Measuring walking and running dynamics using skin mounted accelerometers

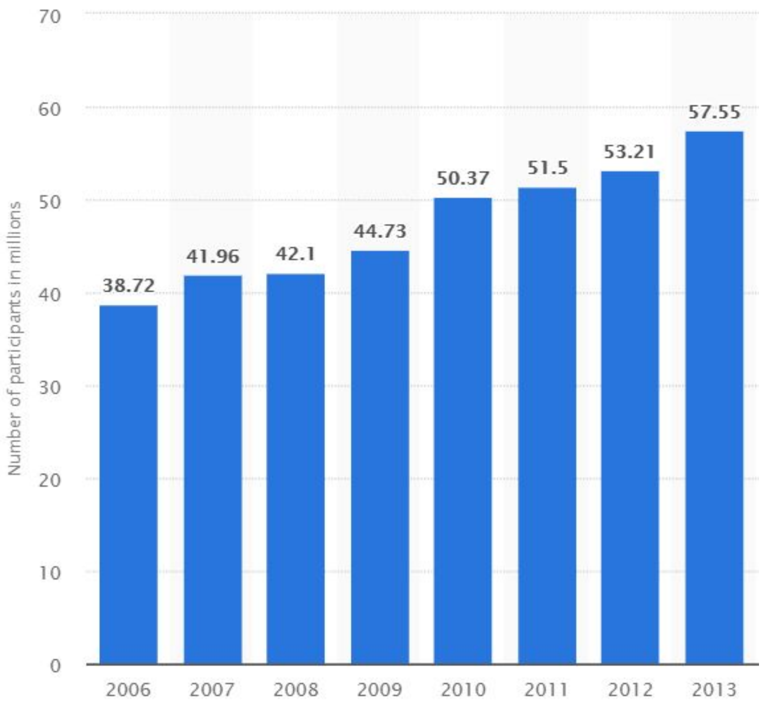
Surjo Dutta and David Friedman

Introduction

- Tibial stress fractures make up about 45% of lower limb injuries in runners
- These injuries have short and long term effects on the performance of the athletes
- They also lead to heavy medical costs, and shorten their career

Introduction

- The number of runners in the US has steadily increased over the decade
- We must find methods to study the form and technique of runners

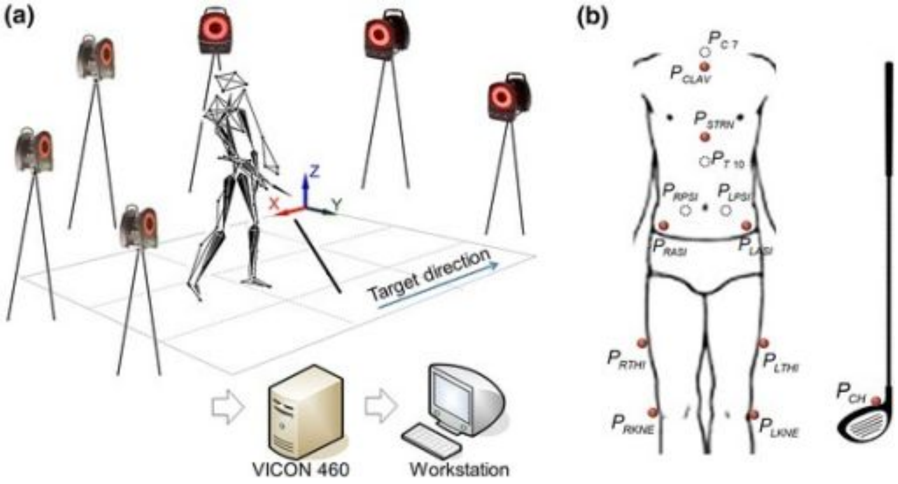


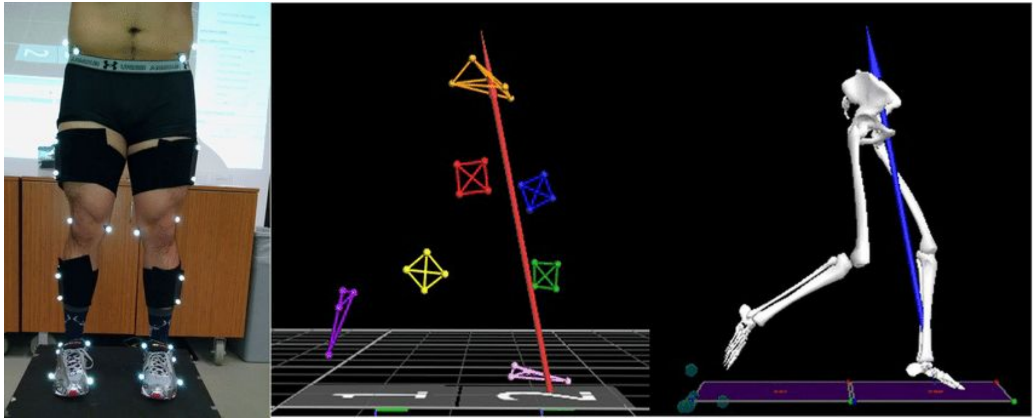
Previous Attempts

- Brayne et al. used a consumer-grade wireless accelerometer called RunScribe
- Sensor was skin mounted, sampled at 1kHz

Previous Attempts

- Milner et al. used the six camera Vicon 512 system
- Runners ran on a force-measuring platform while wearing reflective trackers





Previous Attempts

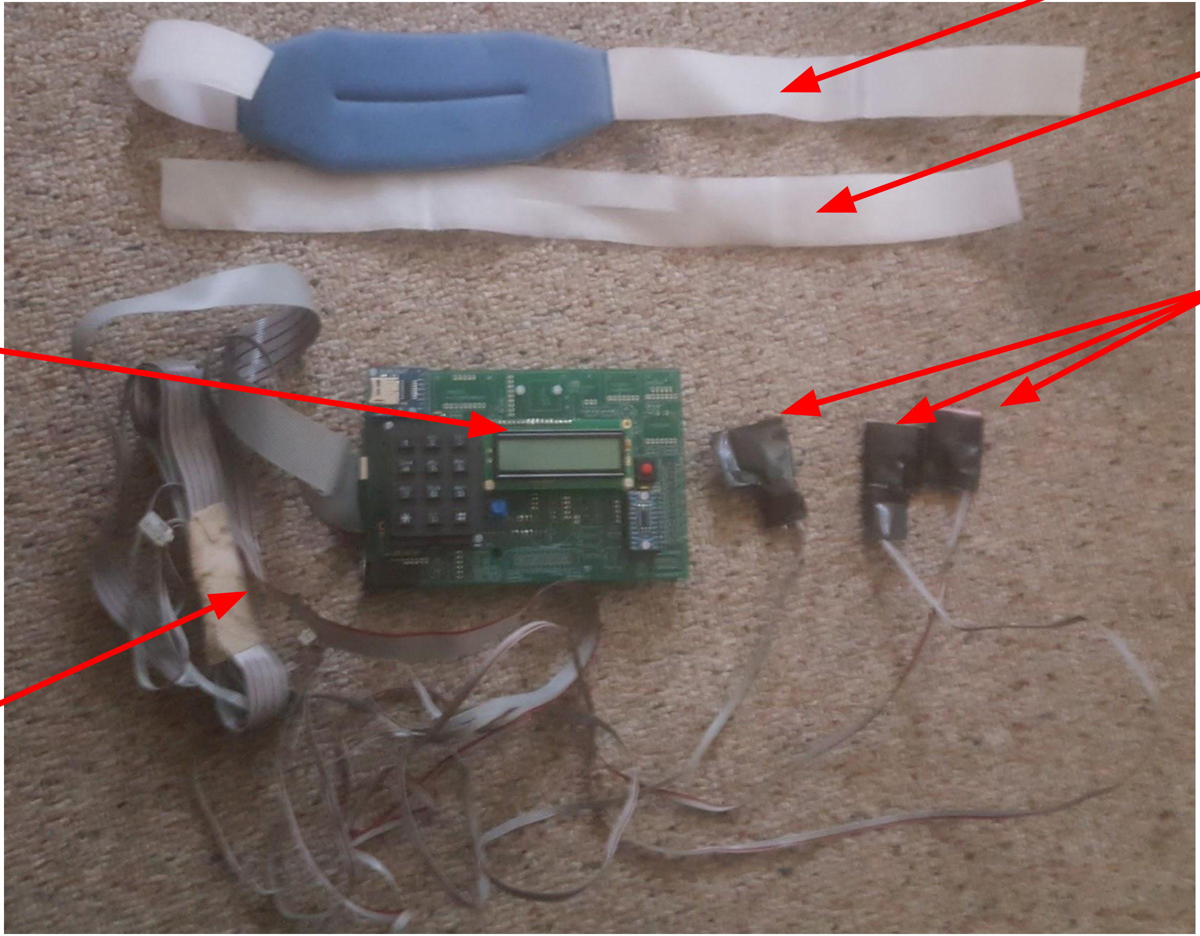
- Lafortune et al. used bone mounted transducers (BMTs) to do the job
- Accelerometers were attached onto the tibia using a 4.7mm diameter Steinmann intracortical pin

Trust us, you don't want a picture here

Our Method

- To our Arduino Mega, we connected three 9-axis Accelerometer-Gyroscope-Magnetometer sensors
- We had to use a I2C multiplexer because the sensors are identical, and hence have the same I2C address
- The bottlenecks to our sample rate were the address switching by the multiplexer and the writing of the data to the SD card
- Which meant we could read 3-axis accelerometer and 3-axis gyroscope from each sensor at 110Hz

Our device (one big pedometer)



Track running/walking setup

- The arduino, PCB and 9V battery supply were kept in a backpack with the wires to the sensors coming out of it
- A sensor was attached to each ankle using tight velcro straps
- Another one was attached to the belt buckle
- We used velcro straps at the thighs to guide the wires and keep them from dangling

Treadmill running/walking setup

- The setup on the treadmill was simpler since we could simply keep the device in the cup holder
- And this meant we could take a video of each of our running techniques


INTELLIGENT SUSPENSION

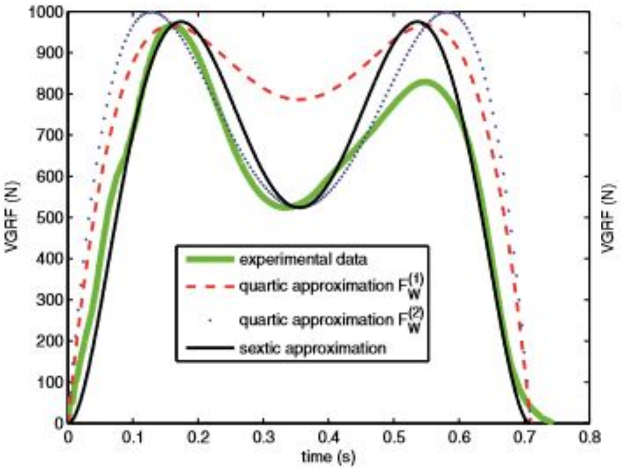
Running and walking gait characterization

- Two main phases:
  - Stance phase (A-B):
    - Begins with contact with ground, ends with leaving ground
    - Contact phase (A) - contact with ground
    - Propulsion phase (B) - push off from ground
  - Swing phase (C-D) - foot moving through the air:
    - Begins with lift off from ground, ends with contact.

