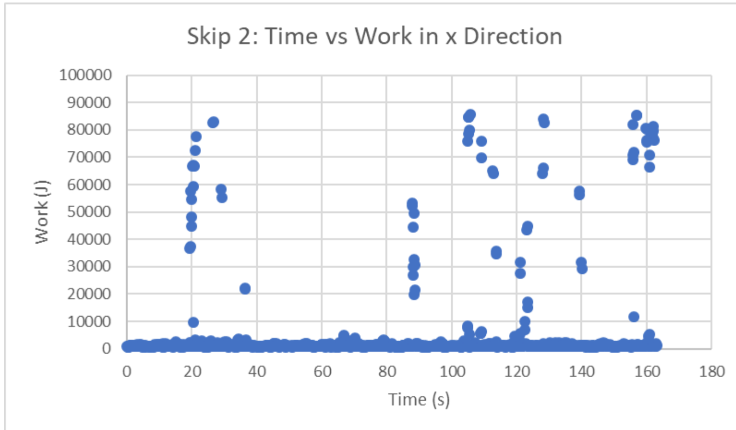


Figure 15.16 - Time vs Work in x direction for the second skip trial.

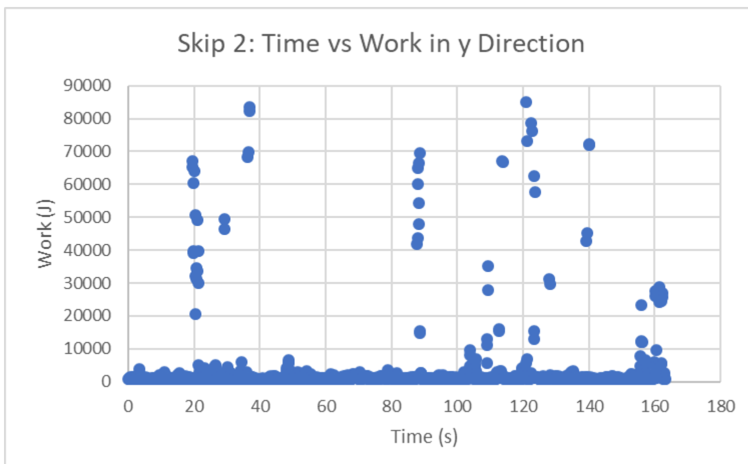


Figure 15.17 - Time vs Work in y direction for the second skip trial.

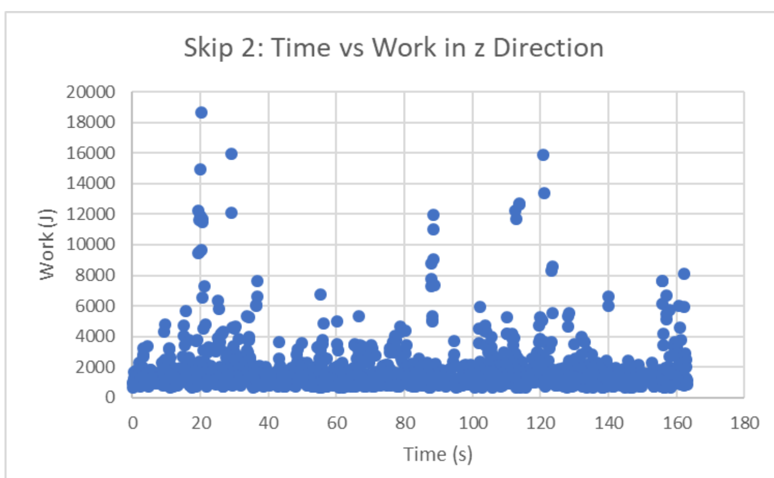


Figure 15.18 - Time vs Work in z direction for the second skip trial.

6. Knee angles and angular velocity

To calculate knee angles, we used the RTHI, RKNE, and RTIB markers. We first turned the position of RTHI and RTIB into vectors originating from RKNE by subtracting the coordinates of RKNE from both RTHI and RTIB.

Then, we found the dot product of these vectors using the following formula.

$$(X_1 * X_2) + (Y_1 * Y_2) + (Z_1 * Z_2) \qquad \text{Equation 6.1}$$

Next, we multiplied the magnitudes of these vectors using the following formula.

$$|a|\,|b| = \sqrt{X_1^{\ 2} + Y_1^{\ 2} + Z_1^{\ 2}} * \sqrt{X_2^{\ 2} + Y_2^{\ 2} + Z_2^{\ 2}} \qquad \text{Equation 6.2}$$

Where subscripts 1 and 2 correspond to RTHI and RTIB respectively.

The inverse cosine of the dot product divided by the magnitudes, gives us the angle of the knee, in radians. Multiplying by 180/pi converts radians to degrees.

$$\theta = acos\left(\frac{dot\ product}{|a|\,|b|}\right) * \left(\frac{180}{pi}\right) \qquad \text{Equation 6.3}$$

The knee angle during each recorded gait is shown in the following graphs.

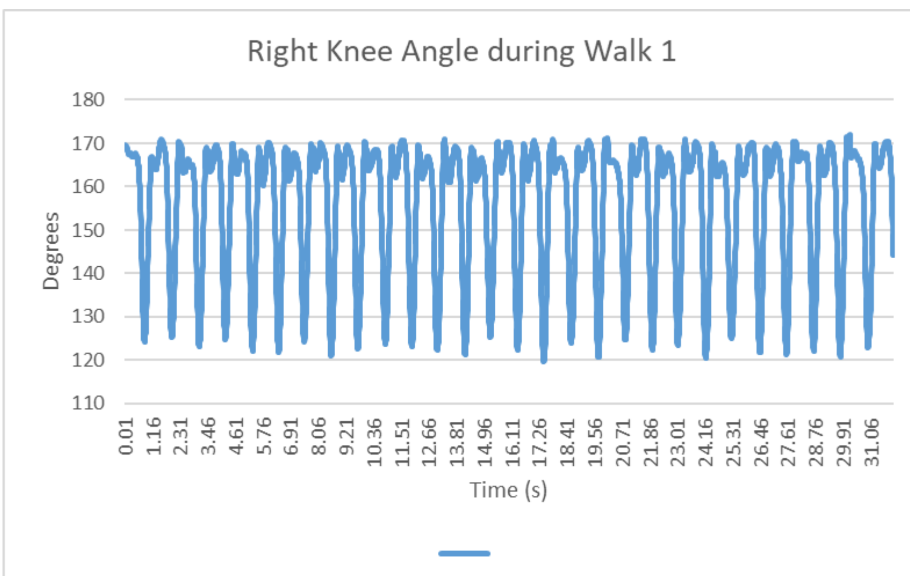


Figure 16.1 - Right knee angle during the first walk trial.

