계단 하강 보행의 상태 예측을 위한 상태 변수 생성에 대한 연구

Research of Generating Phase Variable to Estimate Phase of Stair Descent Walking

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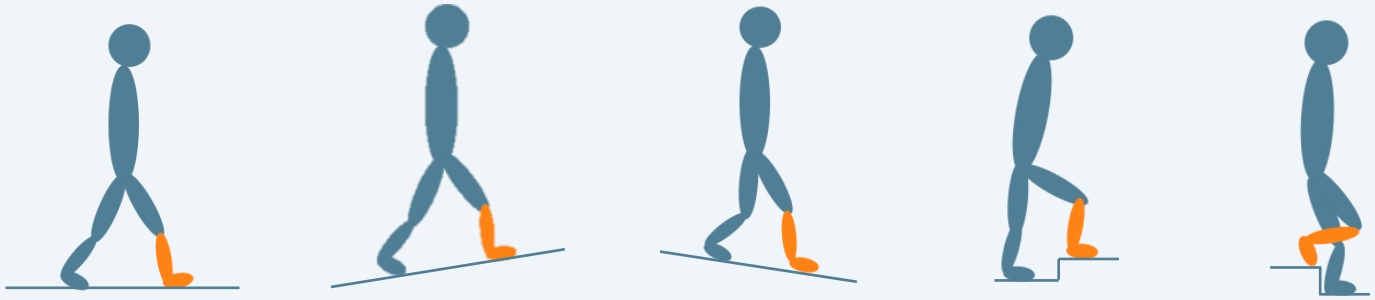
Introduction

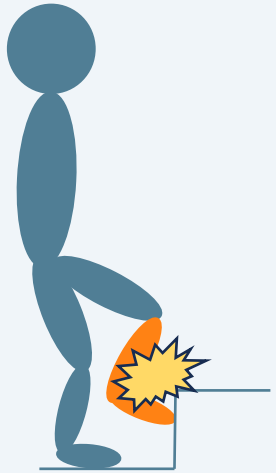


Various walking conditions

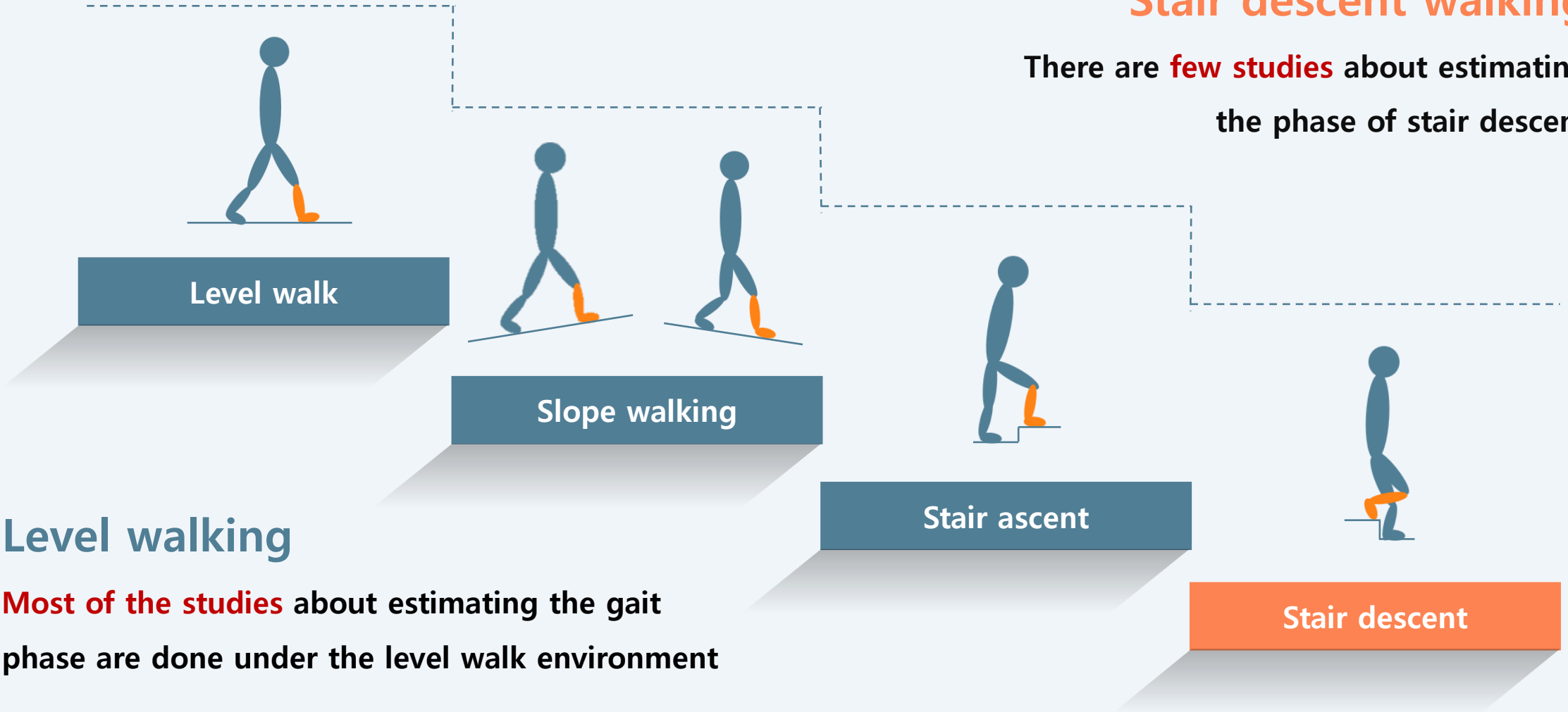
A powered prosthesis must be developed
for various walking conditions

Synchronization

A powered prosthesis must understand the user's intention
to generate appropriate action and safe walking



Introduction



Stair descent walking

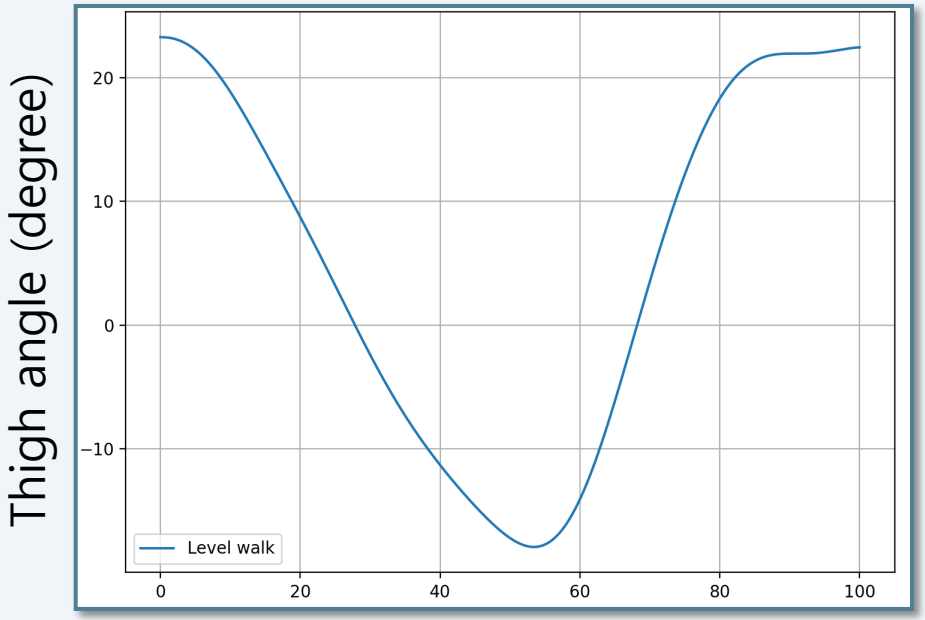
There are **few studies** about estimating the phase of stair descent

Level walking

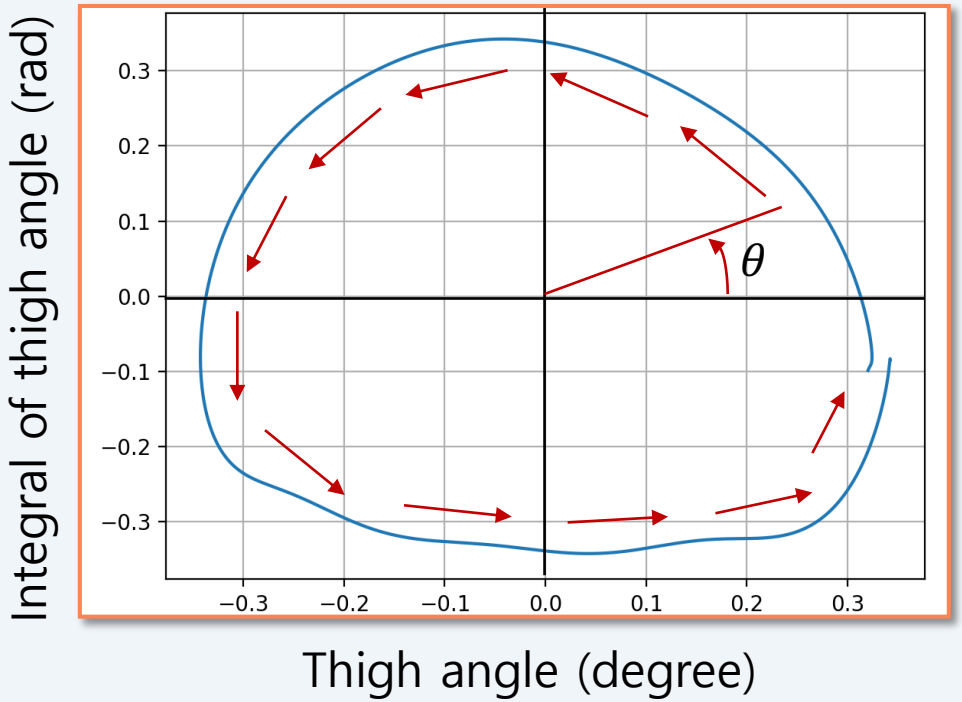
Most of the studies about estimating the gait phase are done under the level walk environment

