

CJ Geeza Midterm

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Introduction

Force production asymmetry between limbs is often used as a predictor of future injury, with asymmetries greater than 10-15% being considered at risk. Increased symmetry as a result of rehabilitation can also be used as a marker of success. Although used as a predictor of future injury, especially in ACL rehab patients, the effect of interlimb force production asymmetry is less clear as it relates to performance. A systematic review evaluating the effects of inter-limb asymmetries on physical and sports performance found a high rate of asymmetry across a range of physical quantities. While not a consistent finding, they also concluded that asymmetry has a detrimental effect on performance. Single leg and horizontal jumps have been shown to detect asymmetries, but their effect on Change of Direction performance appears inconclusive. Some studies have even shown a positive impact of asymmetry in cycling and no effect in swimming. During bilateral jumping tasks, it has been shown that a significant difference in the asymmetry between landing and take off phases exists.

The counter-movement jump is divided into 5 phases with different biomechanical demands: Unweighing, Braking, Propulsion, Flight, and Landing. This project aimed to calculate the average asymmetry between limbs during each phase, as well as visualize the change in asymmetry across the course of the jump. By relating the asymmetry score to the phase being performed, corrective exercise mimicking the demands of that phase may be implemented in an attempt to restore symmetry.

Methods

Data from a single CMJ performed by a 28 year old recreational hockey player was collected on a Vault force plate at a sampling rate of 1000 Hz at the USC Clinical Exercise Research Center on September 2, 2022. The data was exported to a csv file, and initially included 3136 observations and 22 variables. After importing the data in R using the function `read.csv`, the combined function `mean(is.na)` was used to confirm no missing data for the variables representing the force produced in the Z direction for the left and right legs.

```
rm(list=ls())

library(ggplot2)
library(plotly)
```

Attaching package: 'plotly'

The following object is masked from 'package:ggplot2':

```
last_plot
```

The following object is masked from 'package:stats':

```
filter
```

The following object is masked from 'package:graphics':

```
layout
```

```
data <- read.csv("CJ CMJ-Countermovement Jump-2022.09.02-10.33.20-Trial1 - CJ CMJ-Countermovement Jump-2022.09.02-10.33.20-Trial1.csv",
                 skip=9)
mean(is.na(data$Z.Left))
```

```
[1] 0
```

```
mean(is.na(data$Z.Right))
```

```
[1] 0
```

The variable “time” was then shifted to 0 by subtracting the minimum value from each observation for this variable.

```
# Change time to normalize to 0
data$Time <- data$Time - min(data$Time)
```

In order to first visualize the data, forces produced by both the right and left legs in the Z direction were plotted. This visualization was accomplished by first rearranging the data to