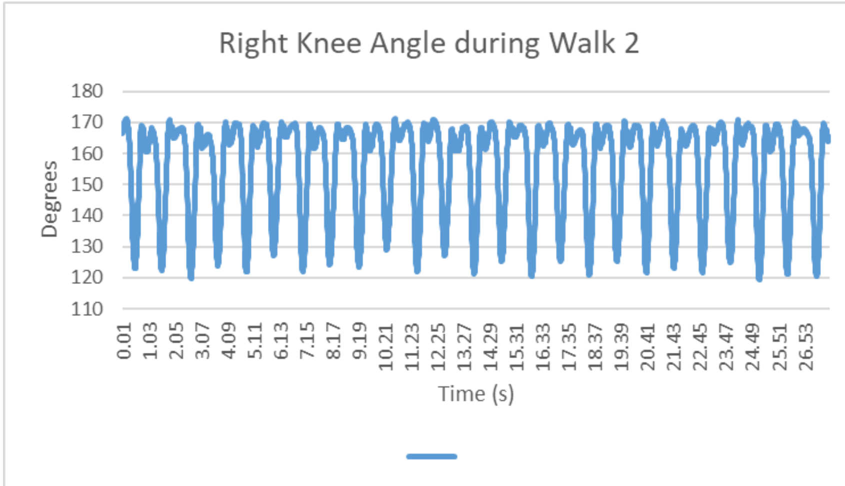


Figure 16.2 - Right knee angle during the second walk trial.

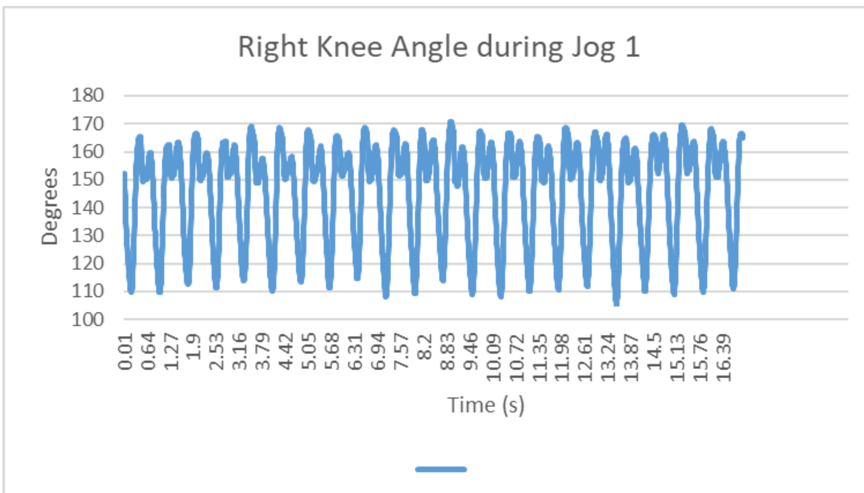


Figure 16.3 - Right knee angle during the first jog trial.

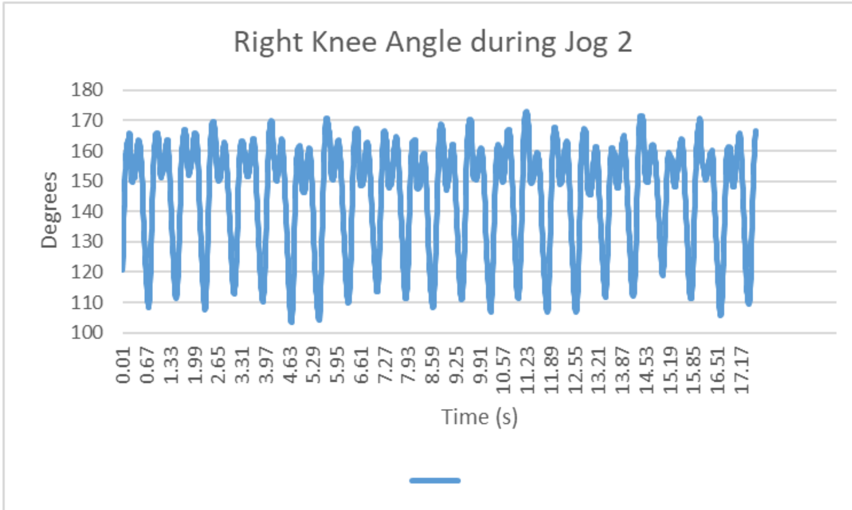
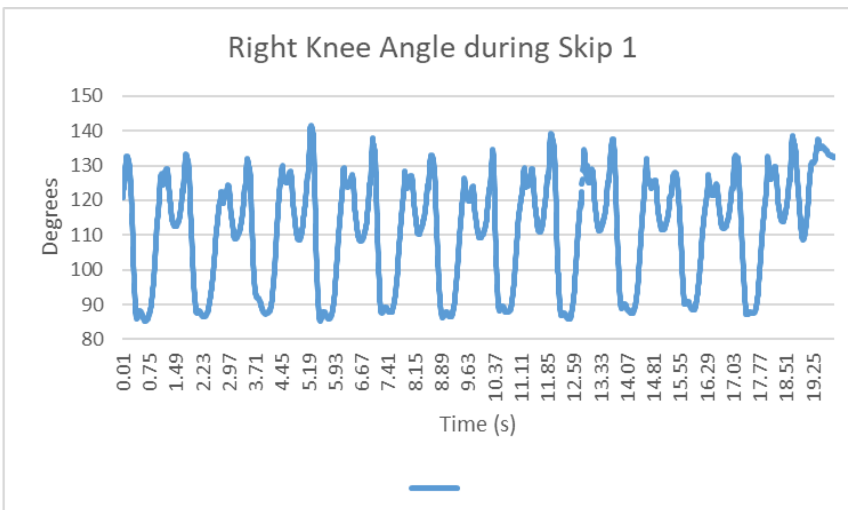


Figure 16.4 - Right knee angle during the second jog trial.

