Estimation of Lower-limb Joint Kinematics with Inertial Measurement Units

Team 1
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Final Presentation

Carnegie Mellon University

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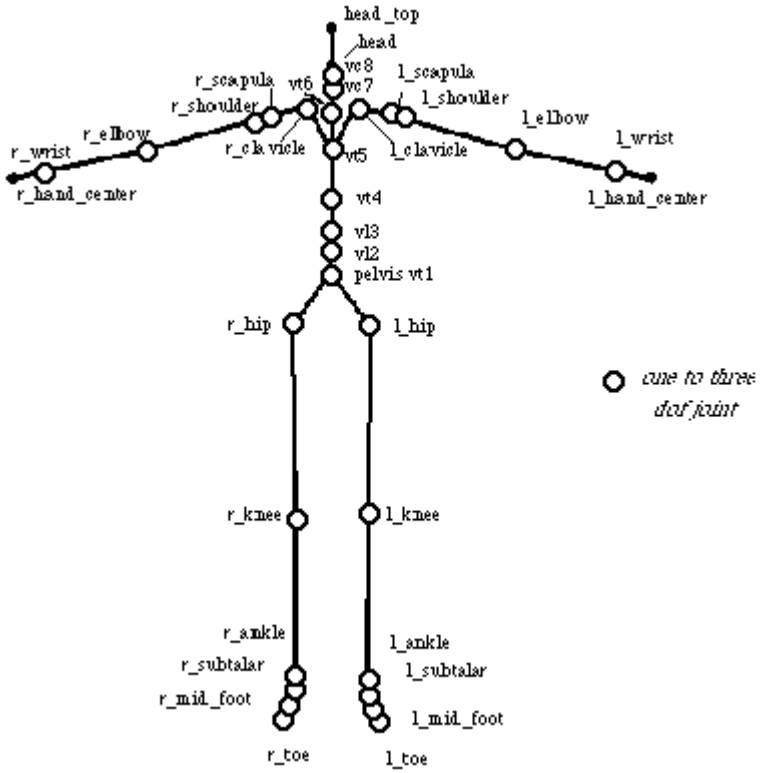
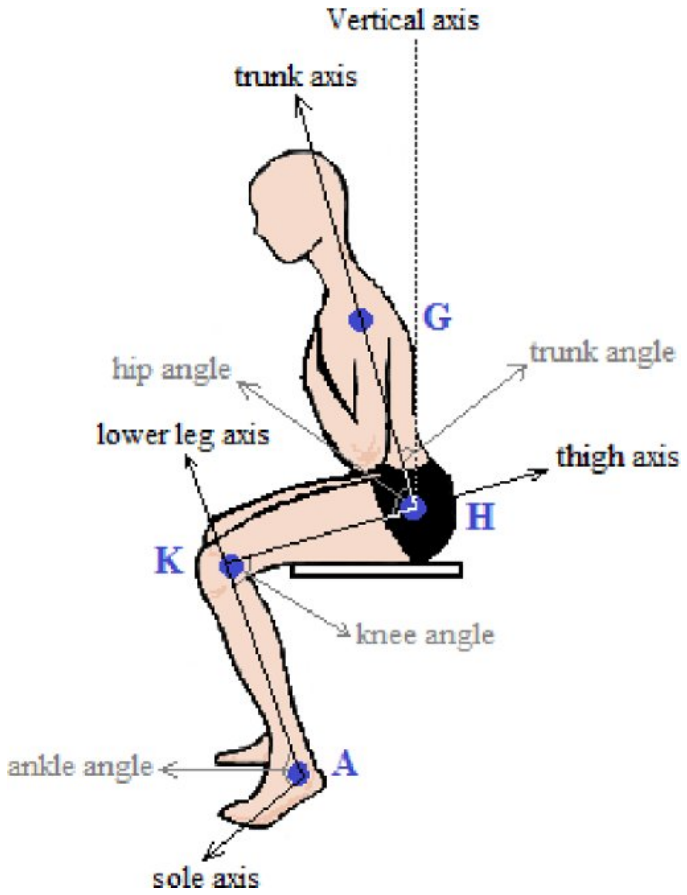
What is joint kinematics?

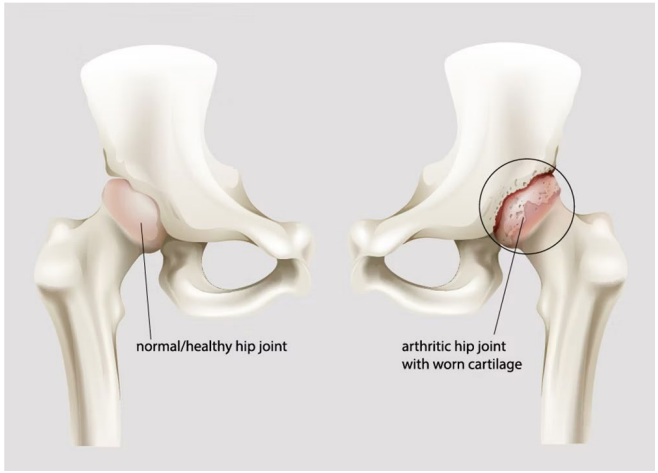


https://www.euclideanspace.com/physics/kinematics/joints/index.htm

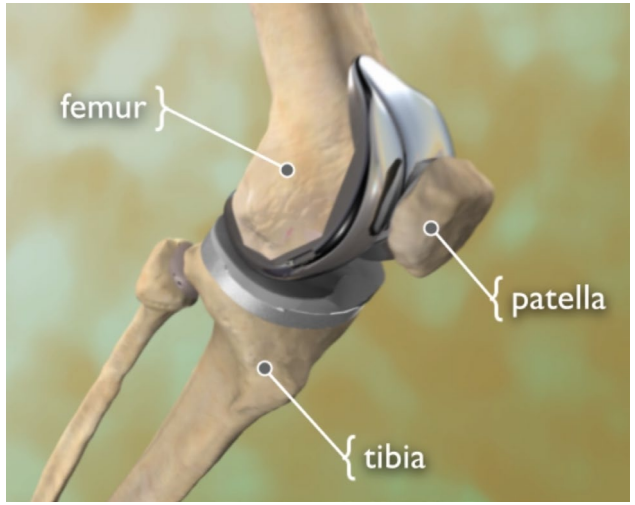


https://www.researchgate.net/publication/312422406_Influence_of_time_restriction_20_minutes_and_946_months_of_visual_information_on_angular_displacement_during_the_sit-to-stand_STS_task_in_three_planes/figures?lo=1

Why do we need joint kinematics estimation?



https://stiwell.medel.com/orthopaedics/hip-arthrosis



https://orthoinfo.aaos.org/en/treatment/total-knee-replacement-animation/

https://en.wikipedia.org/wiki/Achilles_tendinitis

Traditional approaches use cumbersome and expensive marker-based systems for motion capture