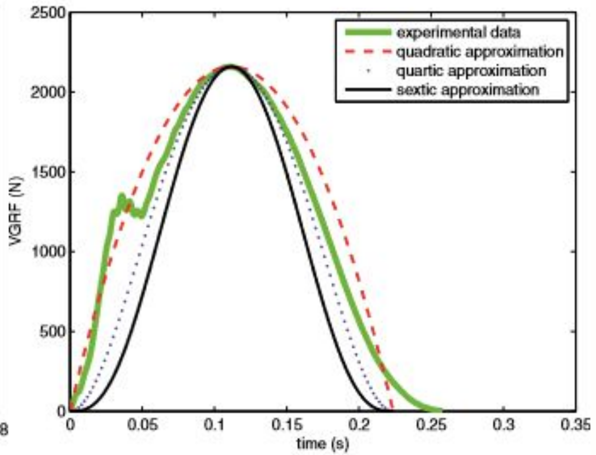
Measuring the accelerations of walking and running

- Used a force pad to measure the “vertical ground reaction force” (VGRF) of walkers and runners
- Sample rate was 2500 Hz

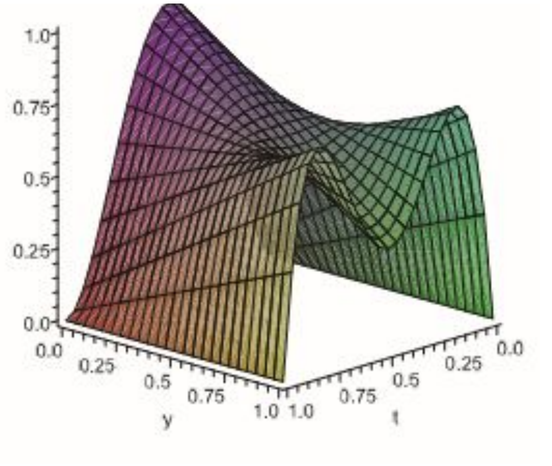
Walking



Running

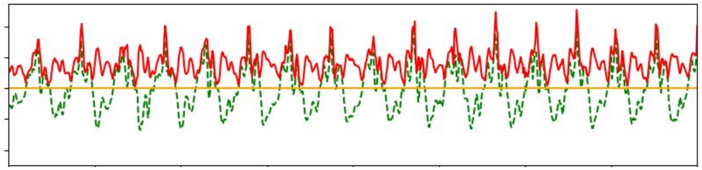


Walking-Running transition

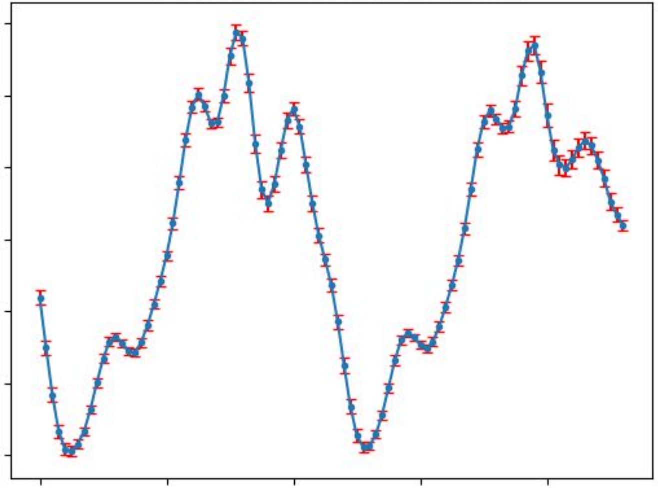


[8] Anthony Tongen, and Roshna Wunderlich.

Data Analysis: Outline

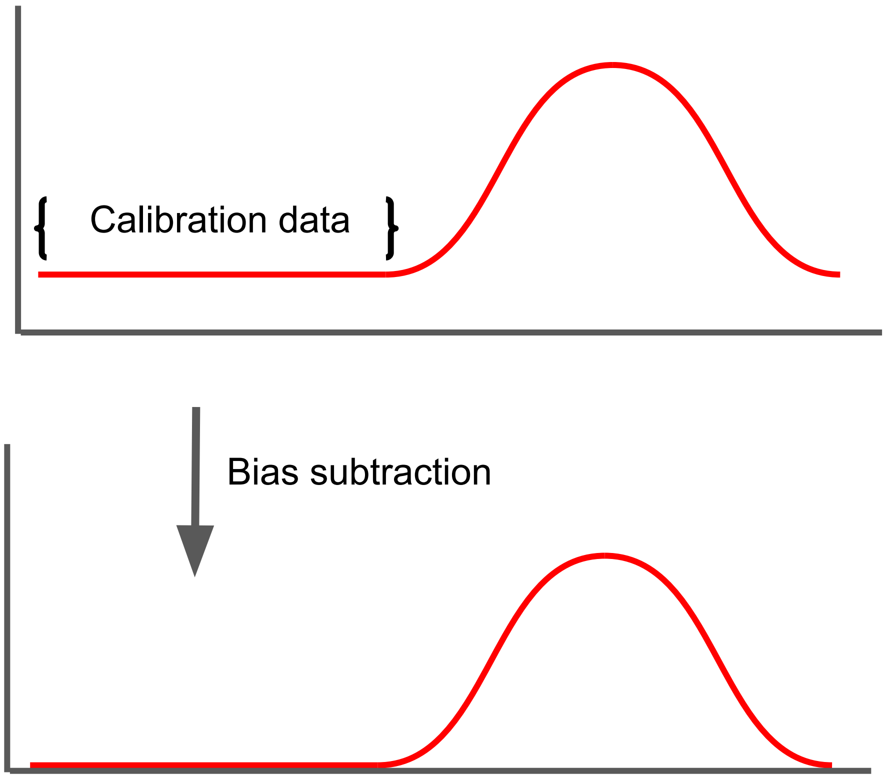


- All analysis was done offline in Python
  - **Step one:** Calibration of raw accelerometer/gyroscope data
  - **Step two:** Correction of accelerometer data using gyroscope
  - **Step three:** Partition of data to define individual steps
    - Partition algorithm problems and pitfalls
  - **Step four:** Optimization
  - **Step five:** Generate average step
  - **Step six:** Error analysis



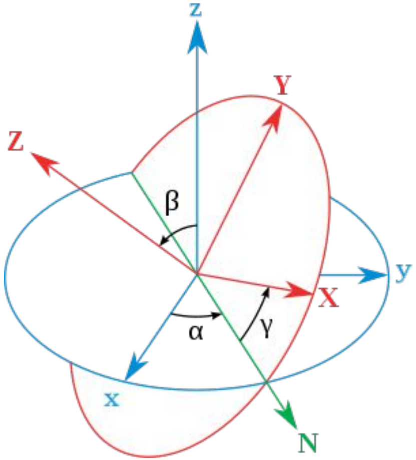
Calibration

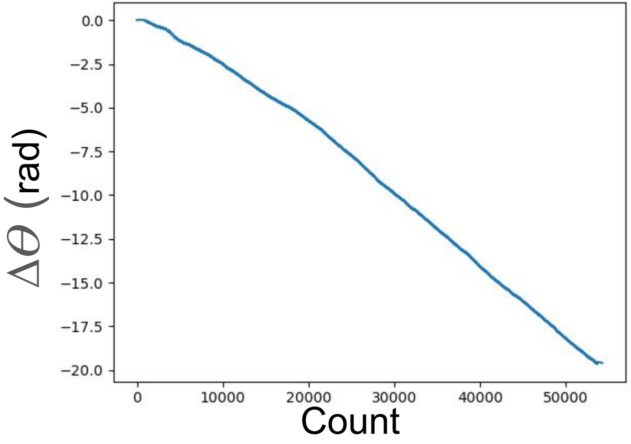
- Based off of the calibration algorithm implemented in the Sparkfun library
- Input:
  - Acceleration and gyroscope data
  - Axis oriented in direction of “g”
  - Calibration data range (for bias determination)
- Output:
  - Acceleration/gyro data with bias subtracted
  - Axis in direction of “g” reads approximately 1.0 g



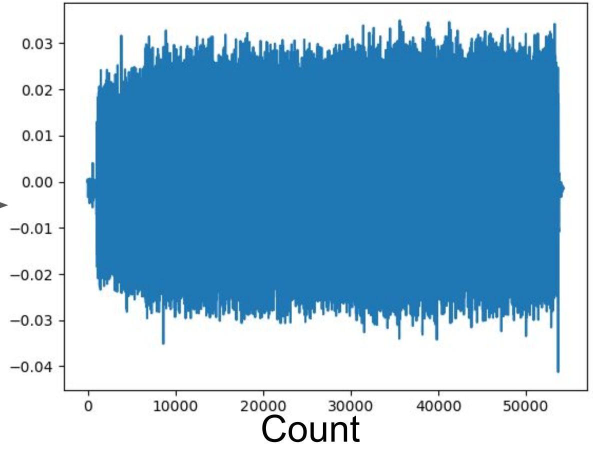
Subtraction of “g” using gyroscope

- Problem: orientation of sensor changes constantly during motion
- Solution: use gyroscope data to calculate $\Delta\Theta$ of the accelerometer
  - Numerically integrate angular velocity to obtain angles
  - What about drift? → use scipy “filtfilt” with scipy butterworth filter
  - Project *g* onto constantly changing accelerometer reference frame using euler angles