only include the forces produced by the two limbs in the Z direction, as well as an added variable that differentiated between right and left limb. This rearrangement was accomplished by using the function `data.frame()` to create two separate data frames for the right and left limbs, each containing the variables `Time`, `Force`, and `Leg`. These data frames were then stacked together using the function `rbind()`. After this data wrangling, `ggplot2` was used to convert the stacked data frame into a line graph that plotted the forces produced by both limbs against time, differentiating by color. Individual point plots for the right and left limbs were also generated for reference.

```
T <- nrow(data)

# re-arrange data to be able to plot left leg against right leg
data_tidy <- data.frame(Time=data$Time, Force=data$Z.Left, Leg="Left")

data_tidy <- rbind(data_tidy, data.frame(Time=data$Time, Force=data$Z.Right,
                                         Leg="Right"))

# Create column for difference between legs
data$difference <- data$Z.Right - data$Z.Left

plot_left <- ggplot(data, aes(x=Time, y=Z.Left)) + geom_point() +
  ylab("Force from Left Leg (Newtons)") + xlab("Time (seconds)")

plot_right <- ggplot(data, aes(x=Time, y=Z.Right)) + geom_point() +
  ylab("Force from Right Leg (Newtons)") + xlab("Time (seconds)")

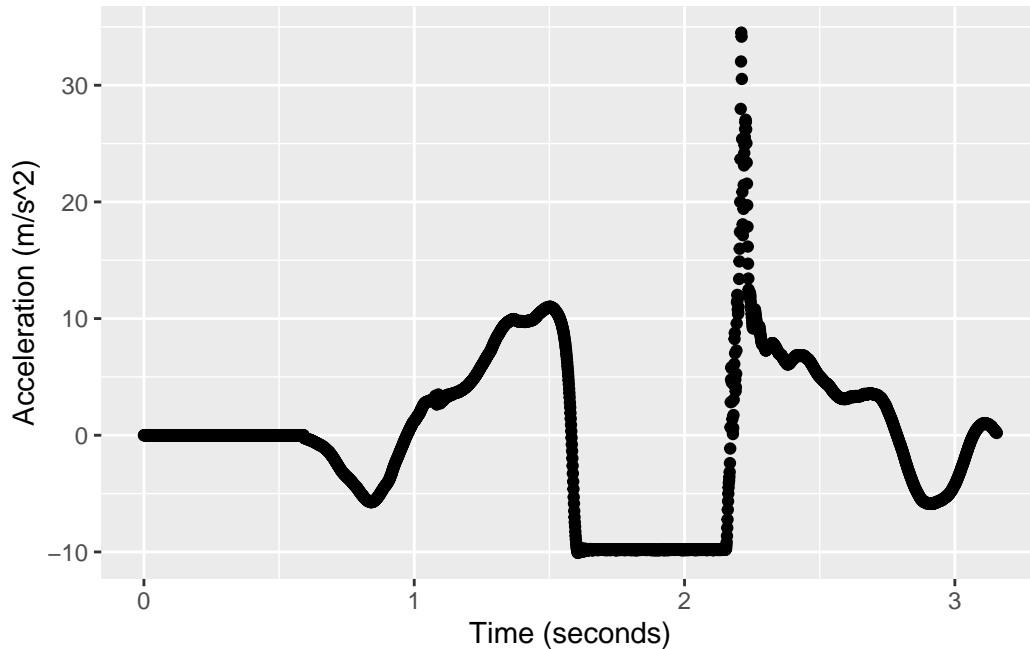
plot_both <- ggplot(data_tidy, aes(x=Time, y=Force, color=Leg)) + geom_line() +
  ylab("Force (Newtons)") + xlab("Time (seconds)")
```

Next, the goal was to first break down the data into Standing, Unweighing, Braking, Propulsion, and Landing phases, and calculate the average absolute asymmetry for each phase. The phases were defined based on values from the `acceleration` variable in the dataset. First, an acceleration vs time plot was generated using `ggplot2` to visualize how the acceleration changed throughout the CMJ.

```
# Acceleration plot

plot_acc <- ggplot(data, aes(x=Time, y=Acceleration)) + geom_point() +
  ylab("Acceleration (m/s^2)") + xlab("Time (seconds)")

plot_acc
```



Using this plot as a guide to read through the data, observations with an acceleration value of 0 were characterized as Standing (indices 1-592), negative accelerations as Unweighing (indices 593-973), and positive accelerations as Braking (indices 974- 1374). The Propulsion phase was defined as the time points between when the acceleration reached its first peak and then started the decline until the time in air (indices 1375:1601). The flight phase was omitted due to lack of relevance. The Landing phase was defined as when the acceleration started meaningfully increasing from -9.8 m/s^2 until the last observation (indices 2155 - `nrow(data)`).

```
# Find standing phase: acceleration 0
# Looks like rows 1 - 592
# data[2100:2600, c("Time", "Acceleration")]
standing_inds <- 1:592

# Find unweighing phase: acceleration negative
# Rows 593 - 973
unweighing_inds <- 593:973

# Find braking phase: acceleration positive
# Rows 974 - 1374
braking_inds <- 974:1374

plot_diff <- ggplot(data[braking_inds, ], aes(x=Time, y=difference)) + geom_point() +
```

```

      ylab("Differences in Forces (Right Leg - Left) (Newtons)") + xlab("Time (seconds)")

# Find propulsion phase: acceleration peaks and starts declining
# Rows 1375 - 1601
propulsion_inds <- 1375:1601

# In the air: acceleration -9.8

# Landing rows: 2155 - T
landing_inds <- 2155:T