https://optitrack.com/applications/movement-sciences/

Study aims

01

Accuracy of Full-Body Kinematics

State Estimation Filters: Madgwick, Mahony, Complementary, EKF, Xsens

Biomechanical Modelling: OpenSense

02

Sensitivity to Sensor-to-Body Calibration Errors

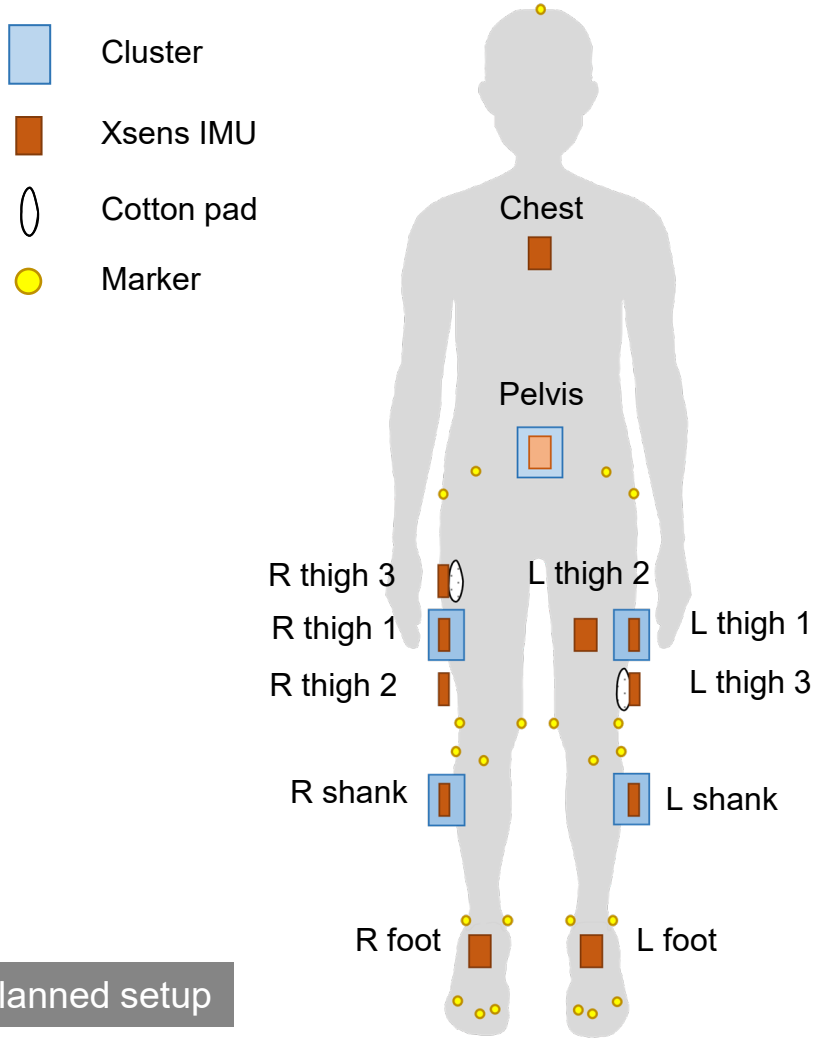
Evaluate the impact of sensor placement errors on estimation accuracy

03

Sensitivity to Skin-motion Artifact

Investigate the influence of skin-motion artifact on the quality of kinematic estimations

Experimental setup



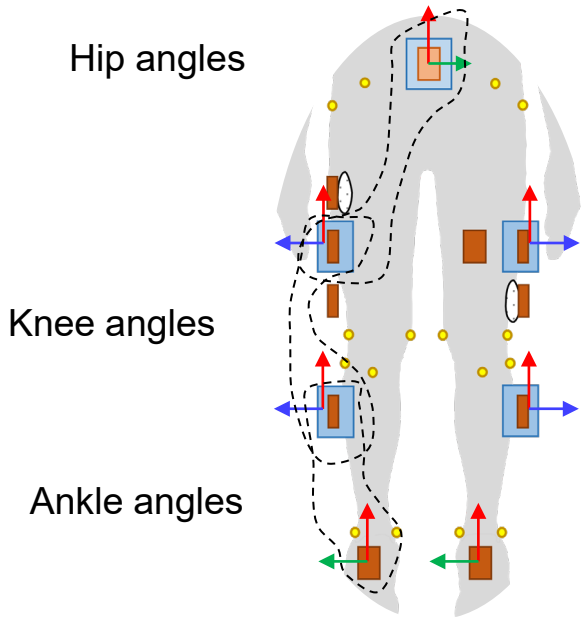
Planned setup

Real setup

Different sensor configurations for different aims of this study

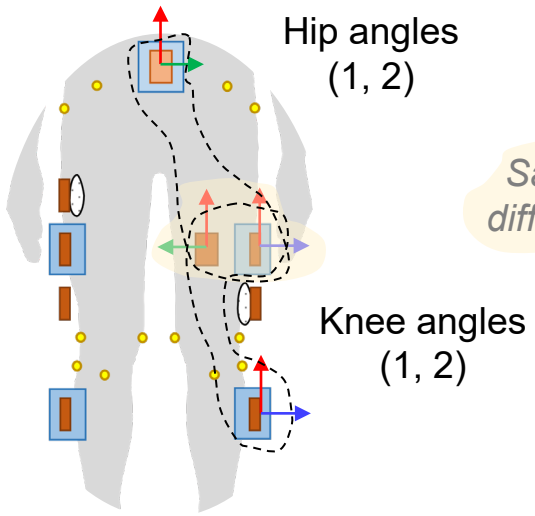
Aim 1

Accuracy of lower-body kinematics using (1) state- estimation filters, and (2) combination of state-estimation filters and biomechanical model



Aim 2

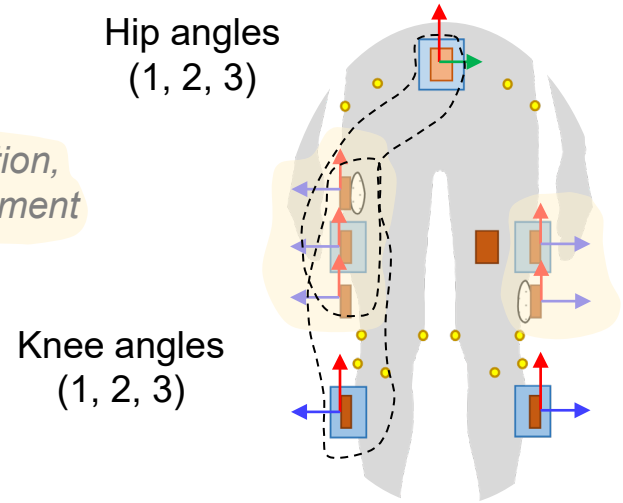
Sensitivity analysis of sensor-to-body calibration errors



