Wearable Coach For Symmetric Walking

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Supervisors

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Contents

Introduction

- Walking activity + Aging factor
- Person may develop/modify unknowing the way of walking
  - Ideal (symmetric) to abnormal (asymmetric) way of walking
- Treatment
  - Avoiding surgery is not always possible
- After the surgery
  - Kinaesthetic feedback for the joints is affected
- Re-learn the same motor skills (walking). Re-learning
  - Physiotherapists role
    - Supervision of motor re-learning of walking
  - Patients role
    - Attending physiotherapy sessions
    - Home exercises

Introduction

- Wearable technology
  - Capable to measure the walking gait
    - Accelerometer
    - Gyroscope
  - Low cost
  - Real-time detection
  - Portable
  - Standalone operation
- Feedback
  - Wearables can also provide feedback
    - Concurrent feedback
- Demonstrates significant therapeutic advantages

Contents

Goal

Develop a prototype of a wearable device that provides necessary feedback to the user in real-time which assists in re-learning the right kinaesthetic feedback to the prosthetic joints for symmetrical walking

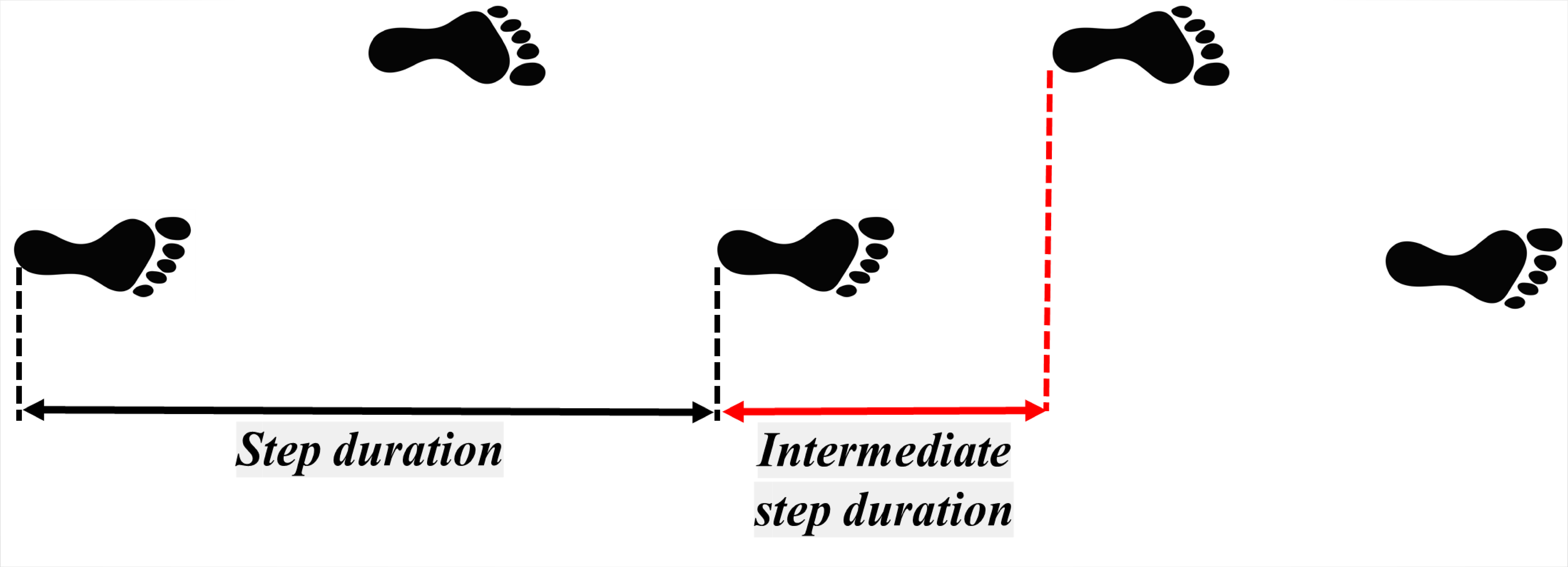
Research Question

How to design a wearable device that gives haptic feedback for motor learning of patients who undergo hip/knee prosthesis?

Contents

Literature reading conclusions

- **Hypothesis:**
  - The intermediate step duration differs significantly for the users with a prosthesis in the hip/leg in comparison to the users without a prosthesis
- Sensors positioned on lower back is a good starting points
- Lower back/hips location for providing feedback looks promising
  - Matches with the physiotherapists feedback location
- Feedback strategy leaves more room for experimentation



Contents

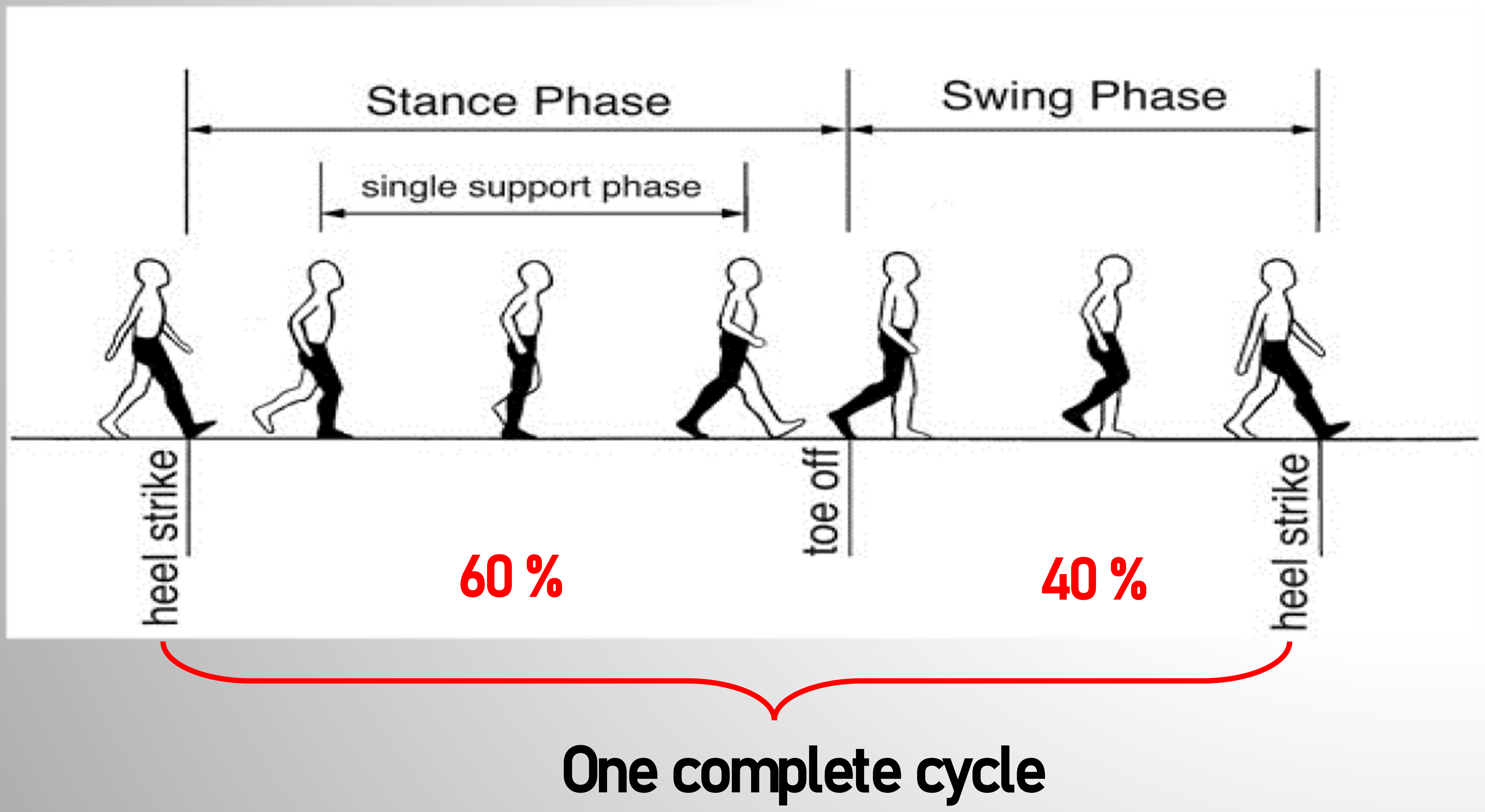
<u>Pre-Study</u>

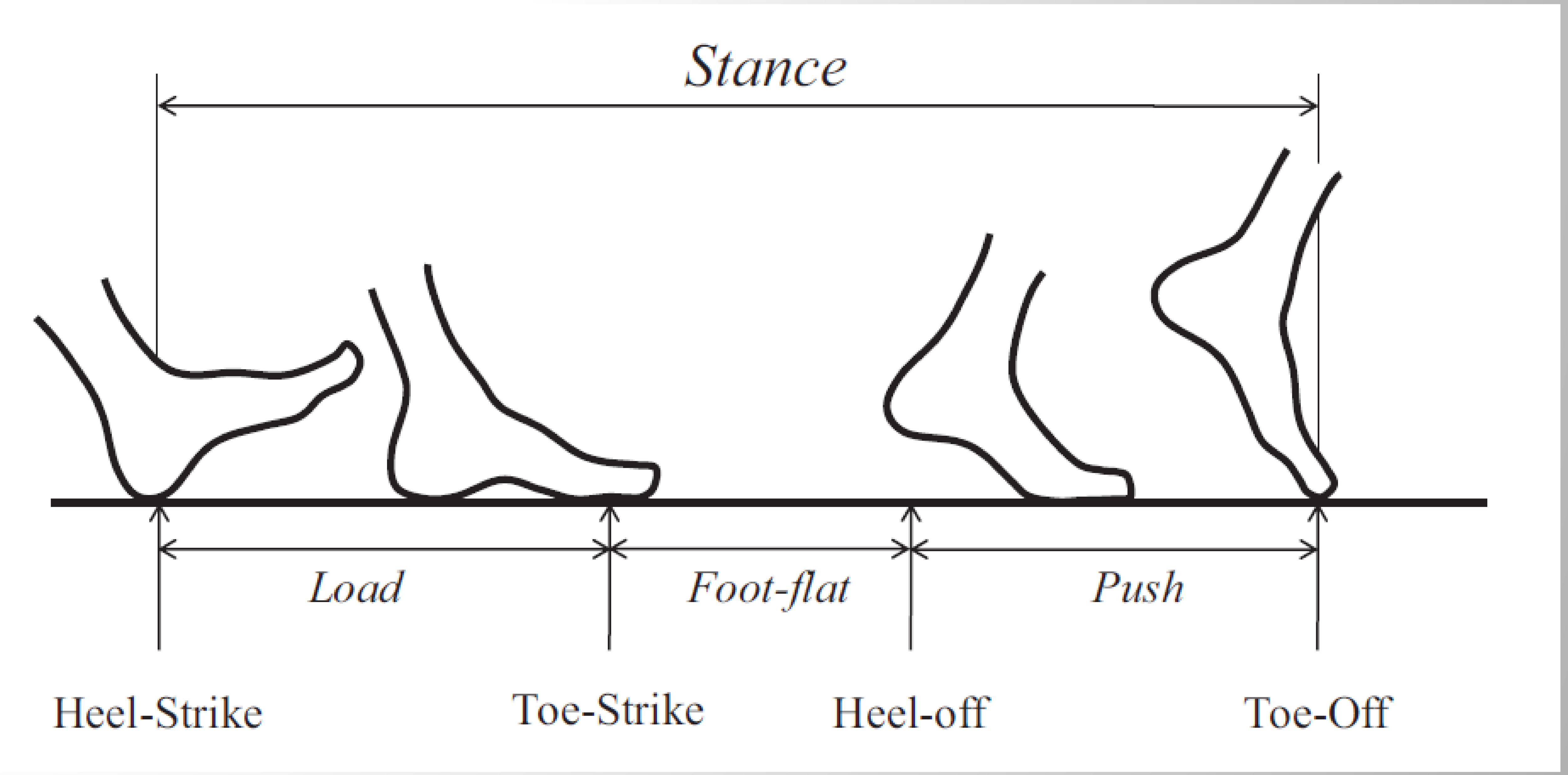
- First development
  - Designing a device to record the IMU measurements
  - Obtaining walking patterns and understanding them for users **<u>without prosthesis</u>**
- Second development
  - Upgrading the device to match the wearable design requirements
  - Obtaining walking patterns and understanding them for users **<u>with prosthesis</u>**

Biomechanics of walking

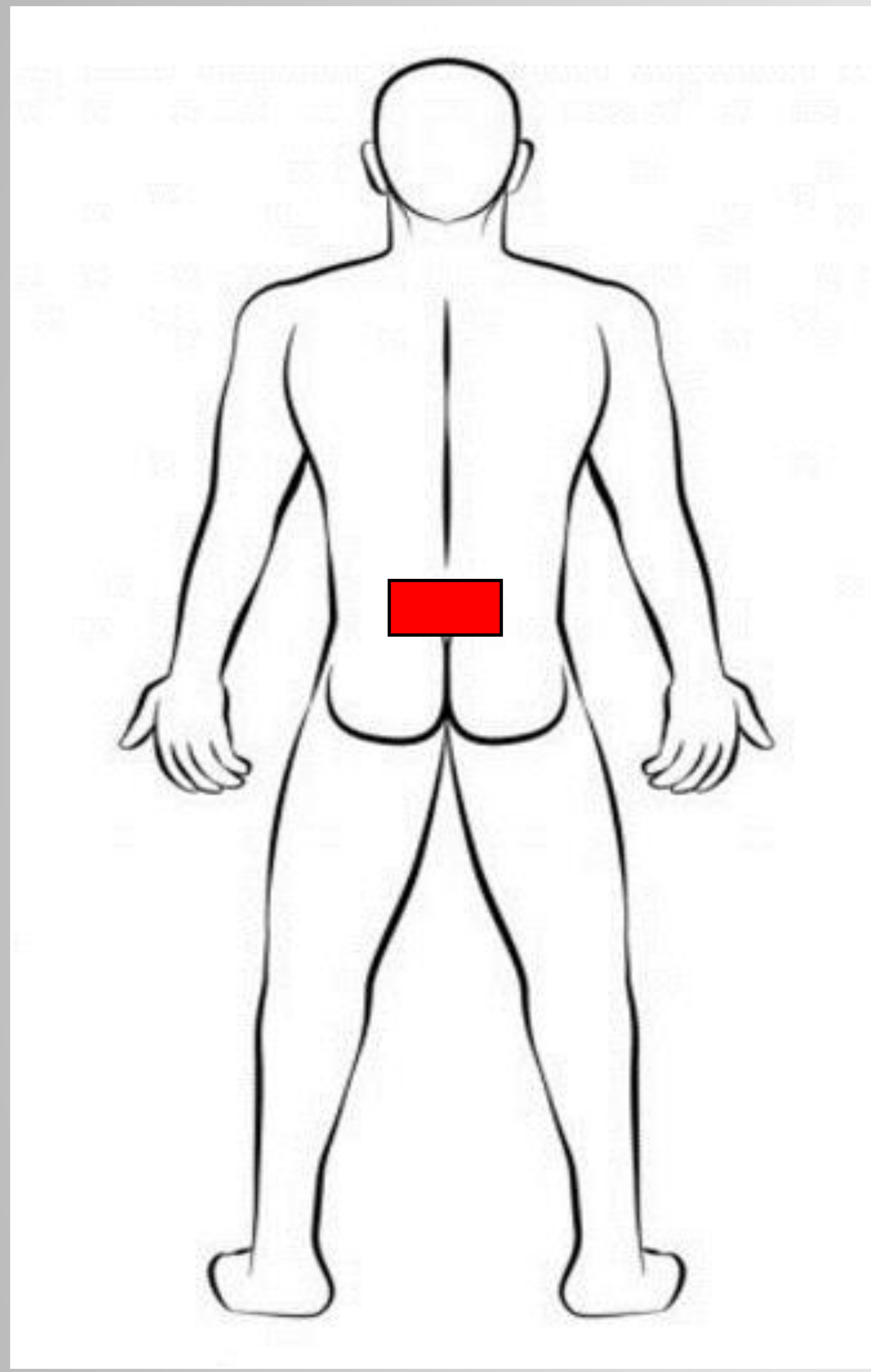
- Walking activity
  - Stance phase
  - Swing phase
- One complete cycle
  - Stance phase + swing phase
    $(\approx 1\ sec\ to\ 1.2\ sec)$

- Key events in stance phase
  - Heel-strike
  - Toe-strike
  - Heel-off
  - Toe-off