```

The average absolute asymmetry for each phase was calculated by first inserting a new variable into the data that described the absolute difference between the force produced in the right and left limbs. This was accomplished by taking the absolute value of the force produced by the left limb subtracted from the right limb, and dividing this quantity by the maximum of these two values for each observation (using the function `pmax`). This quantity was then multiplied by 100 to give a percent value. The average asymmetry for each phase was then calculated by using the `mean` function on data extracted by each phase's corresponding indices.

```

# Calculate the percentage difference between force from left and right legs
# in the z direction at each time
data$pct_diff <- (data$Z.Left - data$Z.Right)/pmax(data$Z.Left, data$Z.Right)*100
data$abs_pct_diff <- abs(data$Z.Left - data$Z.Right)/pmax(data$Z.Left, data$Z.Right)*100

# Average absolute asymmetry during standing phase:
avg_standing_asymmetry <- mean(data[standing_inds, "abs_pct_diff"])

# Average absolute asymmetry during unweighting phase:
avg_unweighting_asymmetry <- mean(data[unweighting_inds, "abs_pct_diff"])

# Average absolute asymmetry during braking phase:
avg_braking_asymmetry <- mean(data[braking_inds, "abs_pct_diff"])

# Average absolute asymmetry during propulsion phase:
avg_propulsion_asymmetry <- mean(data[propulsion_inds, "abs_pct_diff"])

# Average absolute asymmetry during braking phase
avg_landing_asymmetry <- mean(data[landing_inds, "abs_pct_diff"])

```

Finally, the absolute percent asymmetry as a function of time was plotted. For better readability, one plot was generated for the Standing, Unweighting, Braking, and Propulsion phases, and another for the Landing phase. These plots were generated by concatenating the relevant

phases from the data and using `ggplot2`. Dotted red lines at y-intercepts of 10 and -10 were inserted to better visualize asymmetries greater than 10%.

```
df_plot <- data[c(standing_inds, unweighting_inds, braking_inds,
                  propulsion_inds), ]

plot_pct_diff <- ggplot(df_plot, aes(x=Time, y= pct_diff)) + geom_point() +
  geom_hline(yintercept=10, color="red", linetype = "dashed") +
  geom_hline(yintercept=-10, color="red", linetype = "dashed") +
  ylab("Percent Difference") + ggtitle("Percent Asymmetry in Leg Force Over Time")

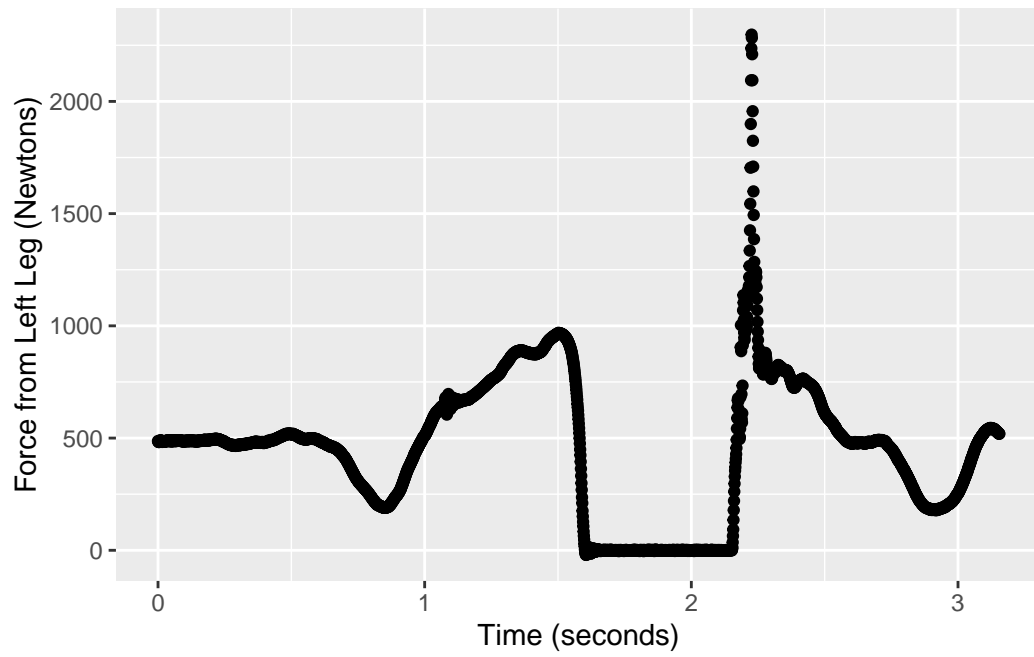
landing_plot <- data[landing_inds,]

landing_plot_pct_diff <- ggplot(landing_plot, aes(x=Time, y= pct_diff)) + geom_point() +
  geom_hline(yintercept=10, color="red", linetype = "dashed") +
  geom_hline(yintercept=-10, color="red", linetype = "dashed") +
  ylab("Percent Difference") + ggtitle("Percent Asymmetry in Leg Force Over Time")
```