Figure 16.5 - Right knee angle during the first skip trial.



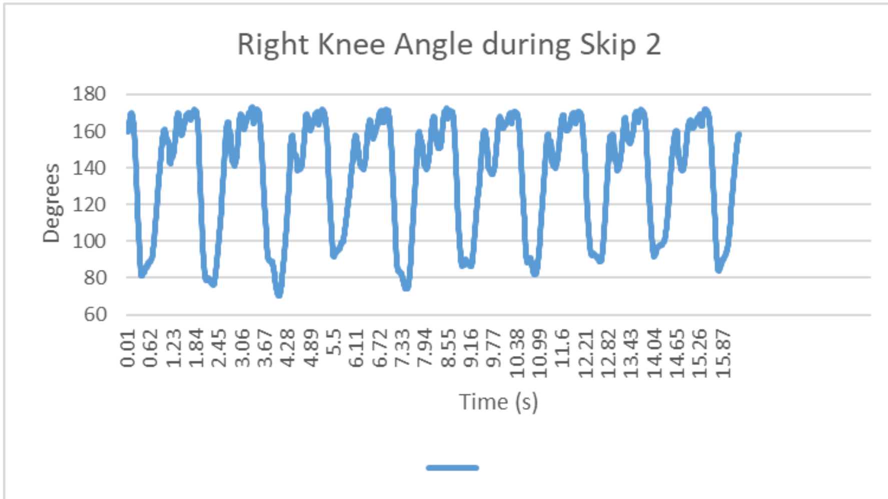


Figure 16.6 - Right knee angle during the second skip trial.

Using the unconverted radians, we can calculate the angular velocity in radians/second using the following formula.

$$\frac{radians_2 - radians_1}{time_2 - time_2} \qquad \text{Equation 6.4}$$

The knee angular velocity during each recorded gait is shown in the following graphs.

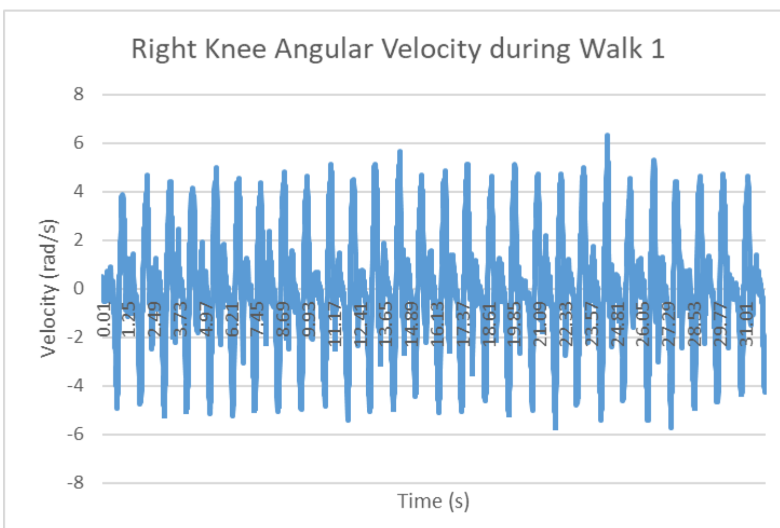


Figure 17.1 - Right knee angular velocity during the first walk trial.

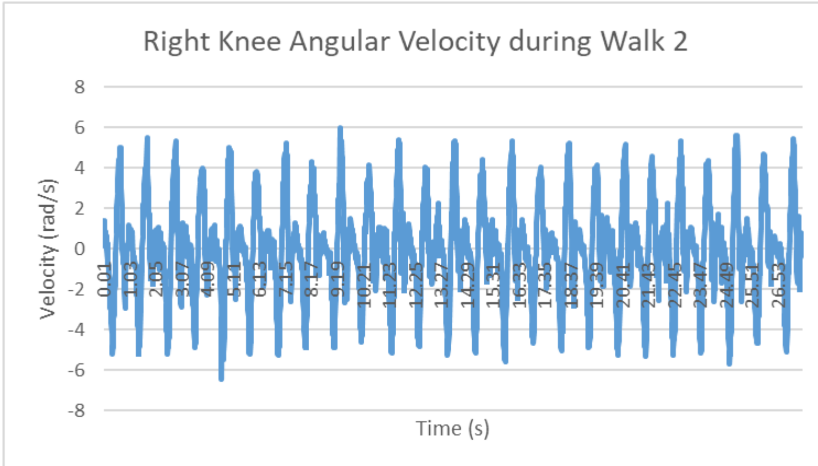


Figure 17.2 - Right knee angular velocity during the second walk trial.

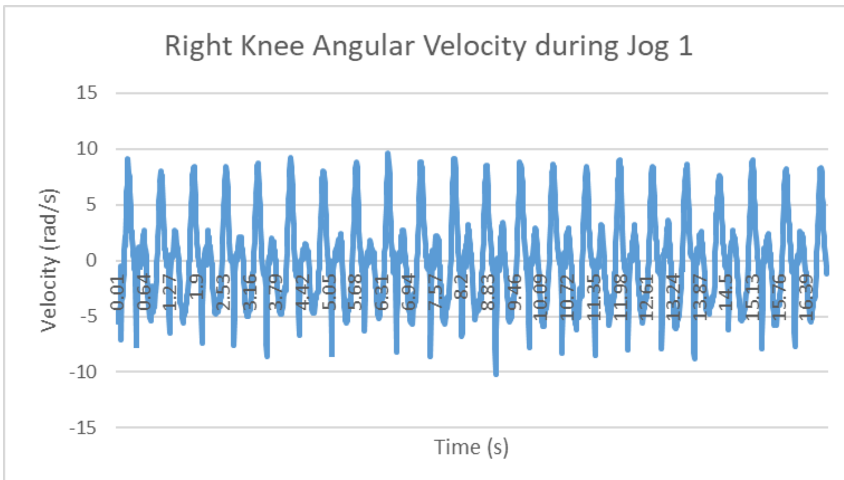


Figure 17.3 - Right knee angular velocity during the first jog trial.