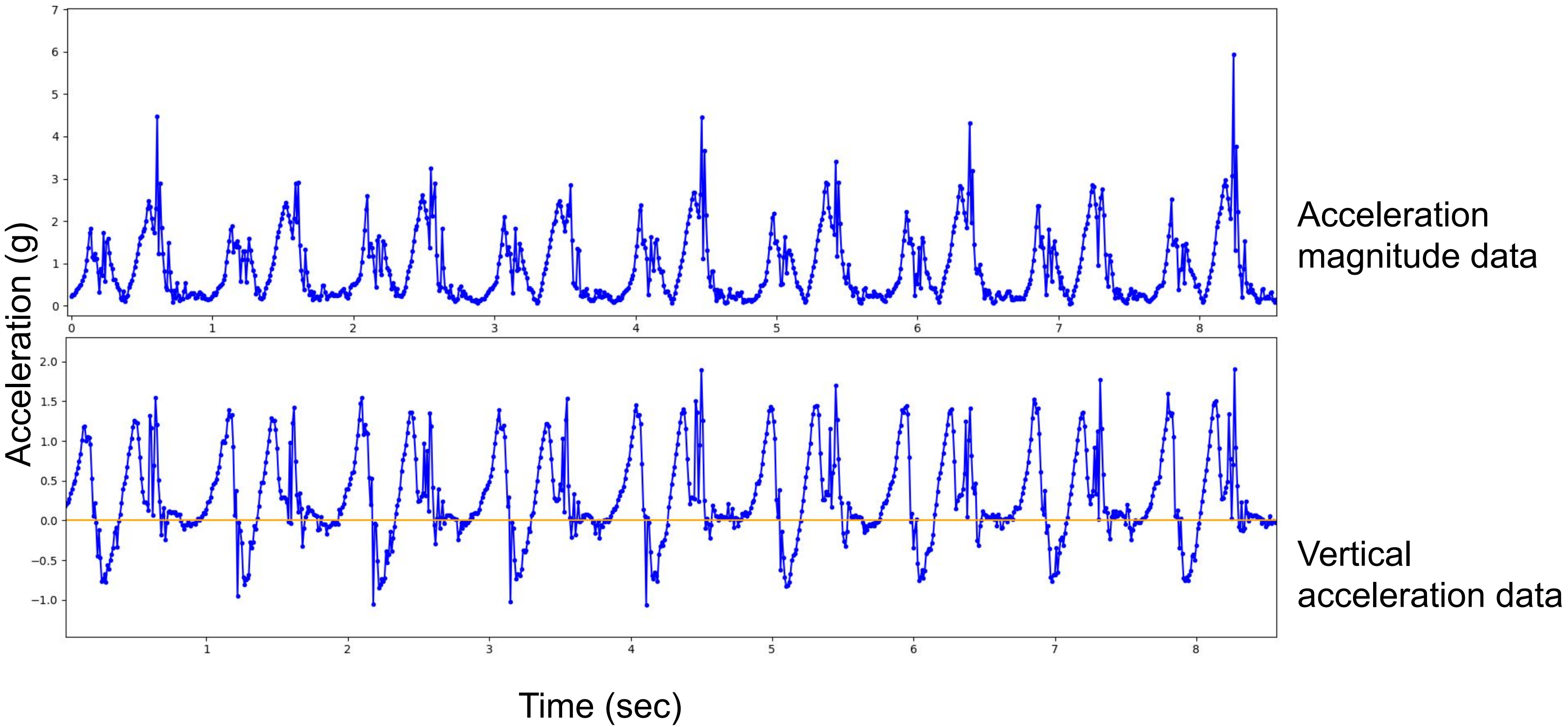




Filter →



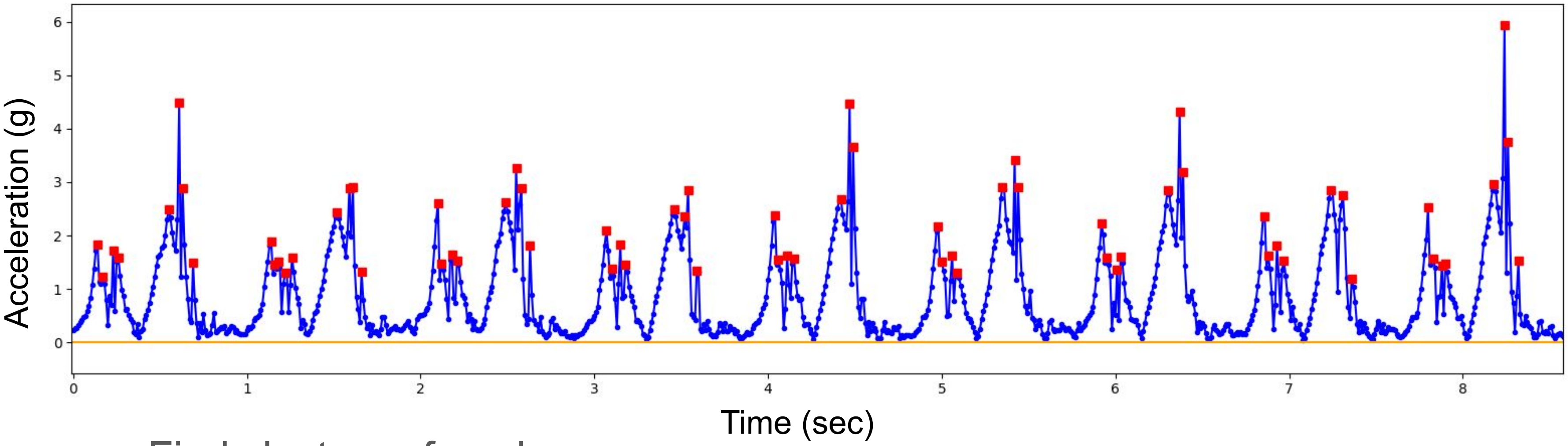
Partitioning of Data into ‘Steps’ (pedometer algo)



- What feature(s) of the acceleration data can be used to define a step?

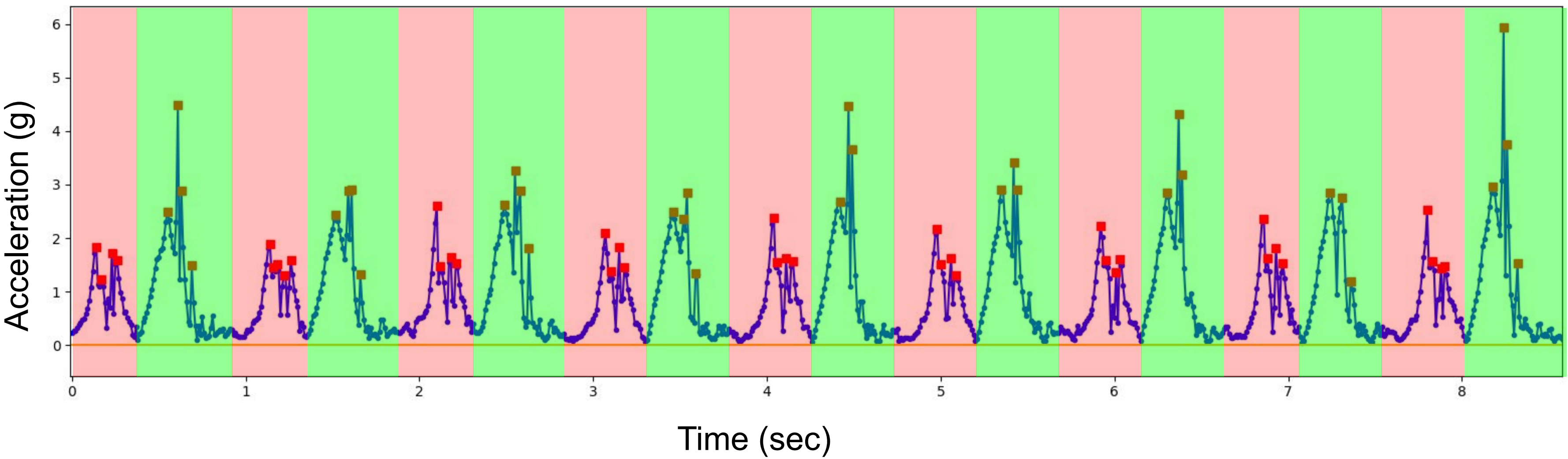
Partitioning of Data into ‘Steps’ (pedometer algo)

- Peak finding works OK for both types of data...
- Using peaks to partition data into steps:



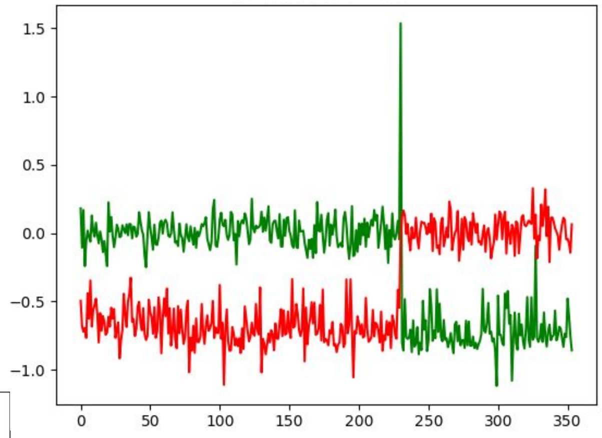
- Find clusters of peaks
    - Can measure the distances between them, want to treat a cluster as one feature

Partitioning of Data into 'Steps' (pedometer algo)