Same orientation, different attachment

Aim 3

Sensitivity analysis of skin motion artifacts in different tasks

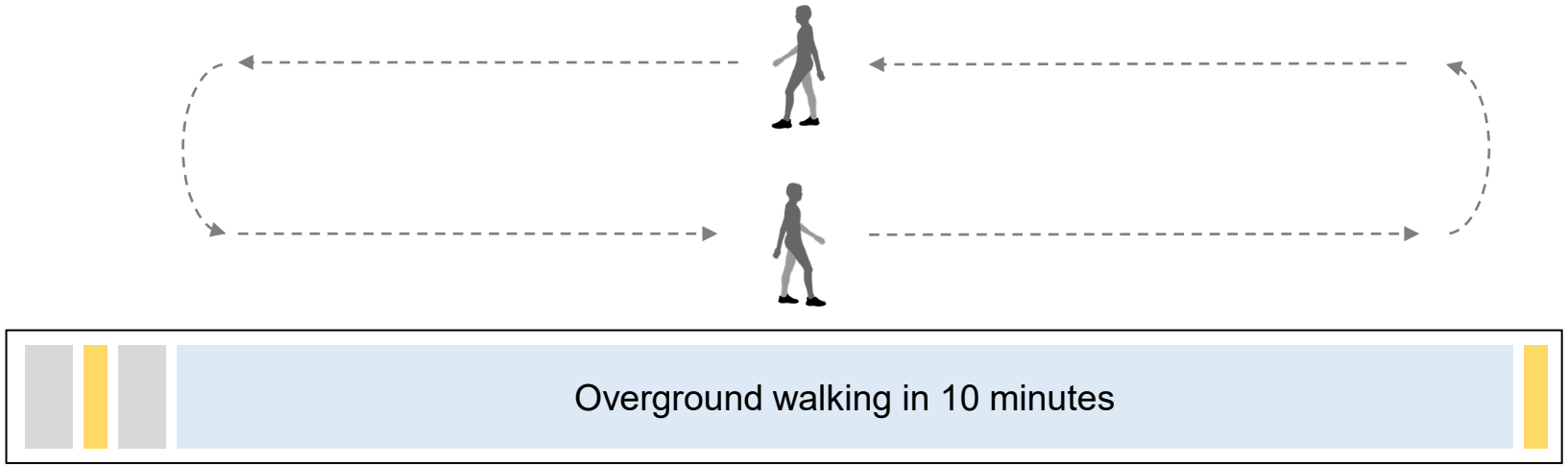


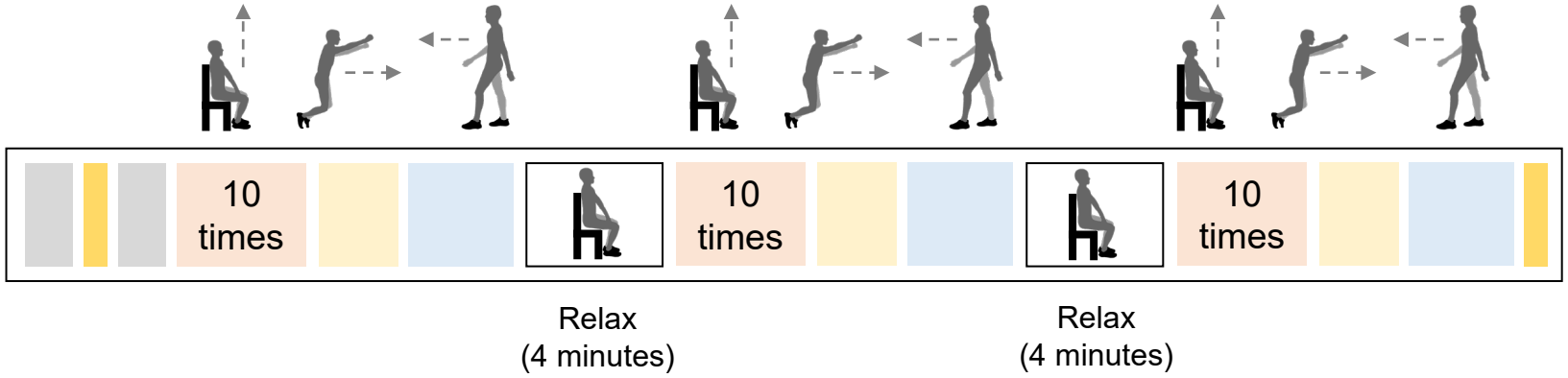
Various tasks were performed, but only sit-to-stand provided high-quality data

N-pose
(5 seconds)

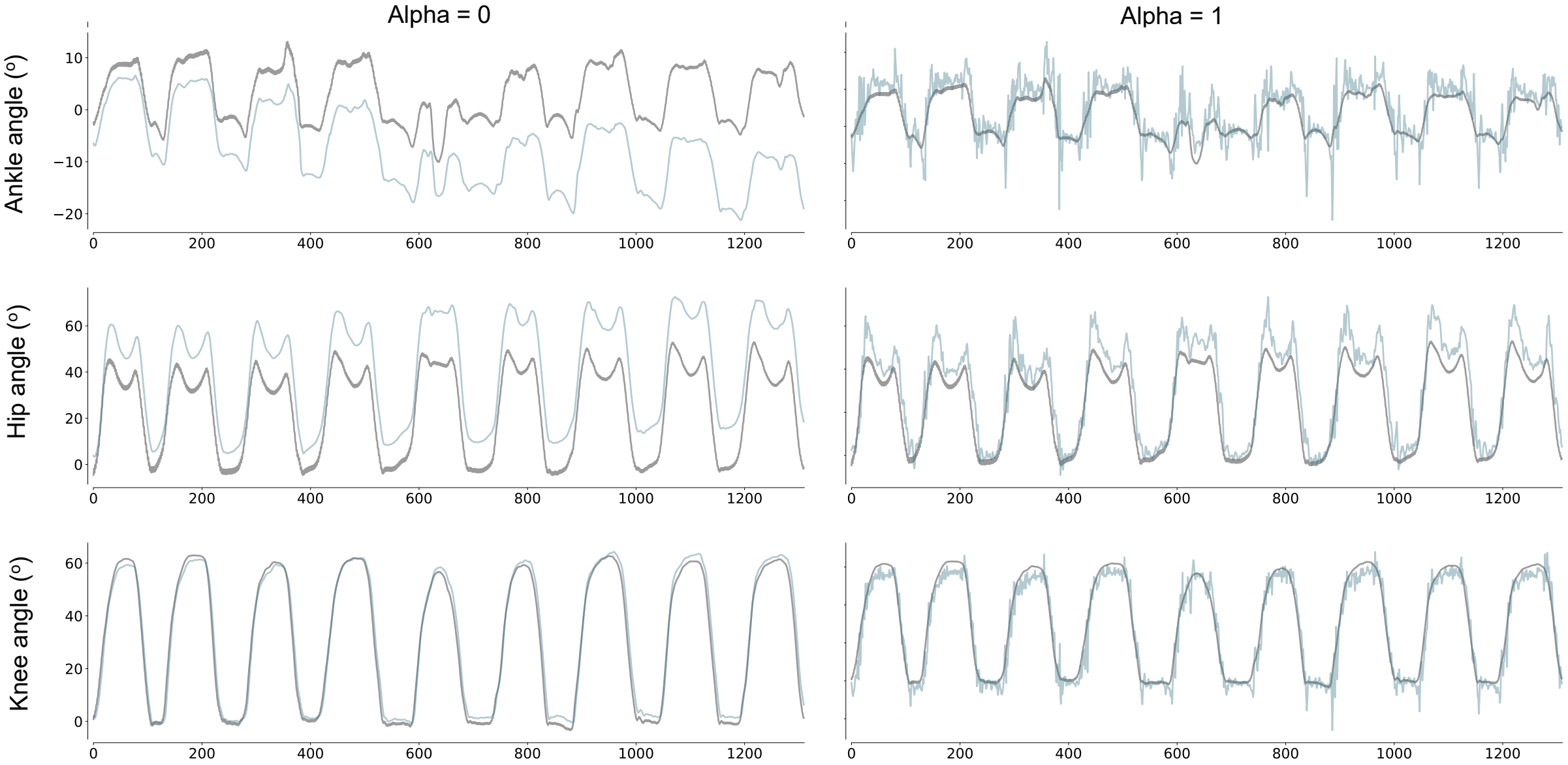
Vertical jump
(3 times)

Sit down





Different sensor fusion methods were manually tuned



How generalizable is tuning?