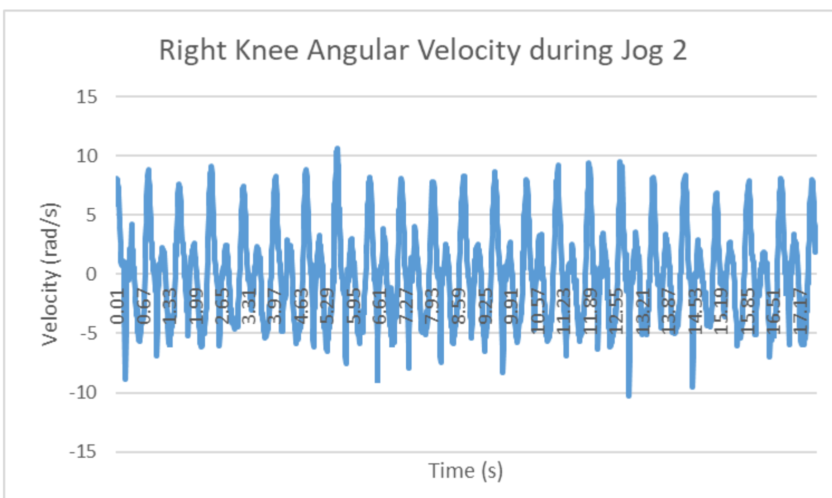


Figure 17.4 - Right knee angular velocity during the second jog trial.

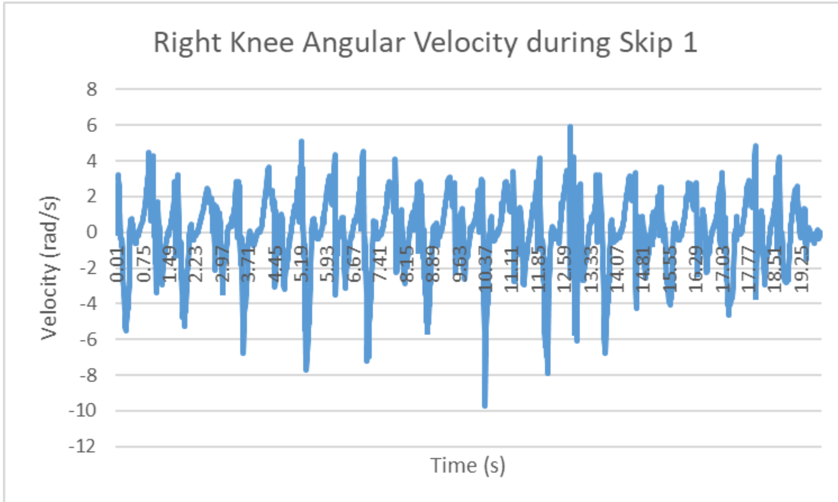


Figure 17.5 - Right knee angular velocity during the first skip trial.

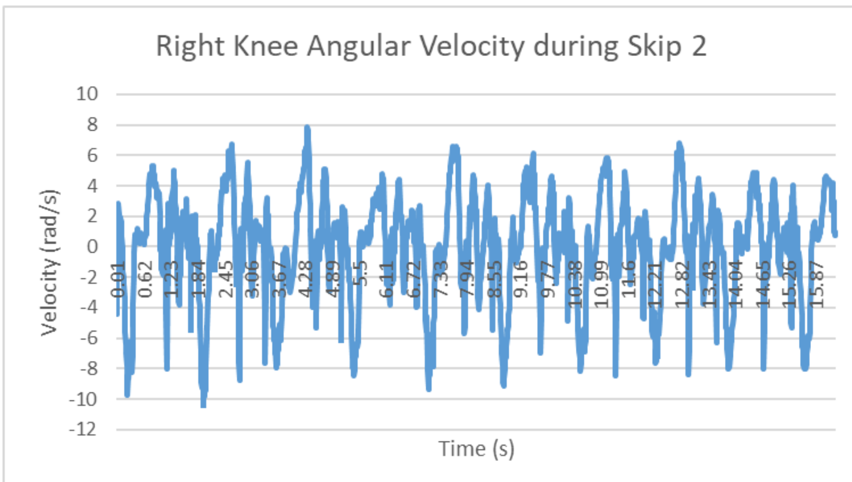


Figure 17.6 - Right knee angular velocity during the second skip trial.

The maximum and average per step values for each gait can be found below.

Gait Trial	Maximum Knee Angle (degrees)	Average Knee Angle per step (degrees)	Maximum Angular Velocity (rad/s)	Average Angular Velocity per step (rad/s)
Walk 1	171.861	156.340	6.309	-0.0135
Walk 2	171.160	166.538	6.013	-0.0007
Jog 1	170.853	145.771	9.643	0.0129
Jog 2	172.873	145.741	10.671	0.0454

Skip 1	141.484	111.383	5.928	0.0058
Skip 2	173.329	135.854	7.823	-0.0045

7. Arm swing angles and angular velocity

This section used the same formulas and procedure as Section 6. The only difference is that the markers RSHO, RASI, and RUPA were used for each gait. RSHO was used as the origin point, and RASI and RUPA were turned into vectors coming from RSHO.

The arm angles for each gait are shown in the following graphs.

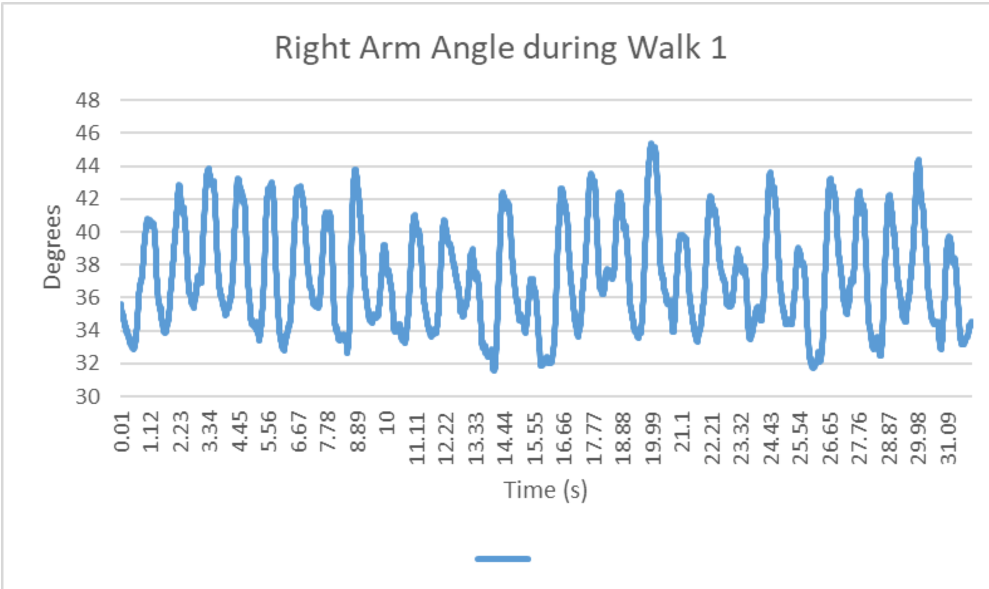


Figure 18.1 - Right shoulder joint angle during the first walk trial.