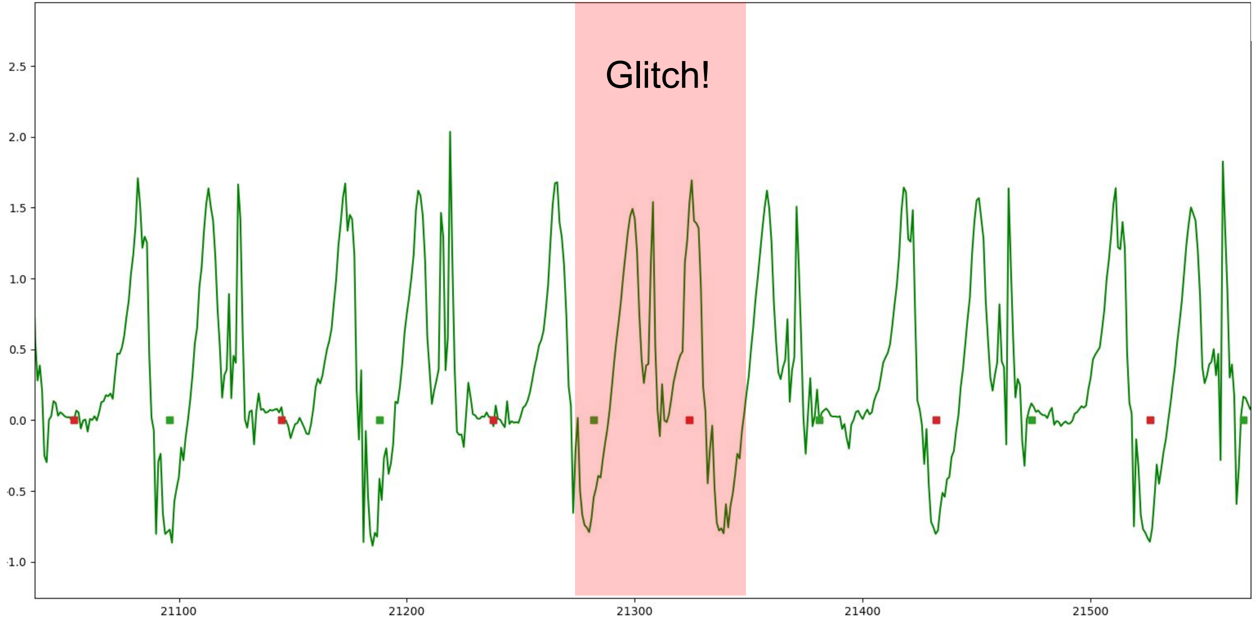


- Split data between clusters of peaks
  - Make a partition if [distance b/w peak i and peak i+1] > average distance between peaks
  - Partition start and end halfway between peak clusters

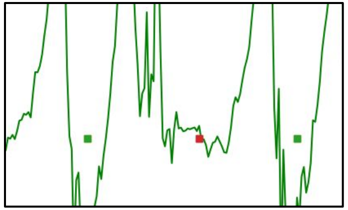
Problems and Pitfalls



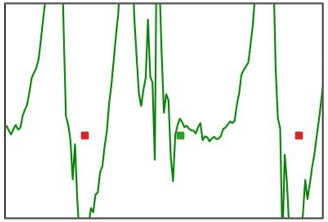
- Jolts and stumbles in the middle of a data set
  - Can cause the partitions to be defined inconsistently



Before glitch

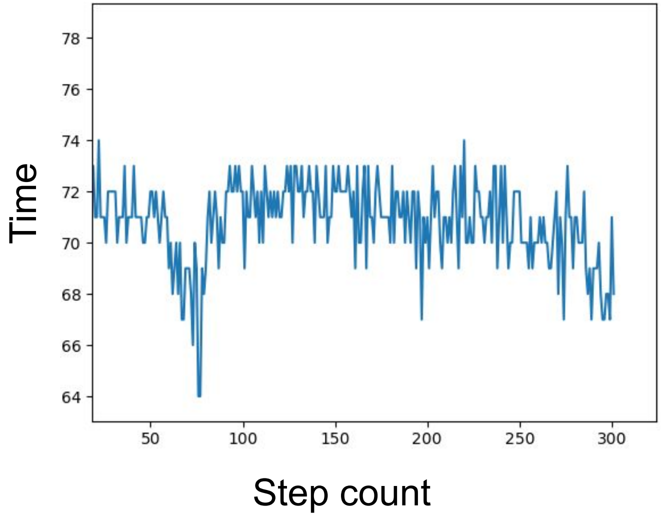


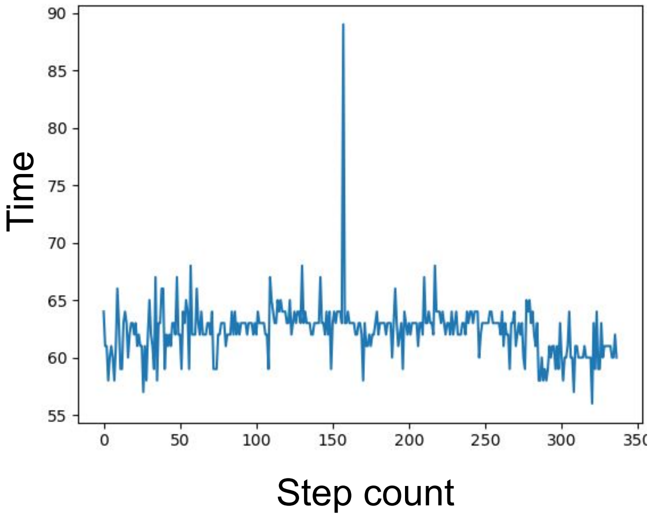
After glitch



Problems and Pitfalls

- Natural, slow changes in the subject's gait
  - Significant changes in step duration over a particular data set
  - Need a different analysis to characterize this
  - Unexplored avenue of gait characterization!

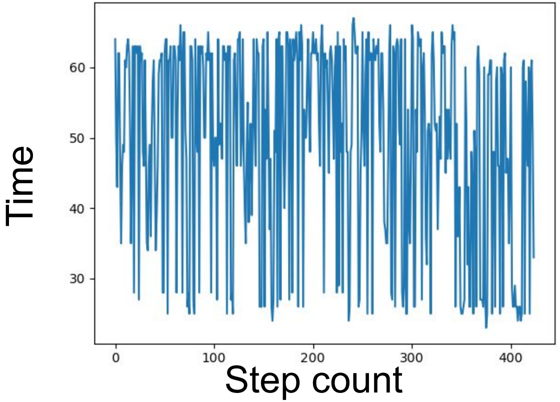




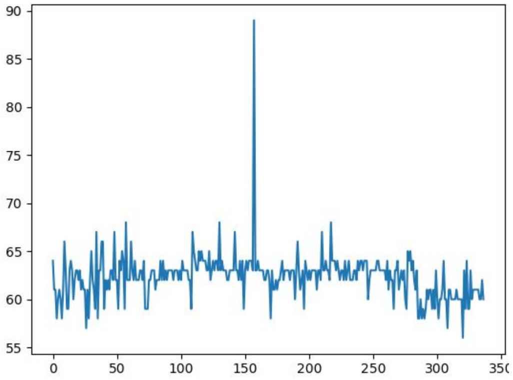
Time duration of steps often change slowly (over 10s - 100s of steps).

Optimization of Partitions

- The partition algorithm can be tuned in the following ways:
  - Threshold value for acceptable peaks
    - Decrease variance in partition sizes and beginning/end points
  - Orientation of data set
    - In acceleration data, some of the “trough” features are more consistent then peaks
  - Correction of inconsistent partition formation
    - Identify inconsistent partition formation, discard problem data, correct inconsistencies

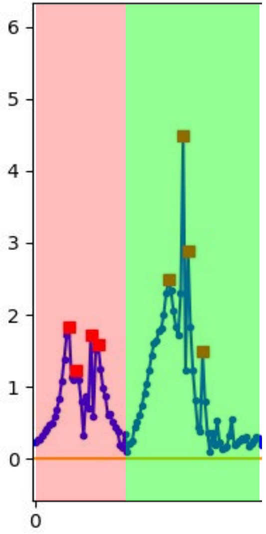


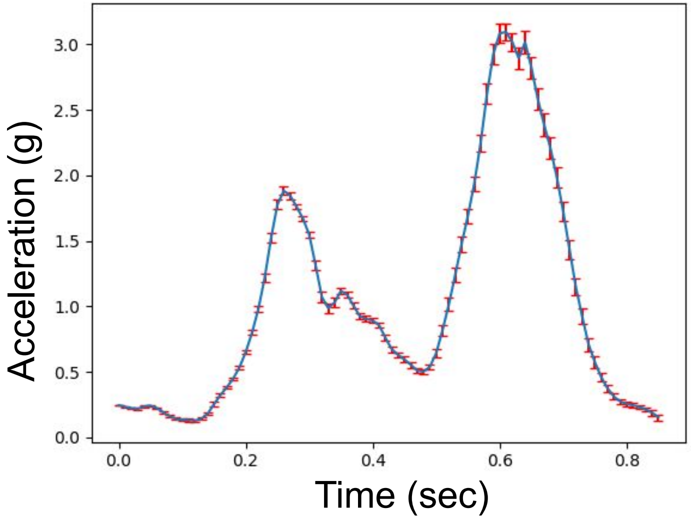
Peak threshold optimization



Generate Average step

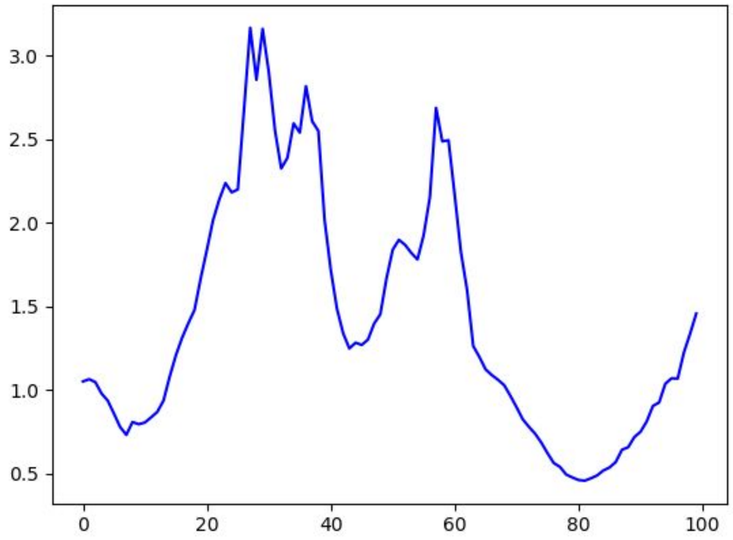
- Input: acceleration data set, partitions generated by partition algo.
  - Use 10 ms bins for data points
  - Plot average of each bin
- Output: Average bin values, uncertainty (acceleration), uncertainty (step duration)