Introduction: Phase estimation for level walking

Thigh angle

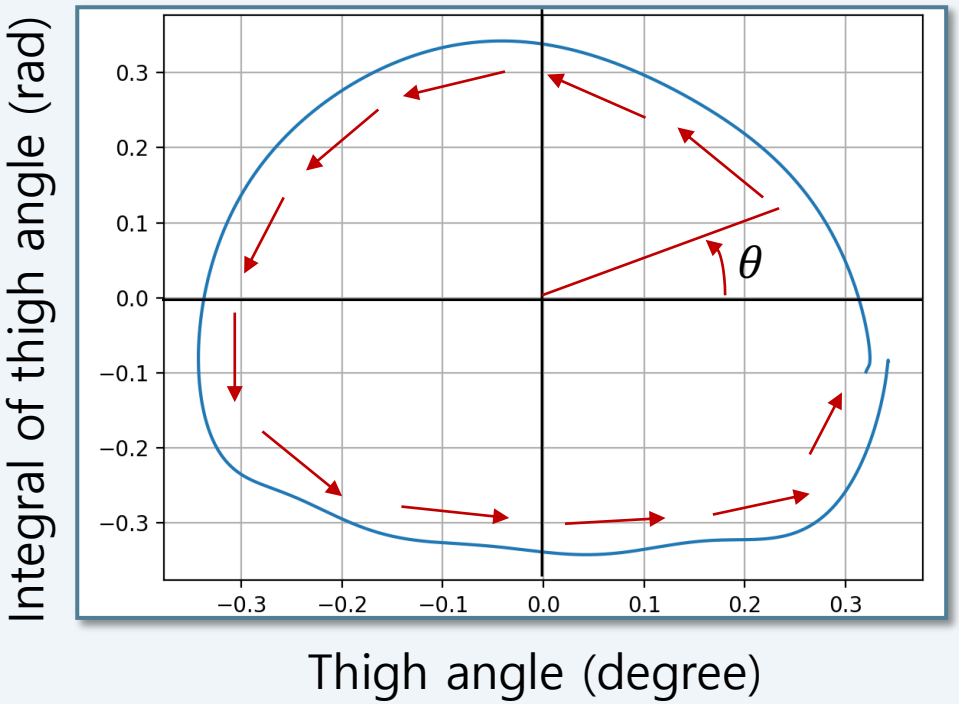


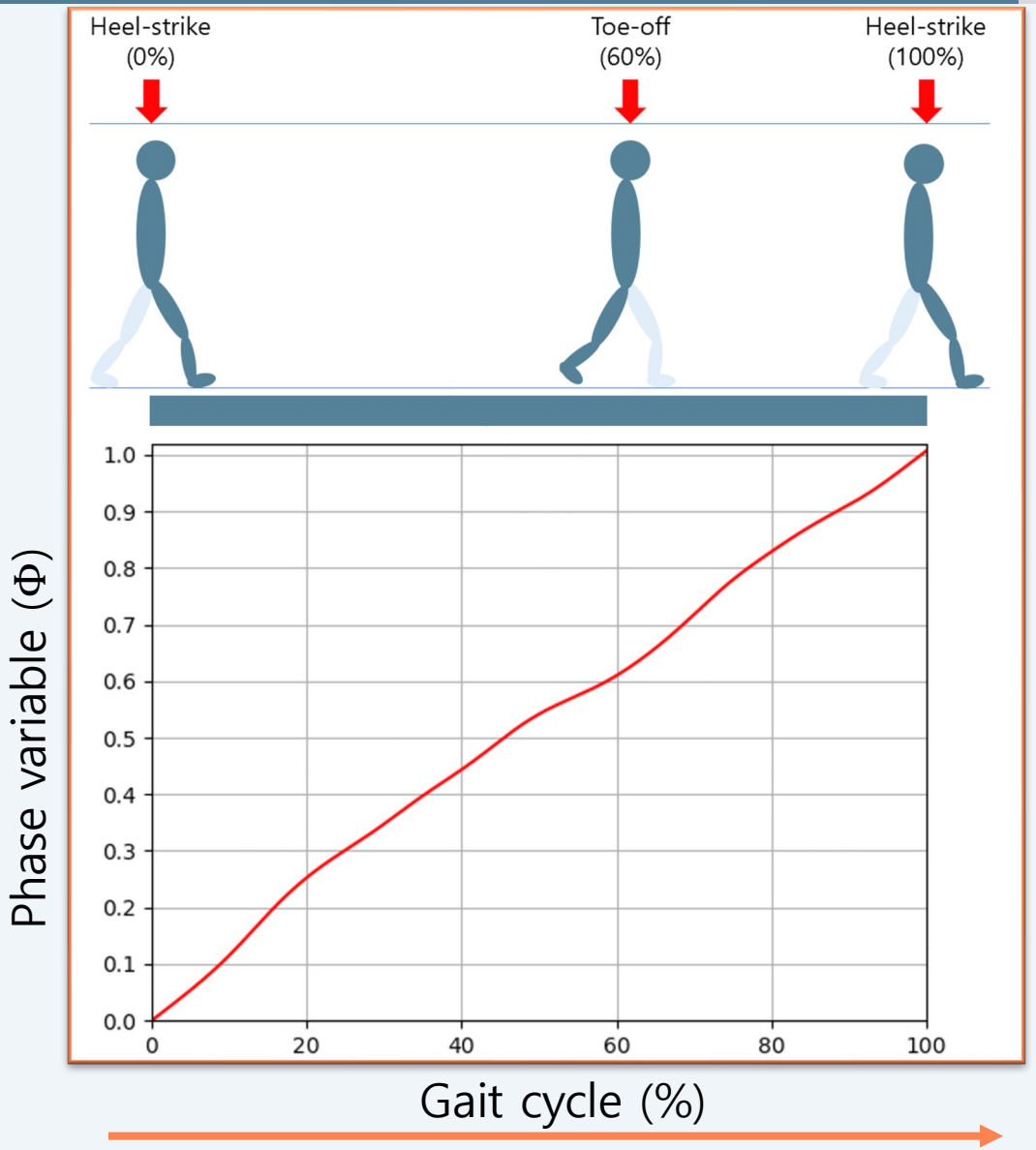
Phase portrait



Introduction: Phase estimation for level walking

Phase portrait





Monotonic
Linear

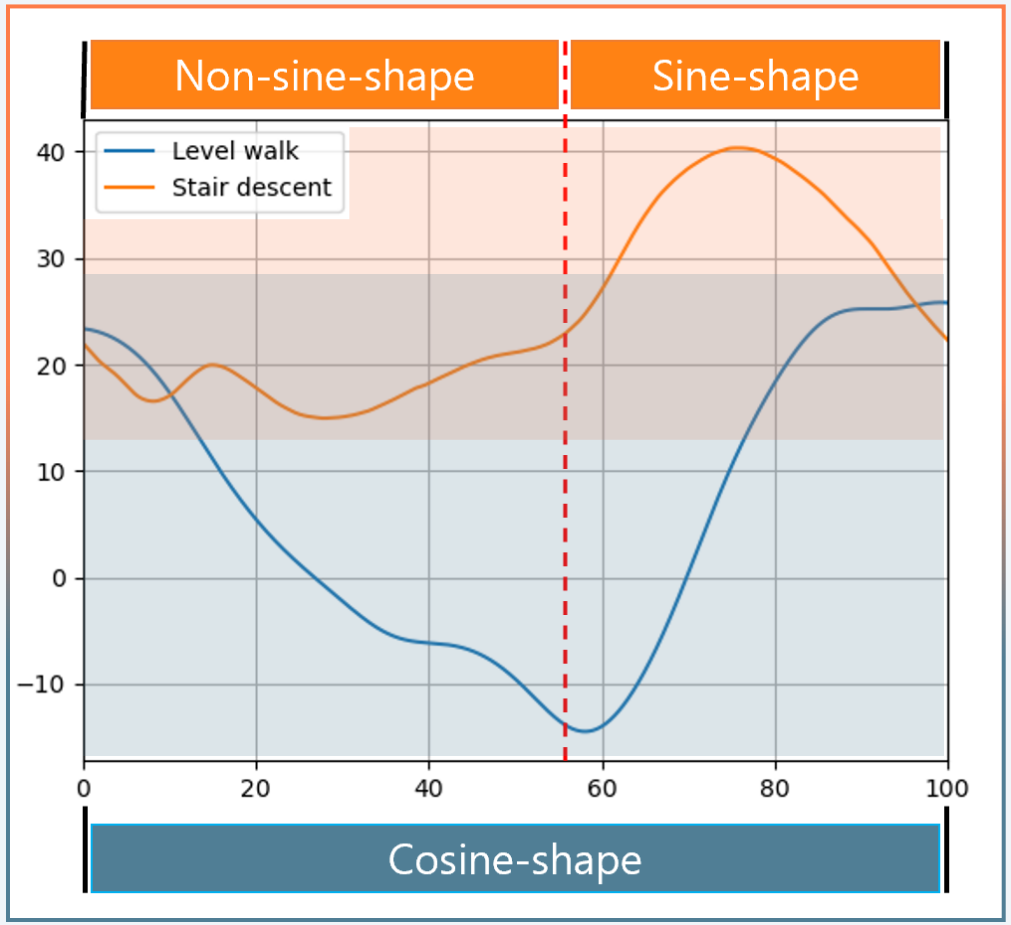
Introduction: problem

Stair descent

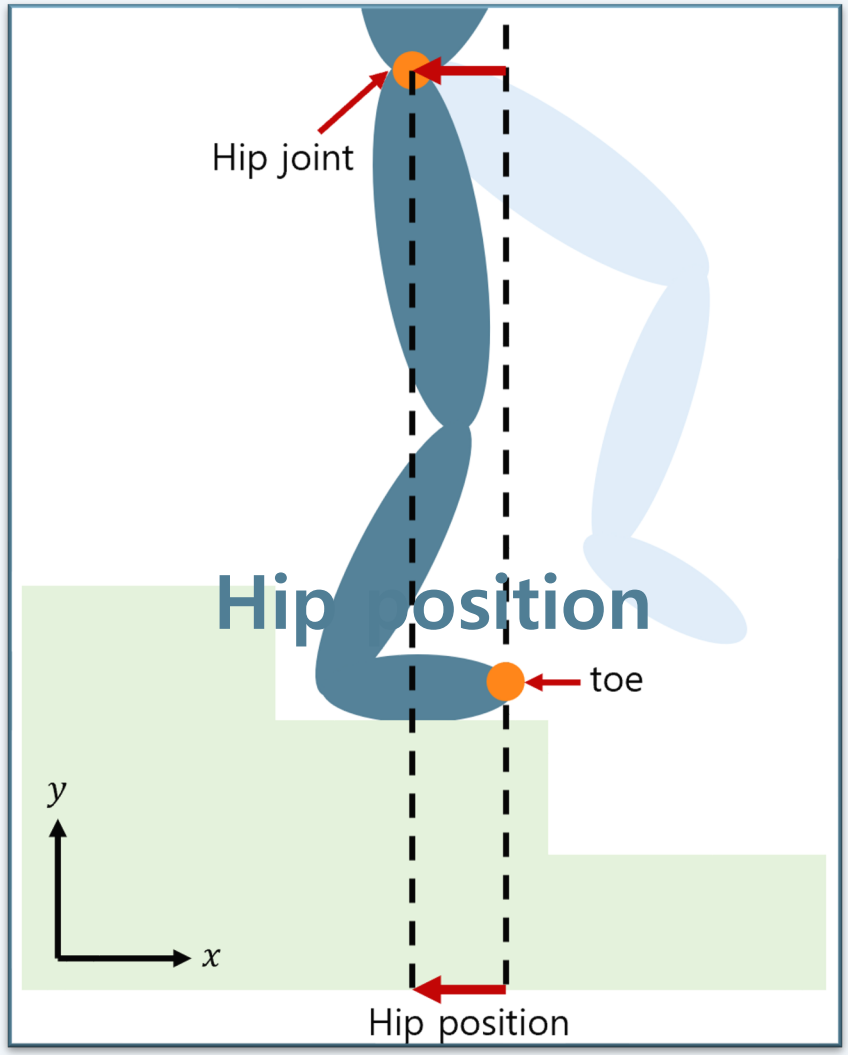
There exists a part where the thigh angle of the stair descent shows the non-sine shape

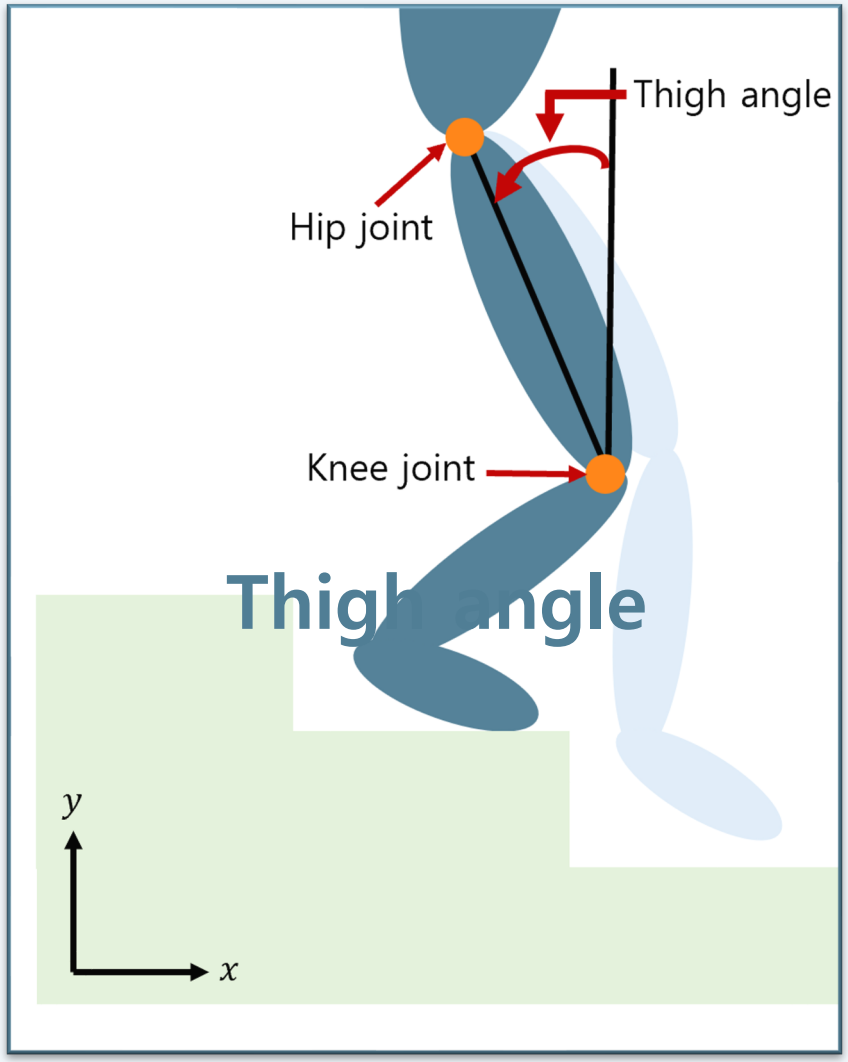
Level walking

The thigh angle trajectory is a cosine-like function for the entire gait cycle for level walking



Methods: Phase variable candidates for stair descent





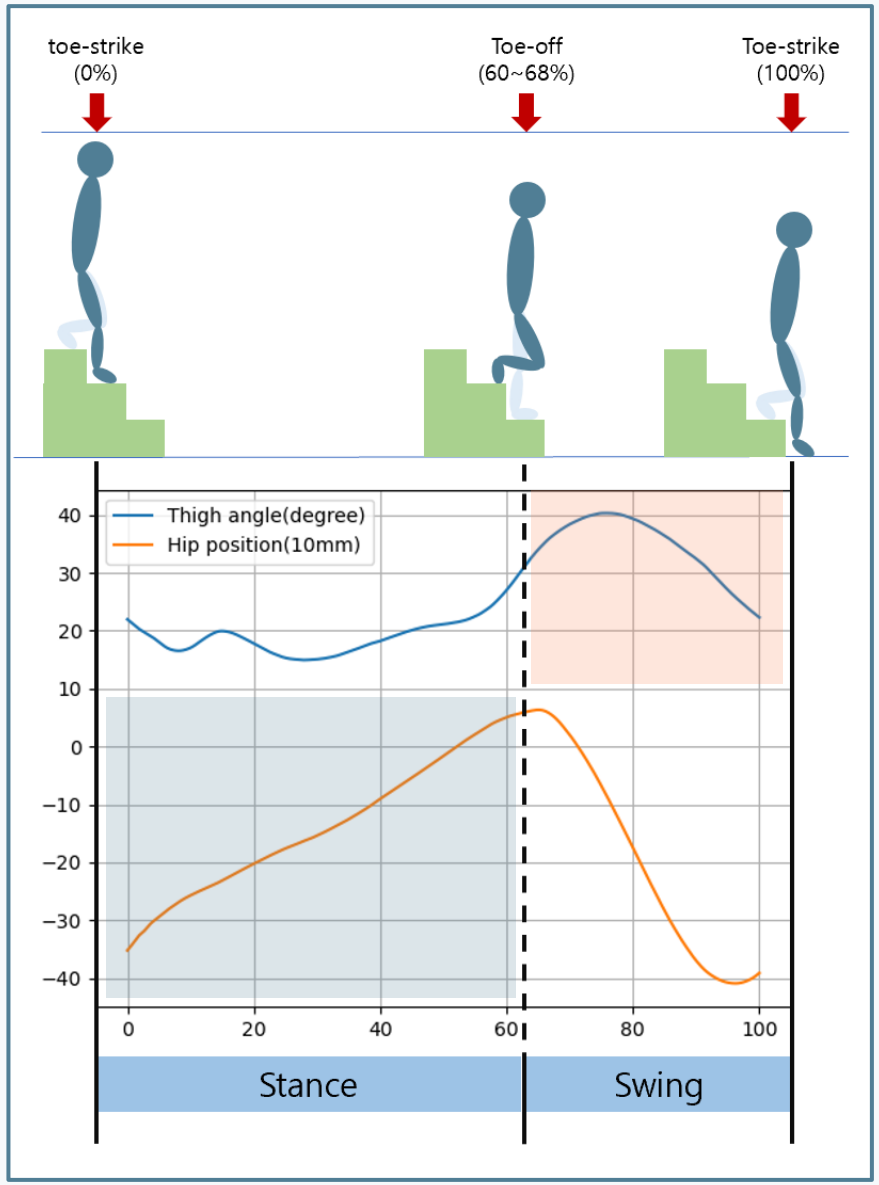
Methods: Phase variable candidates for stair descent

Stance phase

Hip position

Linear and **monotonic**

Calculate the phase variable using **normalization**.