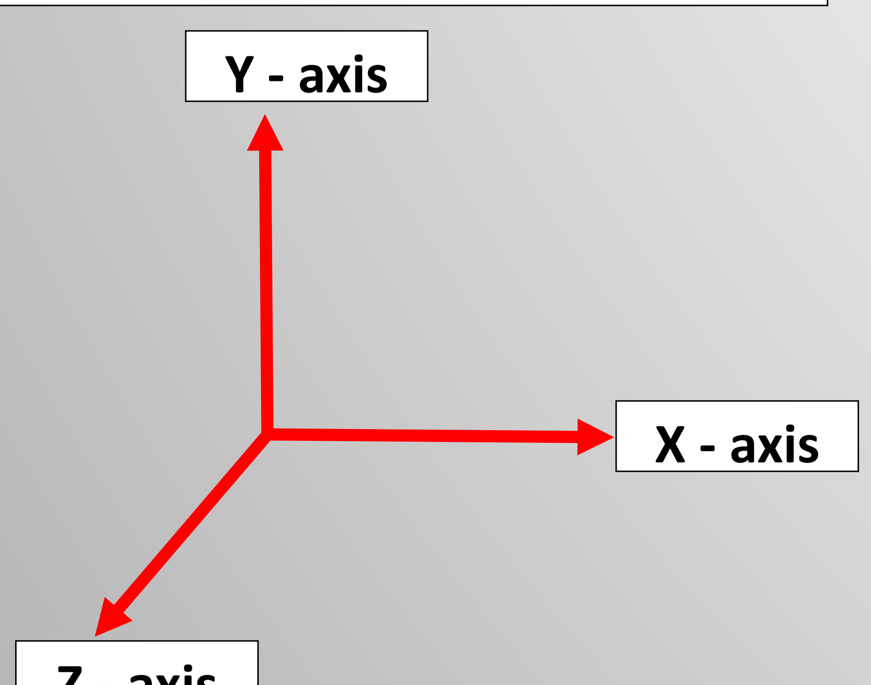




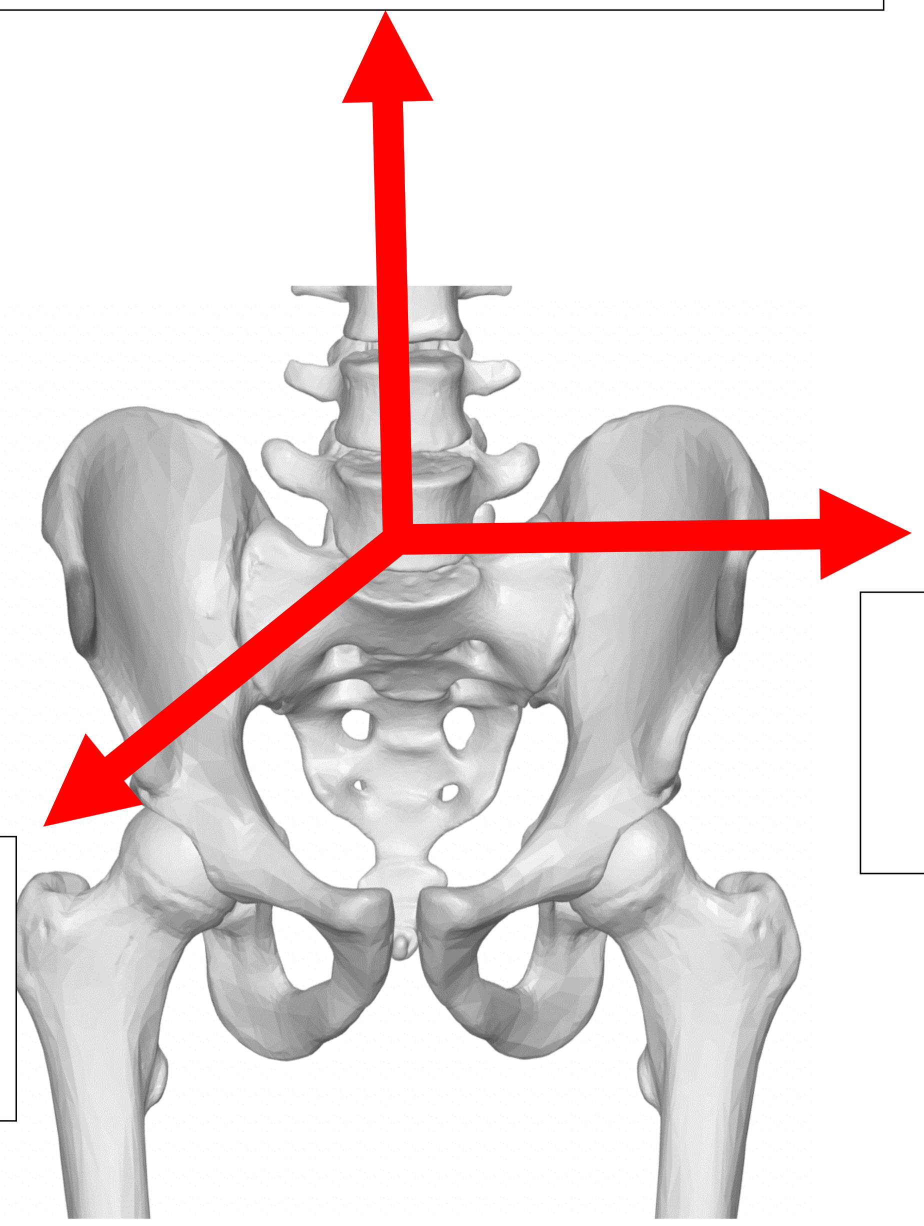
Sensor Location



Lower Back



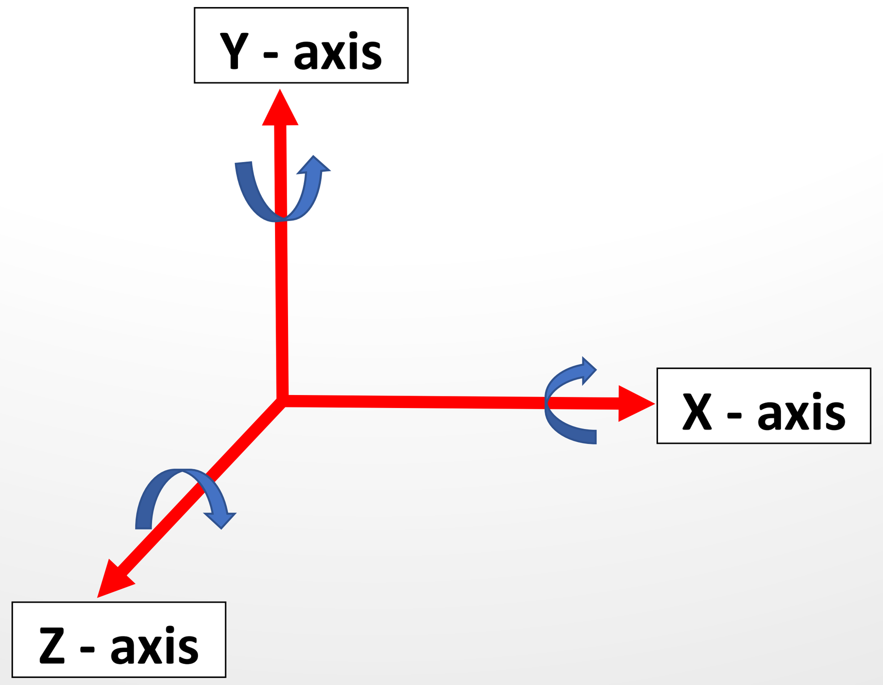
Y – axis/ Transverse Plane



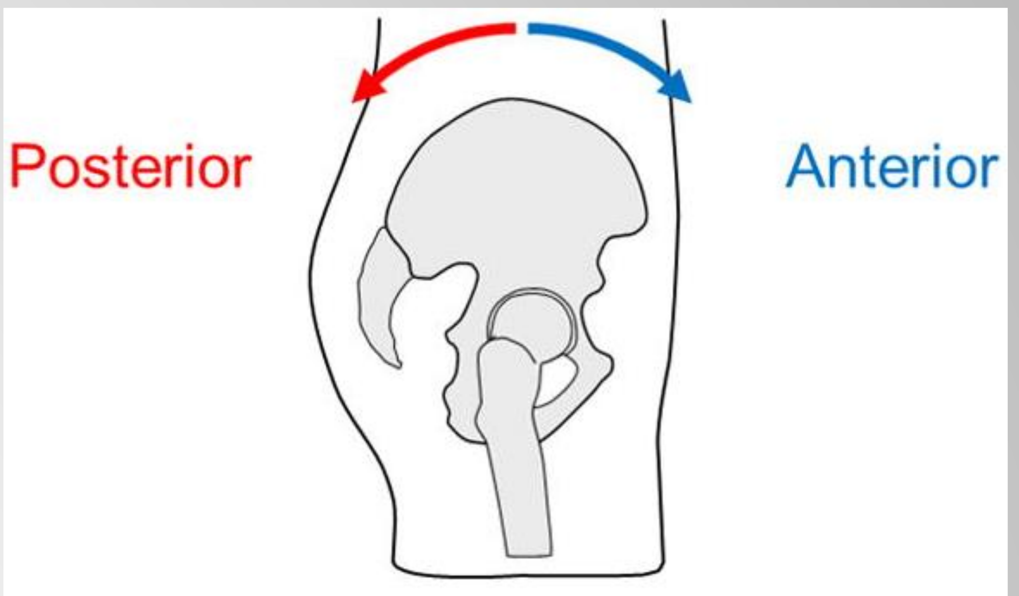
X – axis/ Sagittal Plane

Z – axis/ Frontal Plane

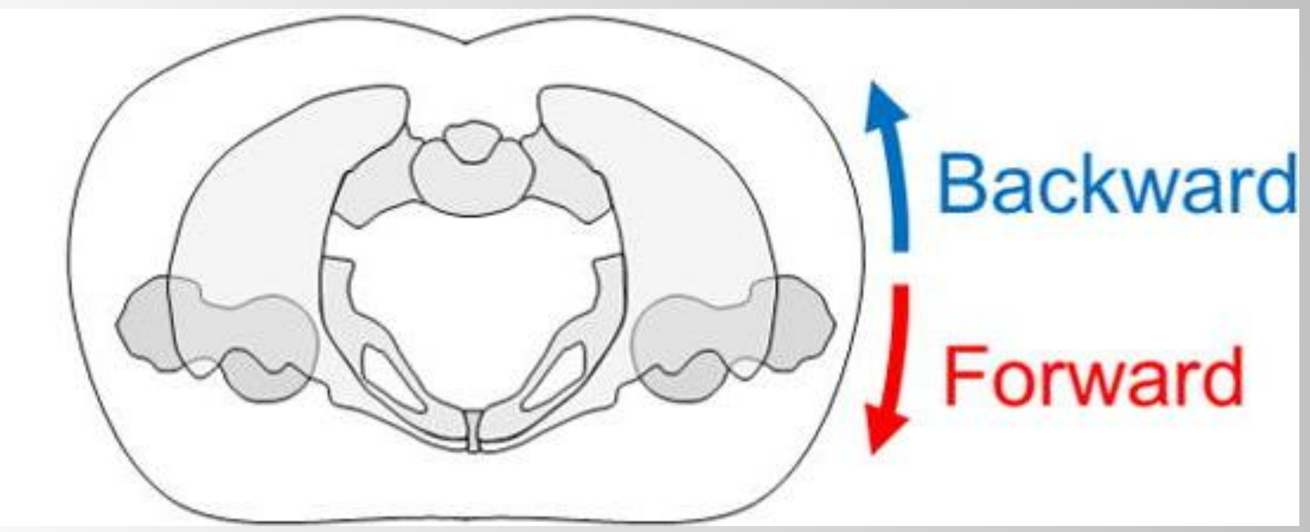
Pelvis



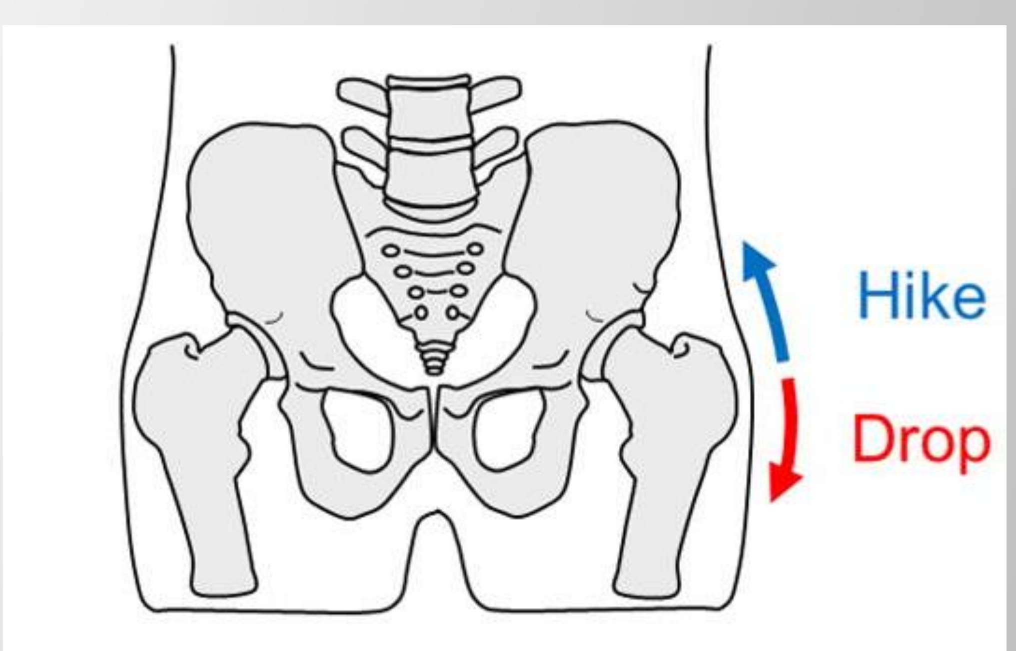
Pelvis Movement During Walking



X – axis/ Sagittal Plane



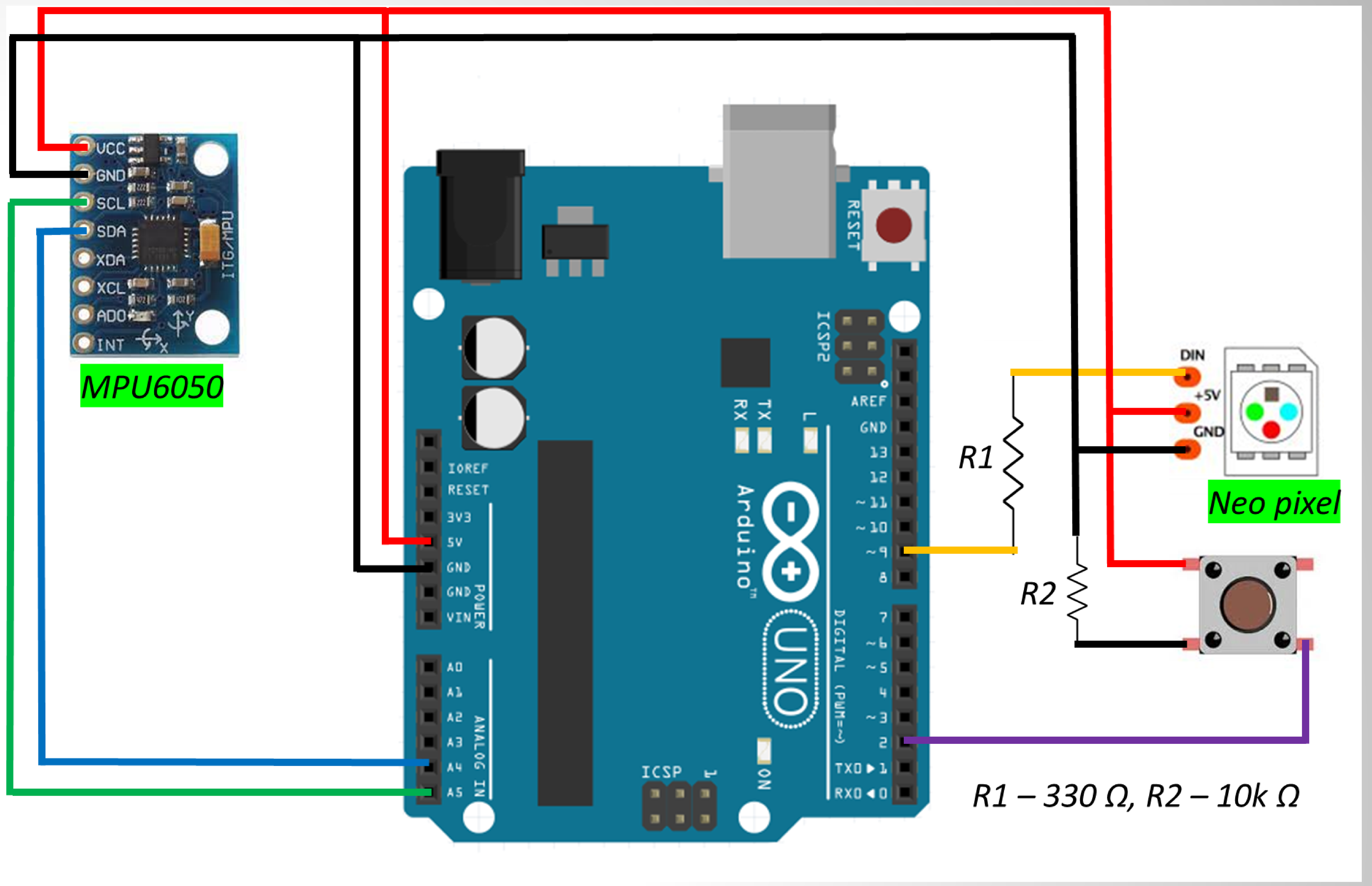
Y – axis/ Transverse Plane



Z – axis/ Frontal Plane

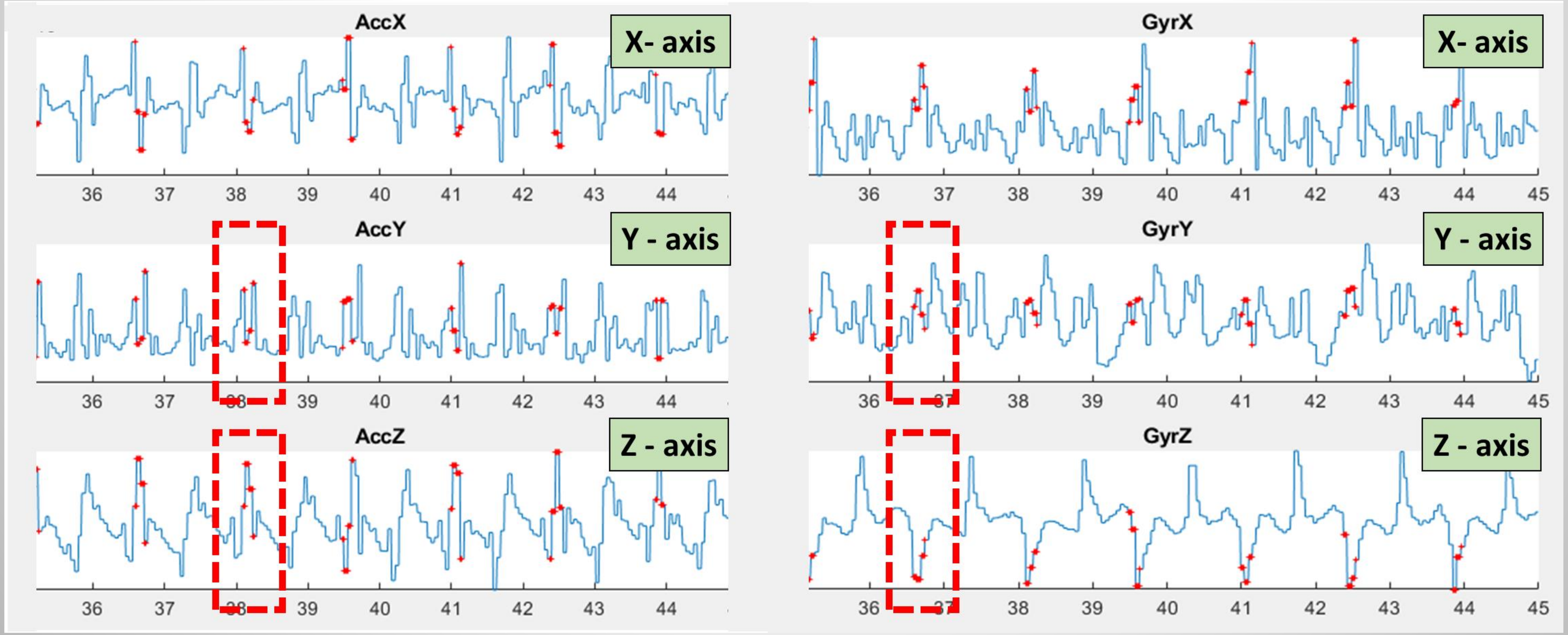
First Development

- Designed wearable device
  - MPU6050 sensor
  - Arduino
  - LED – Neo pixel
  - Button
  - Pouch