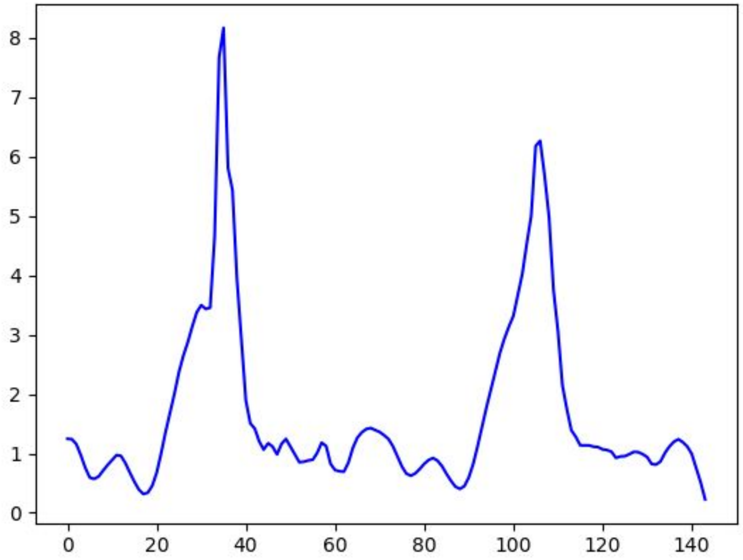


Optimization and average step output

Default peak thresholds (the average value of the data set)

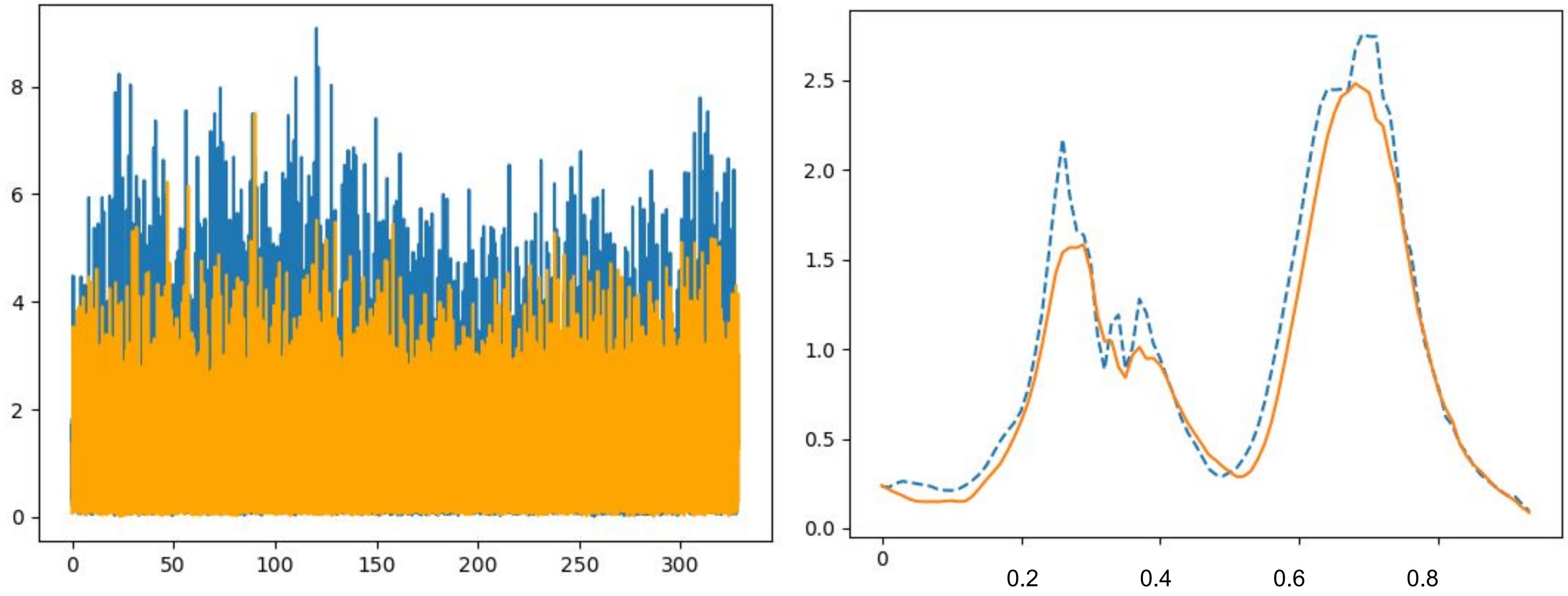


Optimized peak threshold (increased from average)



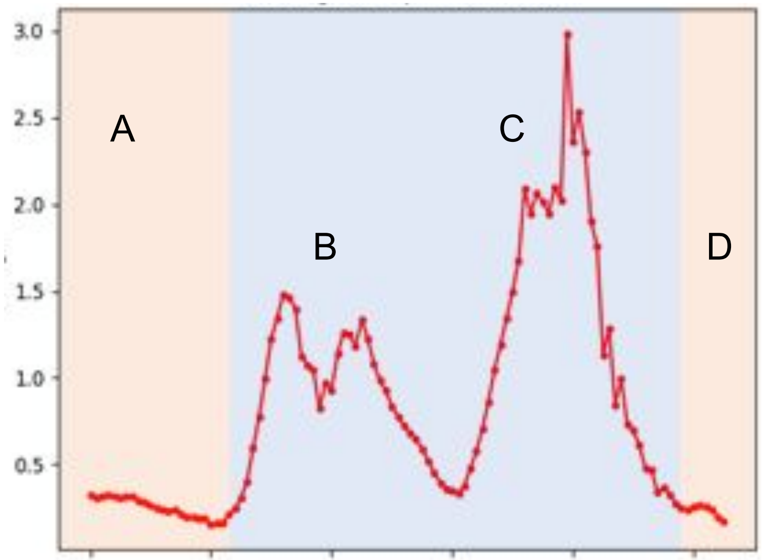
- Raising the peak threshold generally increases the sharpness of the highest peaks
- However, it can muddy peaks that fall below the threshold

Results: How well does the averaging model the data?

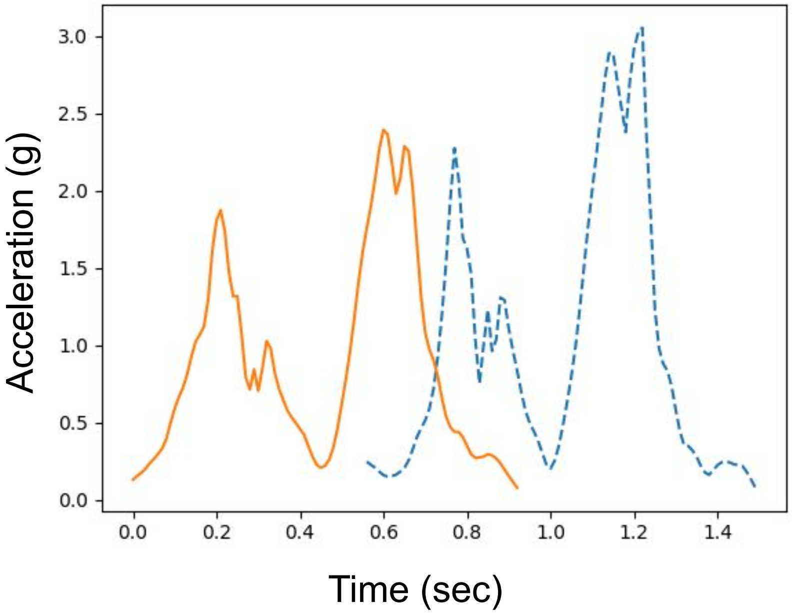


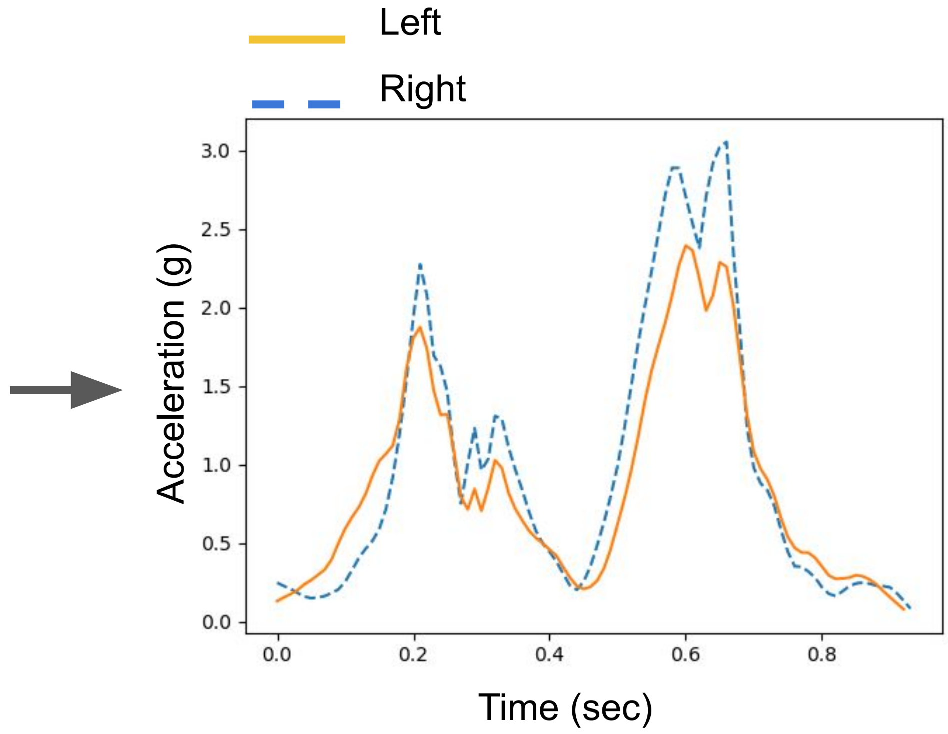
- Very obvious asymmetry b/w orange and blue data sets in raw data (blue > orange)
- Problem: in averaged data, the difference appears less significant
- Averaging tends to smear sharp, low resolution peaks. These peaks account for much of the apparent difference b/w the two data sets.