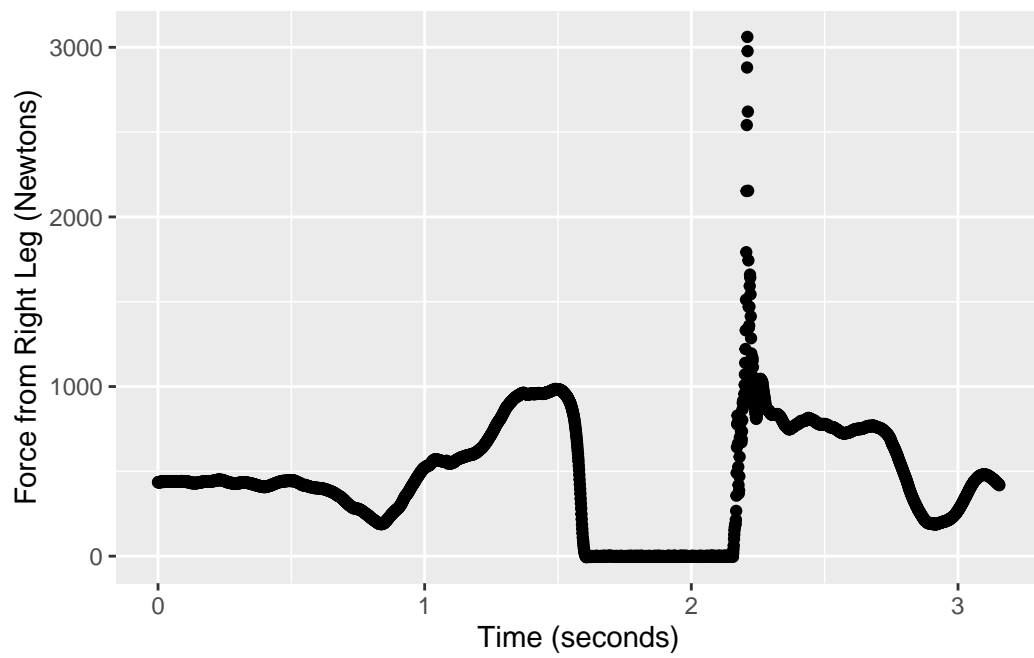
Results

```
# ggplotly(plot_left)
#
# ggplotly(plot_right)
#
# ggplotly(plot_both)
#
# ggplotly(plot_diff)
#
# ggplotly(plot_pct_diff)
#
# ggplotly(landing_plot_pct_diff)

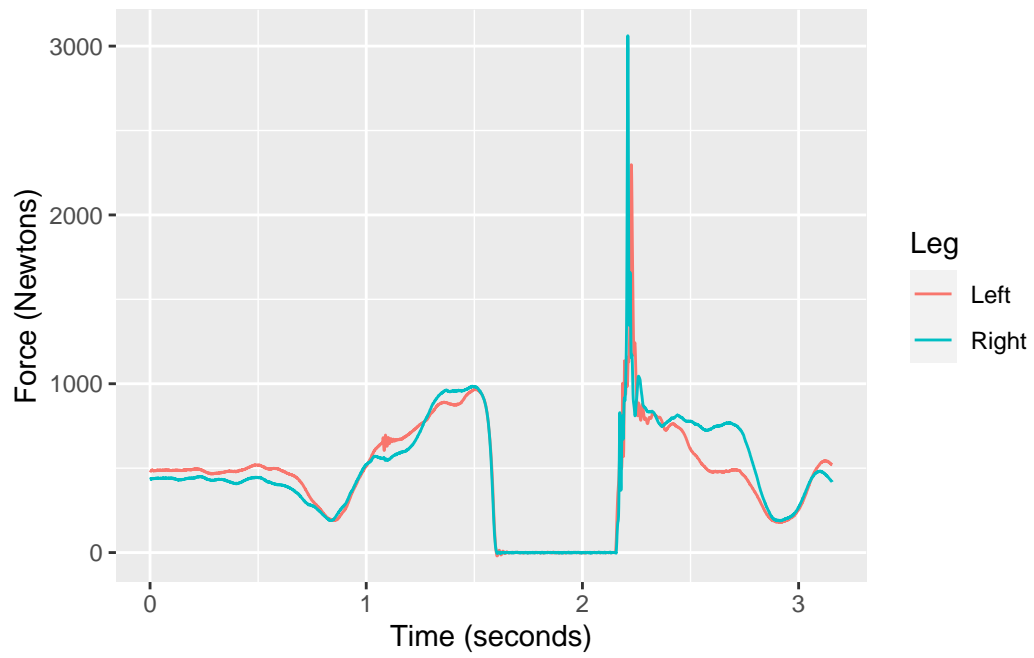
plot_left
```