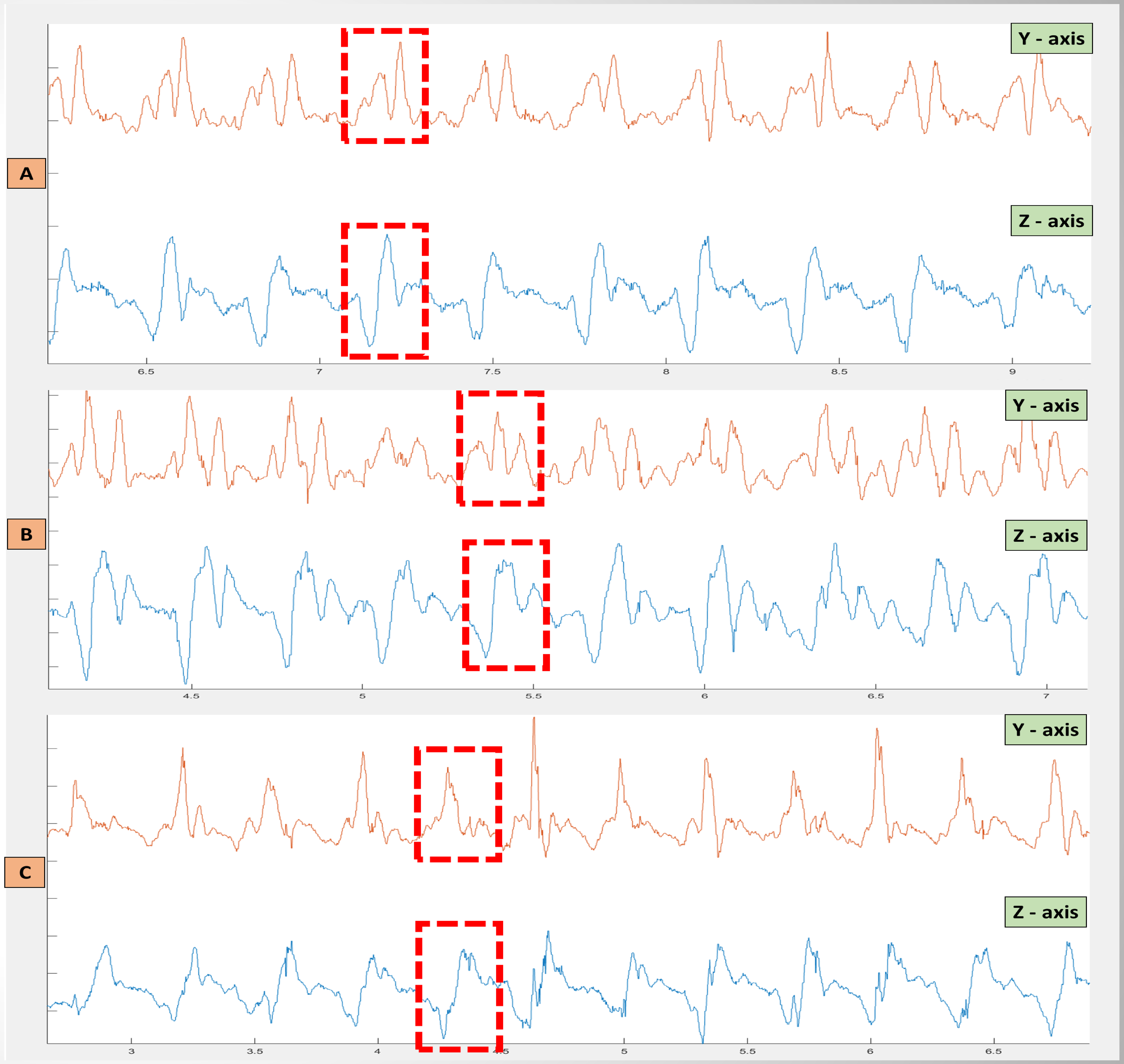
First Development

- Observed walking patterns for a user without prosthesis
- Peaks recorded during heel-strike looked promising to develop a real-time algorithm



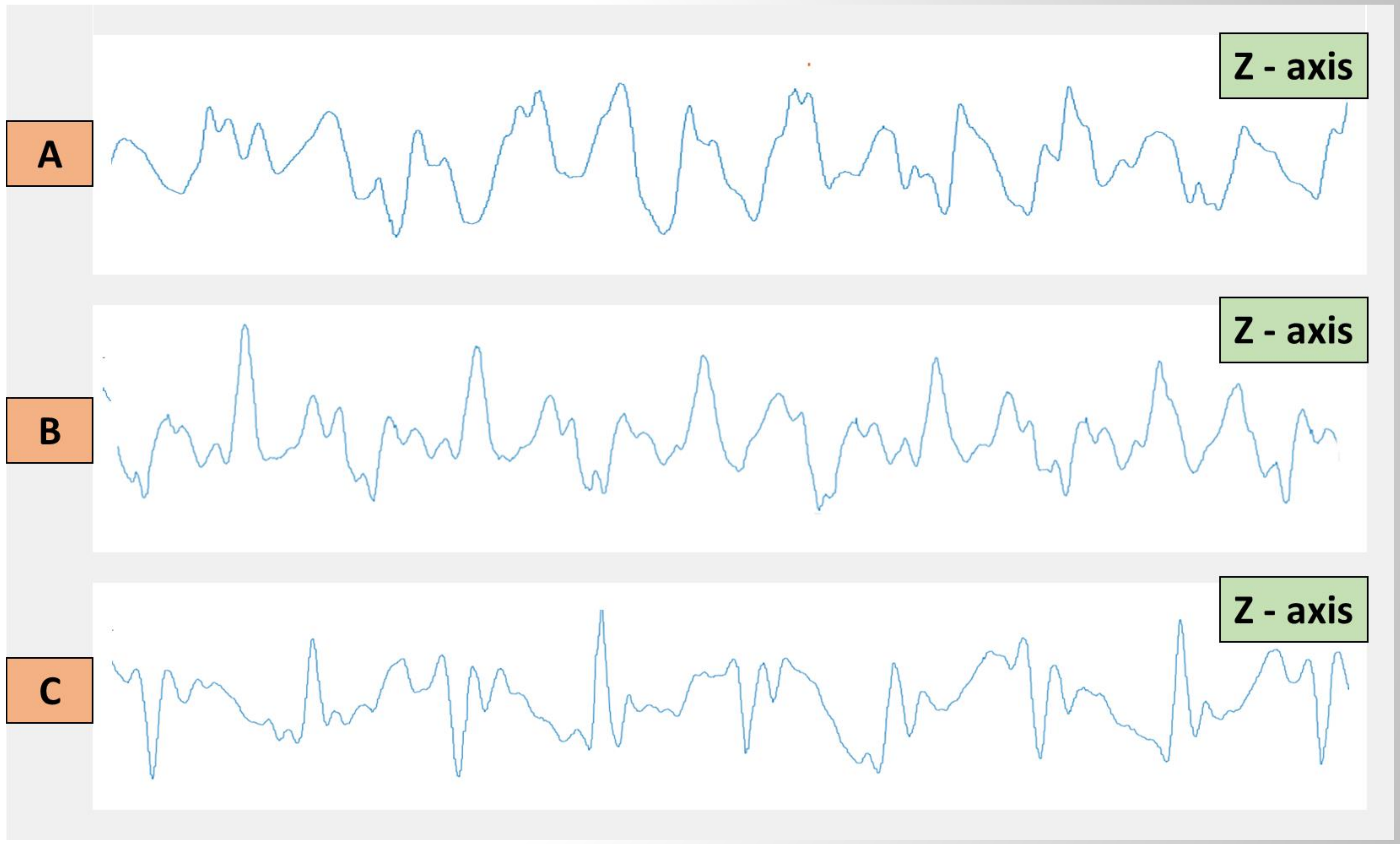
First Development

- When repeated with multiple users
- Measurements along accelerometer Y-axis and Z-axis showcased similar patterns/peaks for the heel-strike event



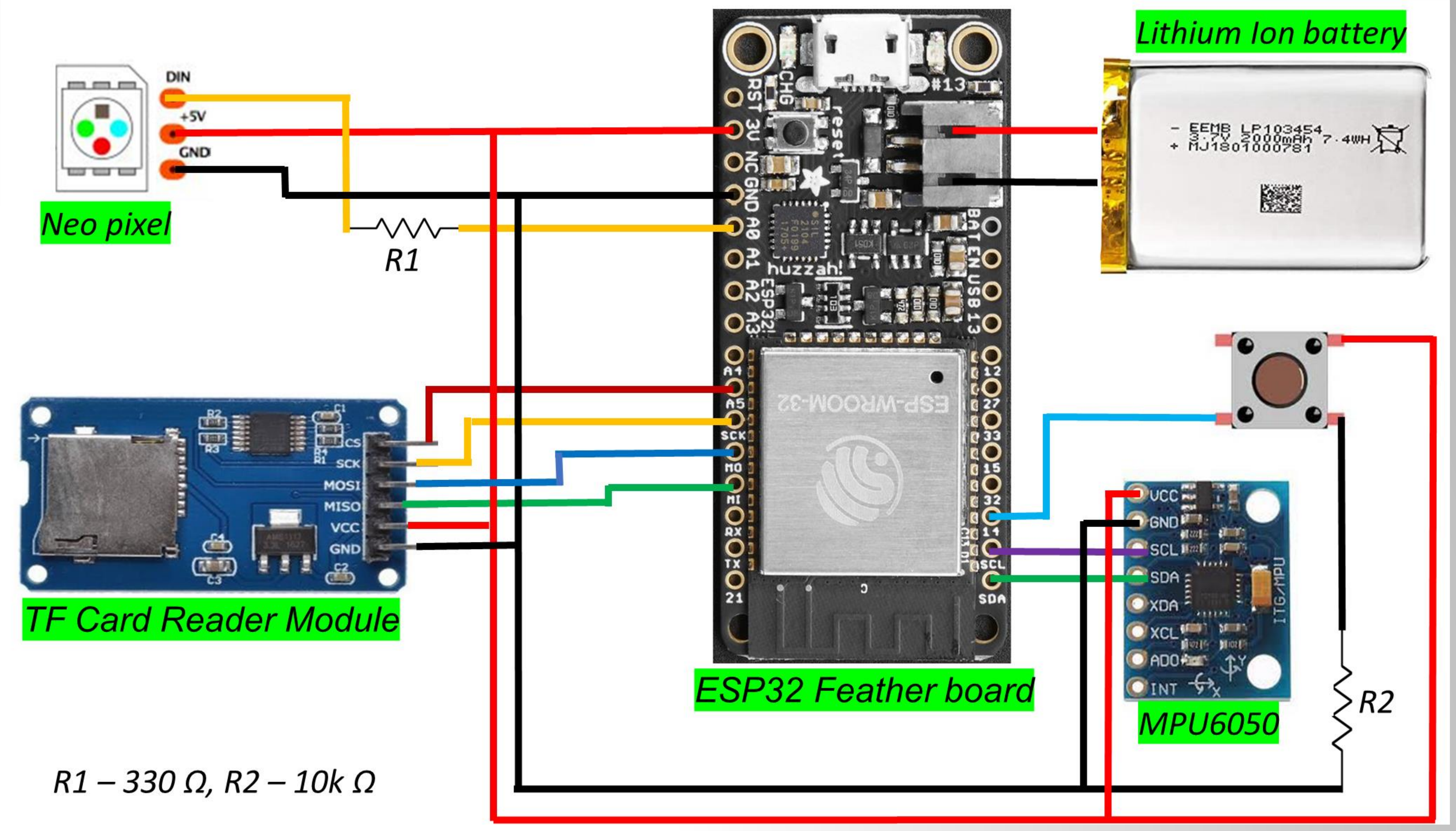
First Development

- But the gyroscope measurements along Z-axis are not similar
- Only accelerometer values are more suitable for developing real-time algorithm



Second Development

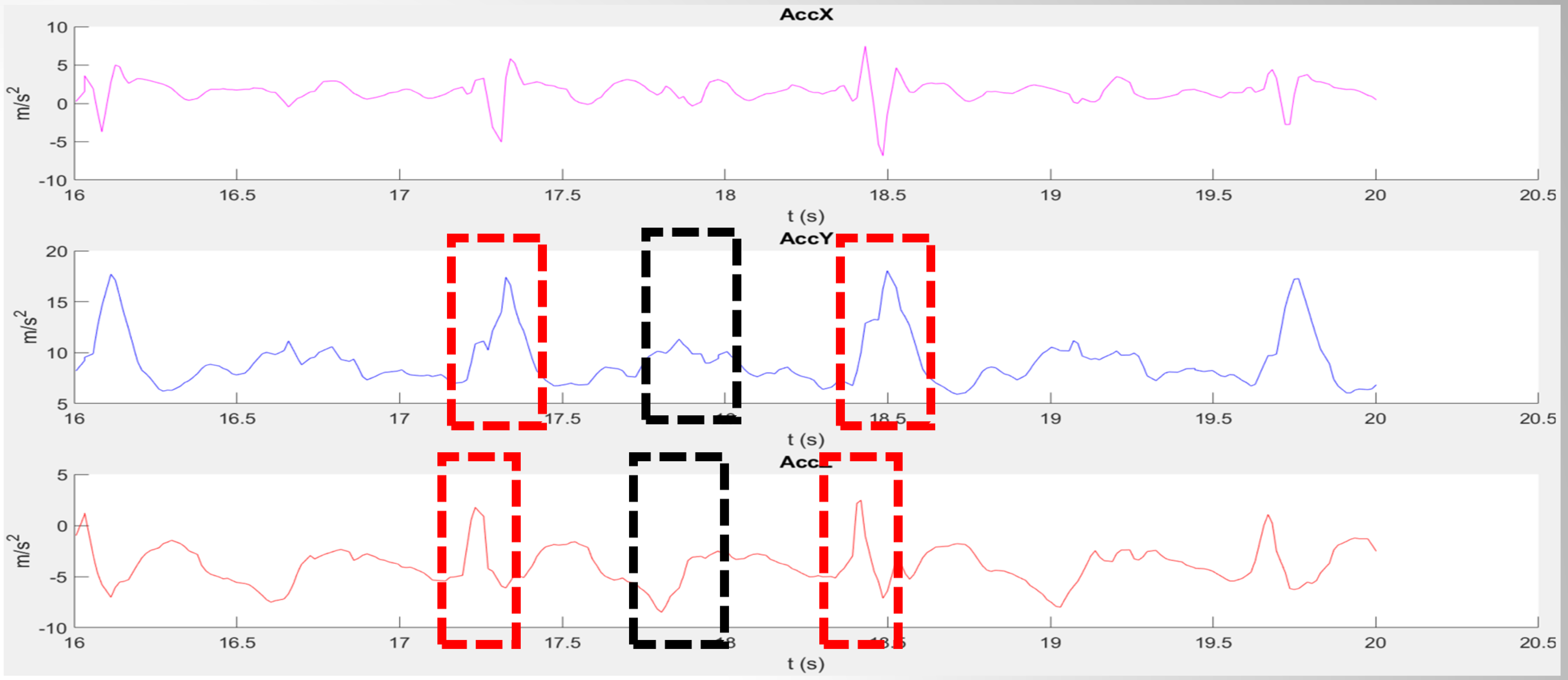
- Designed wearable device
    - MPU6050 sensor
    - ESP32 Feather board
    - LED – Neo pixel
    - Button
    - TF card reader module
    - Waist belt
- Waist belt
    - Soft fabric material
    - Adjustable bands