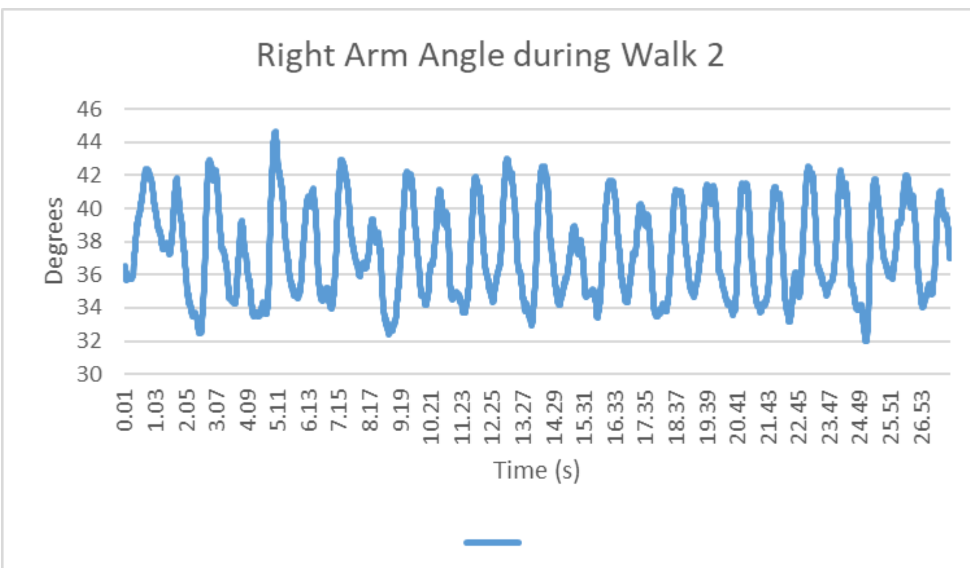


Figure 18.2 - Right shoulder joint angle during the second walk trial.

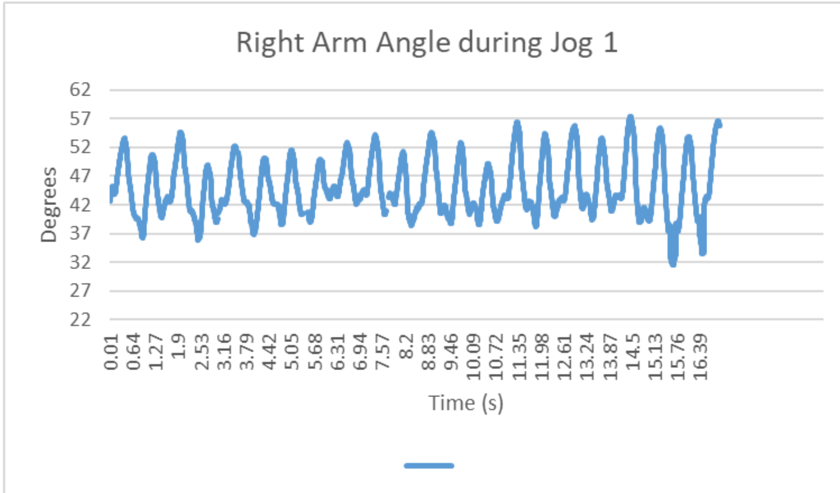


Figure 18.3 - Right shoulder joint angle during the first jog trial.

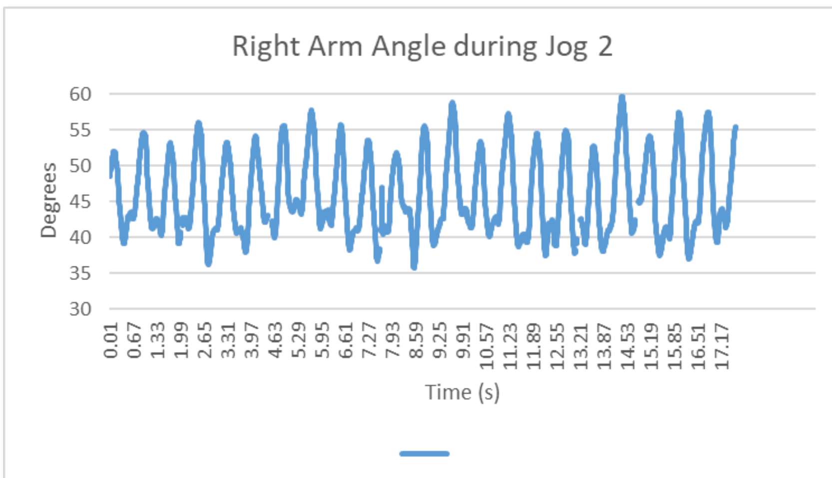


Figure 18.4 - Right shoulder joint angle during the second jog trial.