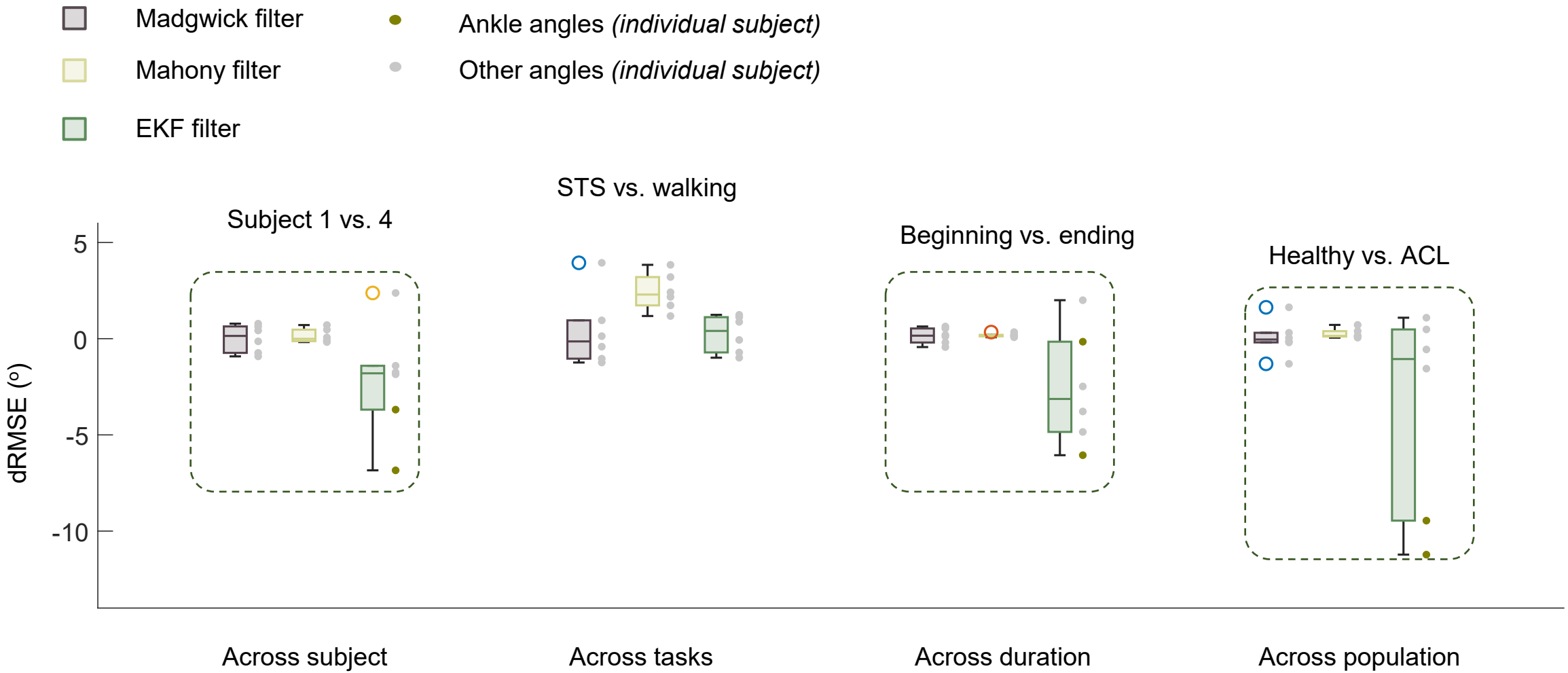
Preliminary observation

Offset on the estimation of EKF that can be resolved by tuning its parameters

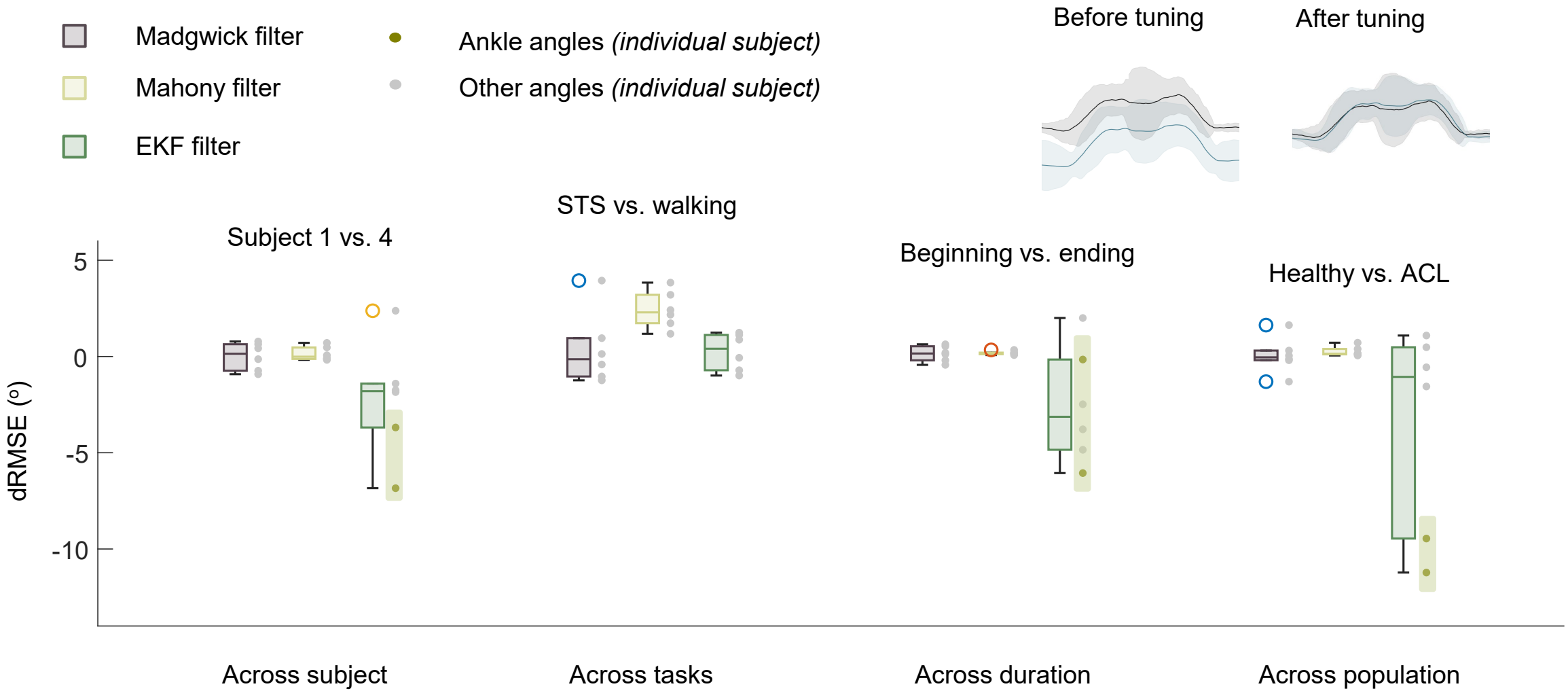
Decision

Tuned all filters before performance evaluation

EKF tuning may be generalizable to different scenarios, e.g., across subject, duration, and population



Tuning may be beneficial for specific joint angles



Which sensor fusion algorithm perform the best?

Would the biomechanical model improve the estimation?