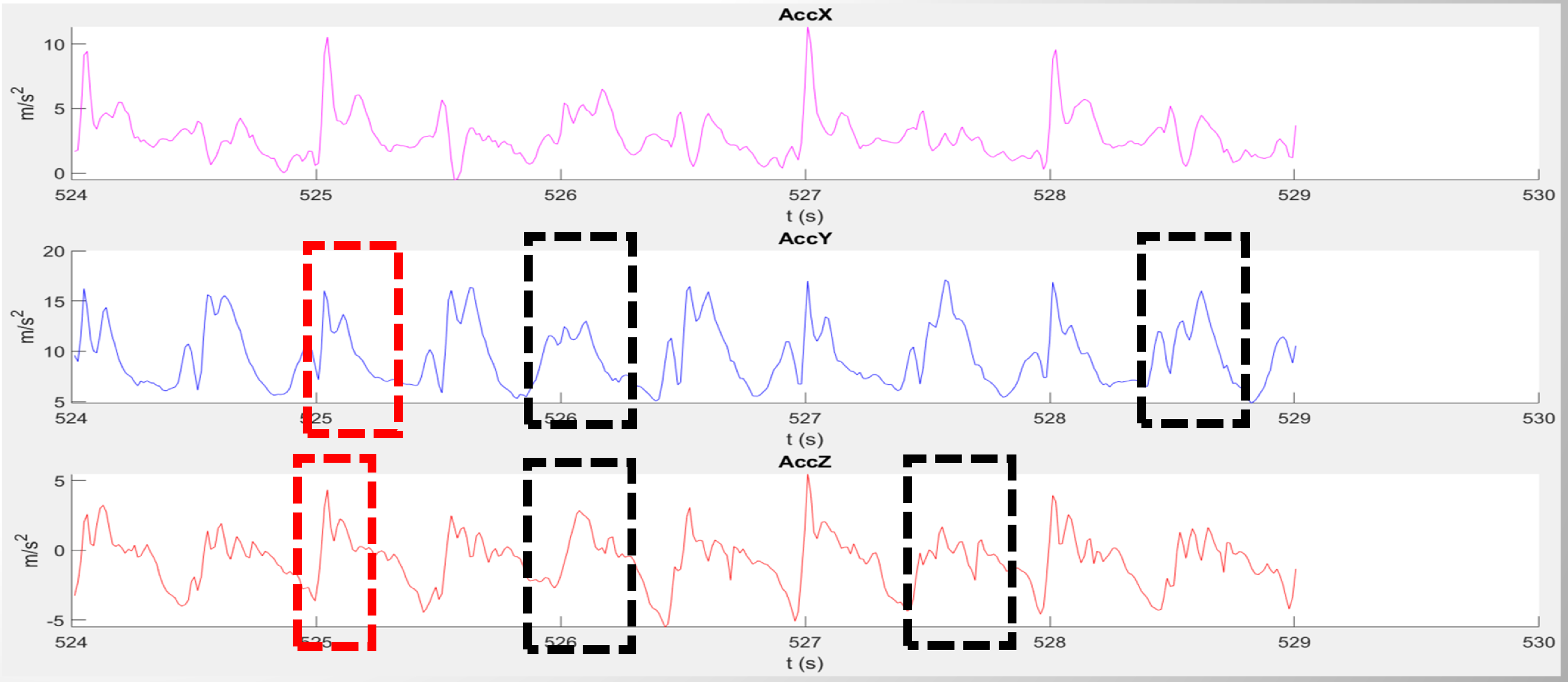
Second Development

- Observed walking patterns for users with prosthesis
- Peaks recorded during heel-strike event looked similar to users without prosthesis (red dotted box)
- There are heel-strike events where identification of peaks are difficult (black dotted box)
- There are more inconsistencies in the patterns

User with prosthesis on right knee

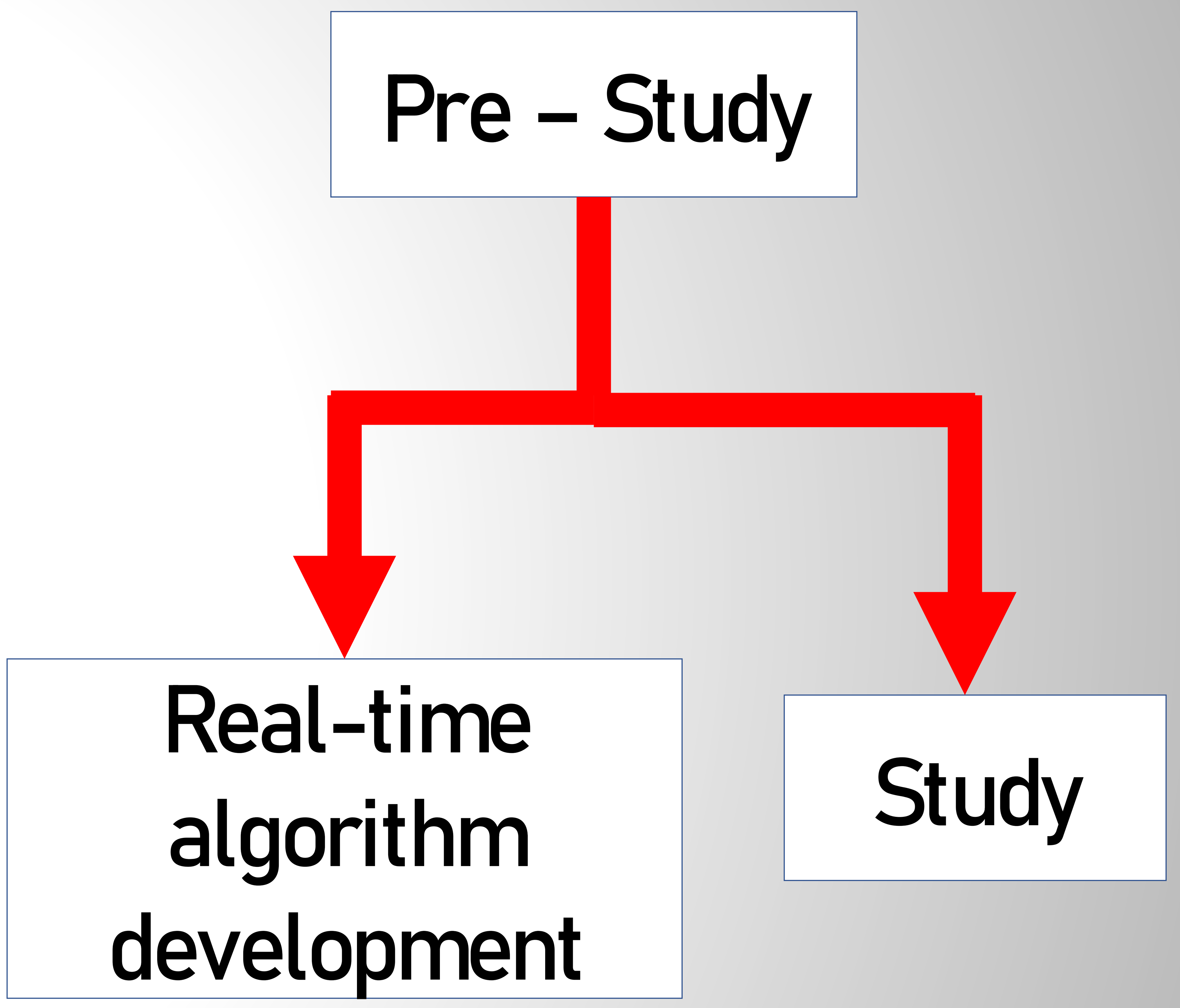


User with prosthesis on left hip



Pre-Study Conclusion

- More users walking patterns are required to analyse the criteria for asymmetry for walking
  - With prosthesis
  - Without prosthesis
- Verification of the hypothesis
- Need for pressure sensor
  - To confirm/understand the heel-strike events
- Validation of the real-time algorithm



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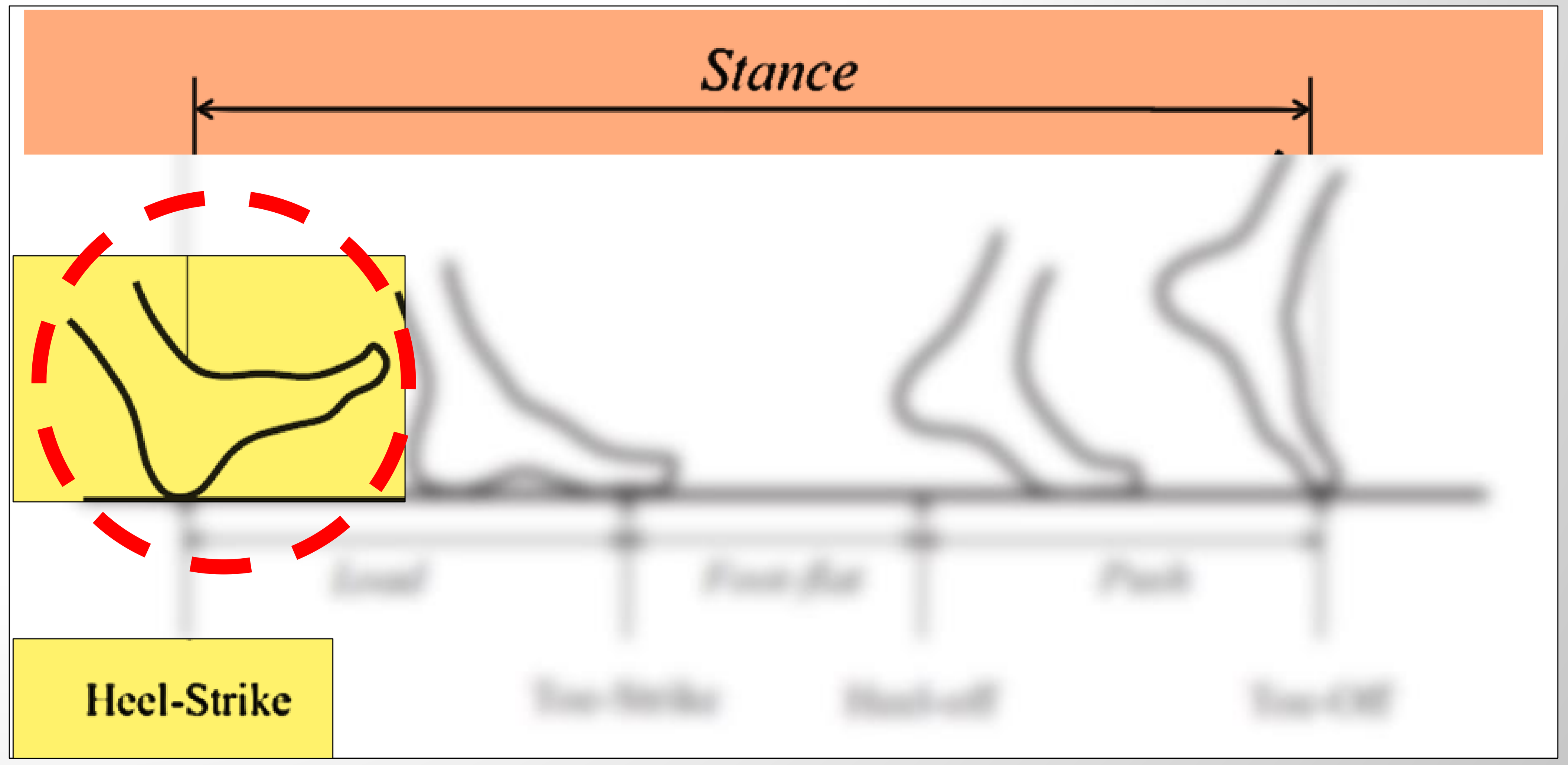
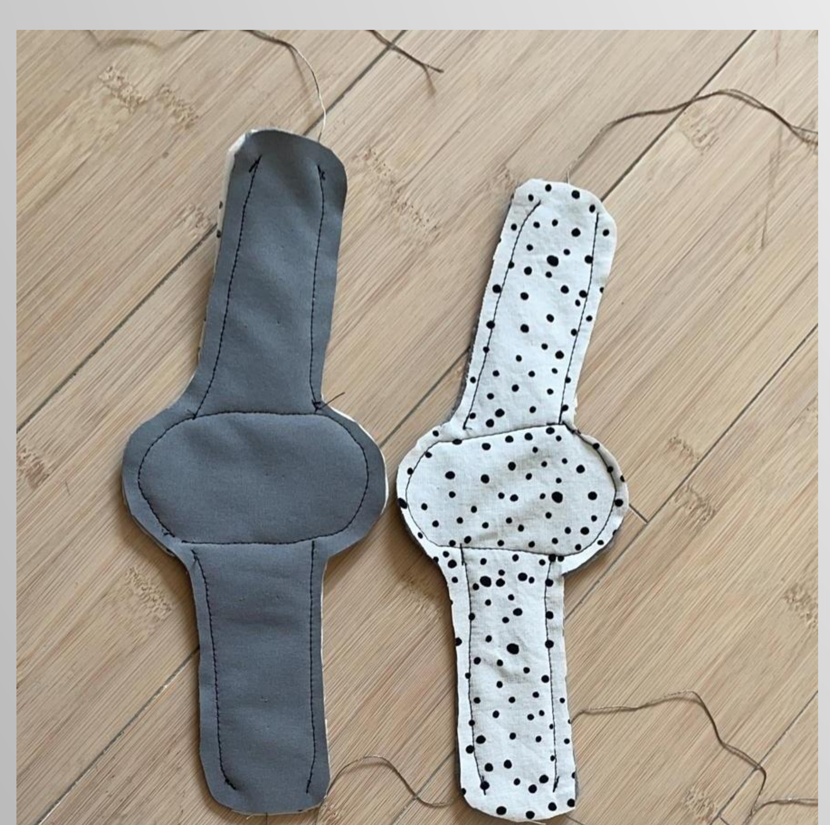
Study

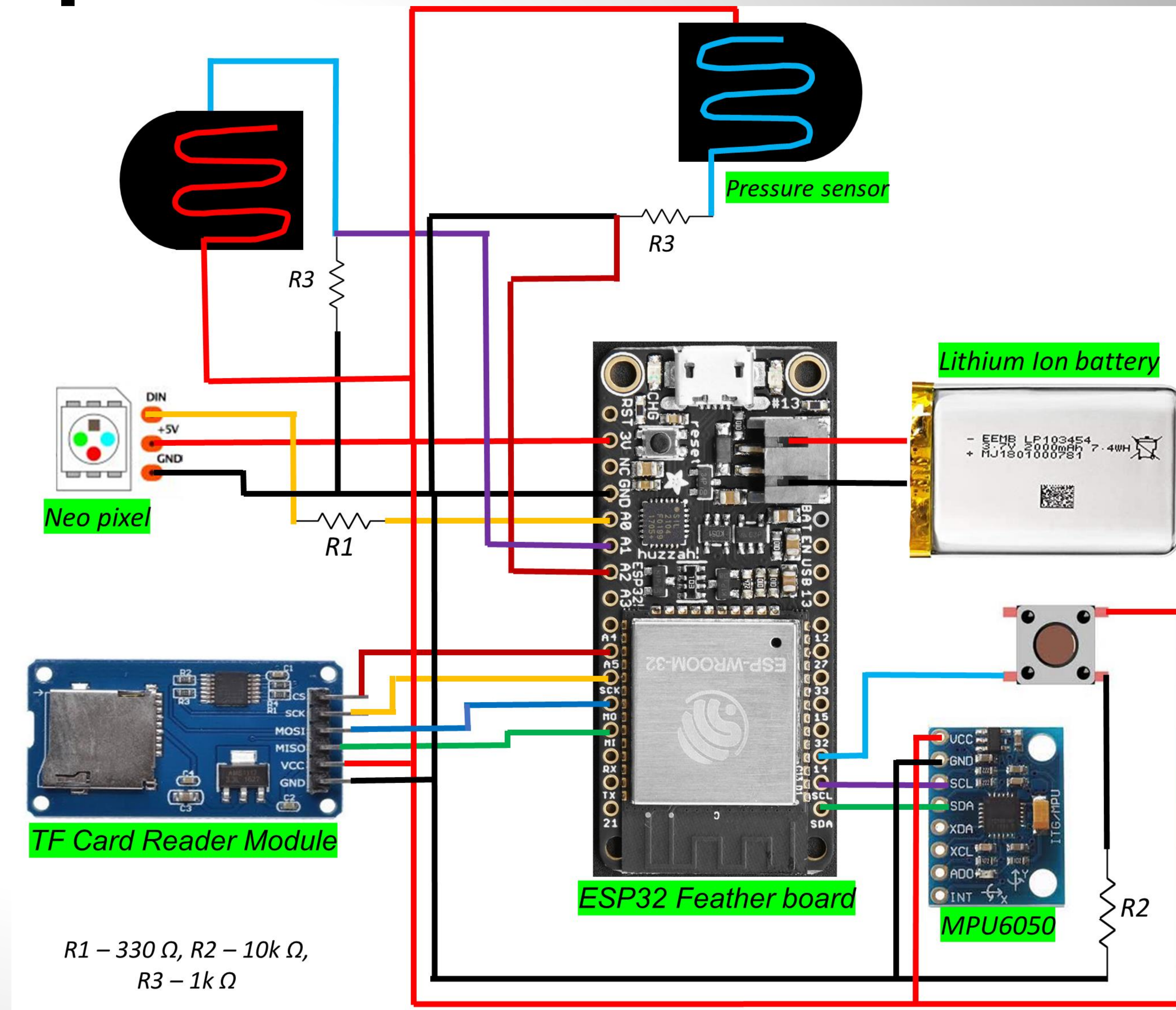
- Temporary addition of pressure sensors
- Study procedure
  - Participants with prosthesis
    - In collaboration with the head physiotherapist Ulf Kaupschfer
      - Personal Communication Physiotherapeut at Ambulantes Physiocenter Gronau, Germany,
    - Users with hip prosthesis
    - Users with knee prosthesis
  - Participants without prosthesis
  - Heel-strike event