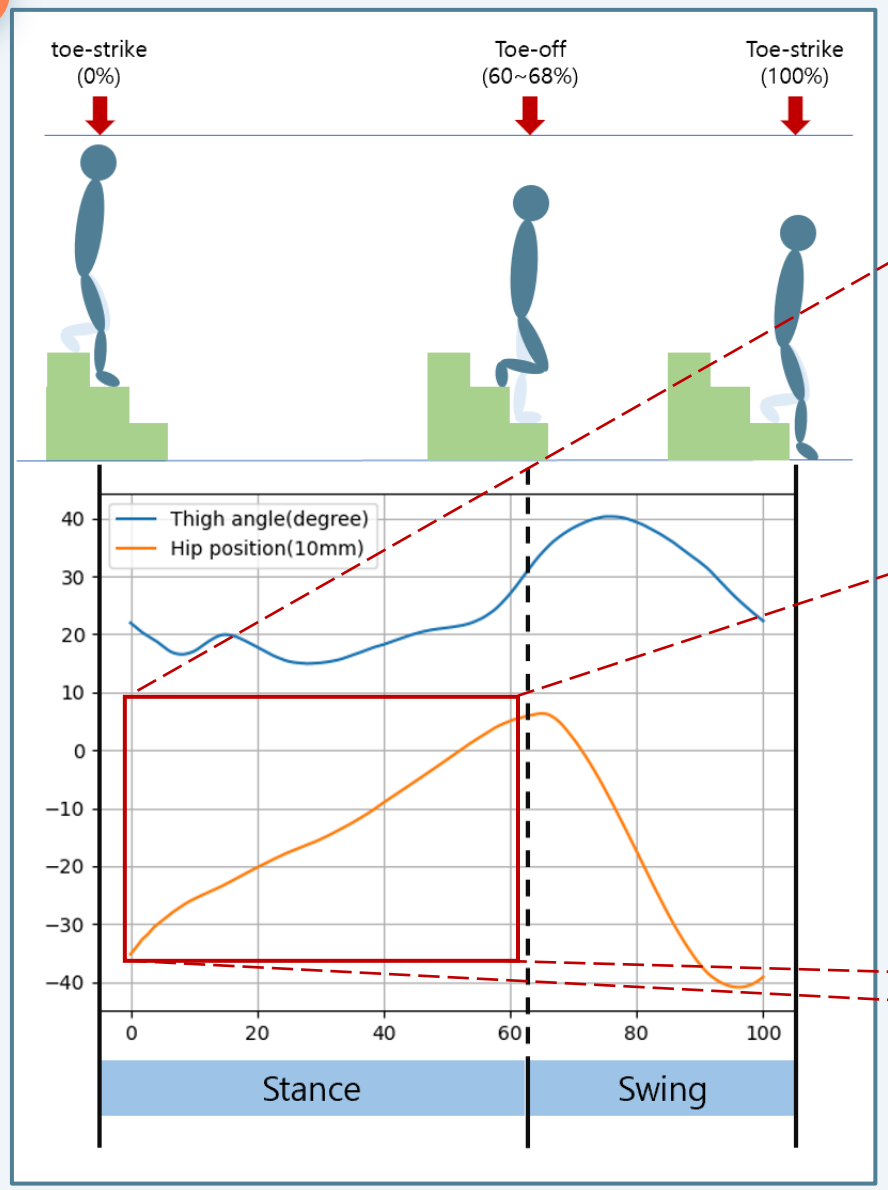
Swing phase

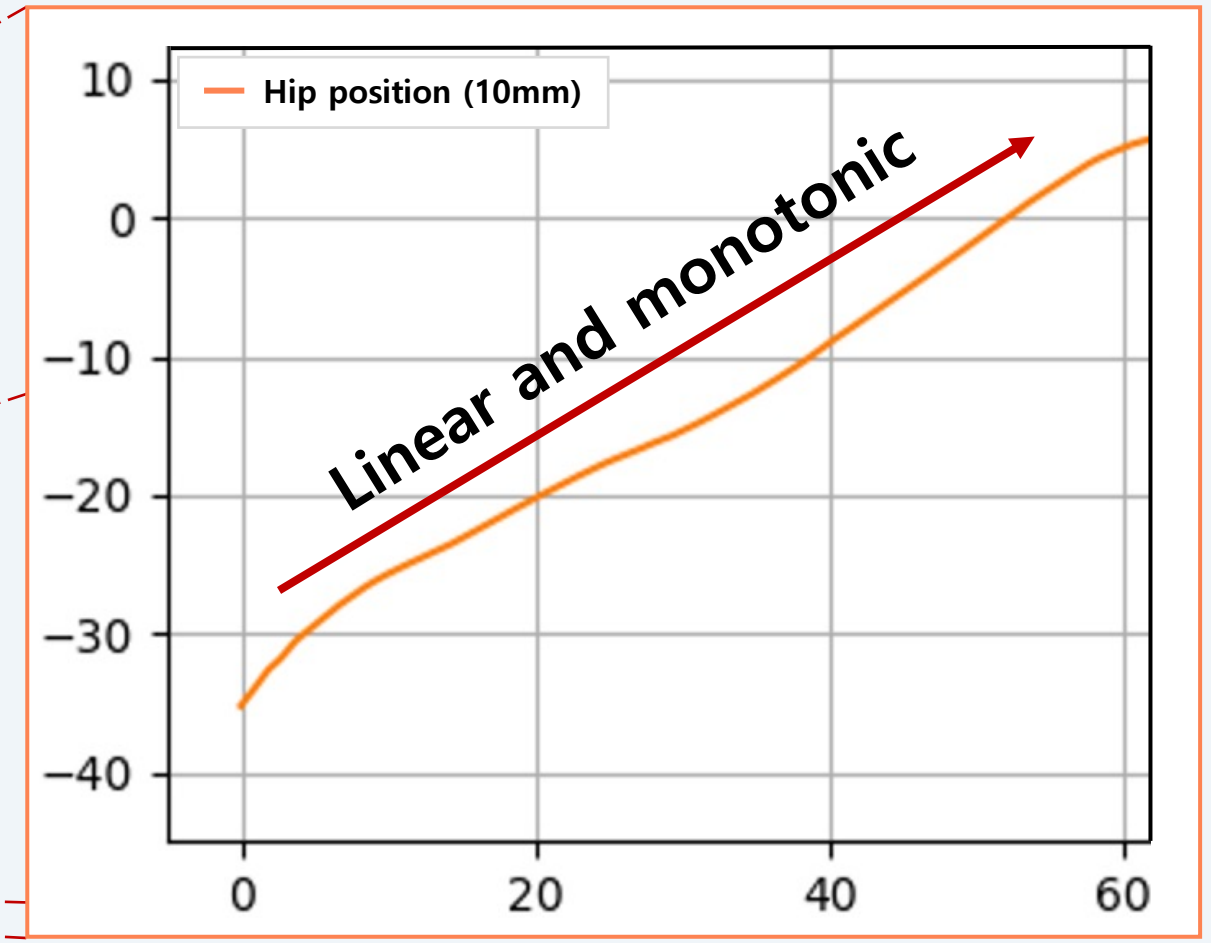
Thigh angle

Sine-like function.

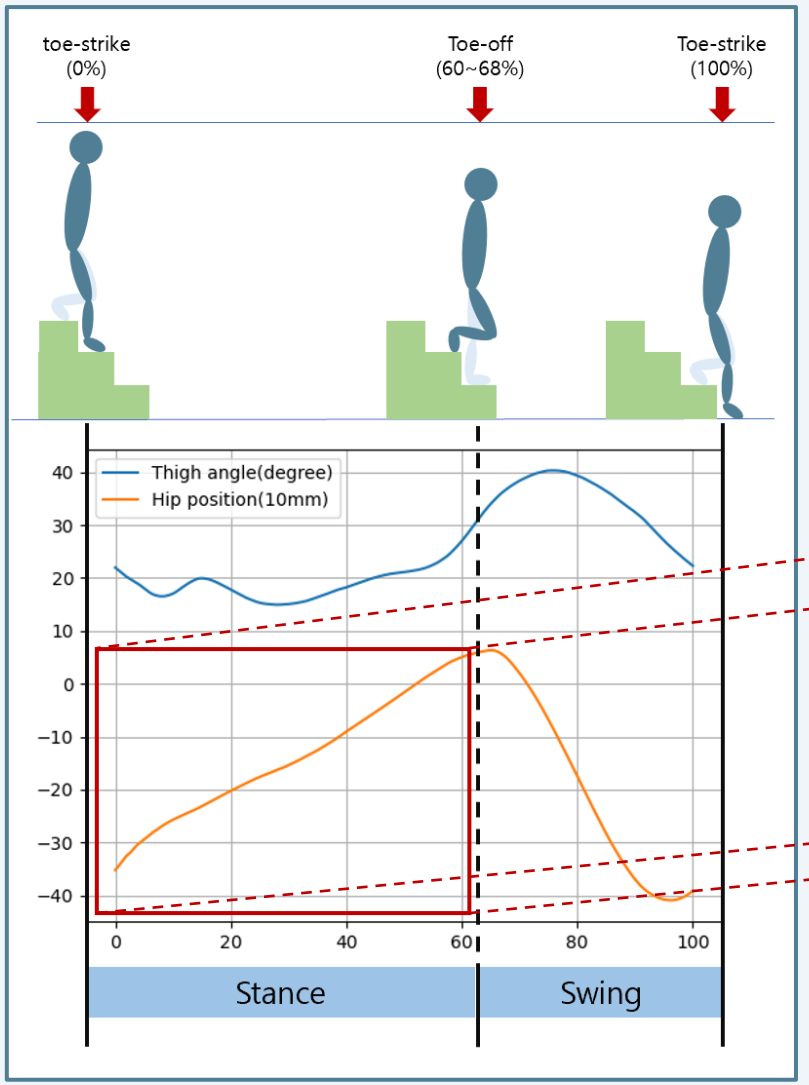
Calculate the phase variable using **phase portrait**.

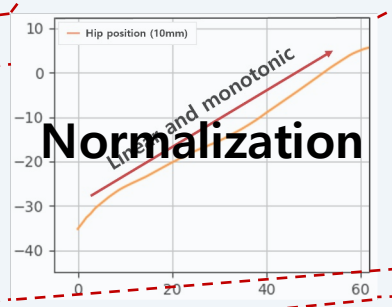
Methods: Phase variable calculation (stance phase)



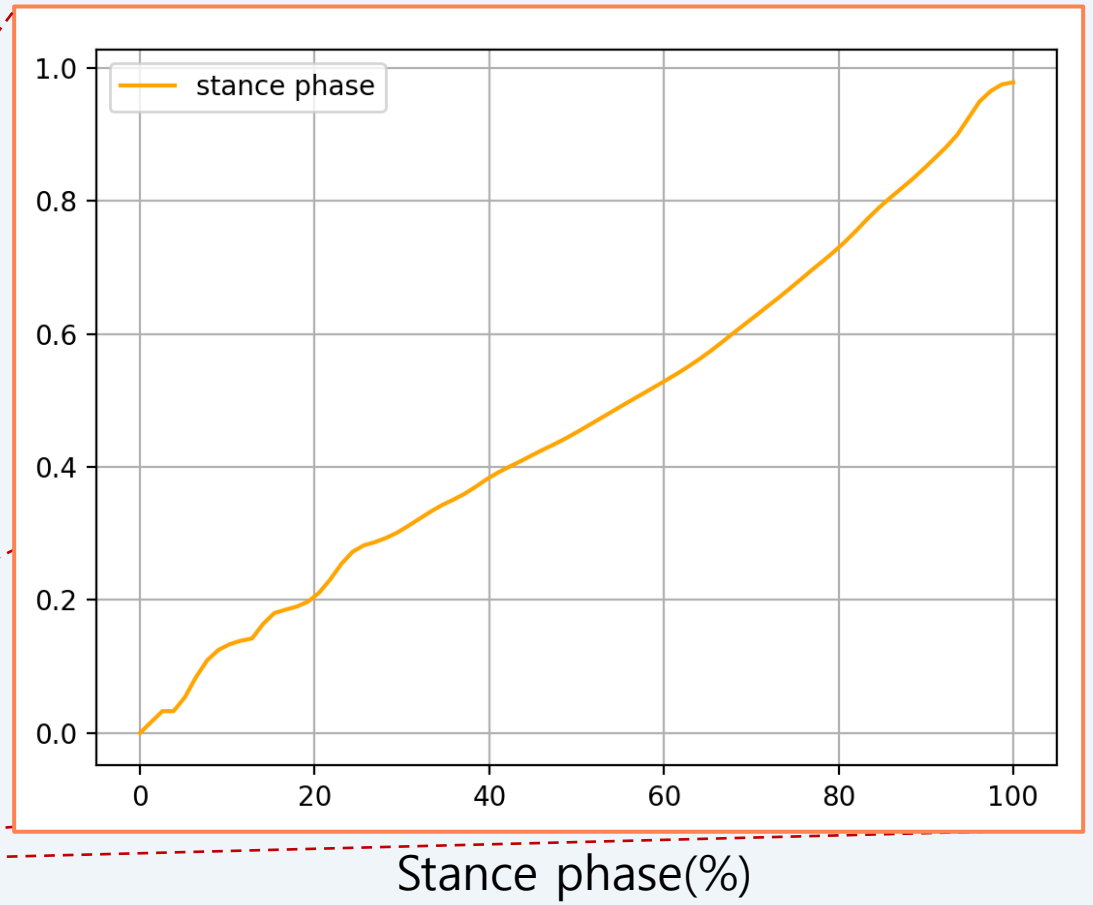


Methods: Phase variable calculation (stance phase)