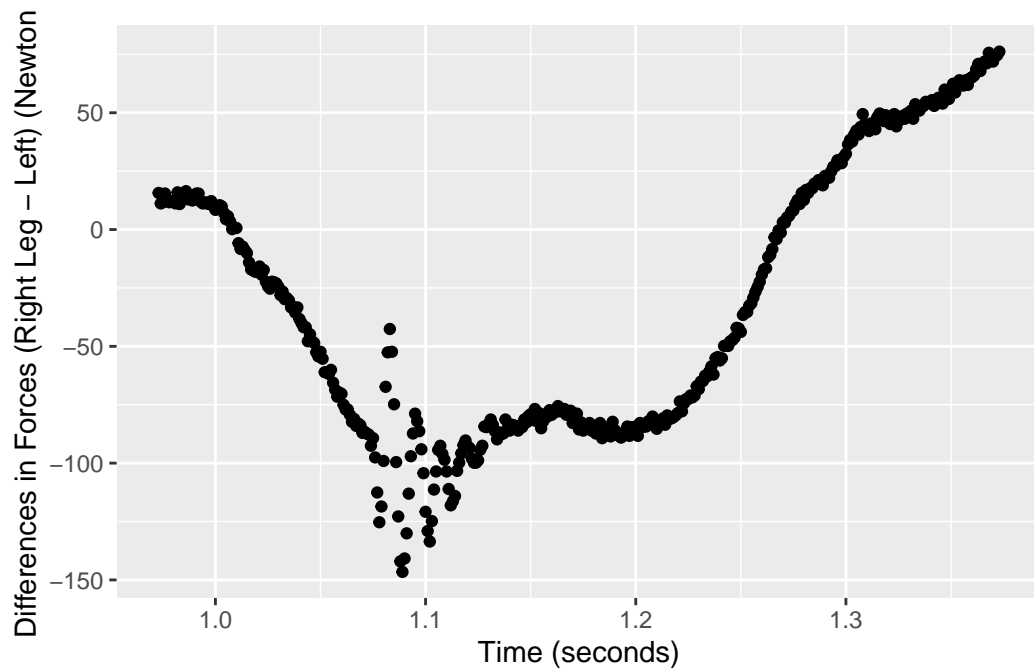
`plot_right`



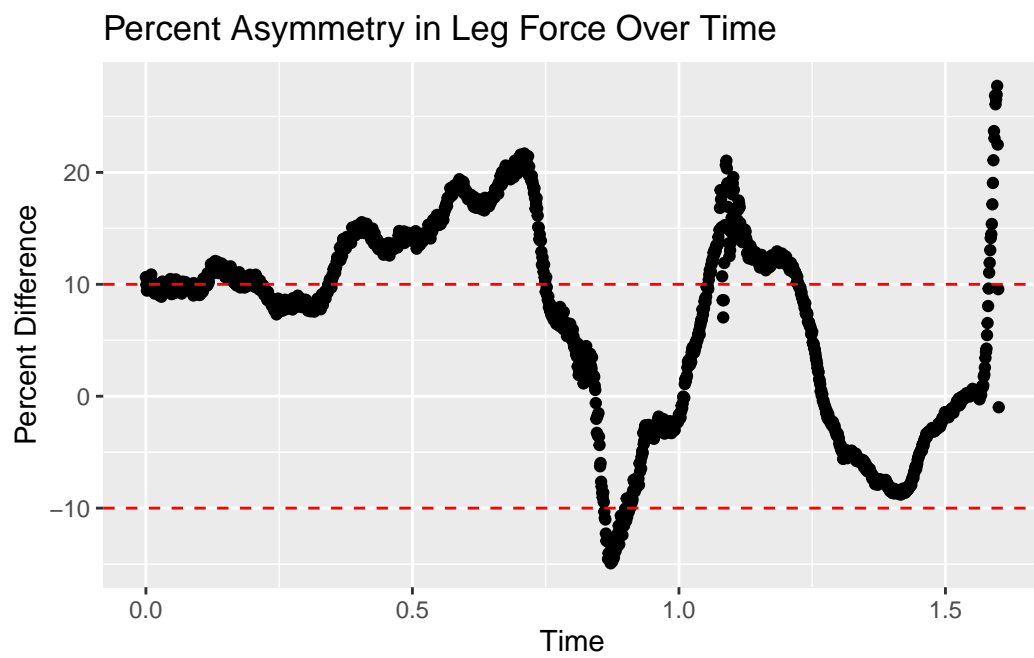
```
plot_both
```



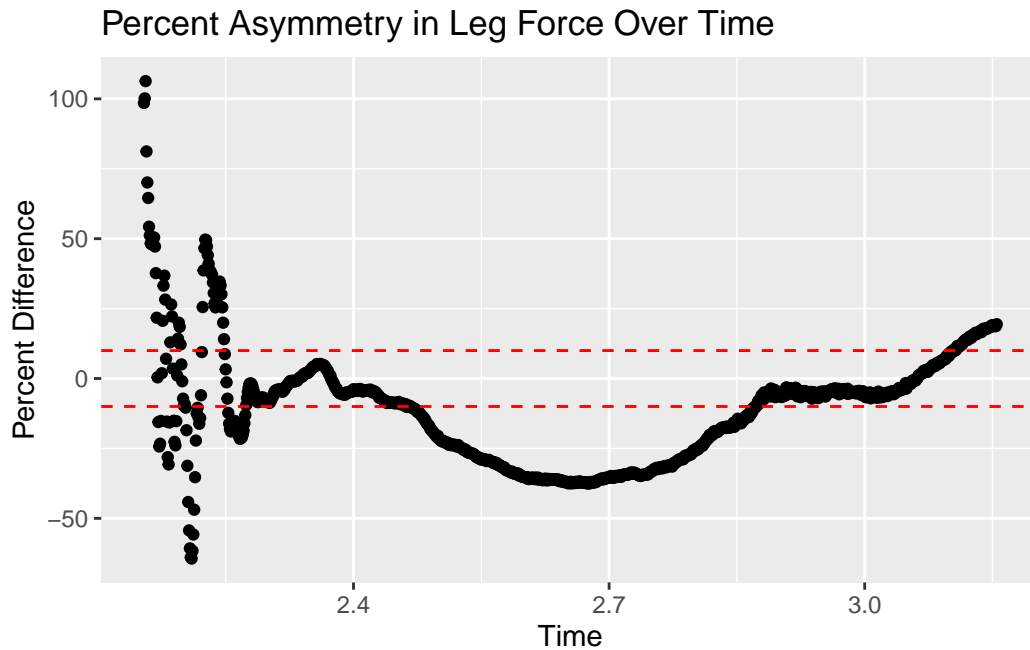
```
plot_diff
```

```
plot_pct_diff
```



```
landing_plot_pct_diff
```



```
# Average absolute asymmetry during standing phase:  
print(paste(round(avg_standing_asymmetry, 4), "%", sep=""))
```

```
[1] "11.6348%"
```

```
# Average absolute asymmetry during unweighting phase:  
print(paste(round(avg_unweighting_asymmetry, 4), "%", sep=""))
```

```
[1] "11.4569%"
```

```
# Average absolute asymmetry during breaking phase:  
print(paste(round(avg_braking_asymmetry, 4), "%", sep=""))
```

```
[1] "8.1898%"
```

```
# Average absolute asymmetry during propulsion phase:
print(paste(round(avg_propulsion_asymmetry, 4), "%", sep=""))
```

```
[1] "5.3161%"
```

```
# Average absolute asymmetry during braking phase
print(paste(round(avg_landing_asymmetry, 4), "%", sep=""))
```

```
[1] "17.8508%"
```

```
# Summary statistics
print(summary(data[standing_inds, "abs_pct_diff"]))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
7.317	9.432	10.643	11.635	14.089	19.390