Temporary addition of pressure sensors

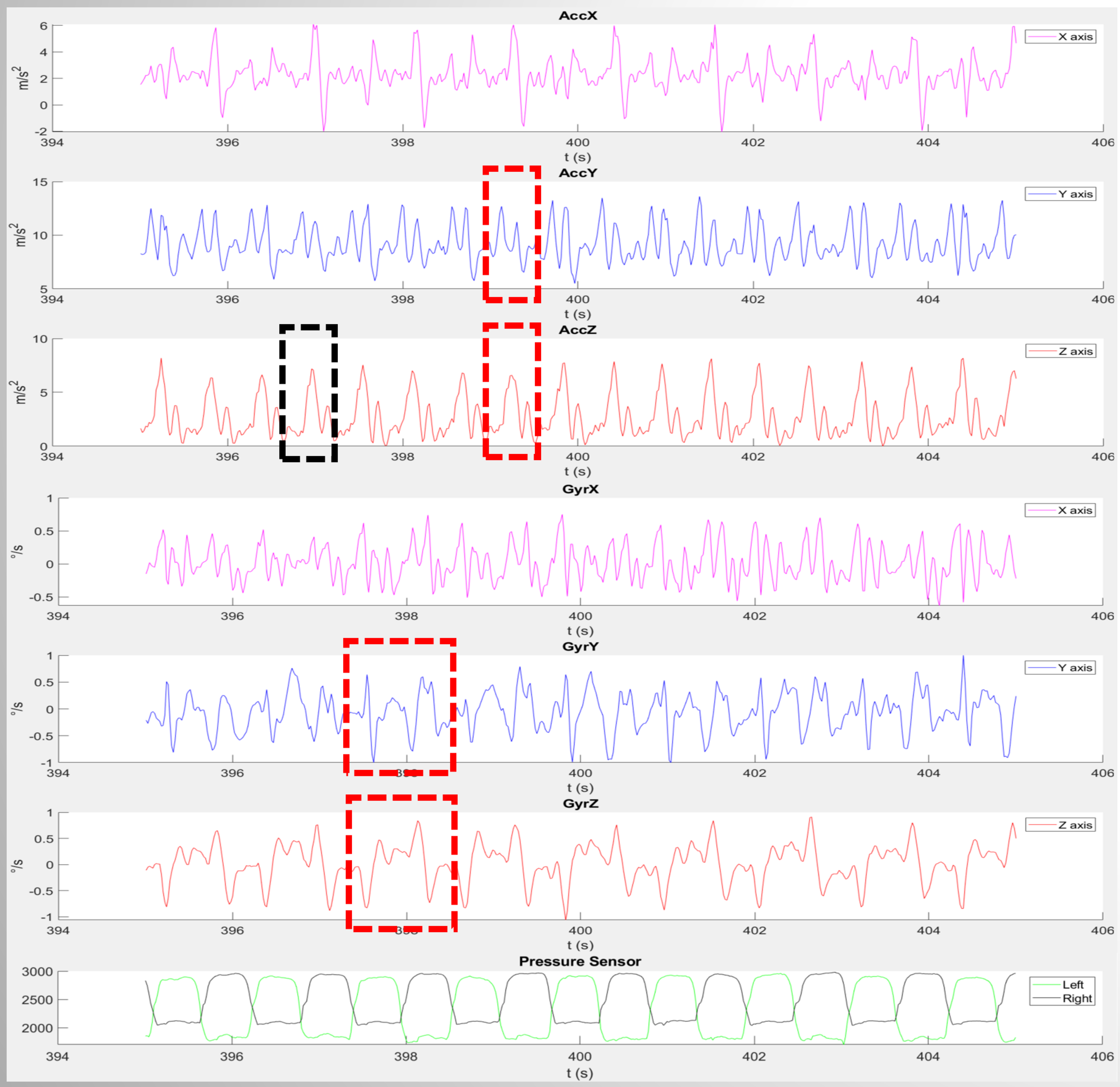
- Designed wearable device
  - MPU6050 sensor
  - ESP32 Feather board
  - LED – Neo pixel
  - Button
  - TF card reader module
  - Waist belt
  - Pressure sensors



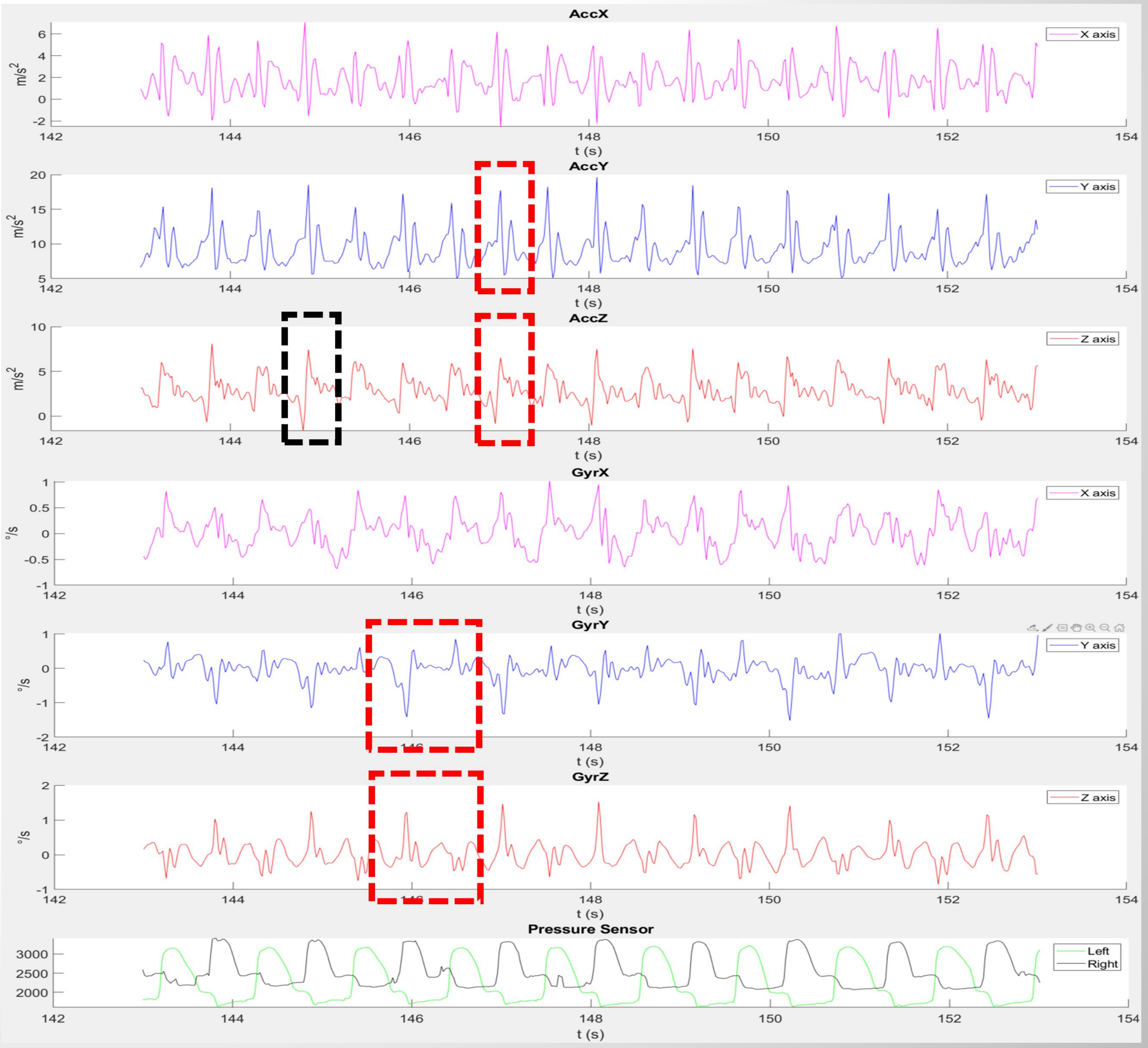


Study Results – Users Without Prosthesis

- Acceleration along Z-axis is consistent

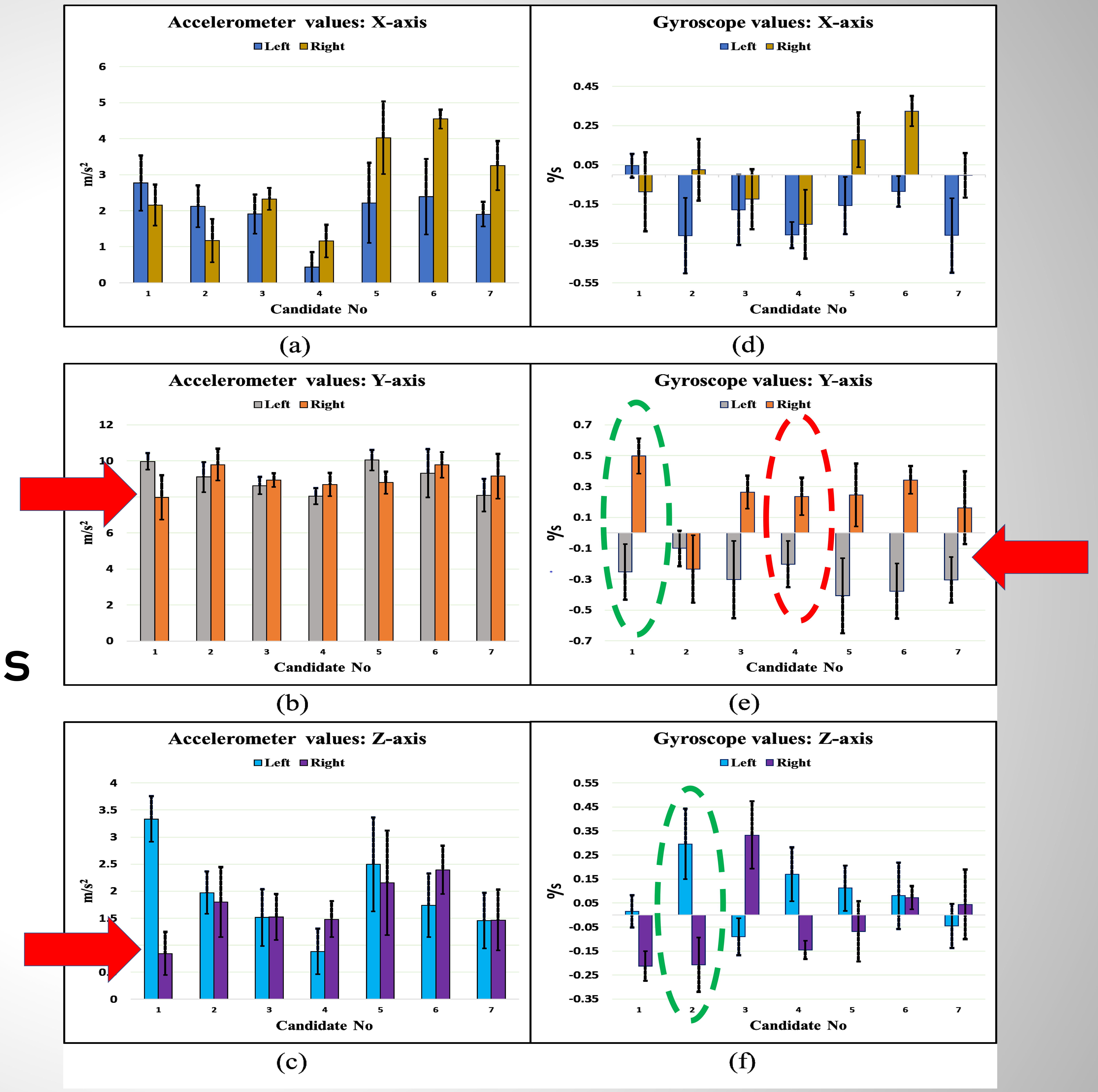


- Repeating patterns along Y-axis and Z-axis



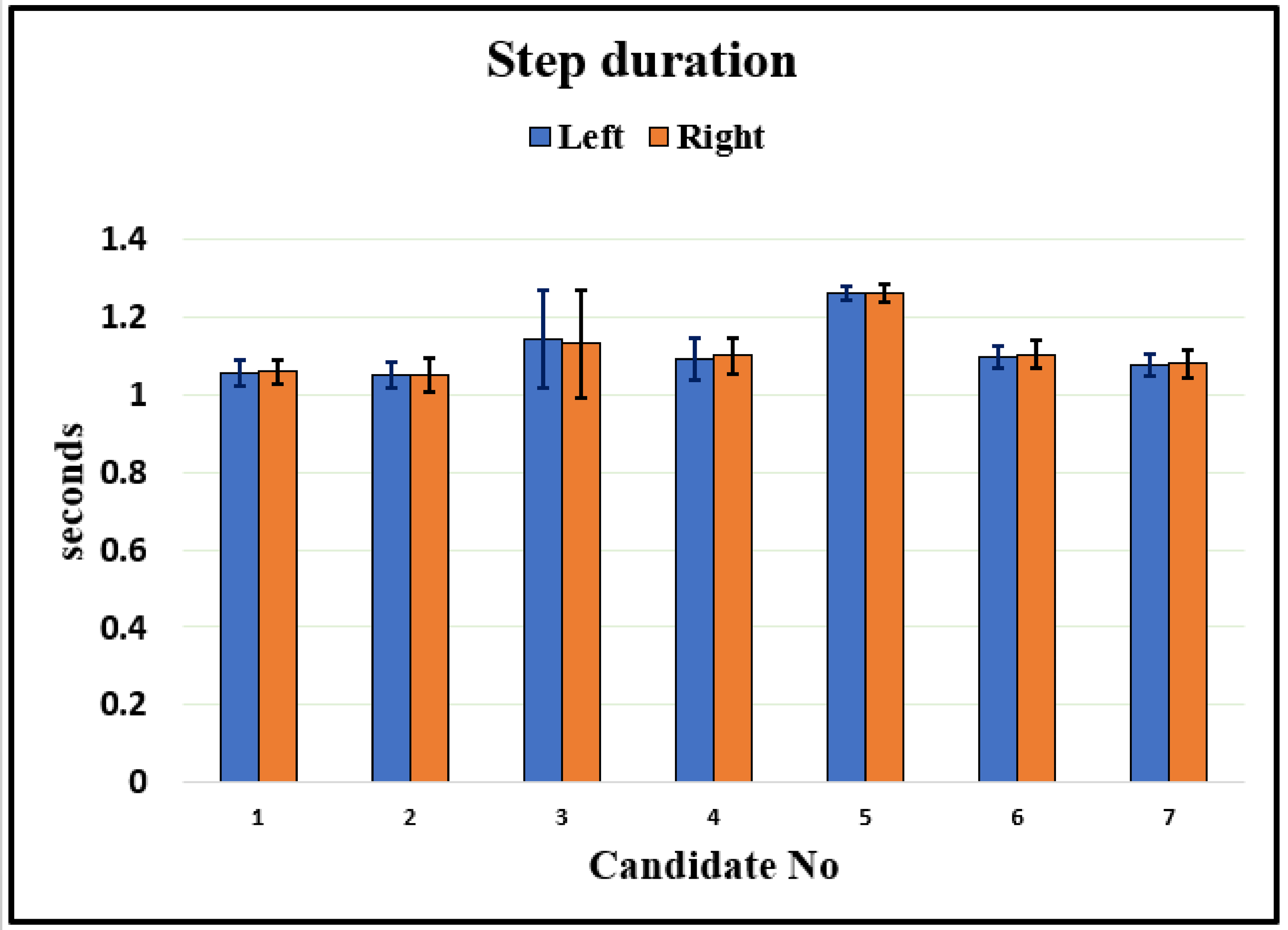
Study Results – Users Without Prosthesis

- Linear accelerations and angular velocities of one foot are higher than the other foot
- Angular rotation measurements along Y-axis and Z-axis are opposite
- Angular velocities are opposite in direction for each foot

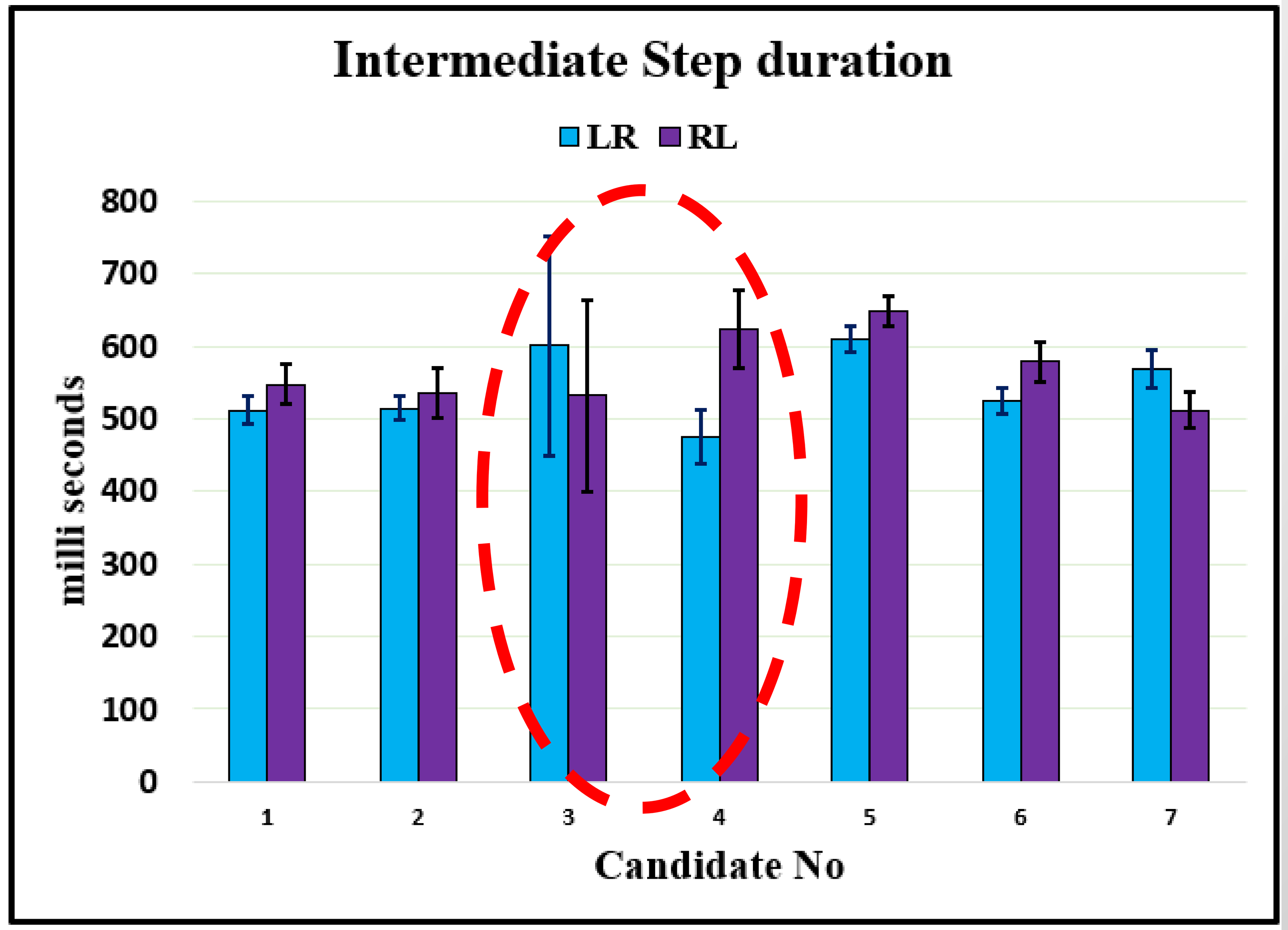


Study Results – Users Without Prosthesis

- Step Duration
  - 1 sec to 1.2 sec
- Intermediate step duration
  - Left and right foot (LR) – 500 ms to 600 ms
  - Right and left (RL) – 500 ms to 600 ms