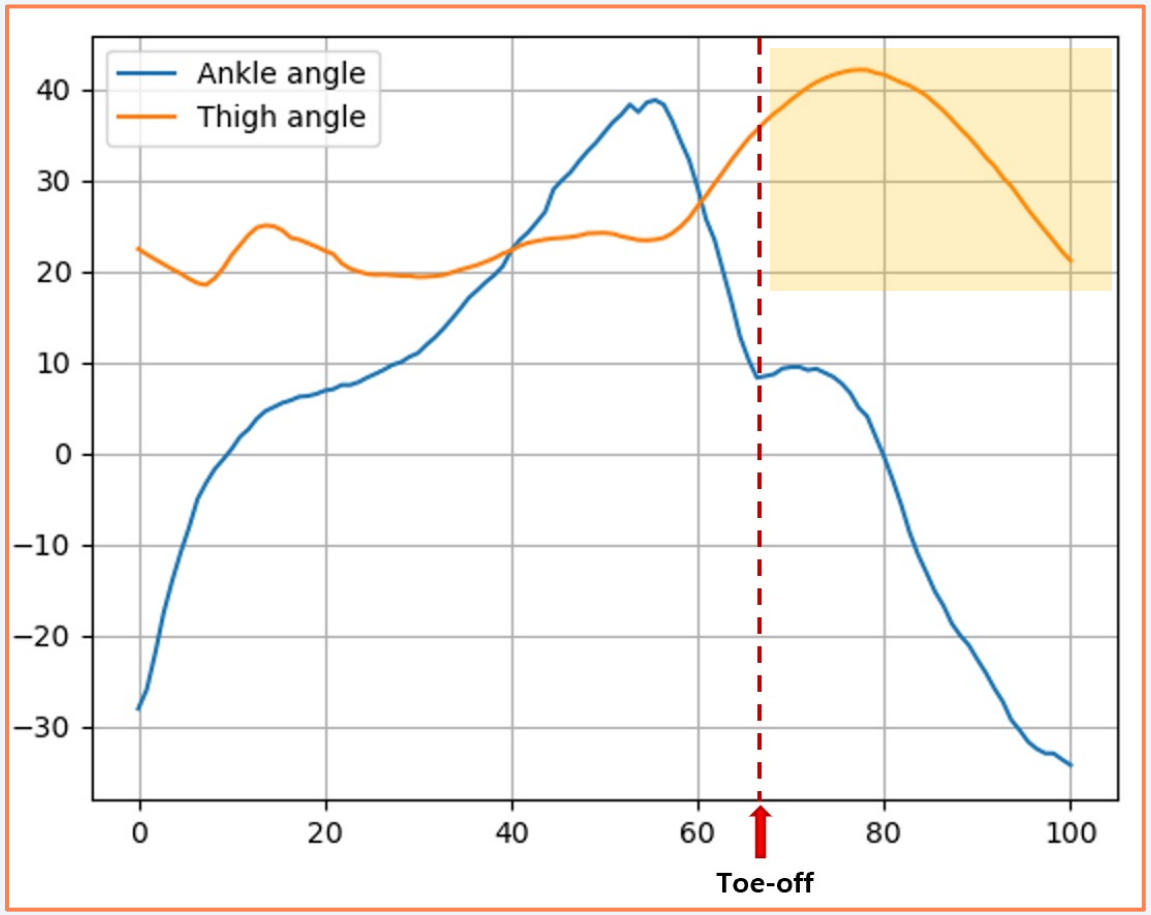


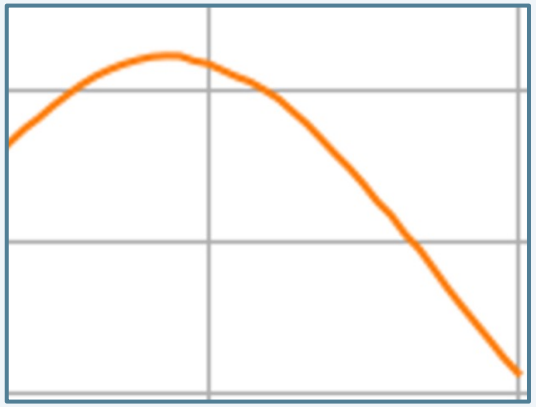


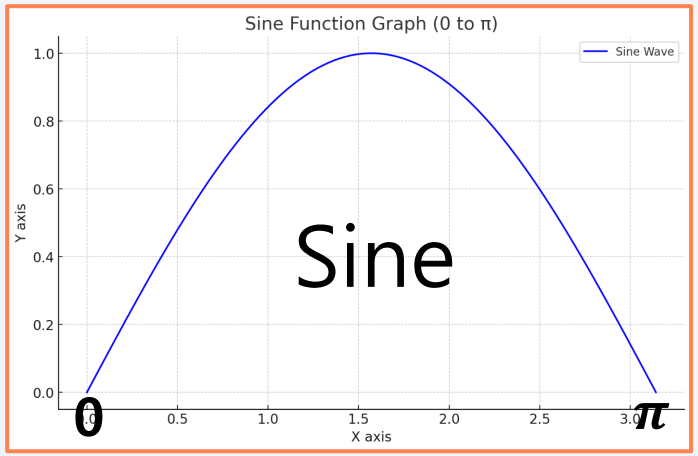
Normalization



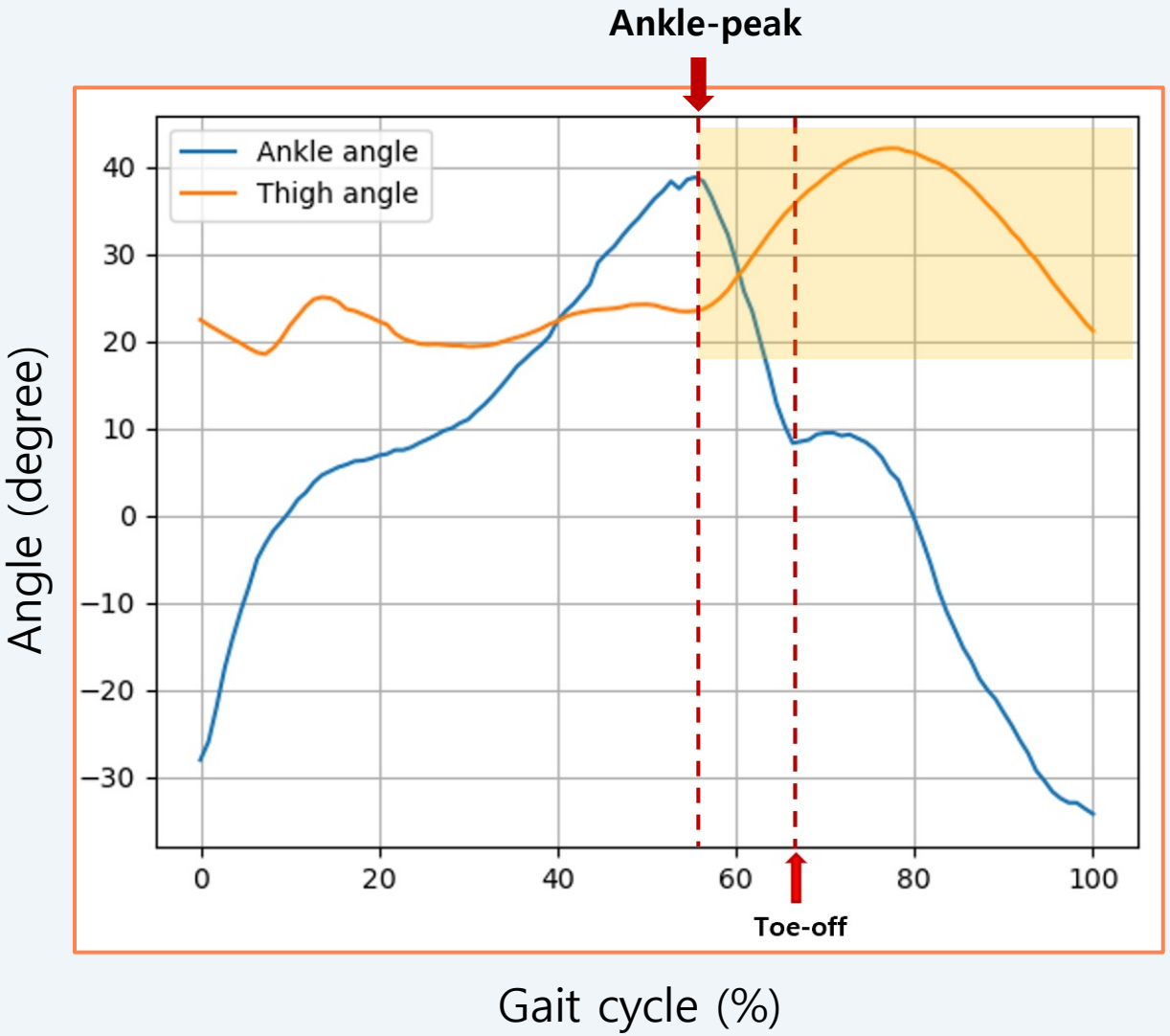
Methods: Phase variable calculation (swing phase)

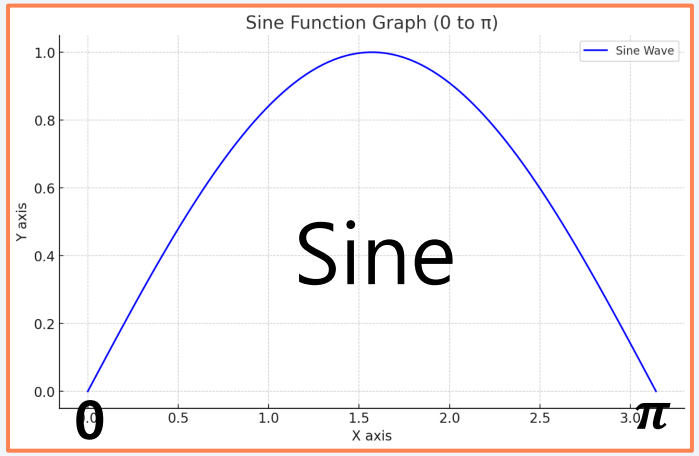




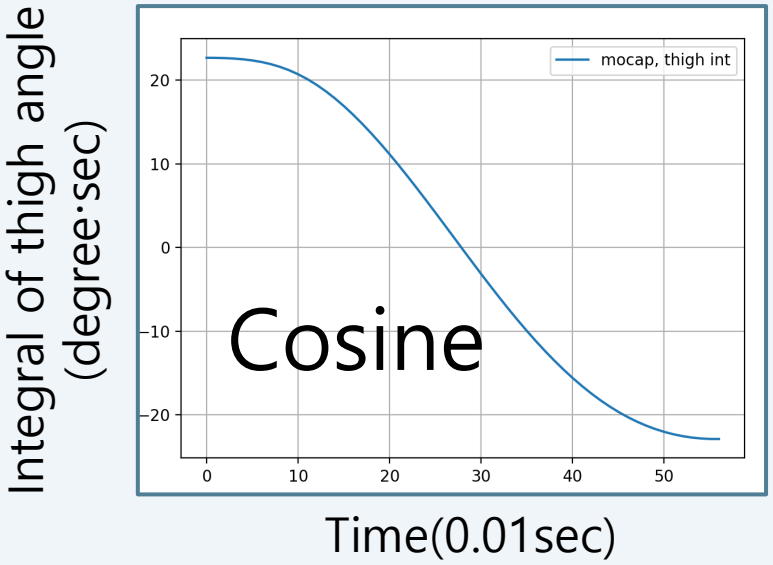


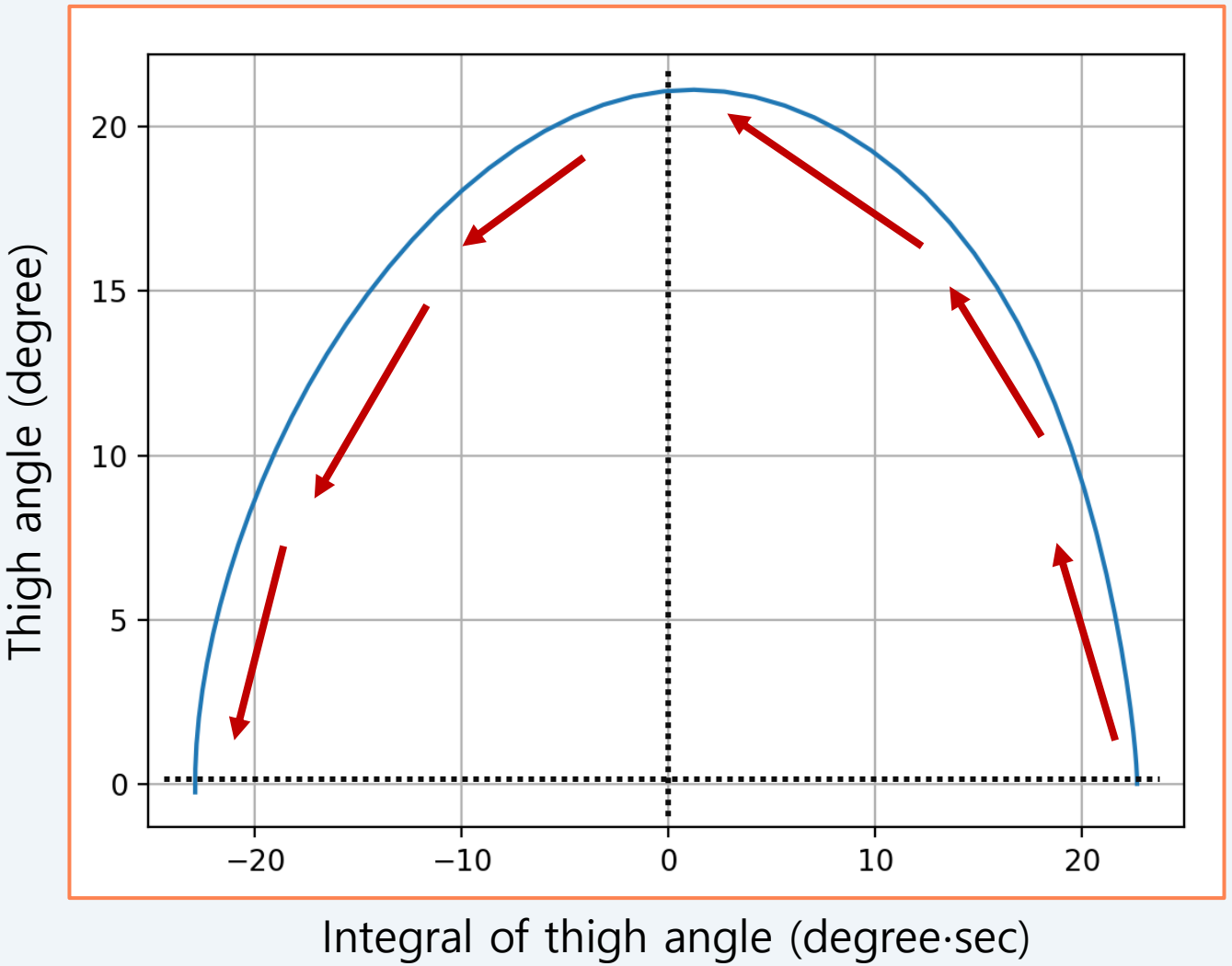
Methods: Phase variable calculation (swing phase)