Interpreting walking data

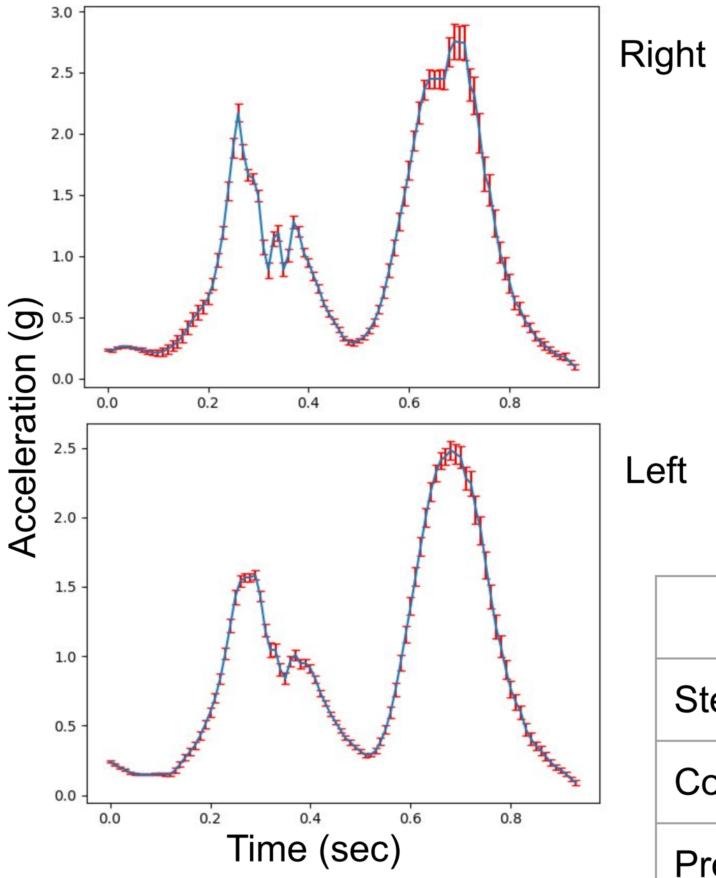


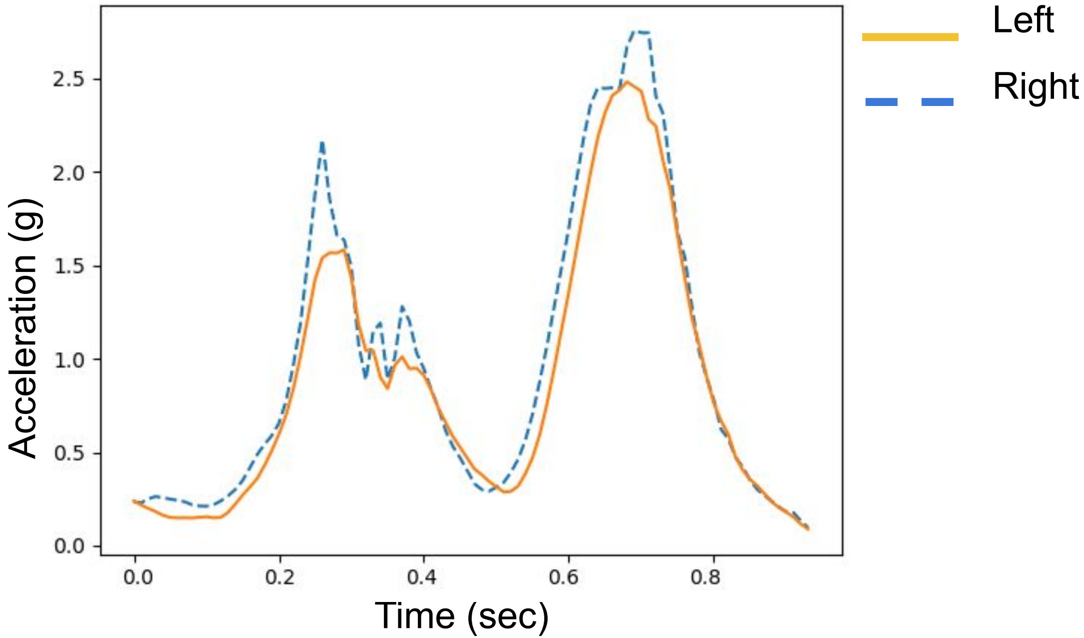
Left and Right leg Time Shift





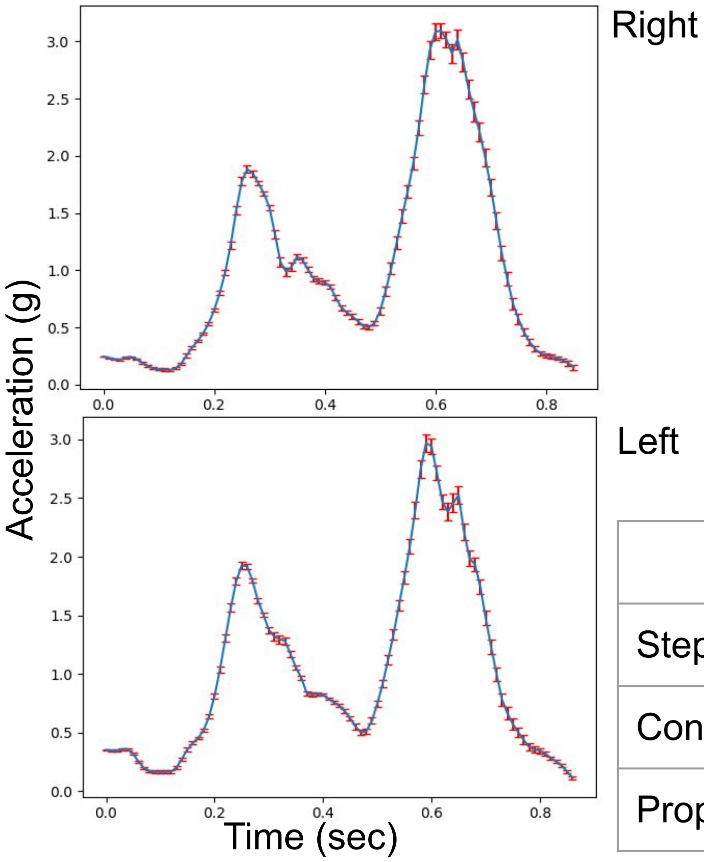
Subject one: walking

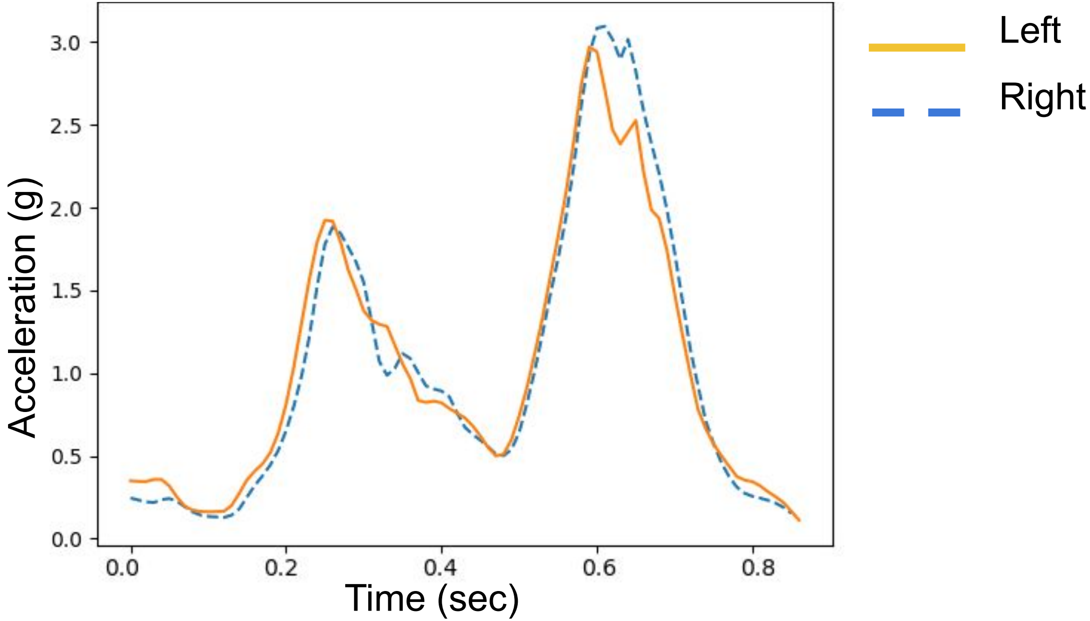




	Right Leg	Left Leg
Step duration (ms)	926.0 +/- 7.8	927.9 +/- 6.9
Contact acc max (g)	2.172 +/- 0.075	1.567 +/- 0.032
Propulsion acc max (g)	2.757 +/- 0.143	2.483 +/- 0.068