```
print(sd(data[standing_inds, "abs_pct_diff"]))
```

```
[1] 2.843784
```

```
print(summary(data[standing_inds, "Z.Left"]))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
465.0	482.4	488.0	489.4	495.0	520.3

```
print(sd(data[standing_inds, "Z.Left"]))
```

```
[1] 12.27255
```

```
# Unweighting
print(summary(data[unweighting_inds, "abs_pct_diff"]))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.5603	5.3698	11.1250	11.4569	17.7465	21.6908

```
print(sd(data[unweighting_inds, "abs_pct_diff"]))
```

```
[1] 6.587761
```

```
# Breaking
```

```
print(summary(data[braking_inds, "abs_pct_diff"]))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.03345	4.13252	7.41280	8.18975	12.24946	21.05138

```
print(sd(data[braking_inds, "abs_pct_diff"]))
```

```
[1] 4.829208
```

```
# Propulsion
```

```
print(summary(data[propulsion_inds, "abs_pct_diff"]))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.01957	1.04534	3.67047	5.31612	8.13031	27.73442

```
print(sd(data[propulsion_inds, "abs_pct_diff"]))
```

```
[1] 5.467503
```

```
# Landing
```

```
avg_landing_asymmetry <- mean(data[landing_inds, "abs_pct_diff"])
```

```
print(paste(round(avg_landing_asymmetry, 4), "%", sep=""))
```

```
[1] "17.8508%"
```

Conclusion

The subject displayed average asymmetries greater than 10% during the Standing(11.63 %), Unweighing (11.45%), and Landing phases (17.85%). Interestingly, the subject's asymmetry decreases as they transition from passive phases (Standing and Unweighing) to power absorption and generation phases (Braking and Propulsion). The large difference between takeoff and landing symmetry coincide with results from Cone et al. Based on these results, the subject should use exercise strategies that target static balance and landing mechanics in order to reduce risk for future injury.

References

1. Bishop, C., Turner, A., & Read, P. (2018). Effects of inter-limb asymmetries on physical and sports performance: A systematic review. *Journal of sports sciences*, 36(10), 1135-1144.
2. Noyes, F. R., Barber, S. D., & Mangine, R. E. (1991). Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *The American Journal of Sports Medicine*, 19, 513–518. [doi:10.1177/036354659101900518](https://doi.org/10.1177/036354659101900518)
3. Bini, R. R., & Hume, P. A. (2015). Relationship between pedal force asymmetry and performance in cycling time trial. *Journal of Sports Medicine and Physical Fitness*, 55, 898–982.
4. Morouco, P. G., Marinho, D. A., Fernandes, R. J., & Marques, M. C. (2015). Quantification of upper limb kinetic asymmetries in front crawl swimming. *Human Movement Science*, 40, 185–192. [doi:10.1016/j.humov.2014.12.012](https://doi.org/10.1016/j.humov.2014.12.012)
5. Cone, S. M., & Lee, S. (2021). Lower limb force asymmetries during landing and jumping exercises: A pilot study. *International Journal of Exercise Science*, 14(1), 544.