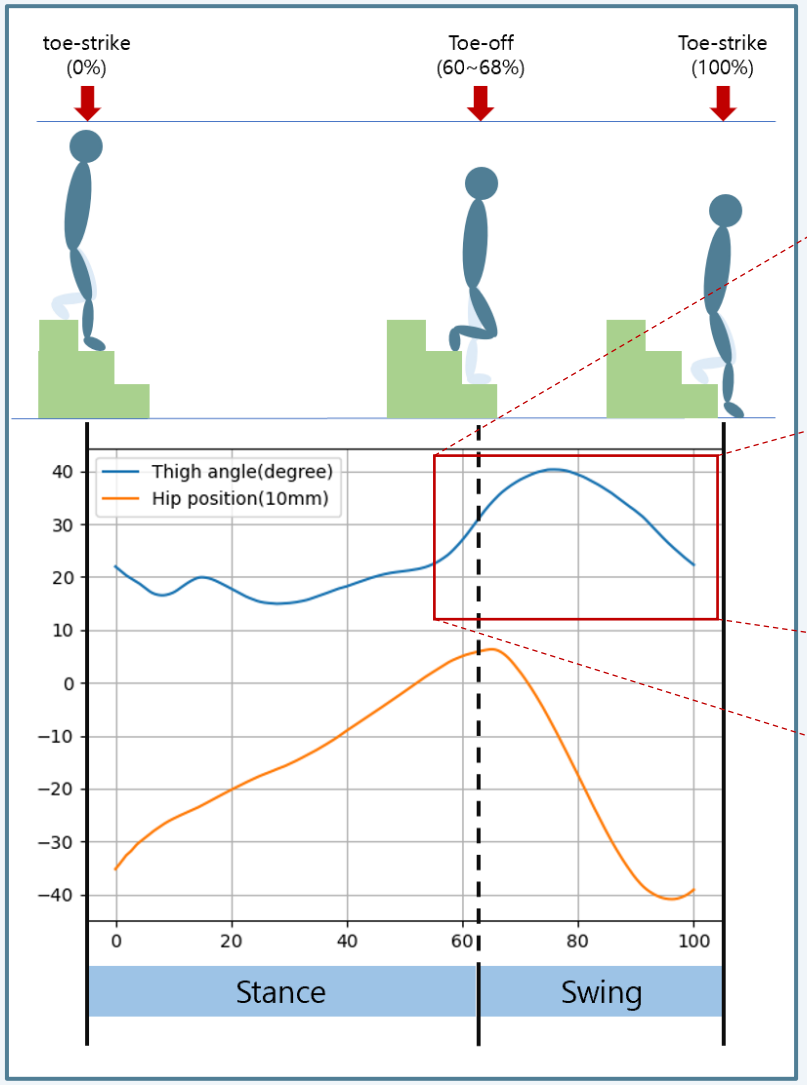


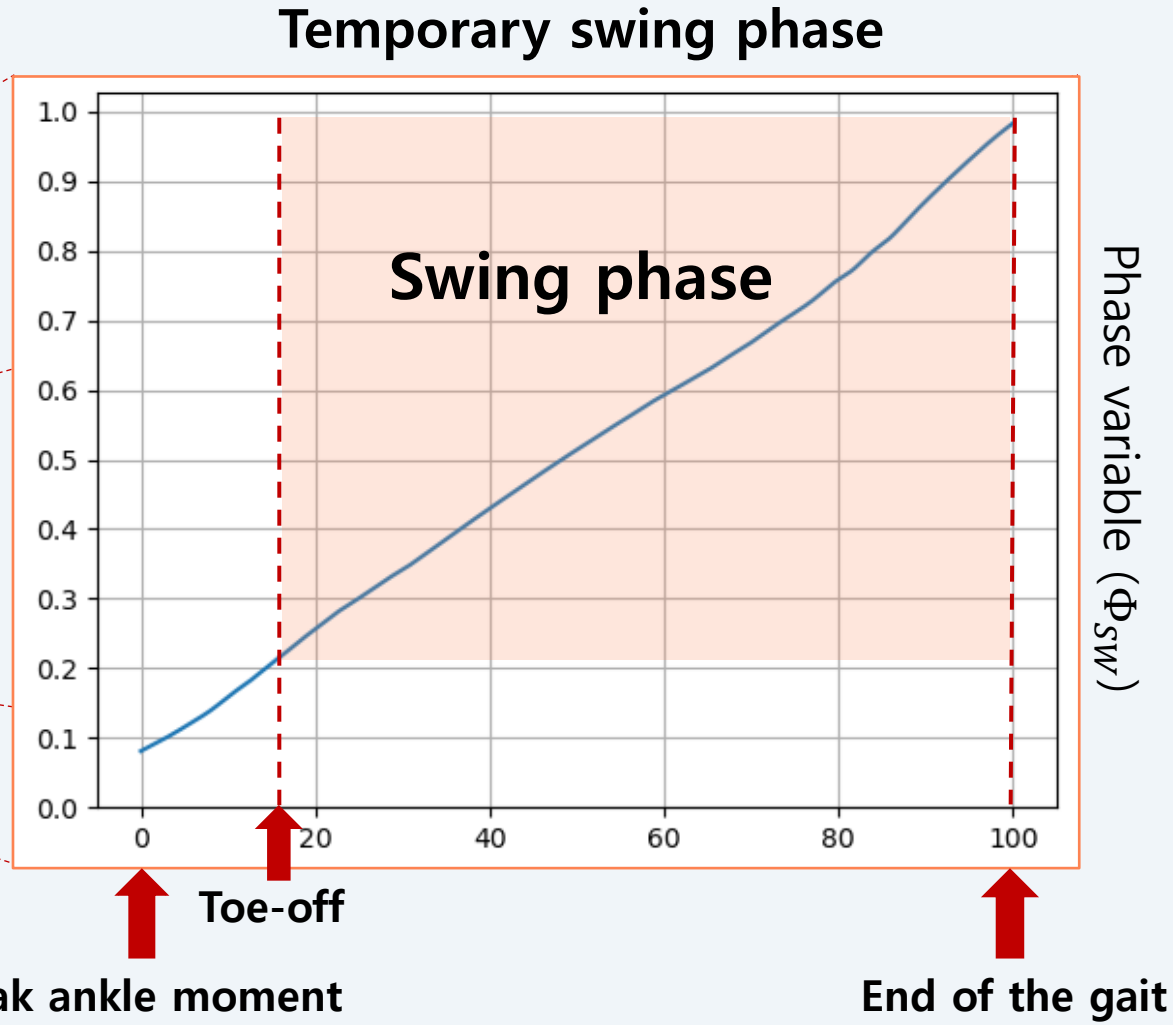
Methods: Phase variable calculation (swing phase)



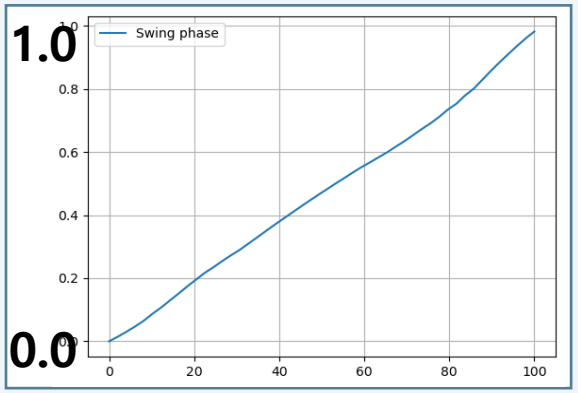


Methods: Phase variable calculation (swing phase)



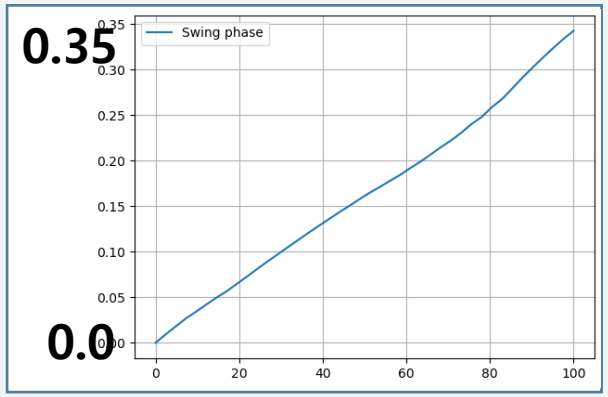


Methods: Phase variable calculation (one gait)

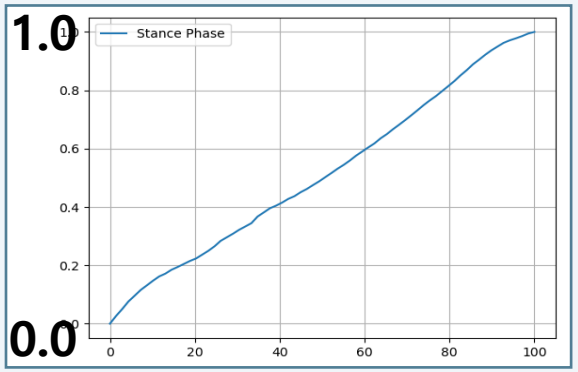


Swing phase (%)

x0.35

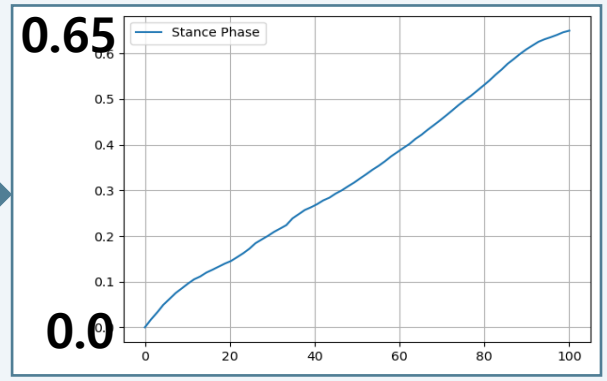


Swing phase (%)



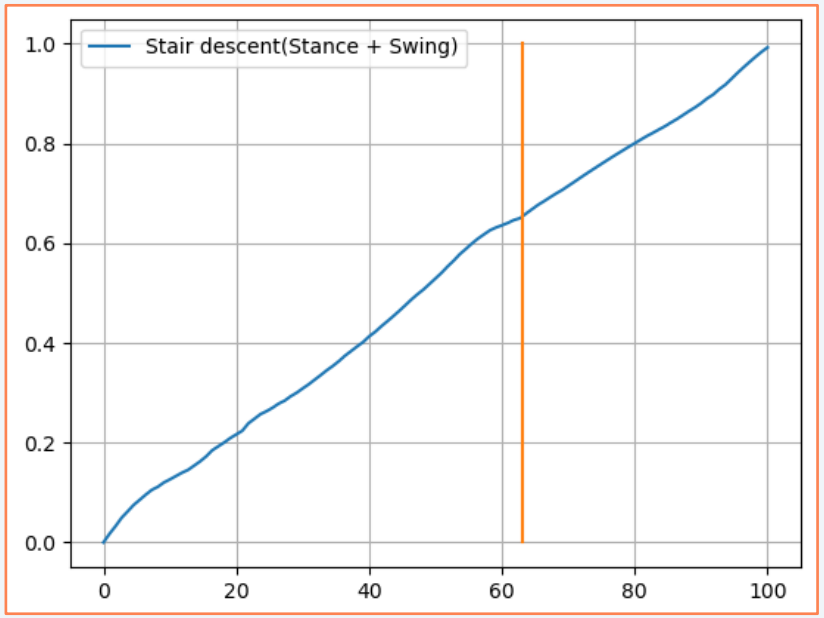
Stance phase (%)

x0.65



Stance phase (%)