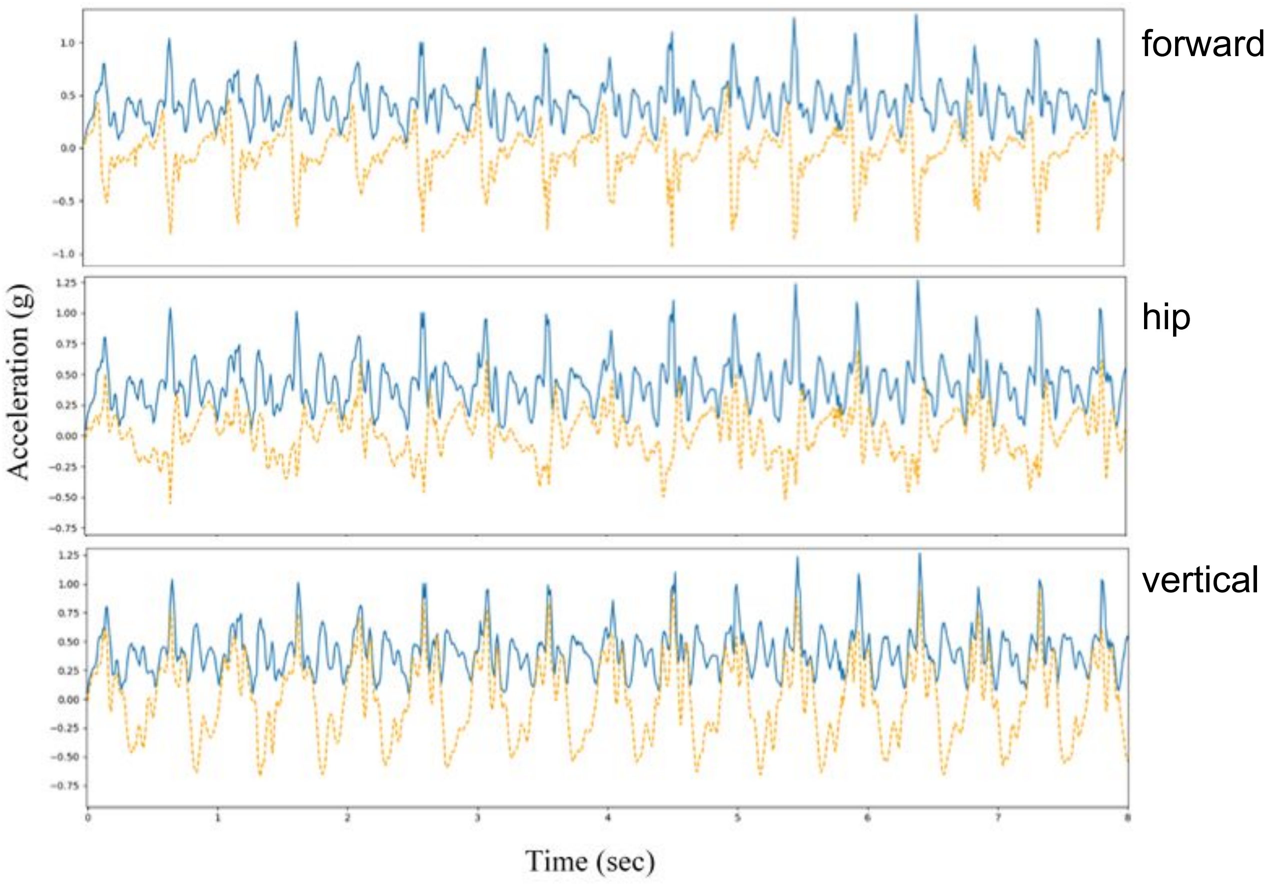
Subject two: walking

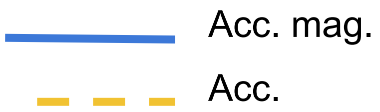




	Right Leg	Left Leg
Step duration (ms)	854.4 +/- 4.51	854.5 +/- 4.5
Contact acc max (g)	1.870 +/- 0.032	1.911 +/- 0.031
Propulsion acc max (g)	3.283 +/- 0.065	2.976 +/- 0.073

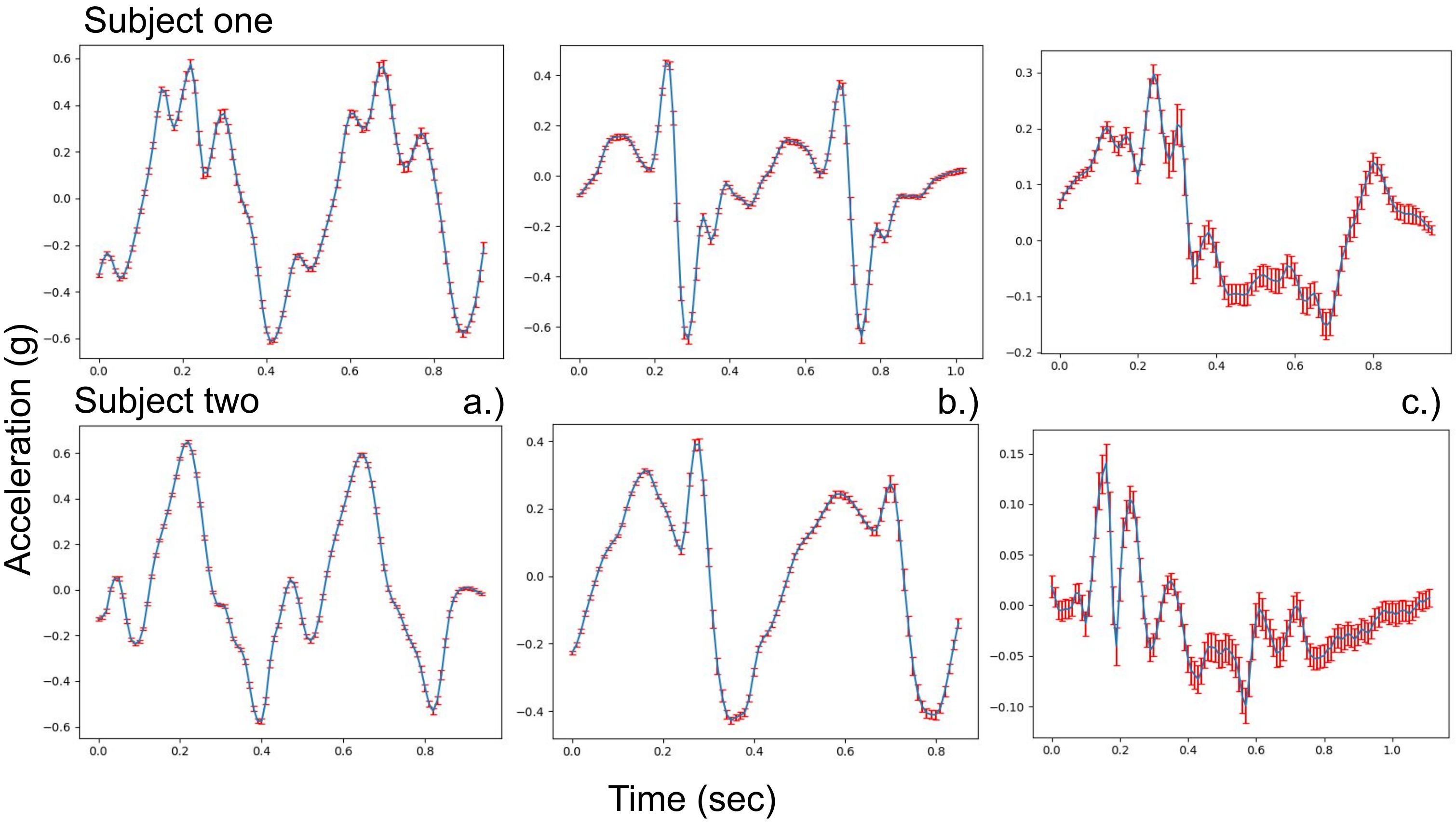
Centre of Mass





- Centre of mass magnitude data is periodic, but complicated.
- It is better to look at the individual components of acceleration

Centre of Mass Averages (walking)