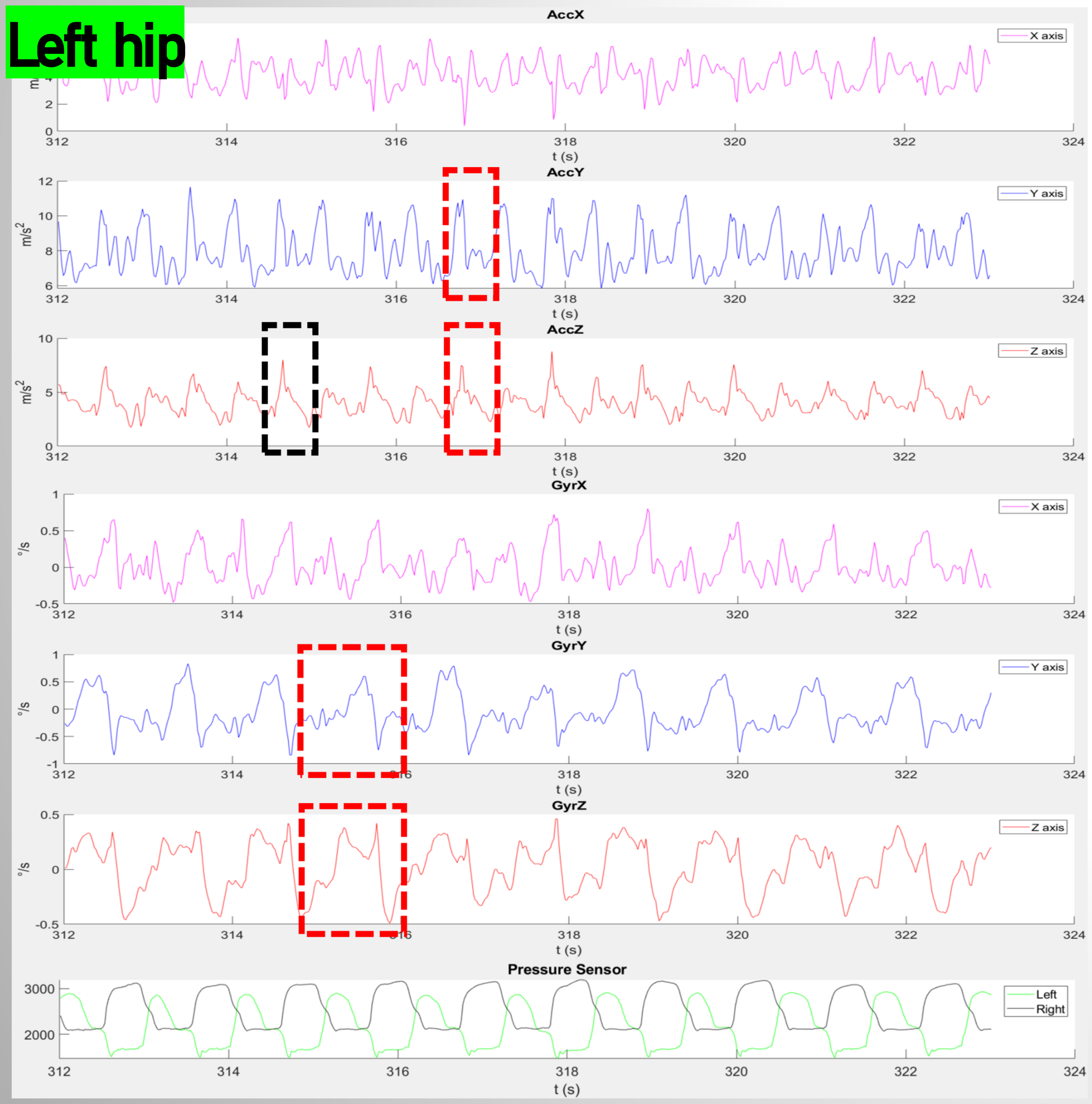
(a)



(b)

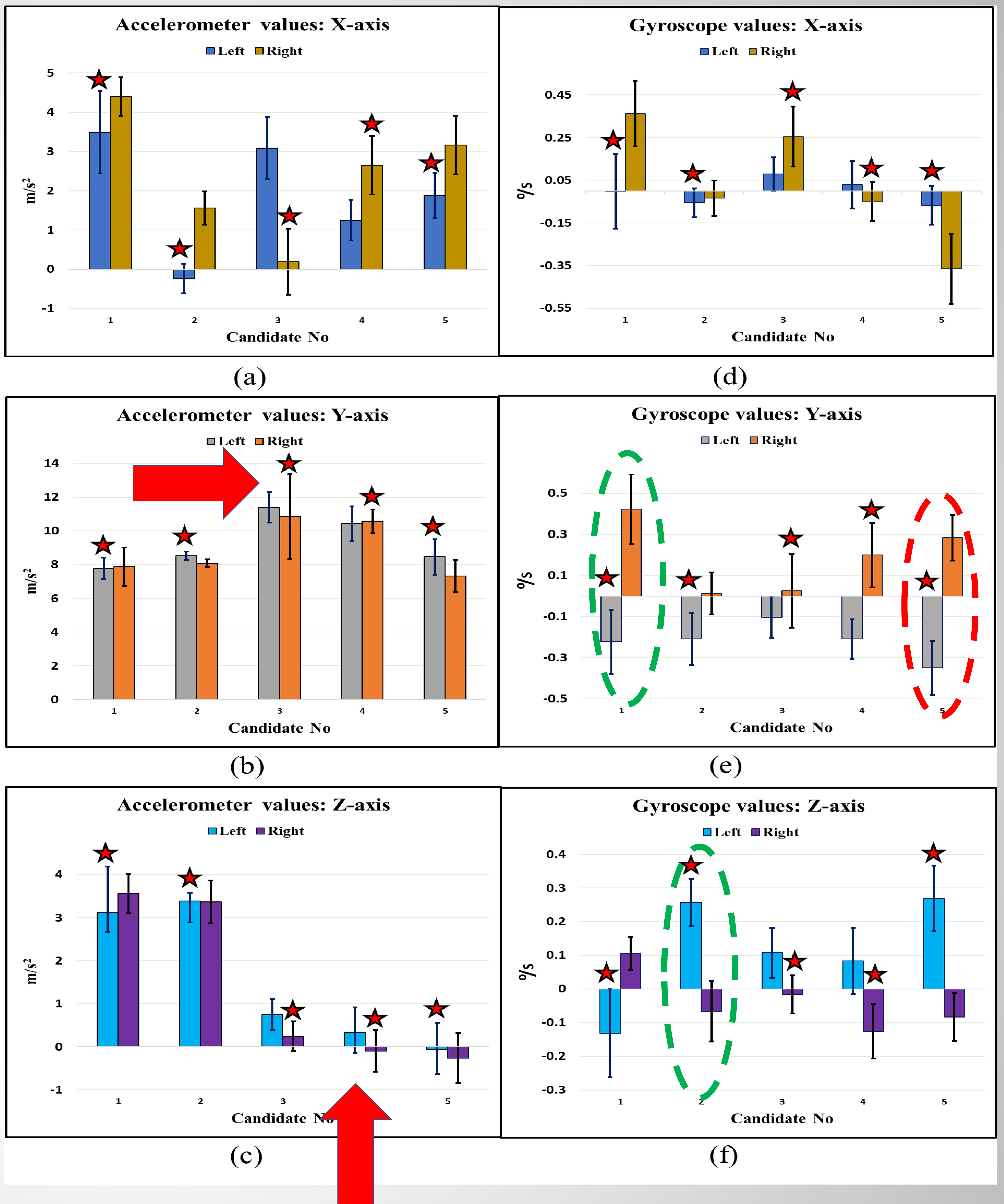
Study Results – Users With Prosthesis

- Acceleration along Z-axis is consistent
- Repeating patterns along Y-axis and Z-axis



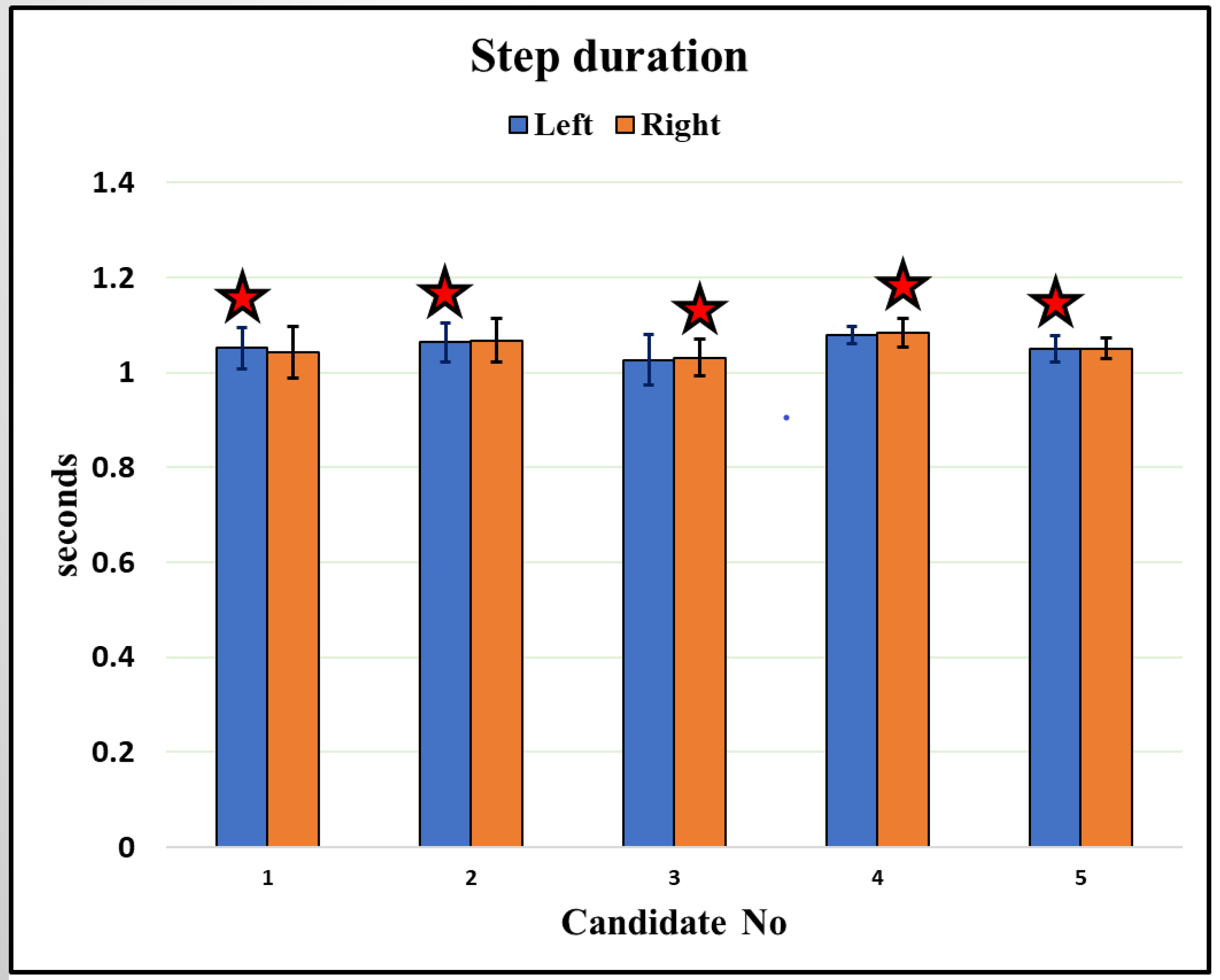
Study Results – Users With Hip Prosthesis

- Linear accelerations of few candidates are small in Z-axis but higher in Y-axis
- Angular rotation measurements along Y-axis and Z-axis are opposite
- Angular velocities are opposite in direction for each foot

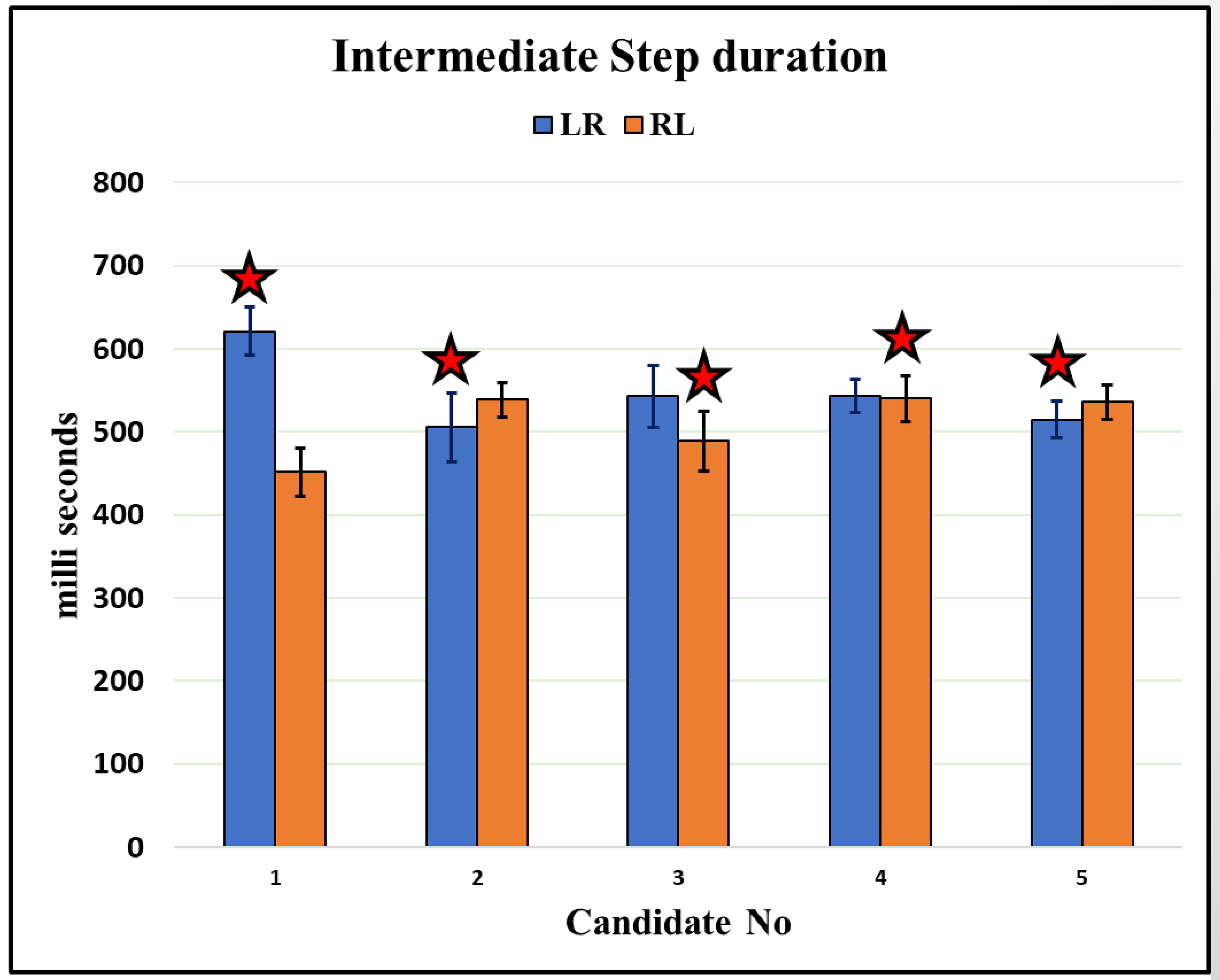


Study Results – Users With Hip Prosthesis

- Step Duration
  - ≈1 sec
- Intermediate step duration
  - Left and right foot (LR) – 500 ms to 550 ms
  - Right and left (RL) – 500 ms to 550 ms