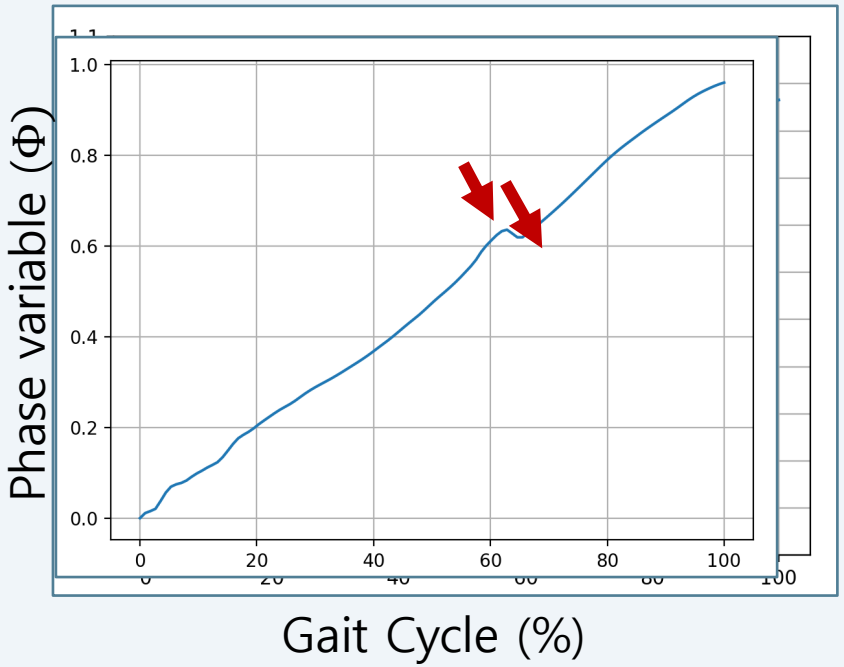
Phase variable for entire gait

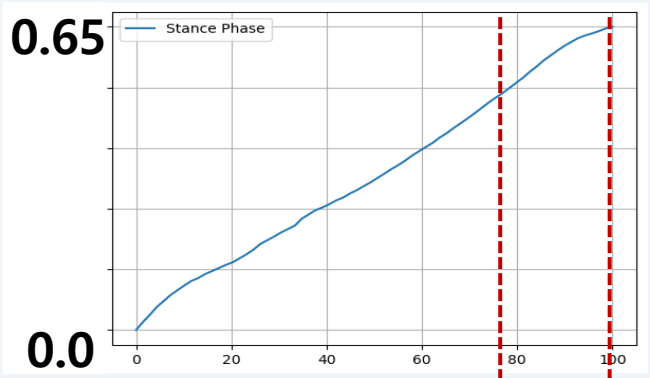


Gait cycle (%)

Methods: Phase variable calculation (blending)

Phase variable for entire gait





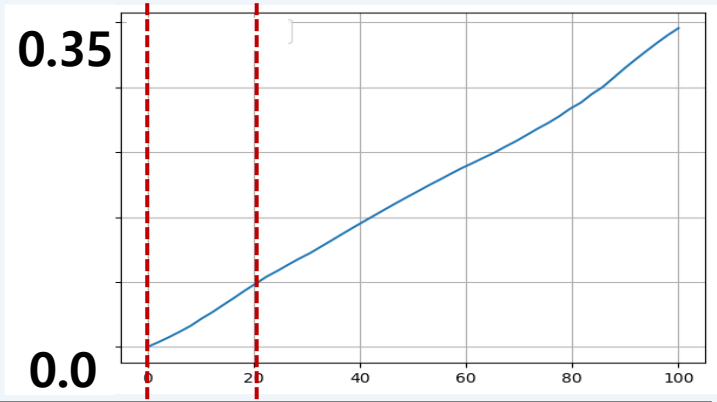
Blending

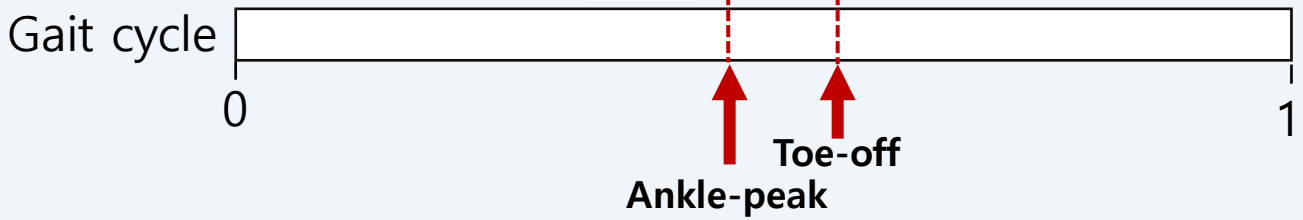
$$\Phi(t) = \frac{\Phi_{sw}(t) + \Phi_{st}(t)}{2}$$

$$t_{ankle\ peak} < t < t_{toe\ off}$$

Stance phase

Temporary swing phase

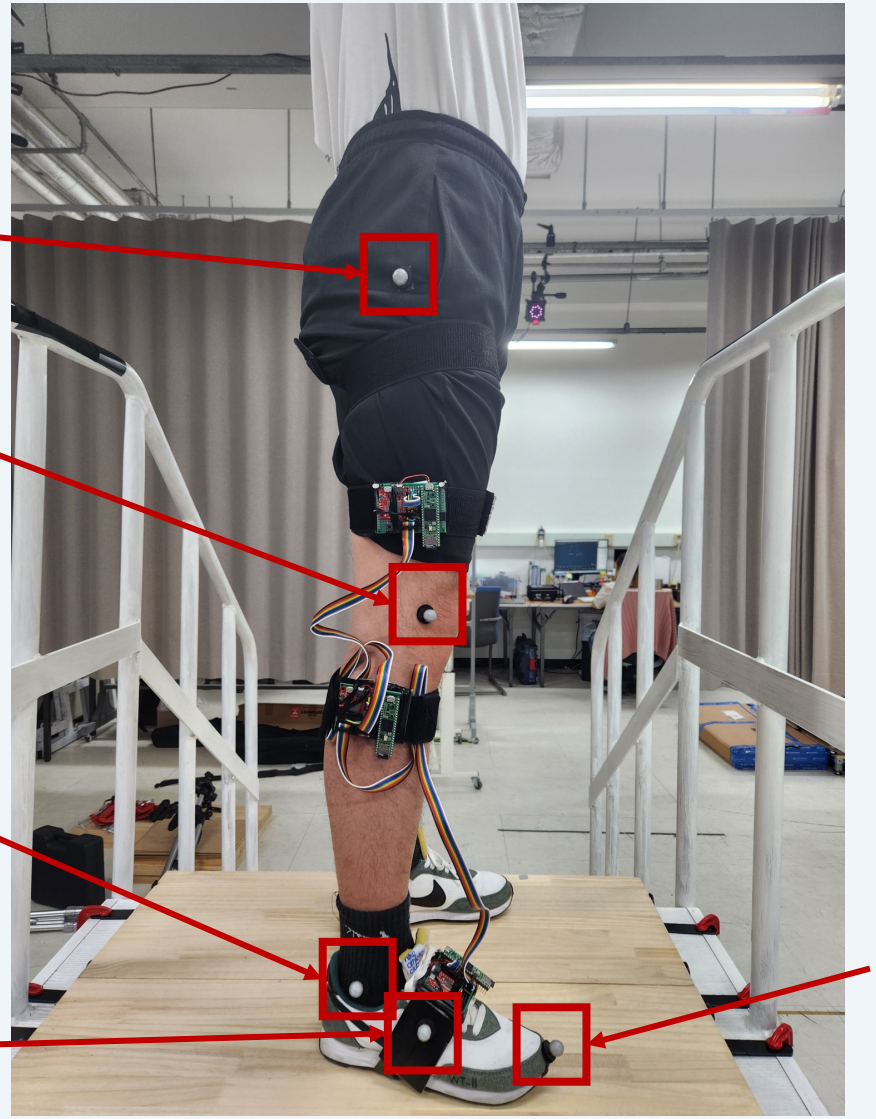


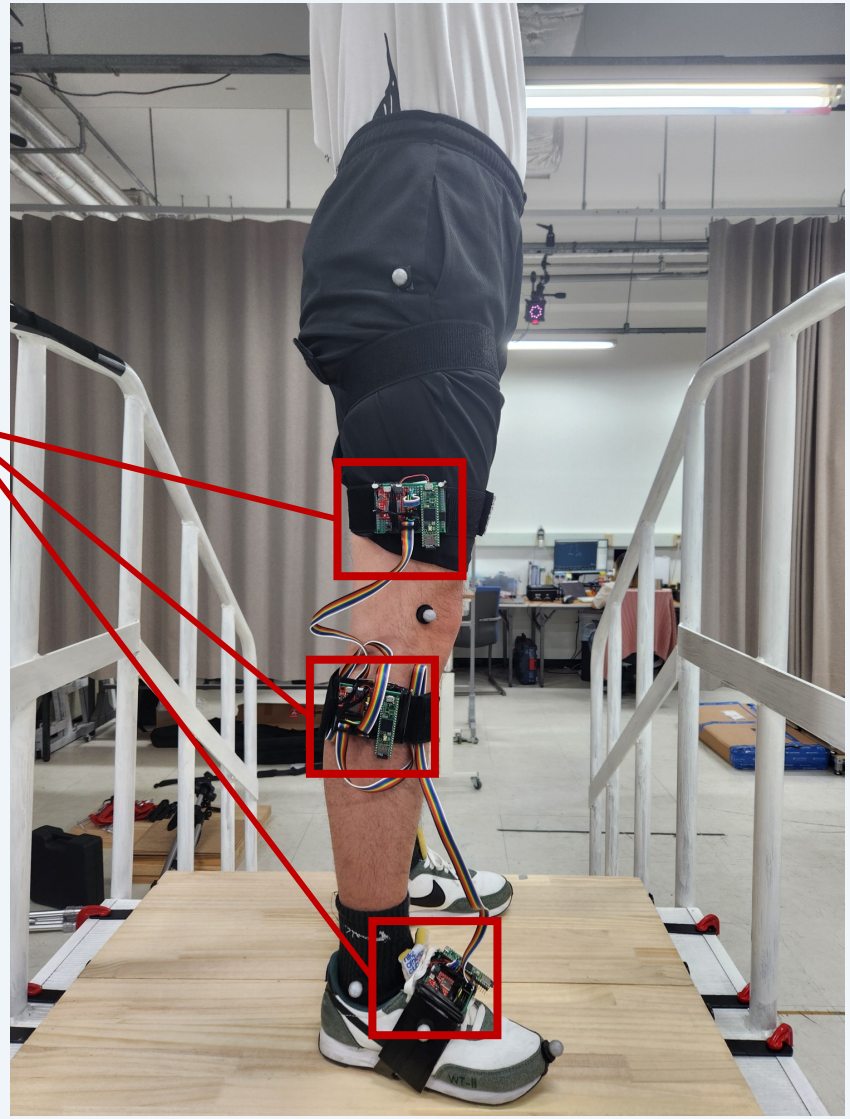


Experiment

- **Motion capture system (Nokov, 100 Hz)**
  - Joint angle, hip position
  - gait event (toe-off, toe-strike)
- **Three IMUs (100 Hz)**
  - Joint angle, hip position
- Stairs
  - Width of 300 mm, height of 185 mm for each stair
- Subject information
  - 5 subjects
  - Gender: 5 males
  - Age: 24.7 ± 2.4 years
  - Height: 177 ± 6.26 cm

Experiment


hip joint
knee joint
ankle joint
fifth metatarsal bone
Toe tip


IMU

Experiment

Training session

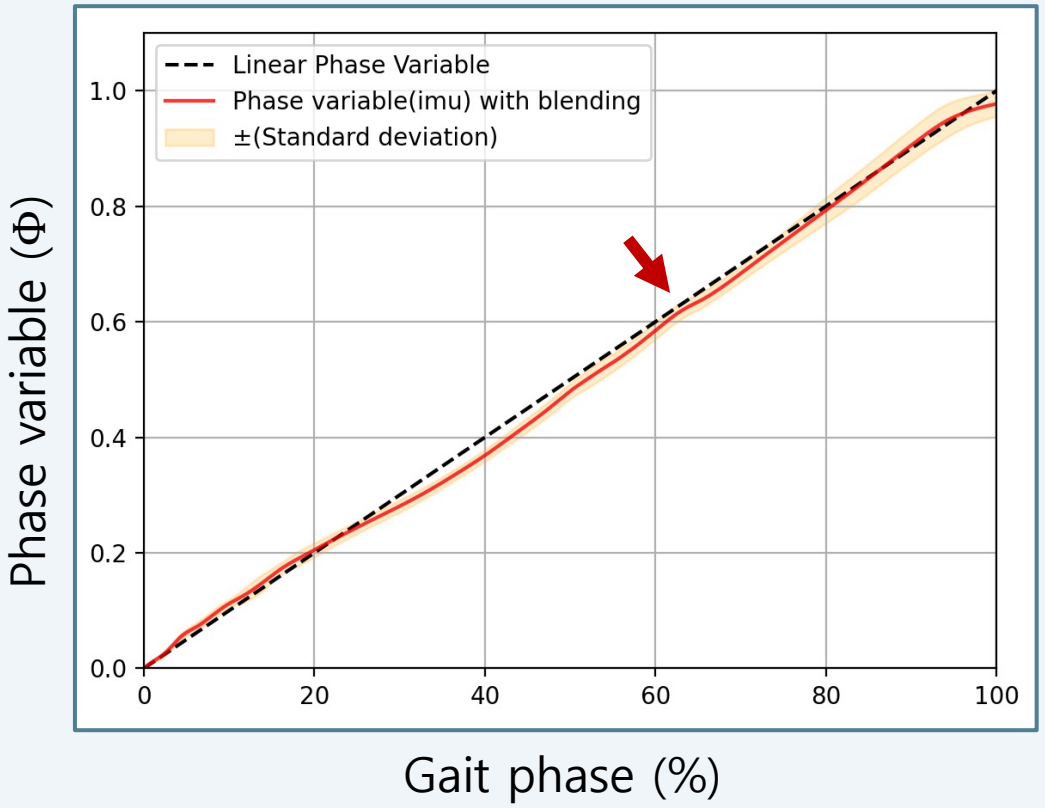
1. The subjects walk down the stairs repeatedly for 5-minutes.
2. If the subject feels walking down the stairs is comfortable enough, training session terminates early.