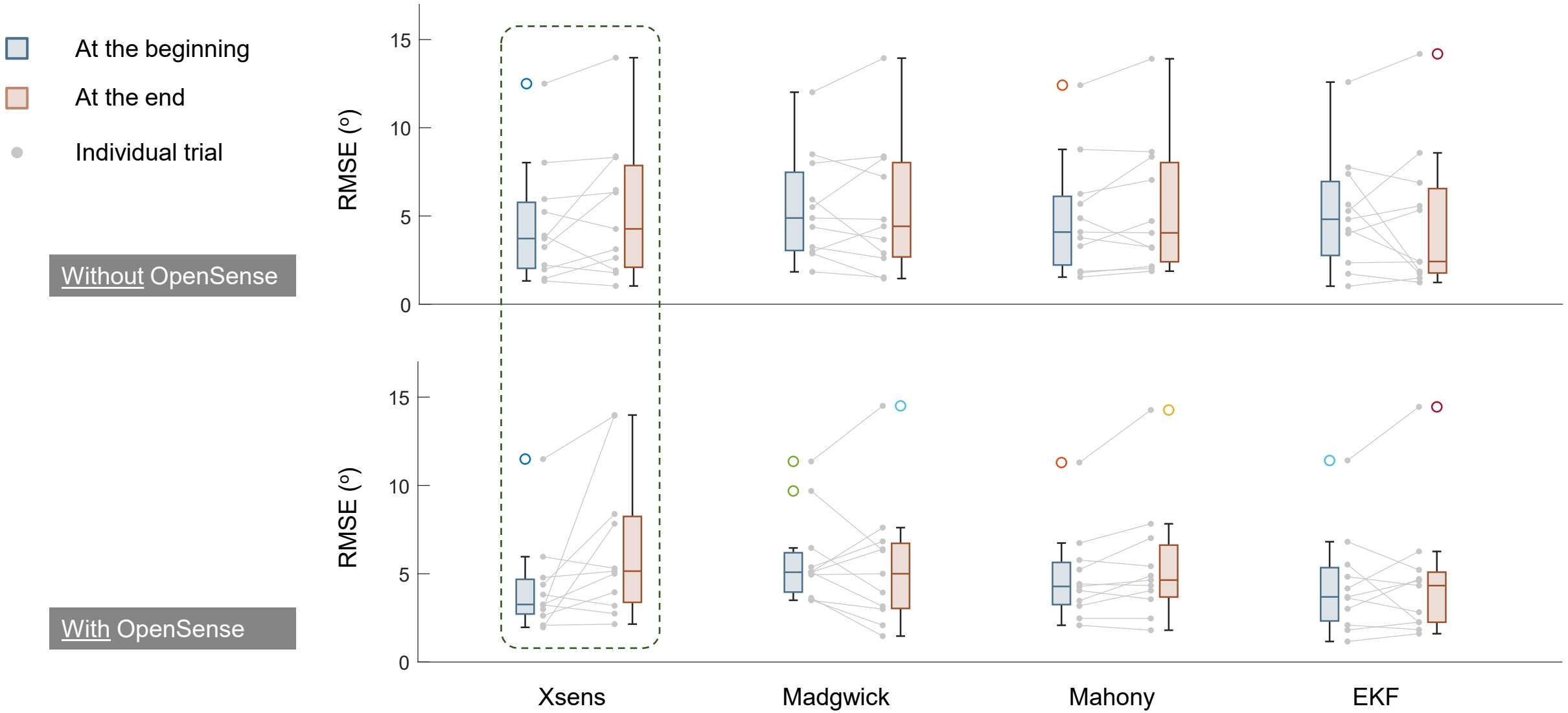
Preliminary observation

Traditional complementary filter resulted in very poor estimation

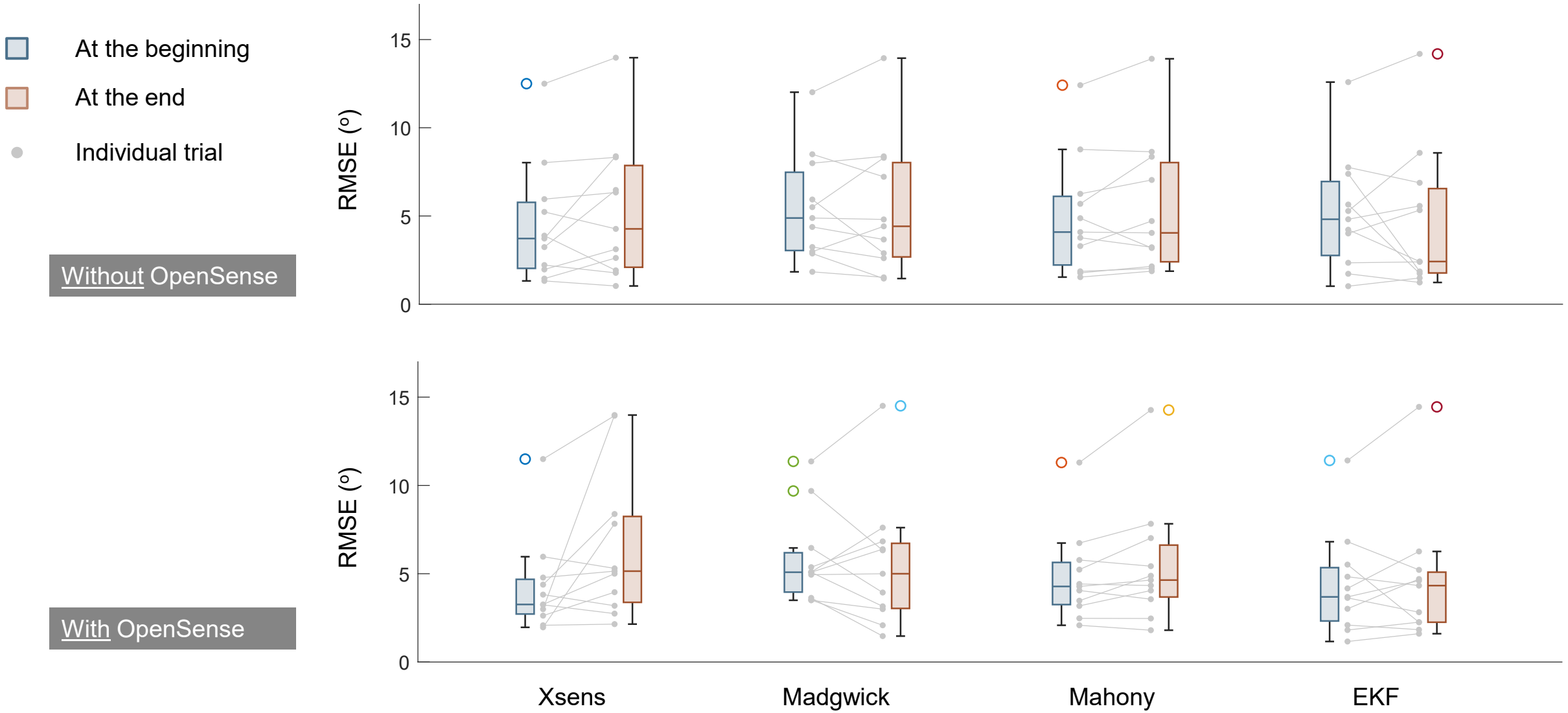
Decision

Removed from the analysis

Sensor fusion methods have similar performance, while Xsens built-in filter may not be tuned for long-duration recordings



No clear evidence of using biomechanical model to improve estimation performance



How does sensor misplacement and skin/soft motion artifacts affect the estimation accuracy?

Would the biomechanical model (from OpenSense) be helpful?

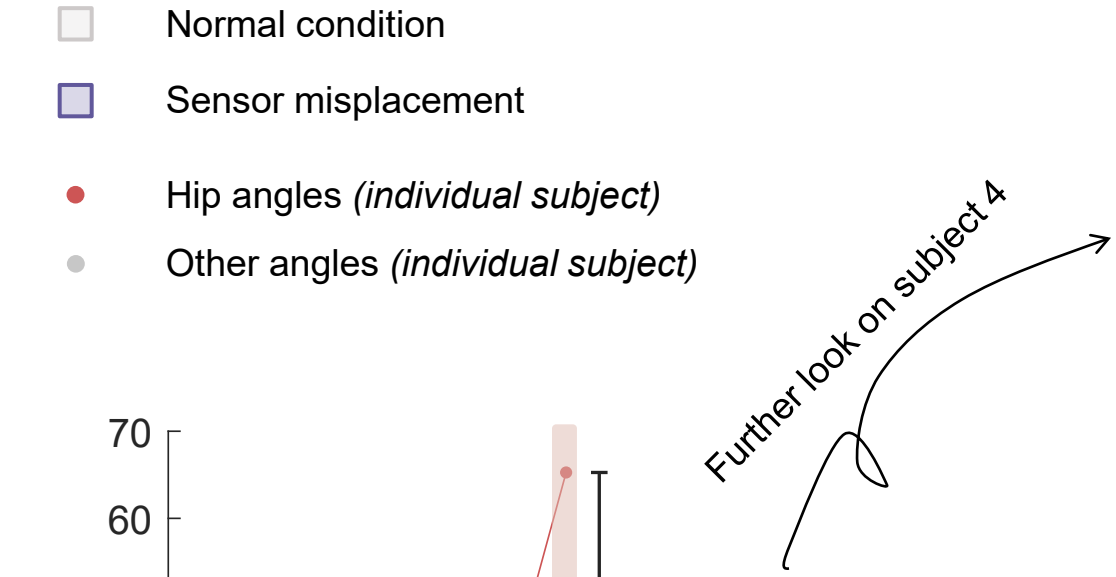
Preliminary observation

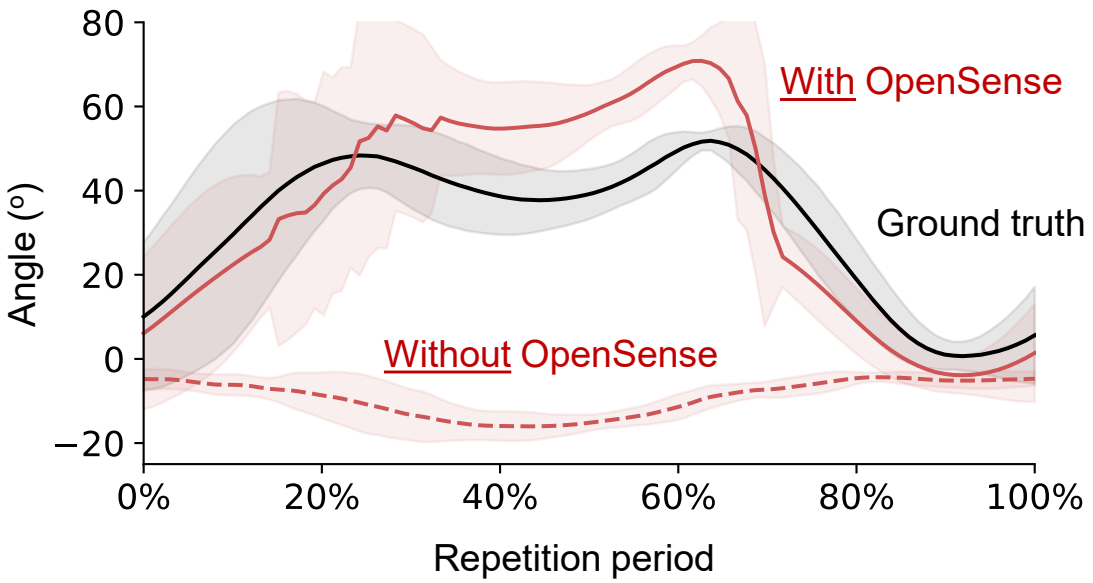
Trend across sensor fusion methods (e.g., increase in error as a sensor is misplaced, etc.)