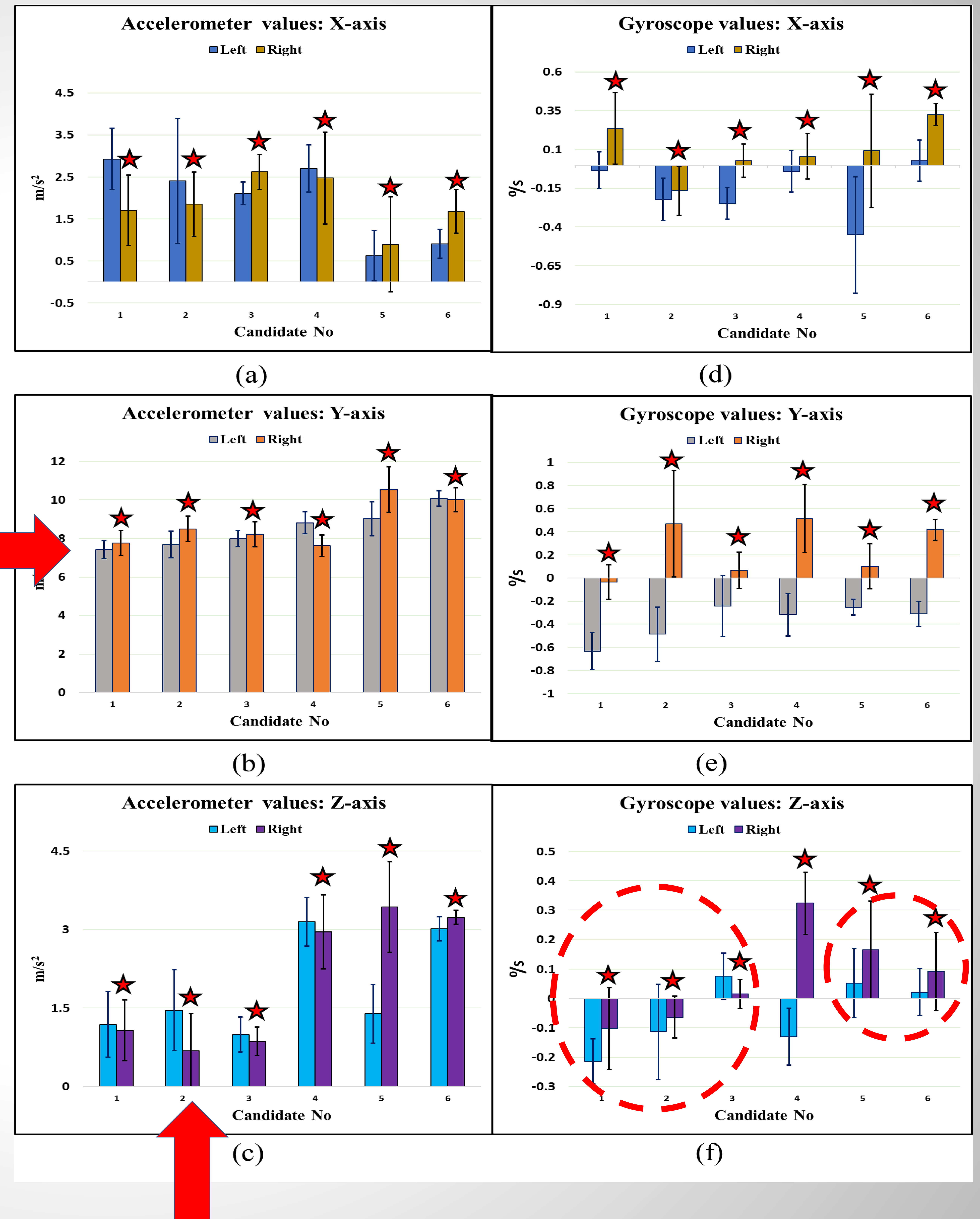
(a)



(b)

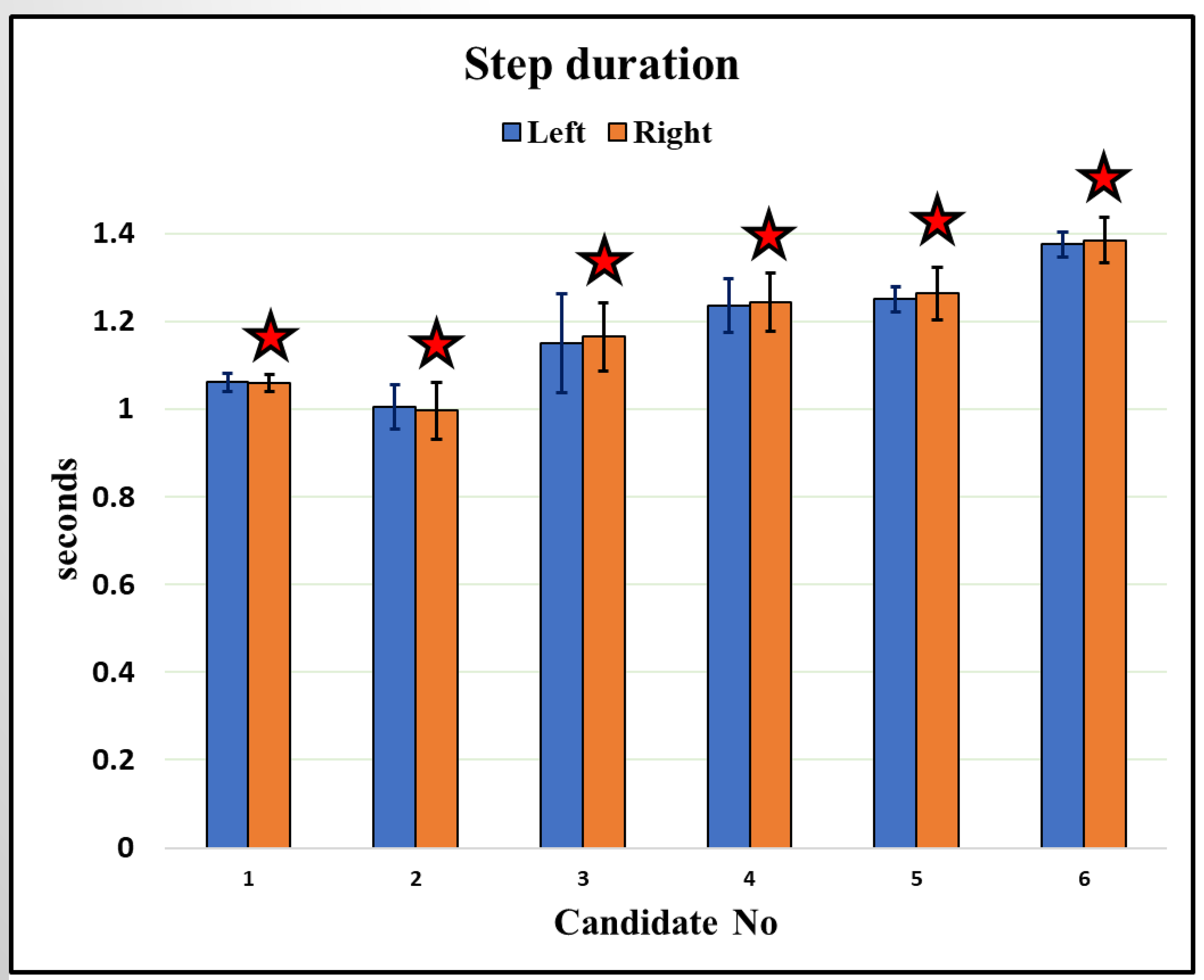
Study Results – Users With Knee Prosthesis

- Linear accelerations of few candidates are small in Z-axis
- Angular rotation measurements along Y-axis and Z-axis are opposite
- Angular velocities are in the same direction for each foot (Z-axis)

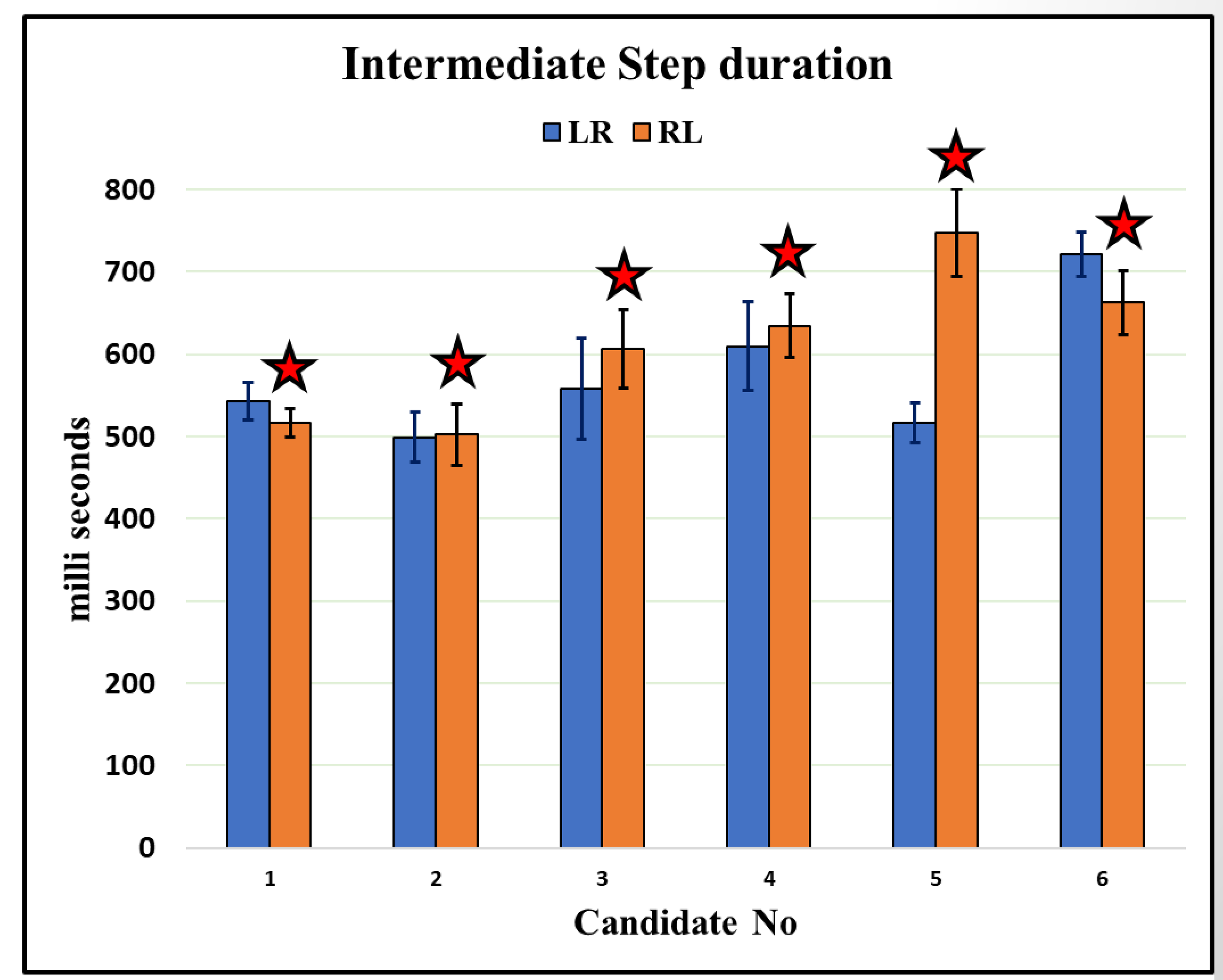


Study Results – Users With Knee Prosthesis

- Step Duration
  - 1 sec to 1.3 sec
- Intermediate step duration
  - Left and right foot (LR) – 500 ms to 650 ms
  - Right and left (RL) – 500 ms to 650 ms



(a)



(b)

Study Conclusion

- Walking patterns recorded for users with and without prostheses are different
- Linear accelerations recorded similar values
  - Slightly less values along Y-axis for participants with prosthesis
- Angular velocities presented more differences
  - Users pelvis rotation is in one direction for both feet heel-strikes
- Intermediate step duration recorded similar results
  - This observation negates the hypothesis
  - No considerable difference to distinguish the user with or without prosthesis
  - Real-time algorithm no longer capable to distinguish the type of walking

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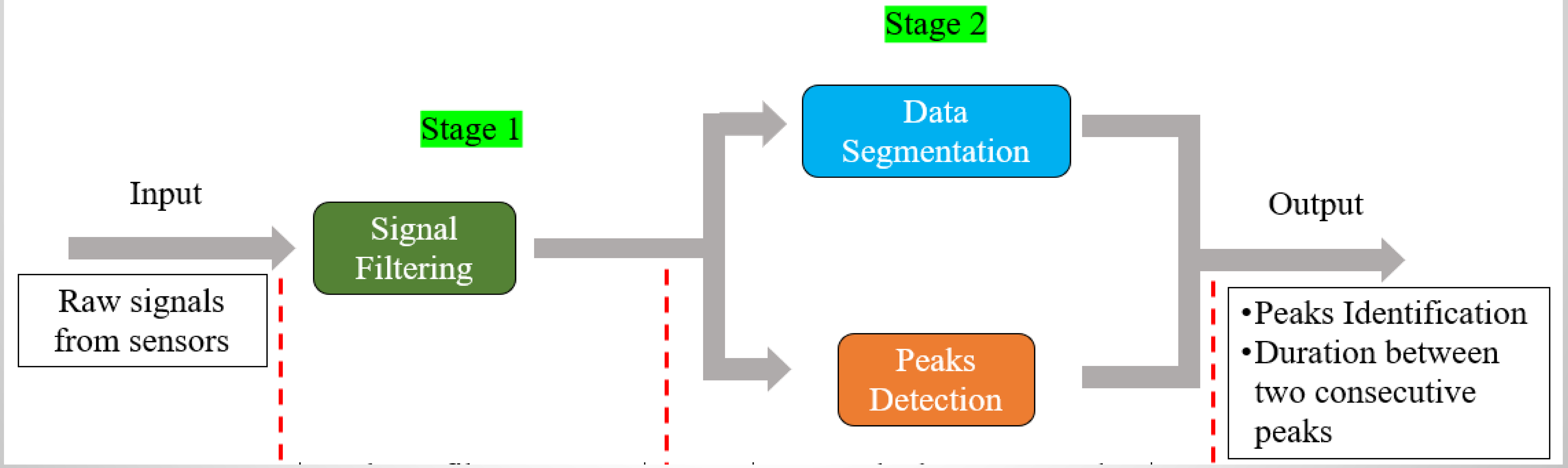
Straight Forward Data Analysis Method

- **Goal:** To determine intermediate step duration
- Focuses only on the heel-strike event
  - Easy to verify the event in real-time
- Developed mainly using accelerometer values



Straight Forward Data Analysis Method

- Signal filtering
  - Kalman filter
  - Exponential Weighted Moving Average (**EWMA**)

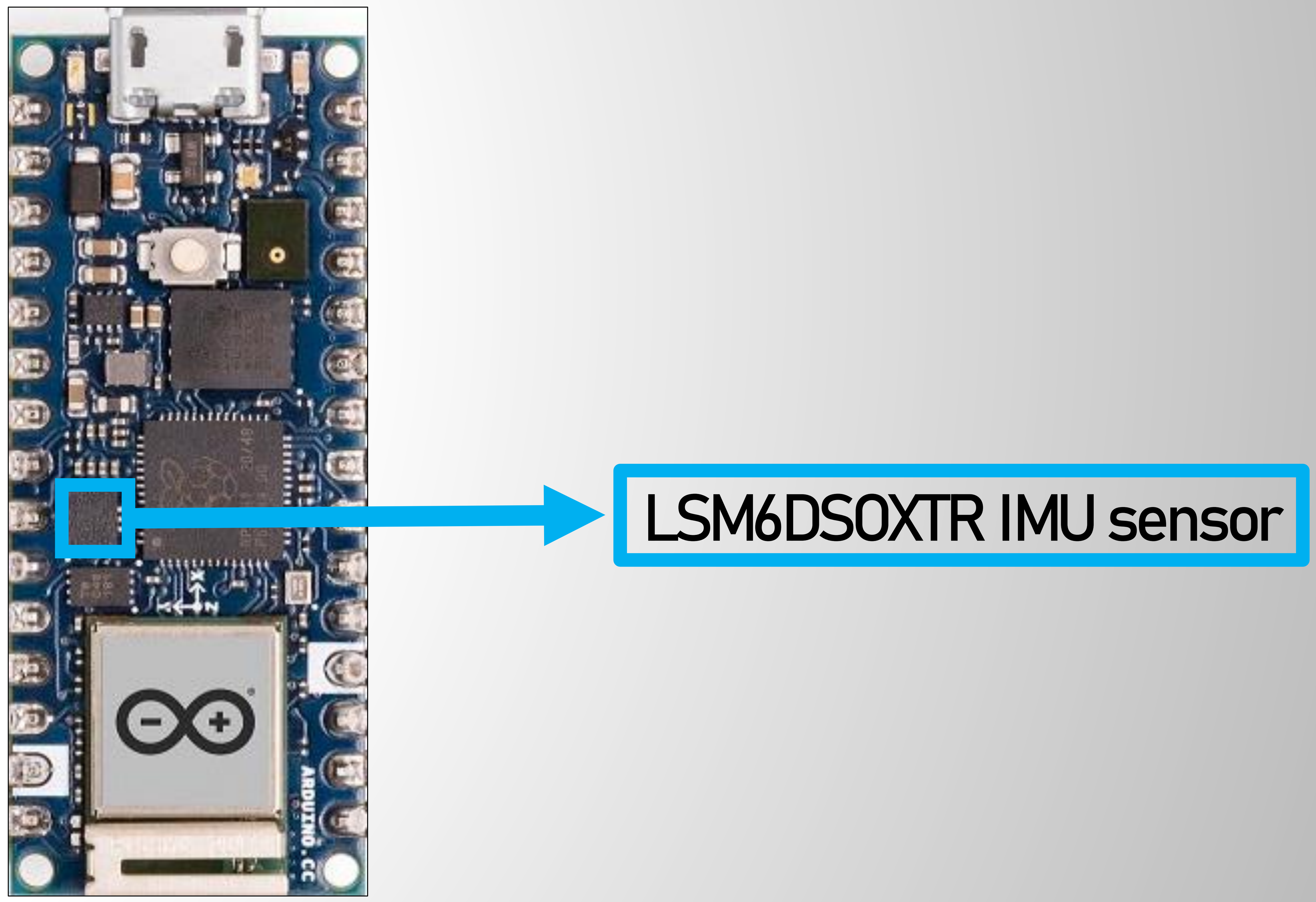
- Peaks detection
  - Z-score Peak detection
  - findpeaks function from MATLAB

- Data segmentation
  - Static Fixed-size Non-overlapping Sliding Window (FNSW)

Machine Learning

- Machine learning
  - Capable of focussing on every event in the walking activity
    - Window sizes (number of samples/ duration)
  - It extracts a feature using accelerometer and gyroscope values
    - Uses this feature classification is done i.e. user walking is symmetric or asymmetric
- Device
  - Arduino Nano Connect
    - On board IMU sensor
    - Dedicated machine learning core capable of running decision tree algorithms

Arduino Nano RP2040 Connect



Procedure

- Data recorded from study
  - Symmetric
  - Asymmetric
- Segmentation
  - Window sizes
    - $\approx$ 3 sec, $\approx$ 2 sec, 1 sec
- Feature: Variance
- Classifier: REPTree
- Accuracy of detecting the user walking is symmetric or asymmetric
  - 96.96 % for window size of 3 sec i.e. almost equal to 3 steps taken by user