Experiment session

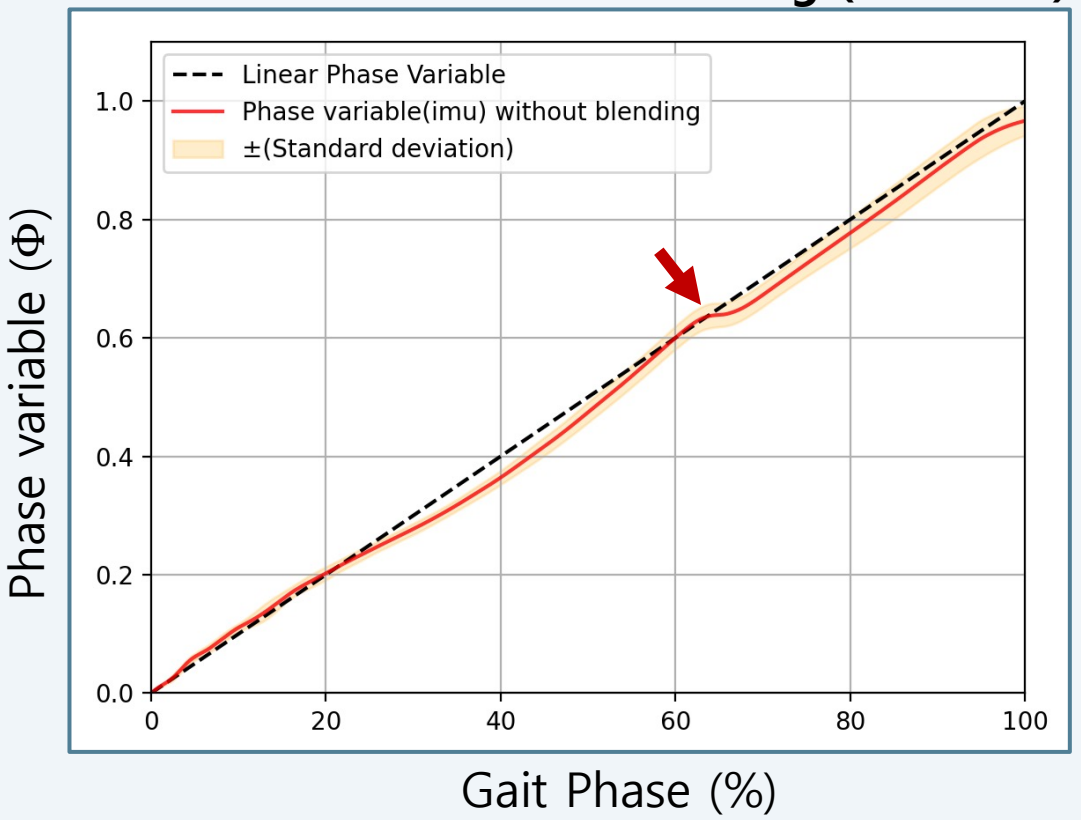
1. Subject **stands on the top of the stairs** in a comfortable pose.
2. After the initiation sign, the subject starts to **walk down the stairs, stepping his right foot forward first**.
3. After the subject **steps on the ground with his right foot**, the subject finishes his walking.
4. **1-3 is done 20 times repeatedly**. If there is any issue with the subject, the experiment will be halted immediately.

Result: Effect of blending

Phase variable with blending (PV-WB)

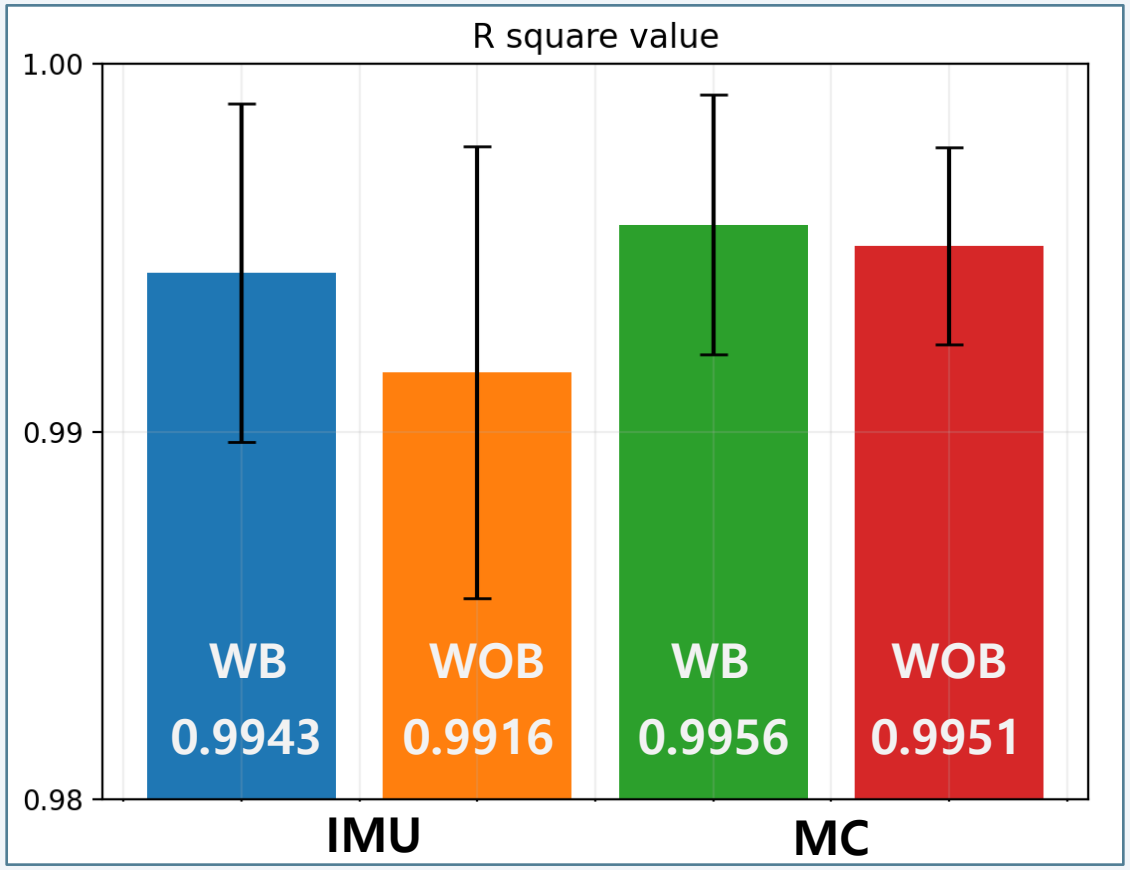


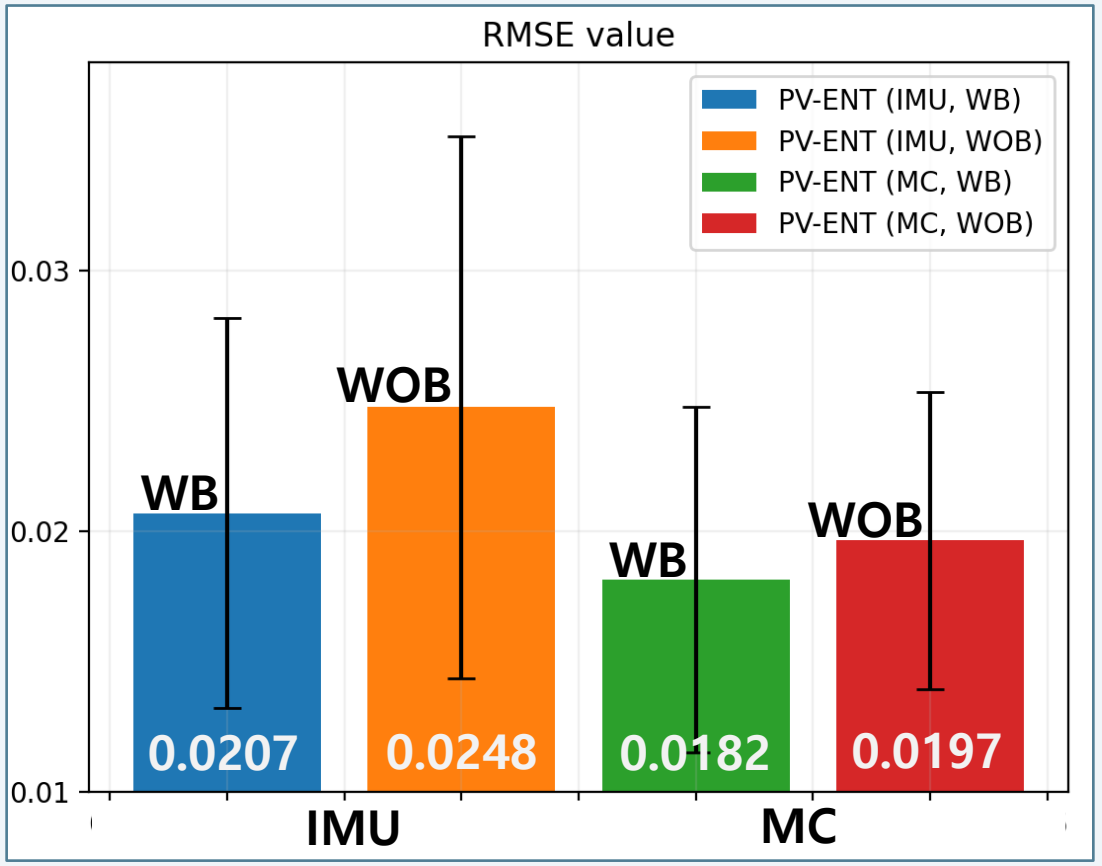
Phase variable without blending (PV-WOB)



Blending method smooth out the phase variable.

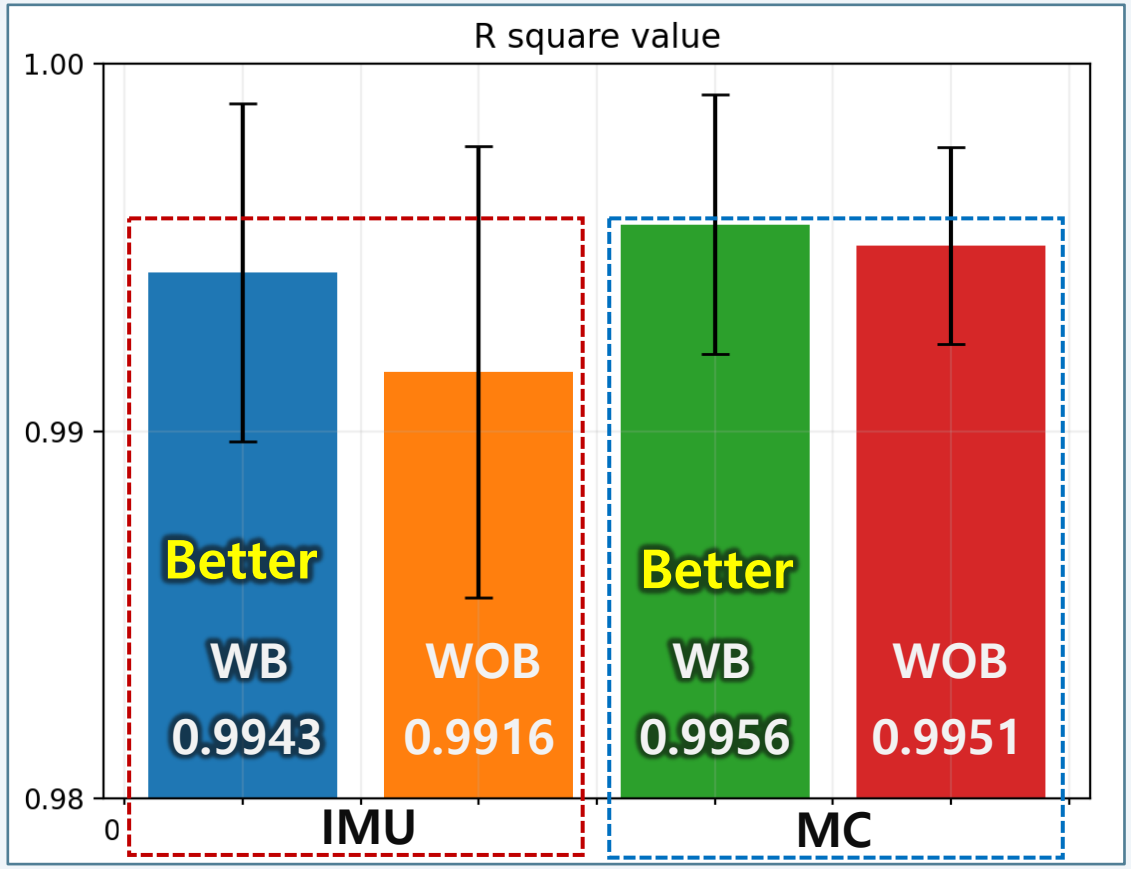
Result: Motion capture vs IMU / with blending vs without blending

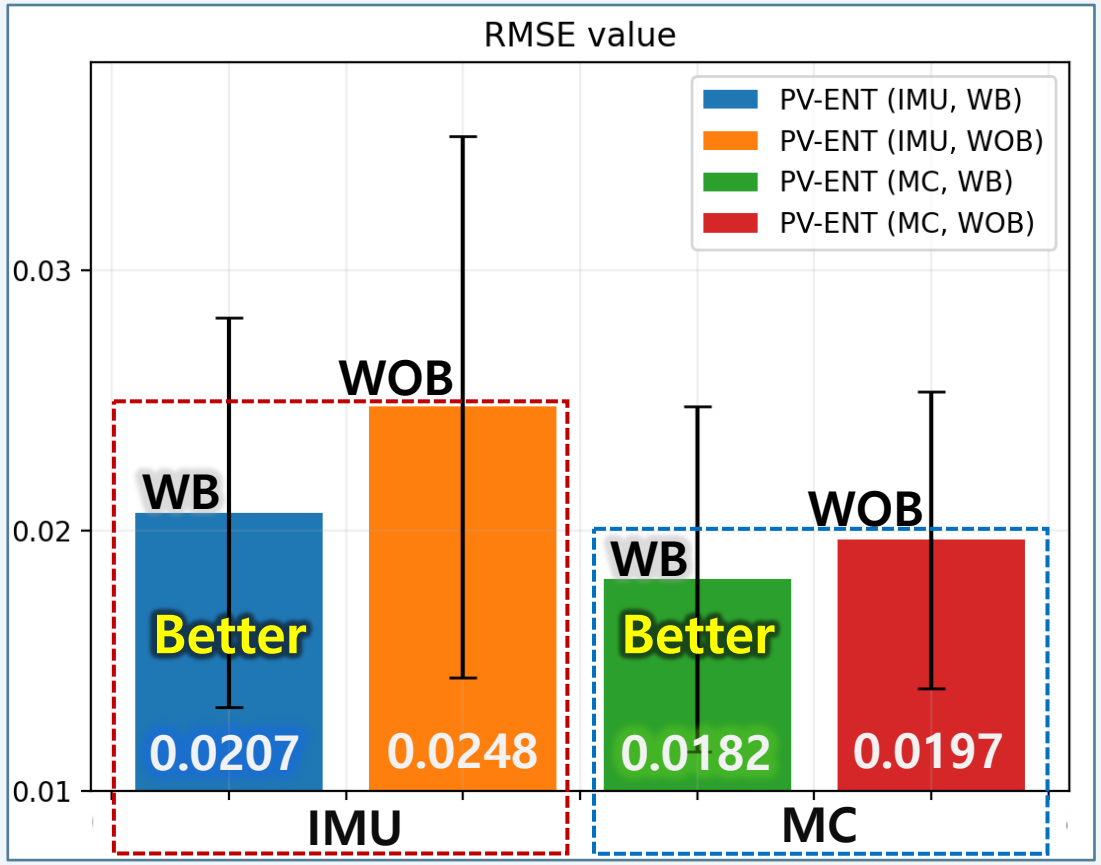




PV-ENT: phase variable for entire gait cycle, **MC**: motion capture, **WB**: with blending, **WOB**: without blending