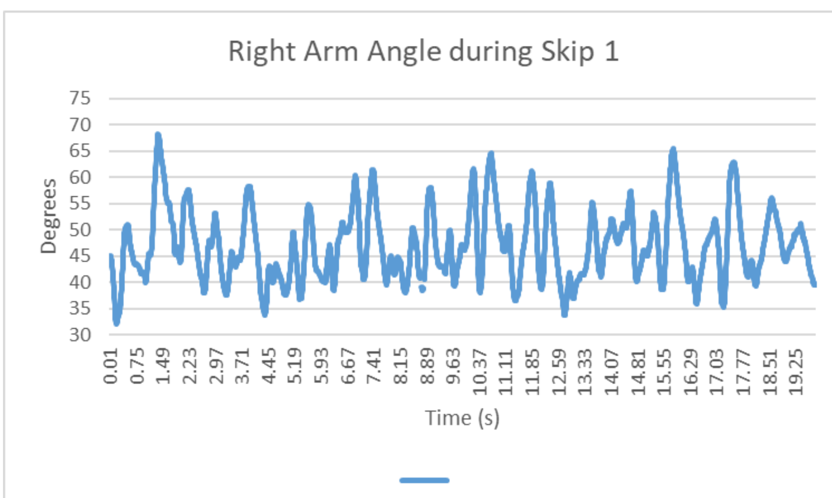


Figure 18.5 - Right shoulder joint angle during the first skip trial.

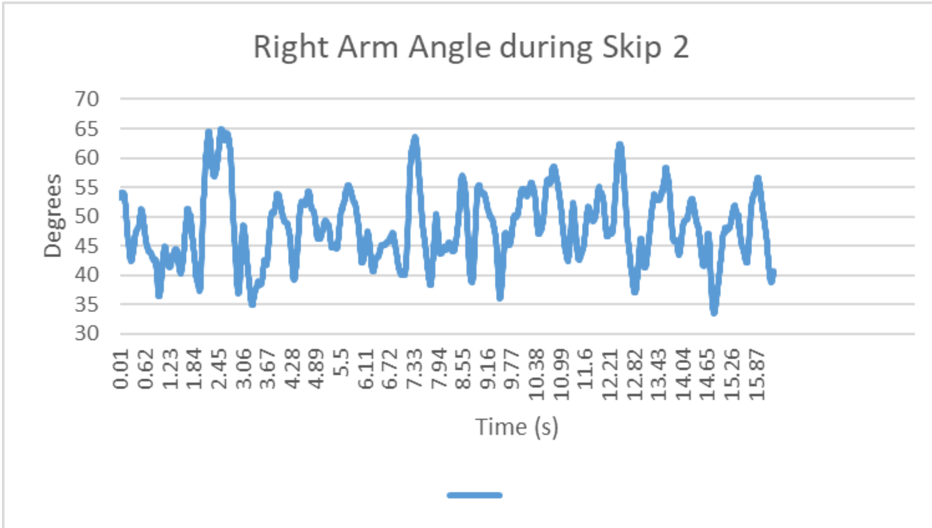


Figure 18.6 - Right shoulder joint angle during the second skip trial.

The arm angular velocity during each recorded gait is calculated the same way as in Section 6 and shown in the following graphs.

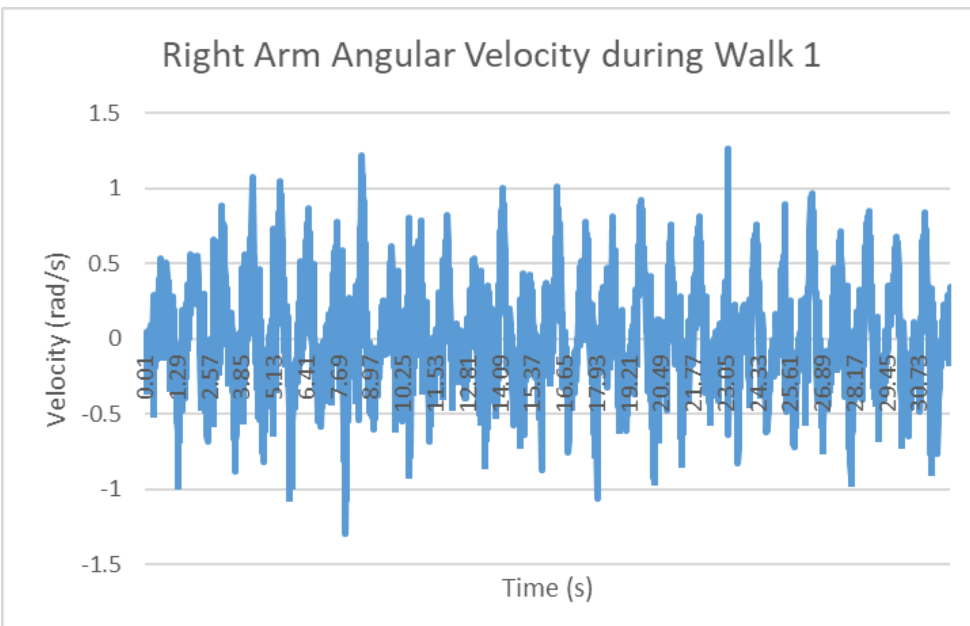


Figure 19.1 - Right shoulder joint angular velocity during the first walk trial.

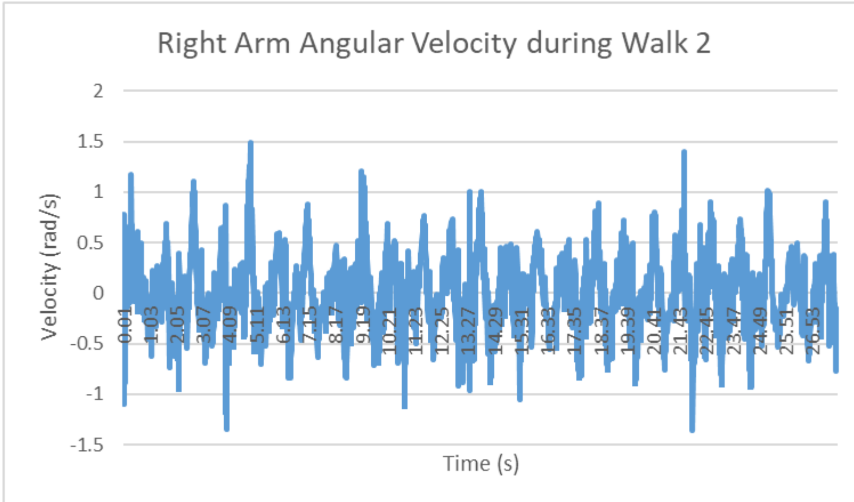


Figure 19.2 - Right shoulder joint angular velocity during the second walk trial.