Window Size (in sample points)	**154**	**102**	**52**
Window Size (in seconds)	$\approx$ **3**	$\approx$ **2**	**1**
Classification Accuracy	**96.9697** %	**95.3177** %	**93.2031** %
Kappa	0.9356	0.9014	0.8566
Mean Absolute Error	0.0474	0.0664	0.0929
Root Mean Squared Error	0.1716	0.2063	0.2426
Relative Absolute Error	9.9935 %	14.0024 %	19.5823 %
Root Relative Squared Error	35.2492 %	42.3746 %	49.8203 %
Size Of the Tree	**9**	**9**	**39**

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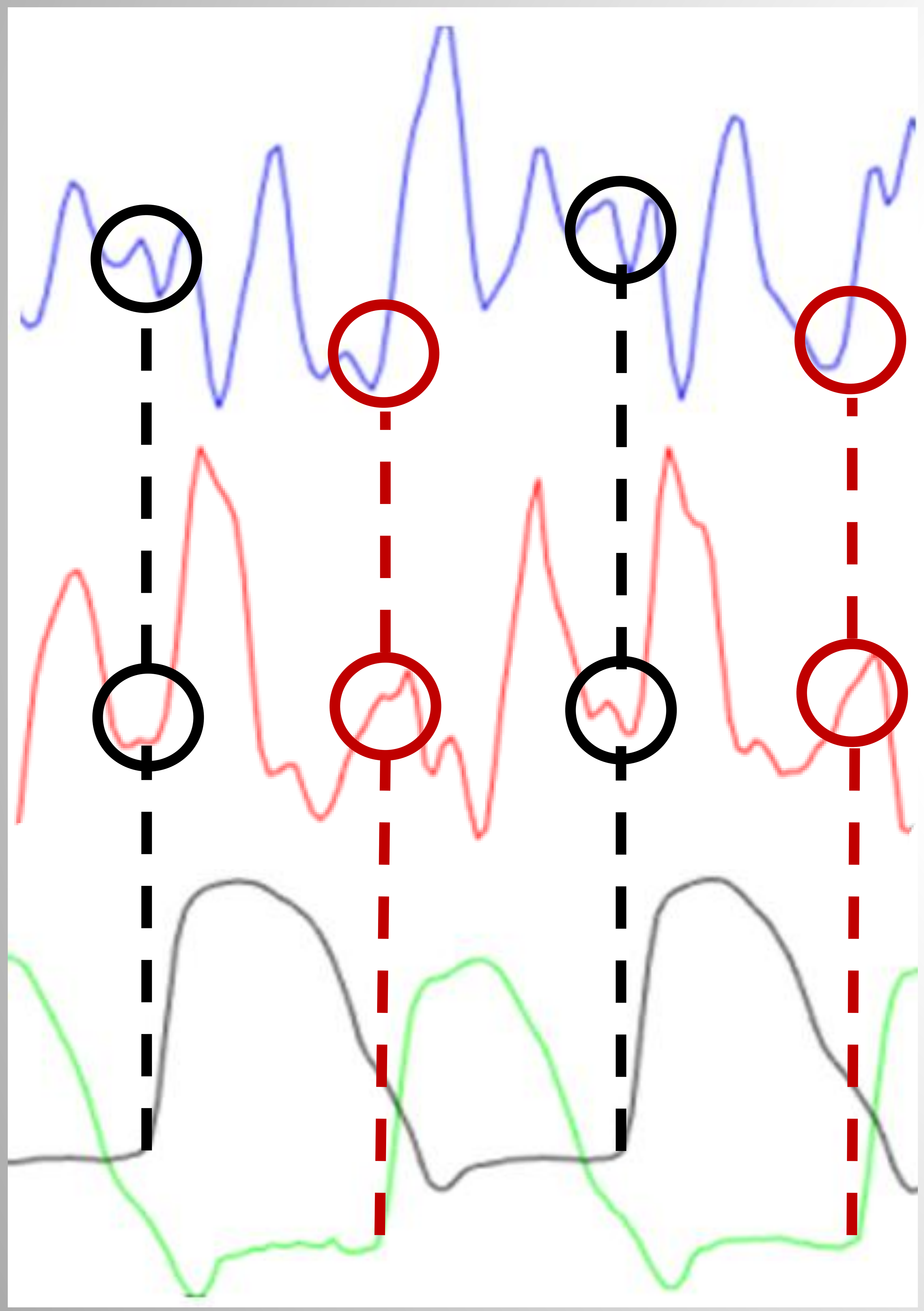
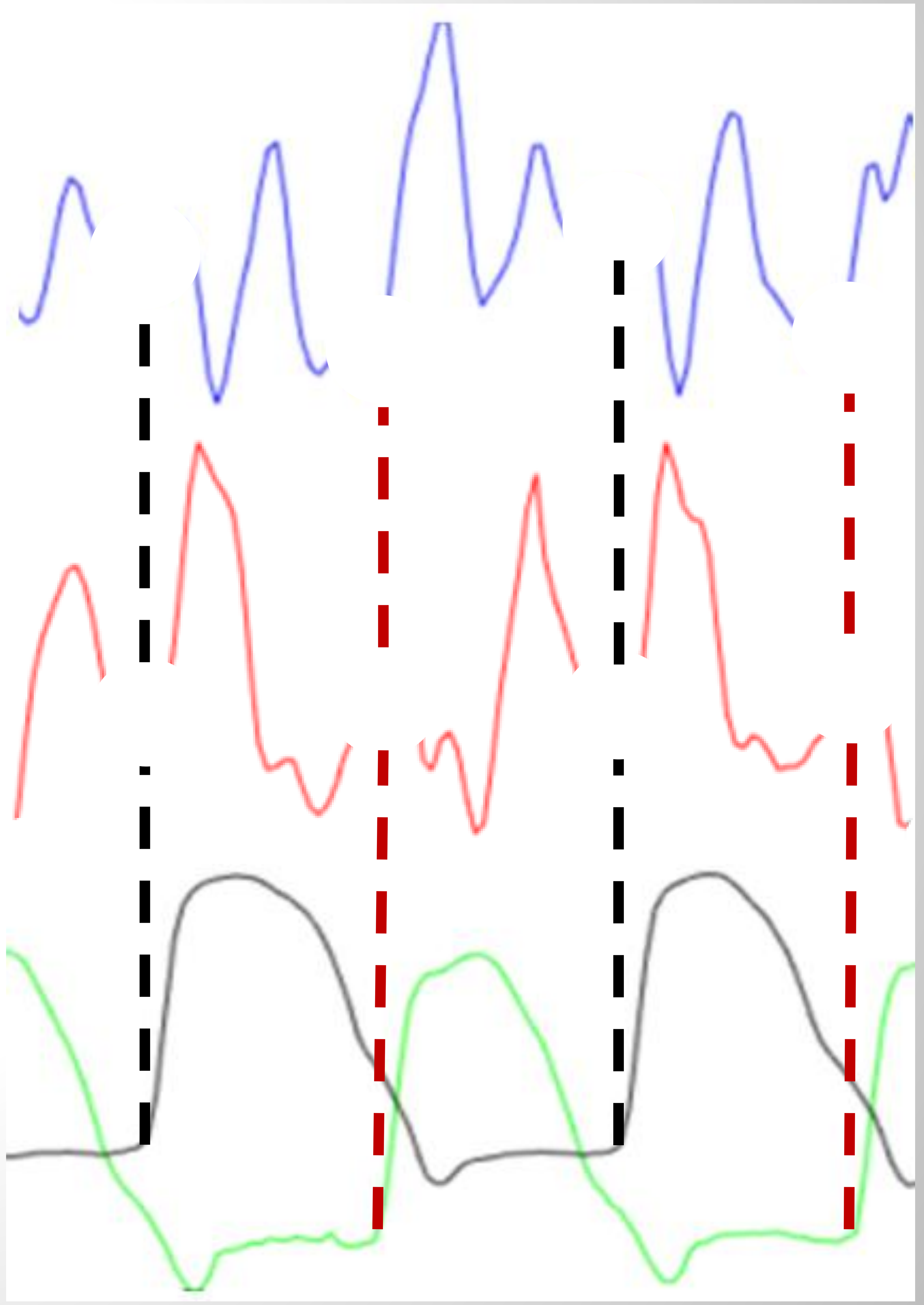
Gait Abnormalities In Hip/Knee Prosthesis Patients



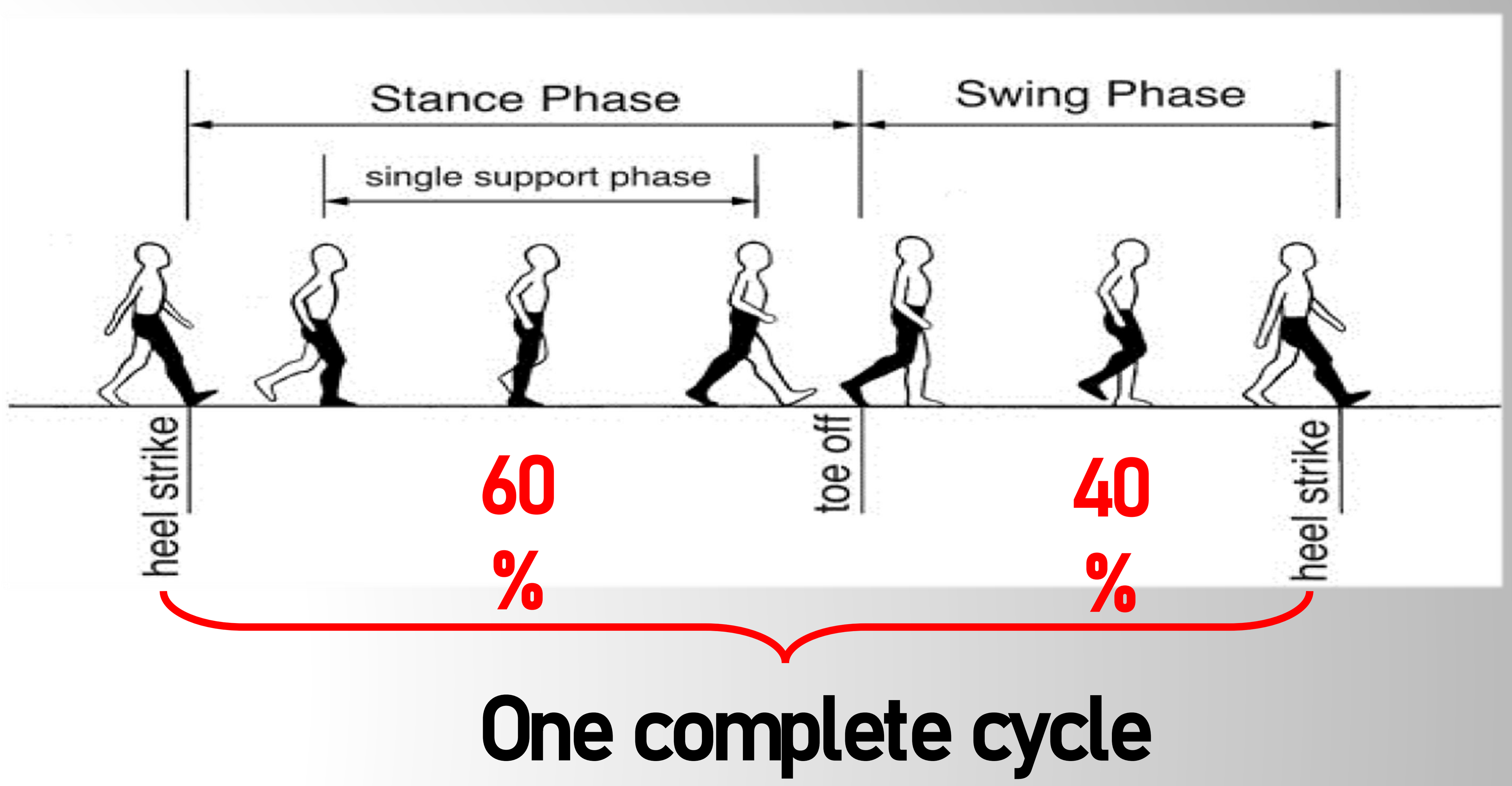
- Heel-strike event
- Remaining event in walking
- Difficulties:
  - One sensor capturing both legs movement
- Post processing the collected data

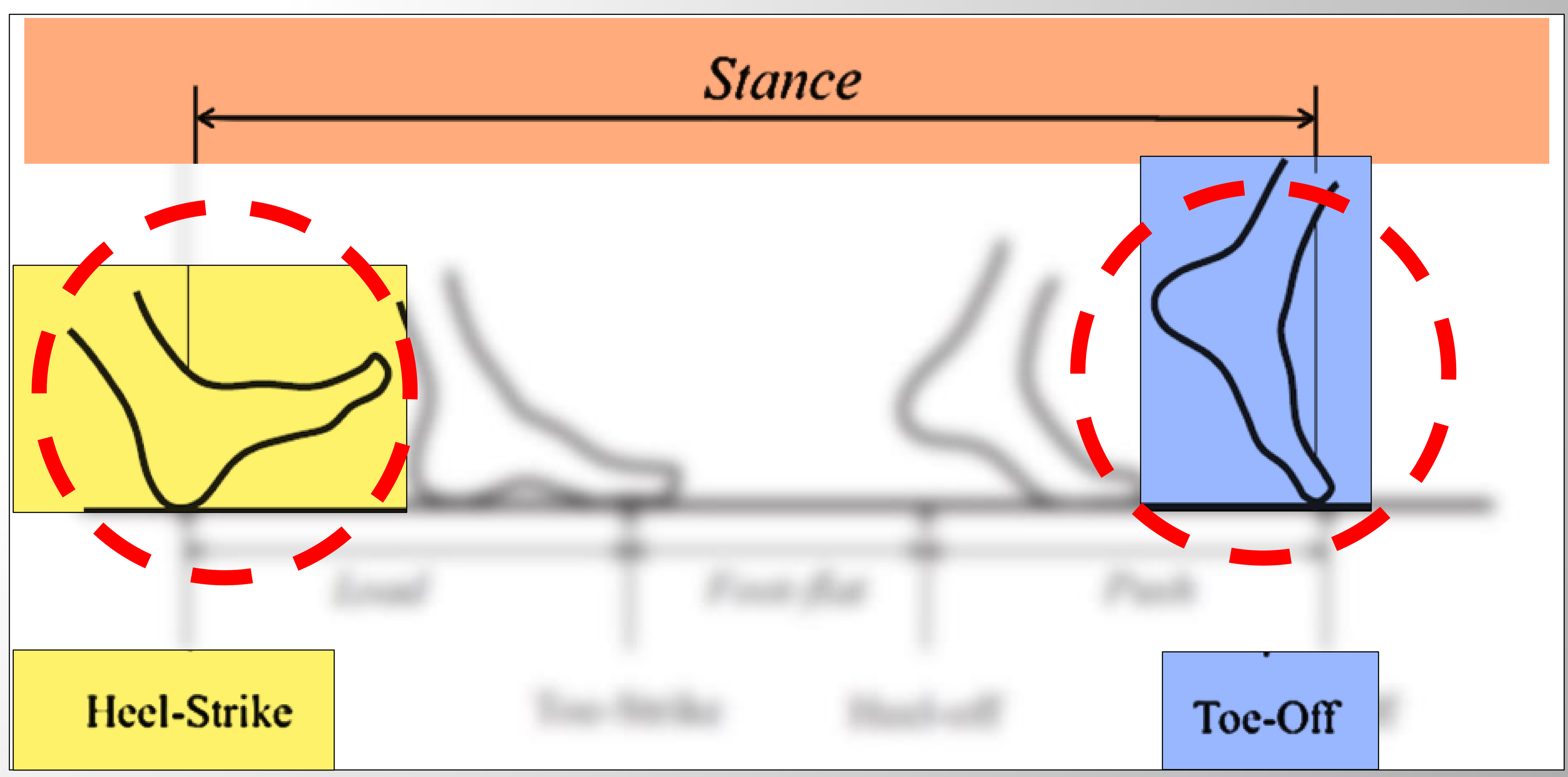
(future work)



Identification Of Gait Patterns

- Study
  - Heel-strike event is considered
    - Easy to identify and verify
    - To calculate intermediate step duration
  - Criteria for asymmetry in walking
    - Intermediate step duration
- Results from study
  - Negates the hypothesis – intermediate step duration is similar
- Some visual observations during study
  - Knee bending is seen during swing phase
- Additional pressure sensor in toe region
  - To identify toe-off event (future work)





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[SQ1] What is the state of art in wearables for motor learning using haptic feedback?

- Sensors
  - Fixed setups – cameras/pressures mats
  - Post processing
- Wearable are used for data collection only
- No real-time feedback implementation

[SQ2] What gait abnormalities are characteristic for post hip/knee prosthesis patients?

- Observations
  - Diverse walking patterns
    - With and without prosthesis
  - Users with knee prosthesis
    - Pelvis rotation is in same direction during both feet heel-strike events
  - Step duration and intermediate step duration is similar
    - Users with and without prosthesis

[SQ3] How to identify the relevant gait pattern?

- Straight forward data analysis method
  - Traditional approach
    - Hypothesis as criteria to identify the asymmetry in walking

- Machine learning method
  - Realization of hardware
    - Real-time
    - Matches wearability requirements
  - Binary classification
    - 96.96 % accuracy

[SQ4] What contributes to wearability for a haptic feedback system?

- Waist belt designed matches the wearability requirements
- Lower back location
  - Capable of identifying asymmetries

[SQ5] What is effective and simple haptic feedback for gait training?

- Cannot answer this question completely
  - Criterion for identifying the asymmetry for hip/knee prosthesis is pending
- Haptics for good starting point
  - Implemented for sports
    - Running
    - Rock climbing
- More experimentation is required

[RQ] How to design a wearable that give haptic feedback for motor learning of patients who undergo hip/knee prosthesis

- Identification of asymmetries in walking
  - Study
    - The parameters measured during heel-strike could not provide a strong criteria to identify symmetry
    - It also showcased the intermediate step duration is also similar
  - Straight forward data analysis method
    - Focused around heel-strike event only
    - Developed based on hypothesis
  - Machine learning
    - Showcased that identification of walking of user -symmetric or asymmetric- is possible
    - Need to consider all the events in walking
- Feedback
  - This is the later part of designing a wearable device
  - Future work

Questions?

Questions?


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