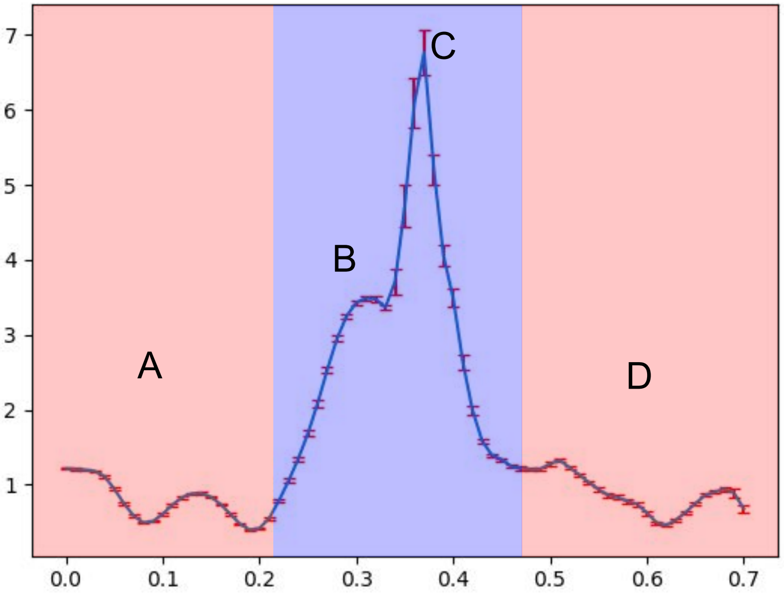


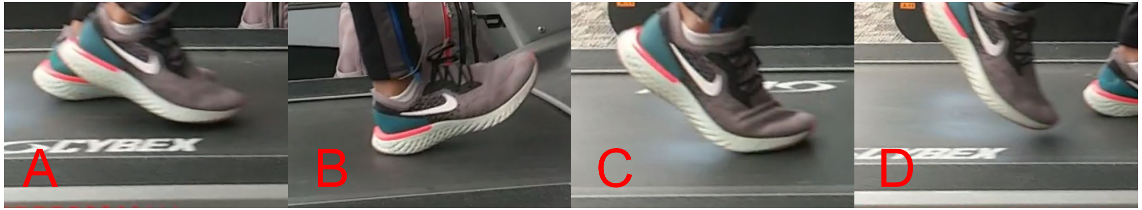
a.) vertical

b.) forward

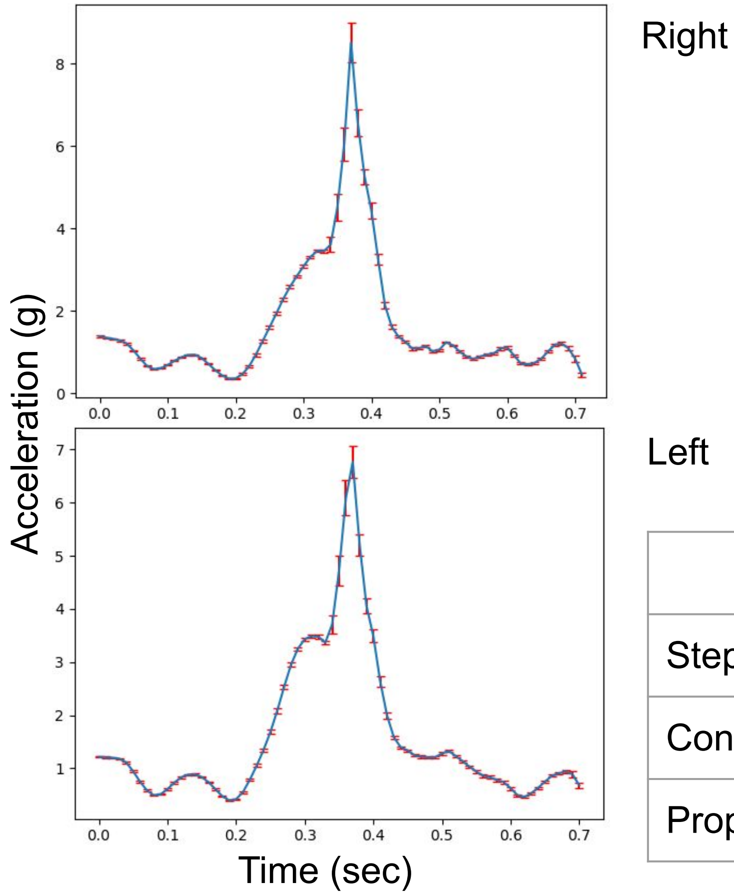
c.) hip

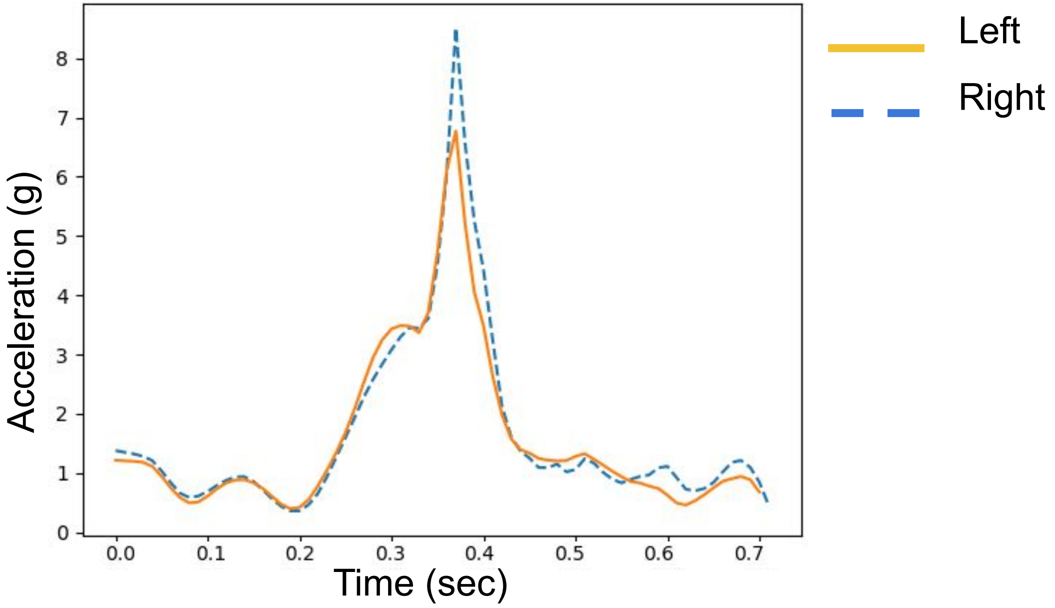
Interpreting running data





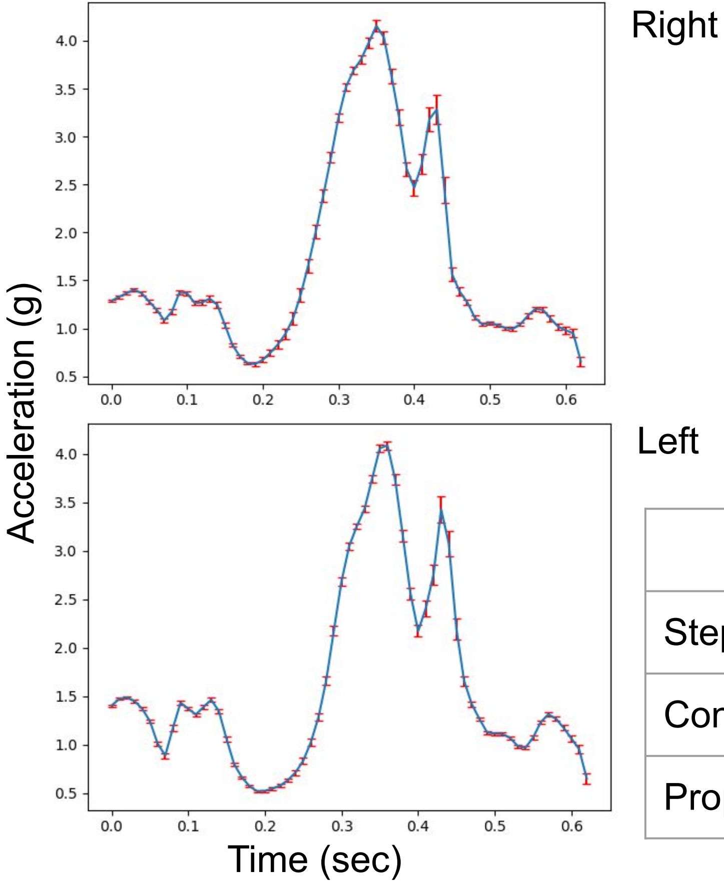
Subject one: Running

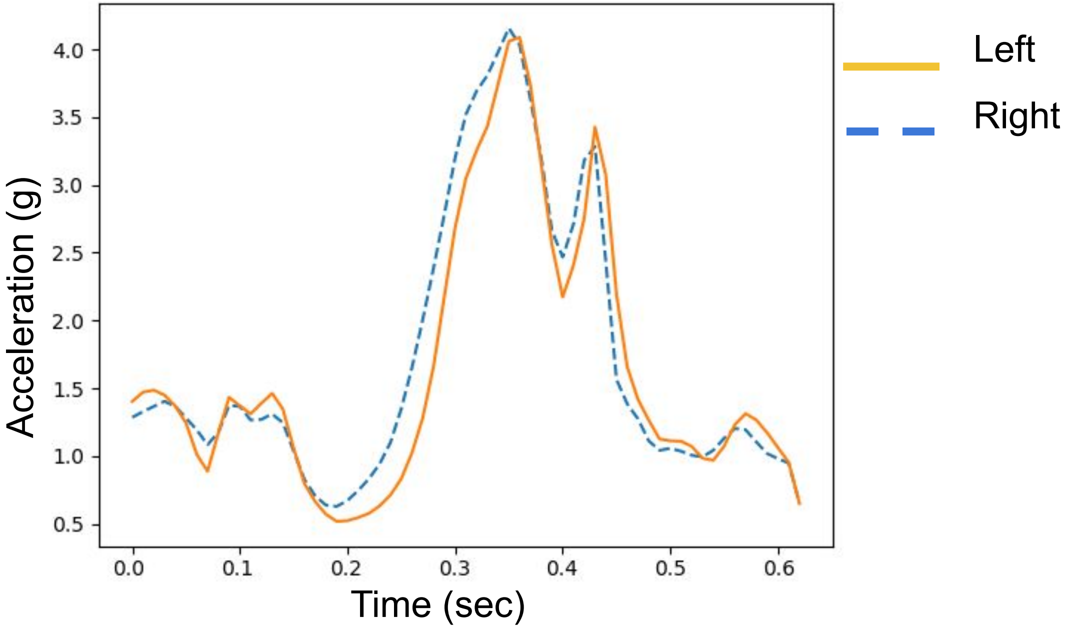




	Right Leg	Left Leg
Step duration (ms)	711.2 +/- 58.1	708.3 +/- 55.3
Contact acc max (g)	N/A	3.488 +/- 0.032
Propulsion acc max (g)	8.511 +/- 0.482	6.769 +/- 0.339

Subject two: Running





	Right Leg	Left Leg
Step duration (ms)	623.2 +/- 48.1	623.4 +/- 48.0
Contact acc max (g)	4.156 +/- 0.063	4.089 +/- 0.043
Propulsion acc max (g)	3.284 +/- 0.148	3.427 +/- 0.131

Discussion: Asymmetries

- It is clear from the graphs, the accelerations experienced by the right ankle of subject one are significantly greater than the left ankle
- Could be a sign of pronation, supination or “leg length discrepancy”
- We have shown it is possible to observe such discrepancies using our method

Discussion: Heel strike vs. Toe strike

- Subject one’s graph exhibits a shoulder pattern right before the large peak
- Subject two’s graph instead shows another smaller peak right after the large peak
- The majority of these differences are probably because subject one uses the Toe Strike technique, where subject two uses the heel strike technique

Conclusions

- Our study demonstrated how, through the collection of raw accelerometer and gyro data we can obtain accurate values of acceleration for an average step of a subject
- Hence, this method can be used for future studies into the techniques used by runners, whether for diagnostic purposes or to improve and perfect a technique
- Such accurate data could also be a useful tool for rehabilitation for patients trying to regain full motion of the lower limbs

References

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