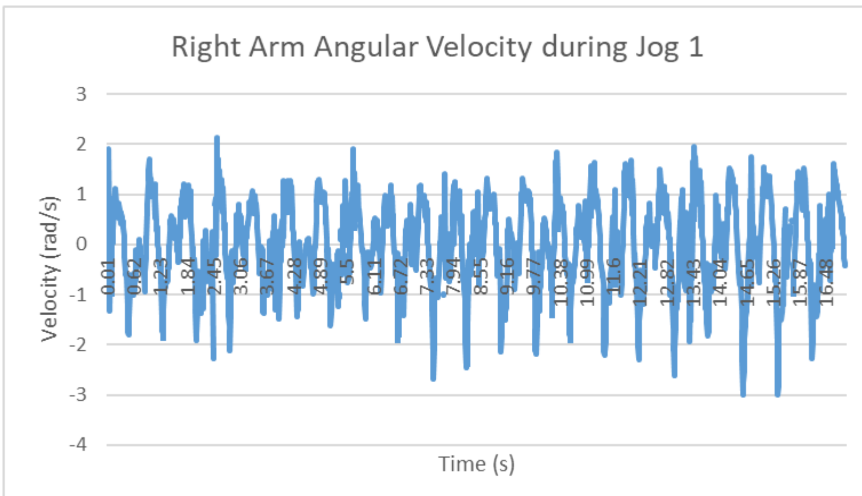


Figure 19.3 - Right shoulder joint angular velocity during the first jog trial.

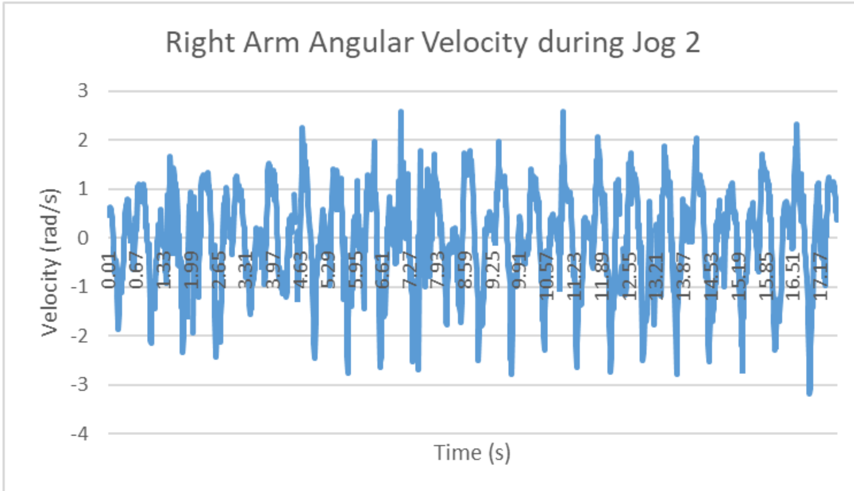


Figure 19.4 - Right shoulder joint angular velocity during the second jog trial.

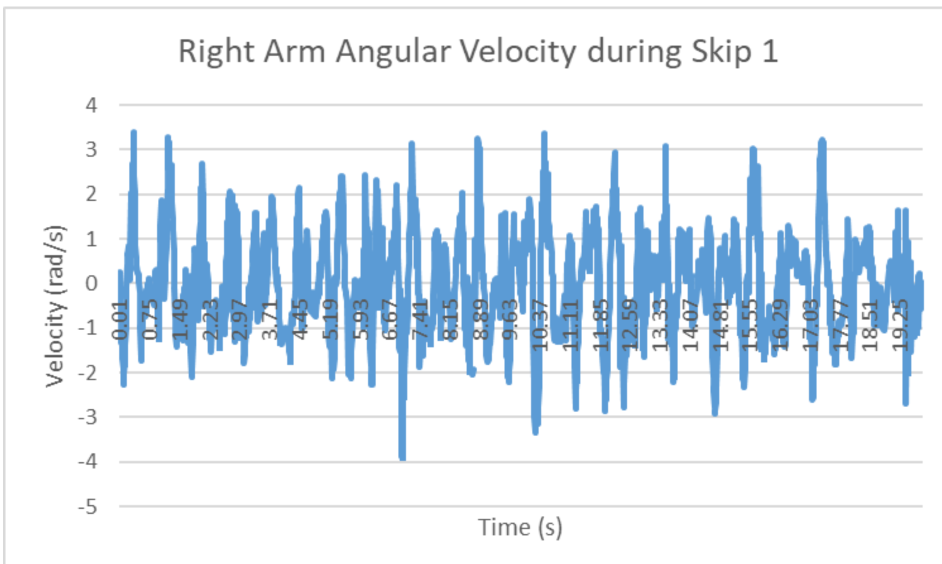


Figure 19.5 - Right shoulder joint angular velocity during the first skip trial.

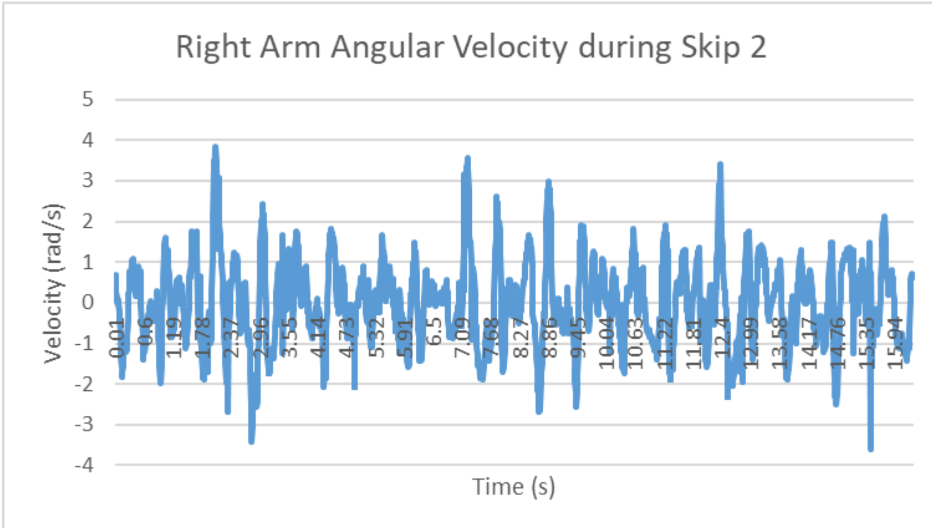


Figure 19.6 - Right shoulder joint angular velocity during the second skip trial.