Result: With blending vs without blending

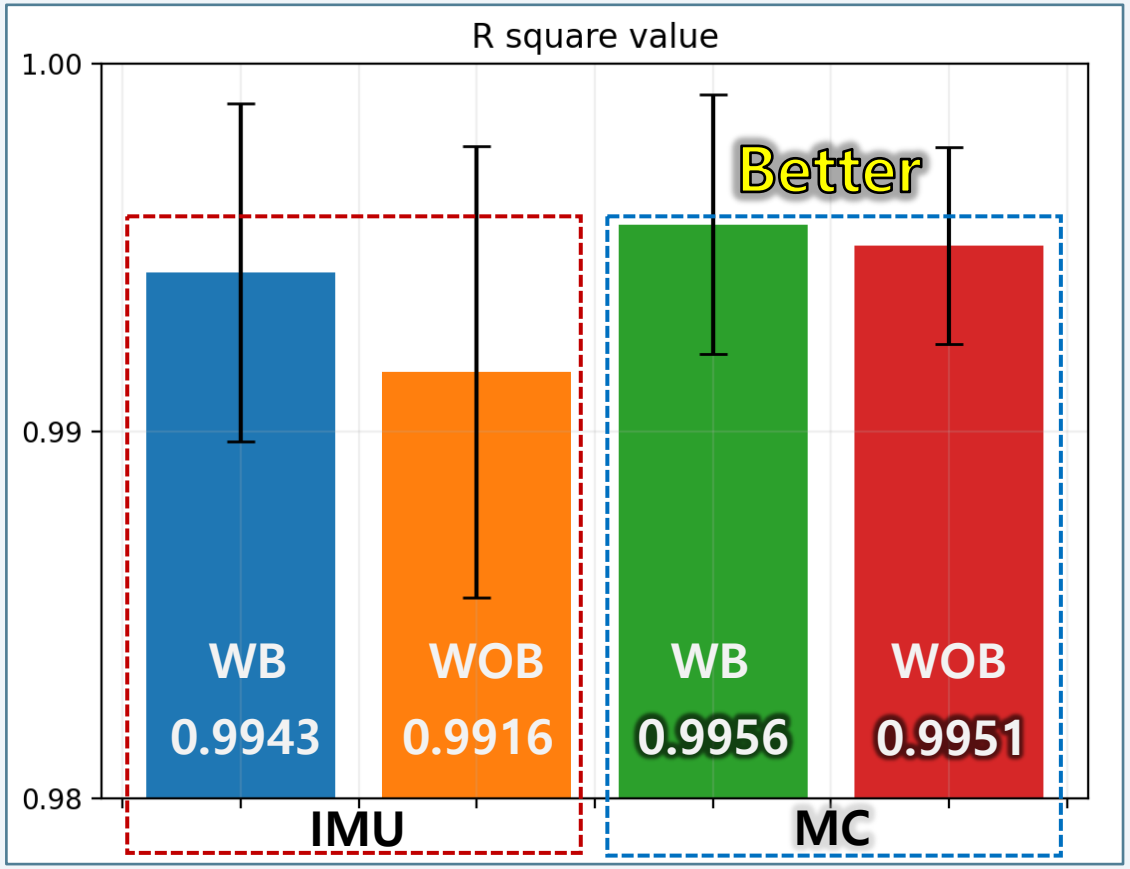


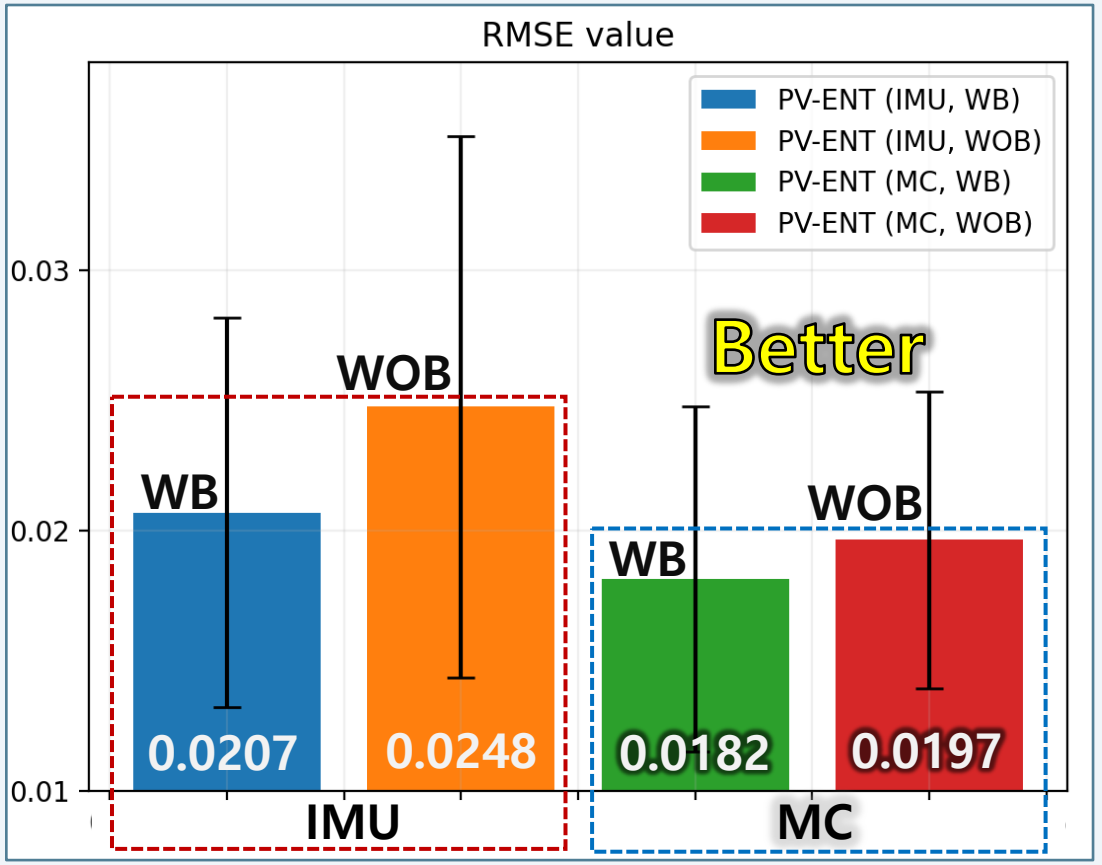


PV-ENT: phase variable for entire gait cycle, **MC**: motion capture, **WB**: with blending, **WOB**: without blending

Phase variable with blending showed better performance than without blending.

Result: Motion capture vs IMU

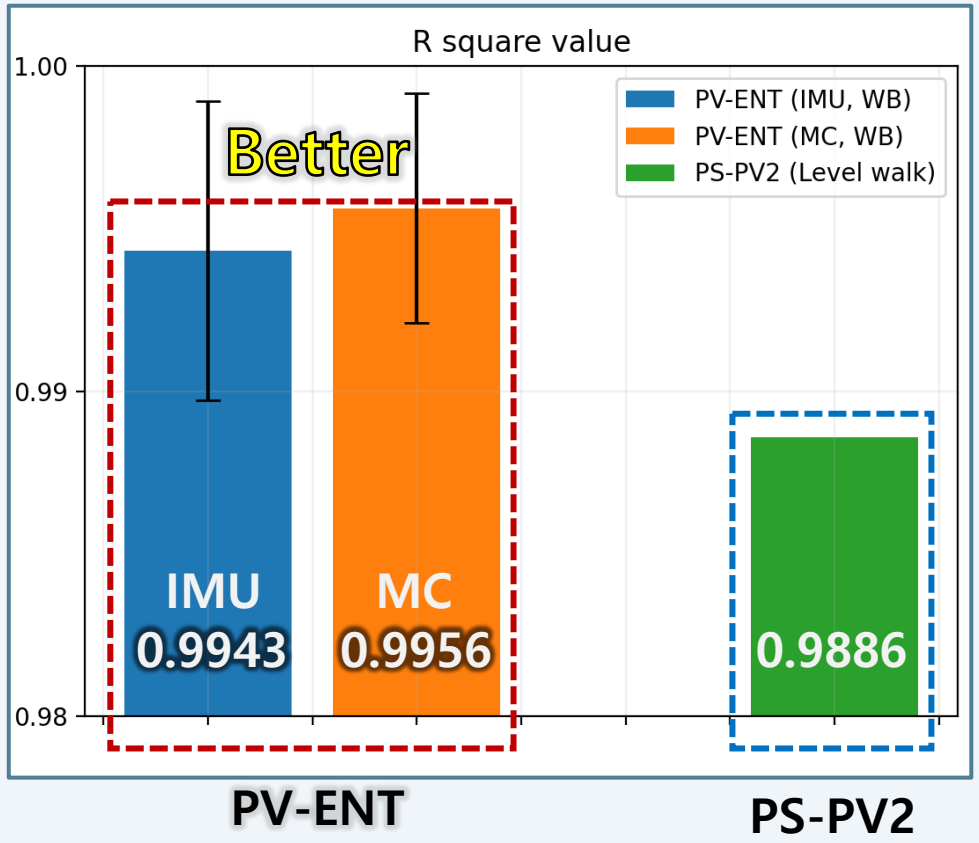


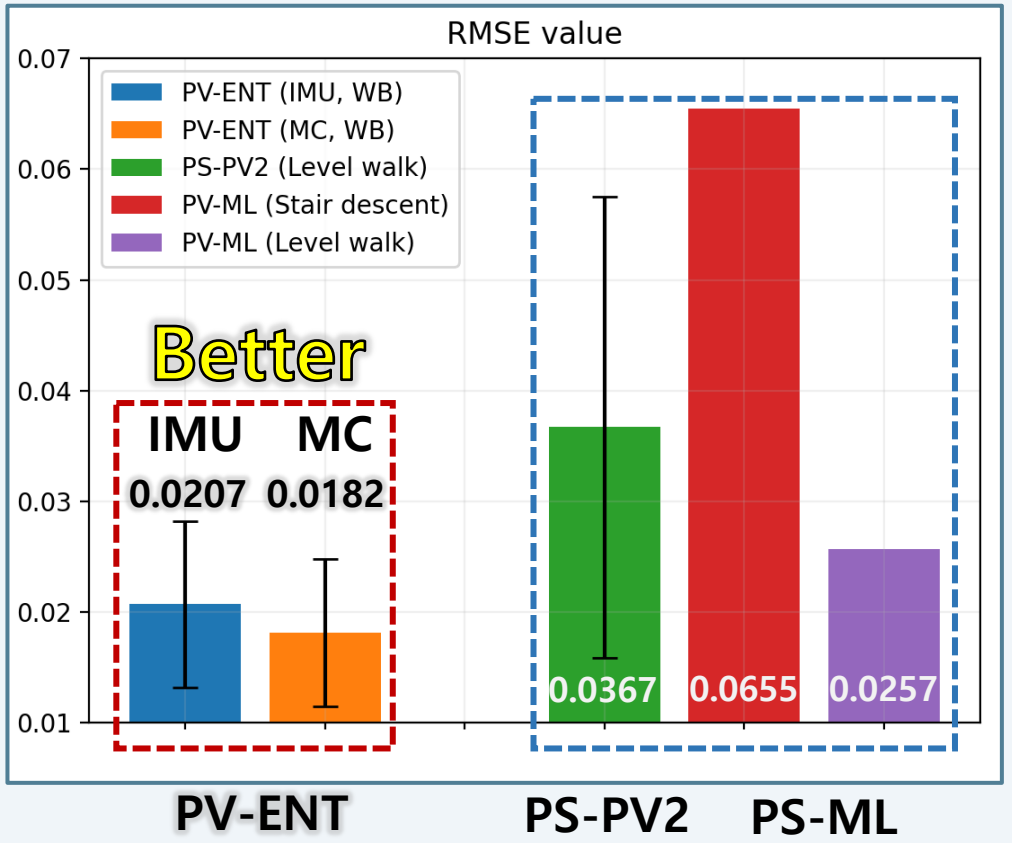


PV-ENT: phase variable for entire gait cycle, **MC**: motion capture, **WB**: with blending, **WOB**: without blending

Phase variable using motion capture system showed better performance than IMU.

Result: Comparison with other studies





PV-ENT: phase variable for entire gait cycle from this research, **MC**: motion capture, **WB**: with blending, **PS-PV2**: phase variable from [1], PV-ML: phase variable from [2]

By comparing PV-ENT with the result of other research,
PV-ENT shows reliable phase estimation performance.

Conclusion and Future work

Conclusion

- **A phase estimation method for stair descent is proposed** with the lack of research in this area
- **Simple blending method can solve the smoothing problem** from connecting different phases.
- **Phase variable using IMU data shows reliable performance**.

Future work

- The phase variable will be validated by **implementing the phase variable to the prosthesis.**
- **The effect of stair height on gait pattern** will be examined.

Reference

[1] Hong, Woolim, Namita Anil Kumar, and Pilwon Hur. "A phase-shifting based human gait phase estimation for powered transfemoral prostheses." *IEEE Robotics and Automation Letters* 6.3 (2021): 5113-5120.

[2] Kang, Inseung, et al. "Real-time gait phase estimation for robotic hip exoskeleton control during multimodal locomotion." IEEE robotics and automation letters 6.2 (2021): 3491-3497


GIST
HUR
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