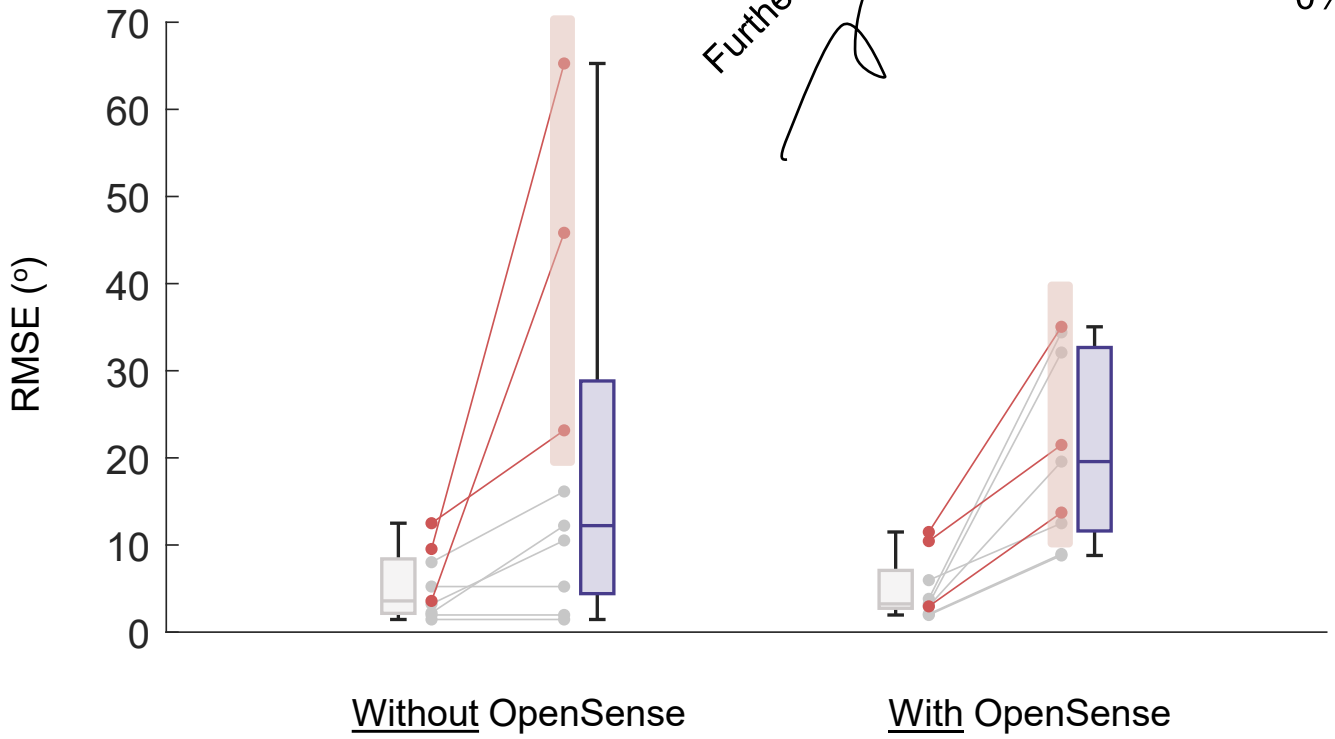
Decision

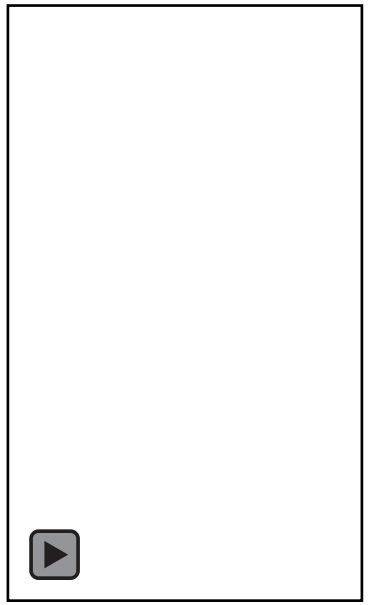
Selected Xsens built-in filter (i.e., standard, commonly used, etc.)

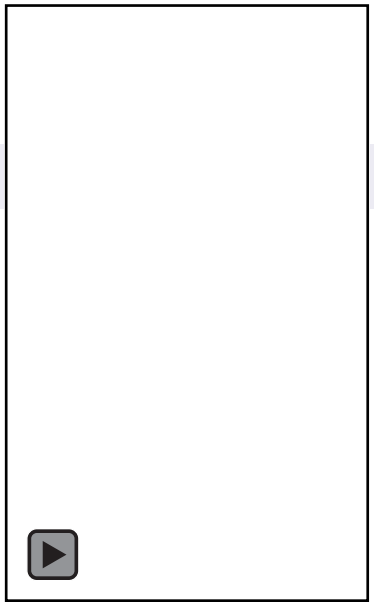
OpenSense improves the estimation of hip angles given sensor misplacement