The maximum and average per step values for each gait can be found below.

Gait Trial	Maximum Arm Angle (degrees)	Average Arm Angle per step (degrees)	Maximum Angular Velocity (rad/s)	Average Angular Velocity per step (rad/s)
Walk 1	45.395	37.286	1.261	-0.0005
Walk 2	44.644	36.094	1.491	0.7732
Jog 1	57.318	45.160	2.136	0.0042
Jog 2	59.575	45.953	2.592	-0.0106
Skip 1	68.121	47.044	3.399	-0.0071
Skip 2	64.995	48.136	3.843	-0.0133

Discussion:

Our ground reaction forces were taken for each direction of every trial. By doing this we were able to calculate the averages of the ground reaction forces per step varied for each trial. The ground reaction force for gait 1 and 2 had the most variation in the y-direction and the least amount of variation in the z-direction. The y-direction also had the largest average ground reaction force per step, meanwhile the z-direction had the smallest value. The z-direction had the largest average ground reaction force per step meanwhile the y-direction had the smallest value. In jog 1 and jog 2 the z-direction had the largest variation and the largest average ground reaction force per step. In skip 1 the x-direction had the largest variation and the z-direction had the least. The z-direction had the largest average ground reaction force per step. In skip 2 the z-direction had the largest variation and the x-direction had the largest average ground reaction force per step.

In our graphs for ground reaction force and linear speed, there are some outliers present, and this can be due to noise of the motion capture system or our subject going out of bounds. Not including the outliers, you can see that for both of our linear speed normal gait trials, the maximum speed for the x and y directions are around 2 m/s, for the jogging trials it is around 2.25 m/s, and for our skipping trials the maximum speed is around 3 m/s. This shows that as the gait type changed, our subject's speed changed as well. In most of our trials the max ground reaction force and linear speed is significantly different than the average, which shows the significance of outliers.

Looking at the trajectory of our subject, you can see that they walked, jogged and skipped 3 laps around the motion capture area. They followed a rectangular/ oval-shaped path throughout the trials. For the normal gait and skip trials, we averaged the LASI and RASI markers to get our measurements about the center of gravity. For the jog trials, we had a large amount of missing data from these markers, so we decided to use the T10 marker for the center of gravity. As you can tell from the graphs, using different markers did not make a significant difference, as our subject followed the same path in each of the six trials.

The graphs for heel height are relatively consistent for both walking and jogging trials. The peaks in these four graphs show the same point during a walking cycle. The skipping trials are unique in that they show two kinds of peaks. These peaks show the timing for a step, but a full skipping cycle would include both a high and a low peak.

Looking at the calculated data, average and maximum step distance is consistent between trial 1 and trial 2 for each gait, except for skipping. Skipping had a large difference in average step distance when going from trial 1 to trial 2. This could be due to a recording error or just a different skipping form. In general though, walking had the shortest steps and skipping the largest steps with jogging in between. The calculated cadence was also very similar between trials for each gait. Walking had the lowest cadence and jogging the highest, while skipping was in the middle this time.

The work done by the body was calculated using the net forces that took place while the subject walked, jogged, or skipped. The net force represents the forces generated by the body as well as the forces generated due to the body weight. By solving for the force generated by the body, we can then calculate the work done by the body. Considering that these are approximations there is some error to consider such as measurement errors or other calculations that were approximated, like the step distance. For work, we used the average step distance for each trial which may cause these numbers to be off. Furthermore, there are outliers in the data which causes the generated graphs to represent some numbers that may be out of the appropriate range. The graphs that we have developed represent the work done by the subject over time in each component direction (x, y, z). The x-axis is time is seconds and the y-axis is the work done.

Similar to step distance, the graphs for knee angle during the walking and jogging trials look similar while the skipping trials show unique features. During the walking trials, the knee angle stays around 120 - 170 degrees, following a cyclical pattern within a short time interval. The only difference for the jogging trials is that the angle changes between 110 - 170 degrees. Skipping created knee angles between 80 - 170 degrees with each cycle taking a larger amount of time compared to walking and jogging. Except for the first skipping trial, every gait had a similar maximum knee angle. This makes sense since the subject would straighten their knee at some point during the gait cycle. The average knee angle is the smallest for skipping and greatest for walking. The knee angles for the first skipping angle are significantly lower than the rest, likely due to a recording error.

The arm angle graphs show a very similar pattern. Walking created the smallest range of arm angles, 32 - 45 degrees. Jogging created arm angles between 32 - 60 degrees, with a similar cyclical timing to walking. Skipping has a similar degree range to jogging, but much more variance and likely noise in the recording. This makes it difficult to see the timing for this cycle. For both average and maximum arm angle, walking was the lowest and skipping the greatest.

The graphs of angular velocity show that a cyclical action such as walking will result in an average angular velocity close to zero. This makes sense since no matter how much the subject moves their knee or arm, it has to also move back to a natural resting position. This is shown in the calculated average angular velocities. The maximum angular velocity for the arm increases from walking to skipping to jogging. For the knee angle, walking is still the slowest, but jogging has a faster average angular velocity than skipping.

Distribution of work/ checklist:

1. **Ground reaction forces**
   - Calcs: LMK, CC, SS graph: CC, LMK max: CC, avg per step/cycle:LMK
2. **Linear speed of test subject**
   - Calcs: LMK, CC, SS graph: CC, LMK max: CC avg per step/cycle:LMK
3. **Trajectory of test subject position**
   - Calcs:CC graph: CC
4. **Step distance (also report cadence)**
   - Calcs: MF, CB graph:MF max:CB avg per step/cycle:CB
5. **Work done (try to normalize across an equal distance or "per step")**
   - Calcs: SS, CB graph:SS max:SS
6. **Knee angles and angular velocity**
   - Calcs:MF graph:MF max:MF avg per step/cycle:MF
7. **Arm swing angles and angular velocity**
   - Calcs: MF graph:MF max:MF avg per step/cycle:MF
8. **Introduction, Methods, and Formatting**
   - CB, CC, LMK, MF, SS

Everyone helped write the results and discussion for the sections they worked on.