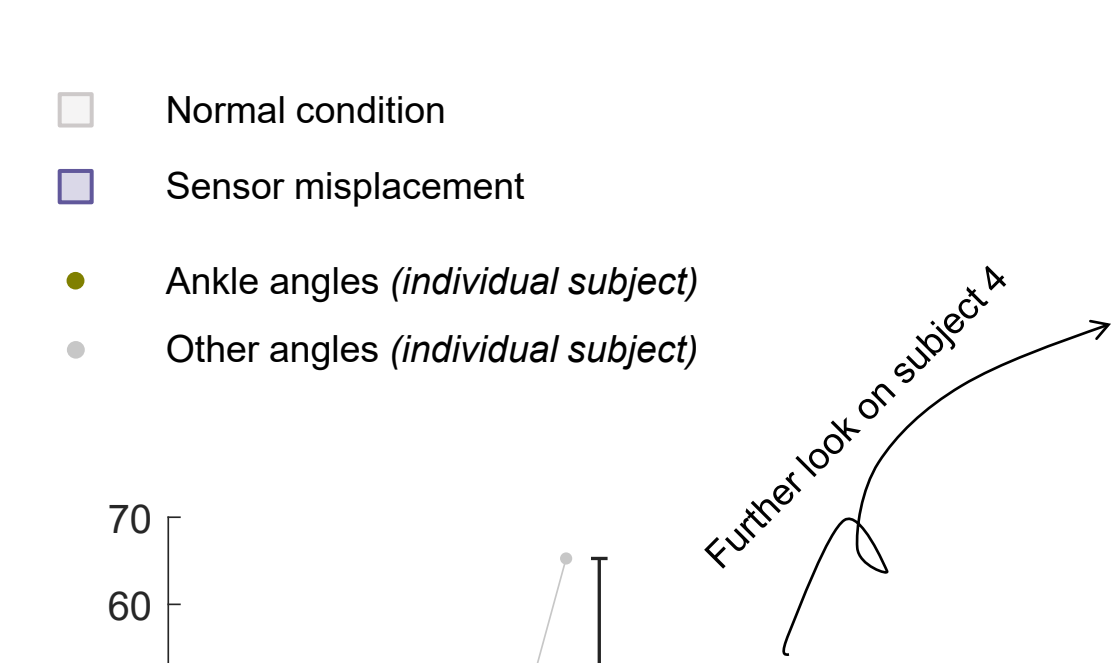


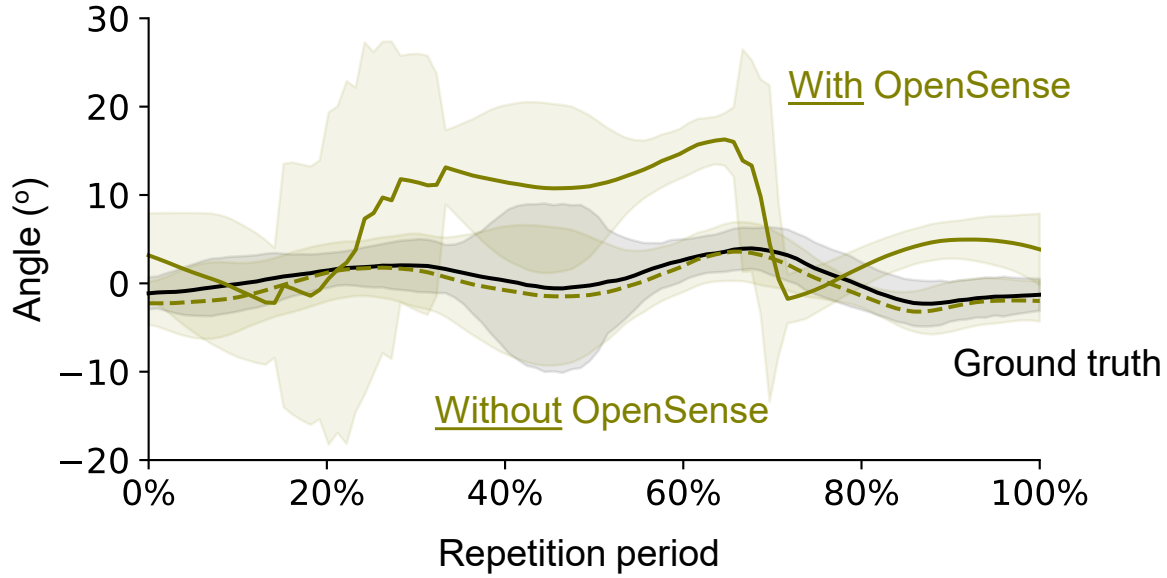


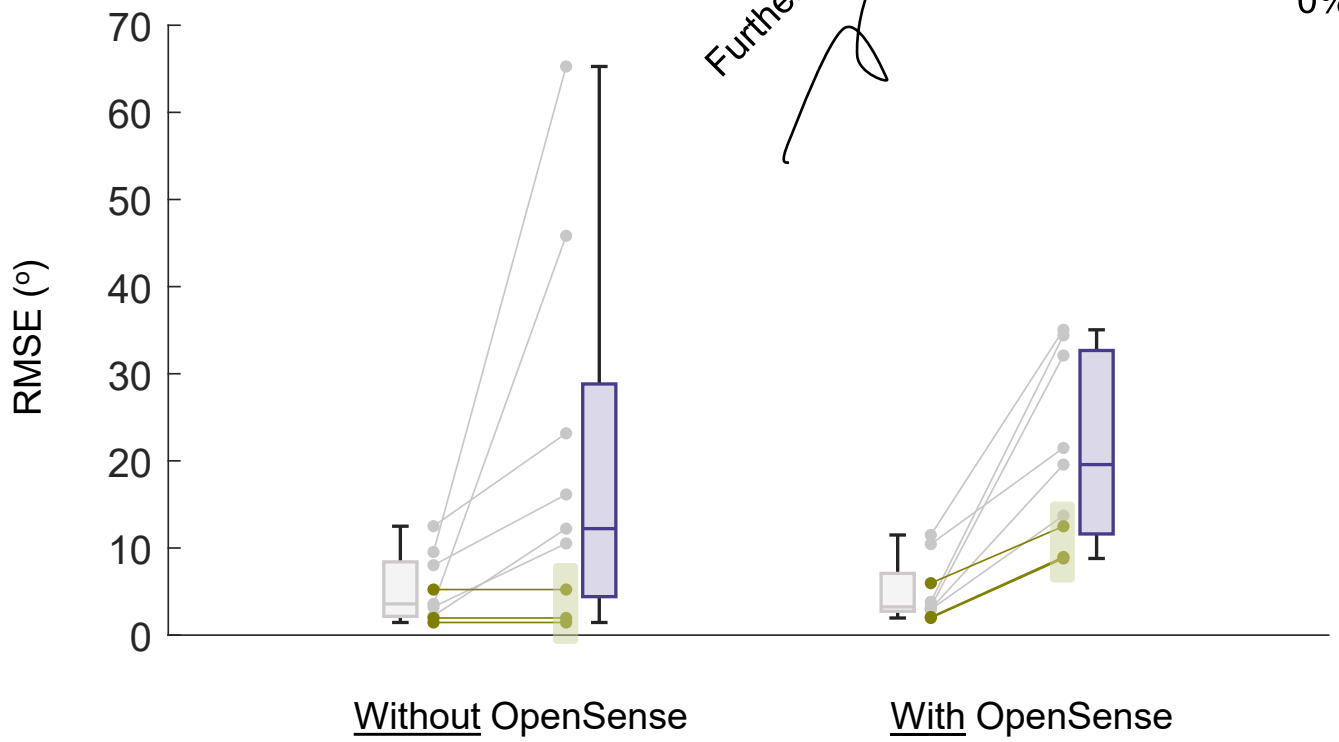


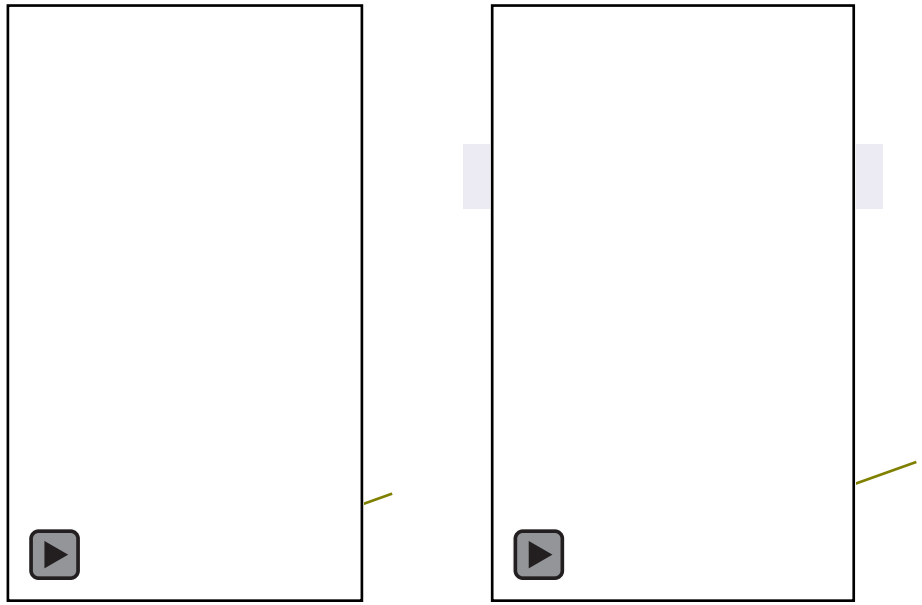


However, estimation of ankle angles was compensated









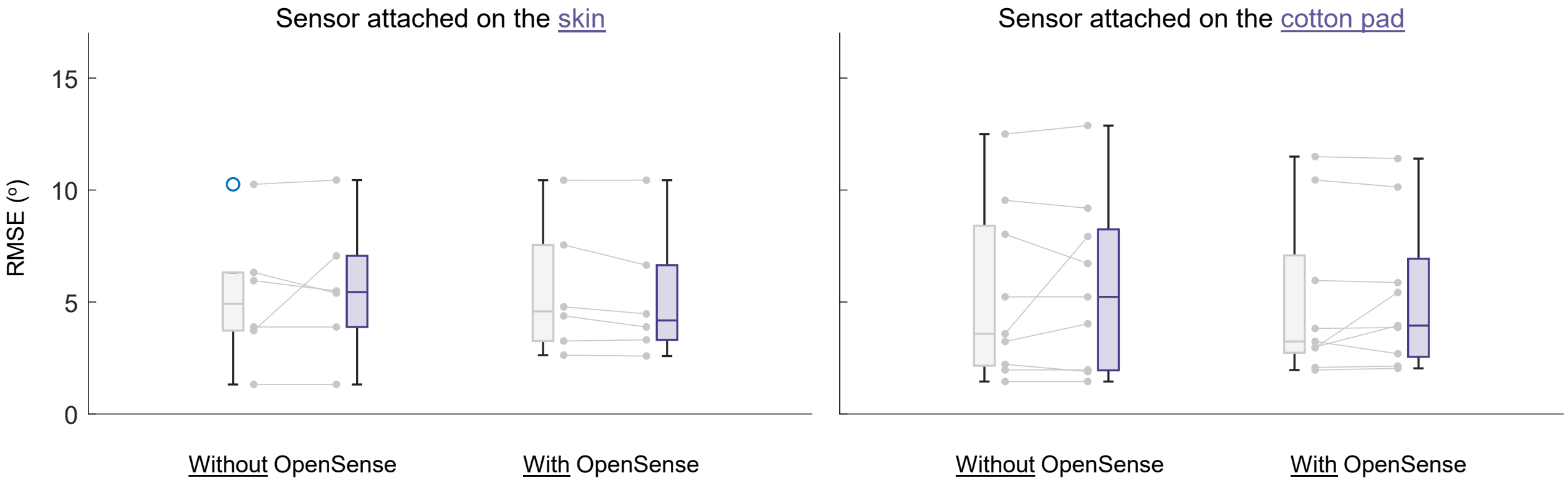
Tight wrapping of sensors could remove the skin/soft tissue motion artifacts

Normal condition

Sensor misplacement

Angles *(individual subject)*

Note: Sensors were wrapped tightly on the body segments.



*One subject was removed from this analysis due to poor-quality motion capture data

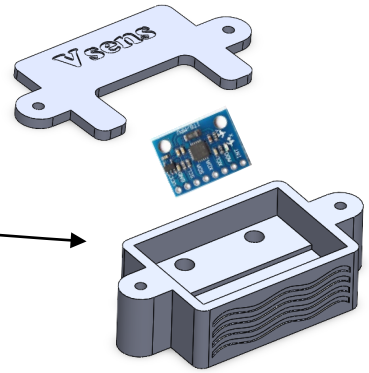
How would these knowledge be valid and translational to real life?

“All theory, dear friend, is grey, but the golden tree of actual life springs ever green”

- Johann Wolfgang von Goethe

6-axis cheap IMU
(< $4, including tax)

Our DIY device

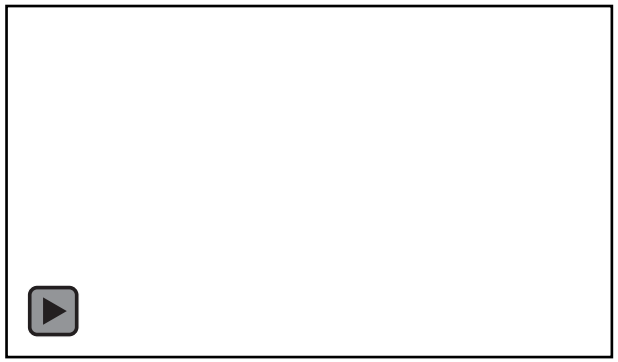


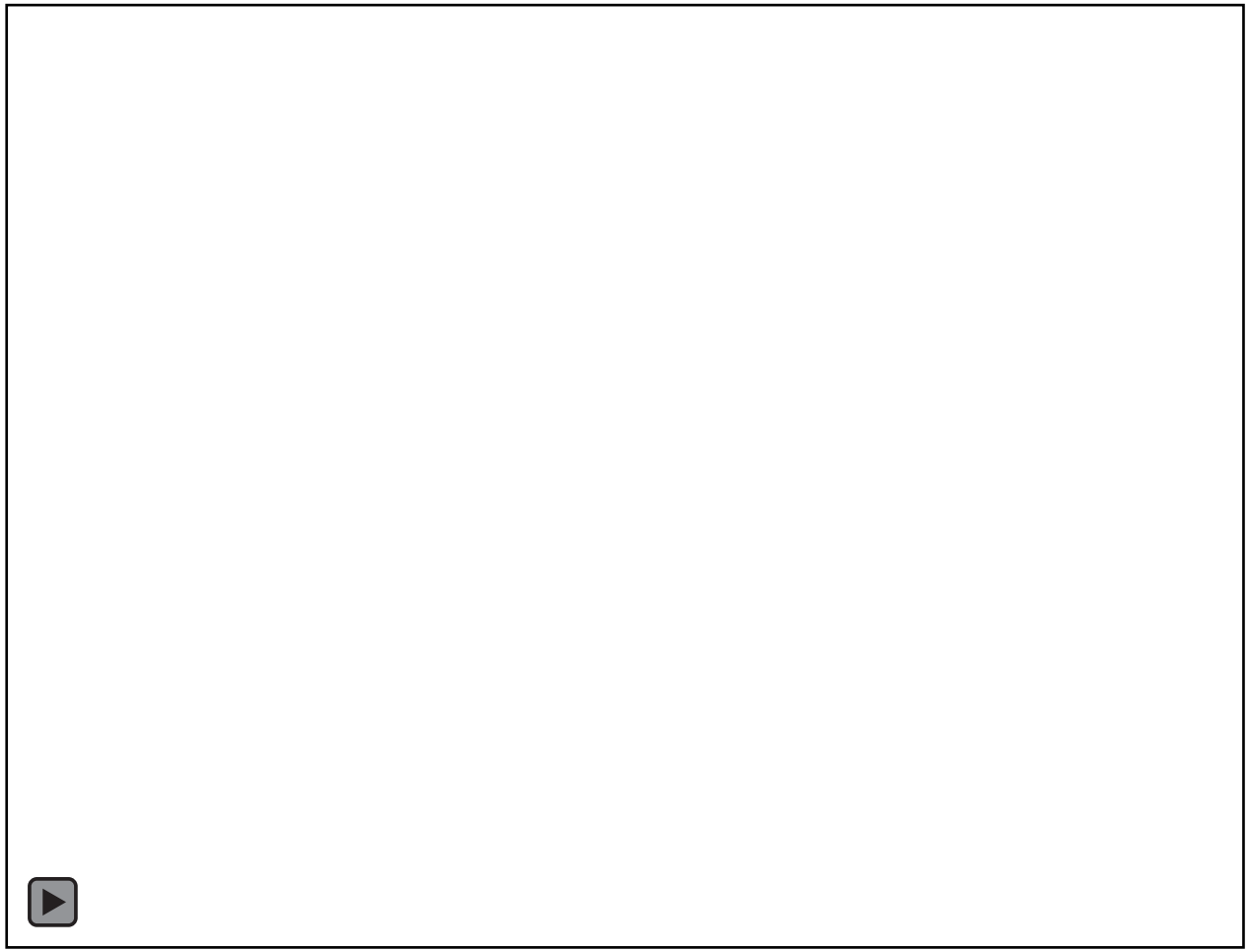
versus

9-axis high-end IMU
($200)

Implementation perspectives

- Lack of magnetometer
- Low robustness
- User experience





Takeaway messages

(Tuning generalizability) The Kalman filter family tuning may be generalizable across various scenarios and tuning may be more generalizable for certain joints, specifically the ankle.

(Filter generalizability) The complimentary filter family may be more generalizable across fields (i.e., no improvement after tuning)

No significant difference between complementary and Kalman filter family given sufficient information (i.e., accelerometer, gyroscope, and magnetometer)

No clear evidence that OpenSense improves the joint kinematics estimation

OpenSense may improve estimation accuracy of a specific joint angle but with some cost on the other angles

Tight wrapping of sensors could remove the skin/soft tissue motion artifacts

Limitations

Limited sample size

Only sit-to-stand task

Thank you for your listening!

Q&A?