Real-Time Soleus EMG Biofeedback for Gait Analysis and Stability Assessment

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19/05/2025 - 25/07/2025

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Context and motivation

Why do elderly people tend to walk more slowly, show reduced stability, and struggle to climb hills?

- Decrease in ankle push-off during walking
- Increase in hip contribution

- Less efficient propulsion → slower speed, reduced stability
- Hip strategy → higher metabolic demand → faster fatigue

Context and motivation

- **Common assumption** (Alfieri et al. 2010, Geirsdottir et al. 2012)

  Sarcopenia and leg muscle weekness → muscle atrophy → strengthening program
  → do not improve the walking abalility

- **Nonetheless,** Franz et al. (2013) proved that

  - Elderly adults (~72 yrs) exert 12% less propulsive force than young adults
  - With real-time visual feedback, they recovered or exceeded young adults' propulsion
  - **Reveals an unused ankle power reserve**

→

- Develop a real-time EMG biofeedback system
- Study its impact on stability

Objective of the internship

1. Develop a real-time EMG biofeedback system targeting the soleus muscle

2. Provide visual feedback of muscle activation during push off phase

3. Assess whether modulating this activation affects whole body stability

Background

- **Gait cycle :** focus on the terminal stance & pre-swing (push-off).
- **Soleus :** single-joint plantarflexor, main contributor to propulsion → ideal for feedback.
- **EMG :** measures muscle activation non-invasively
- **GRF :** Ground reaction forces measured by forces plates

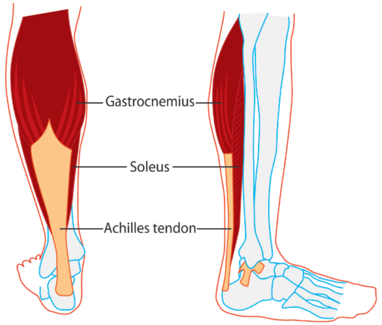

Figure 1 :Calf anatomy

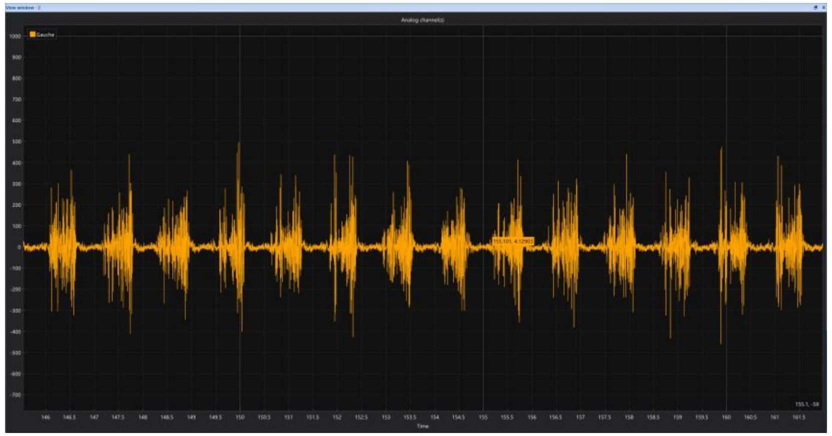

Figure 2: Raw EMG signal

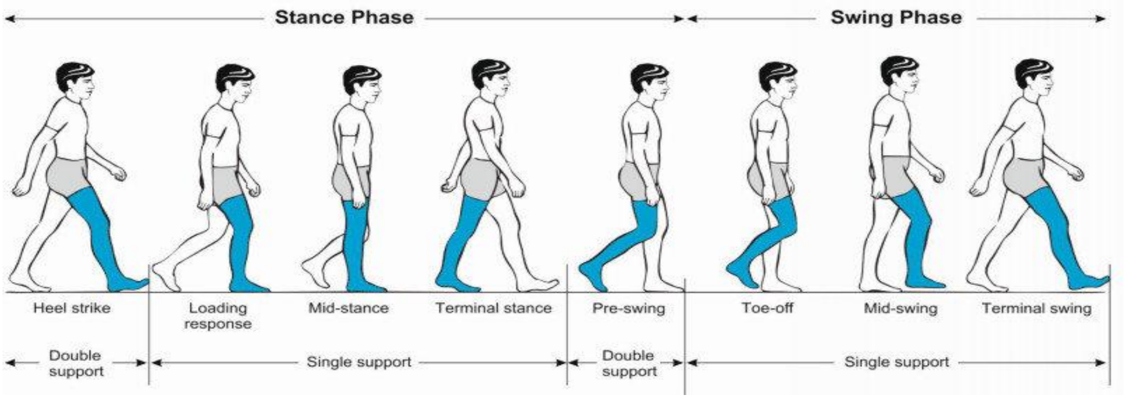

Figure 4 : Gait cycle

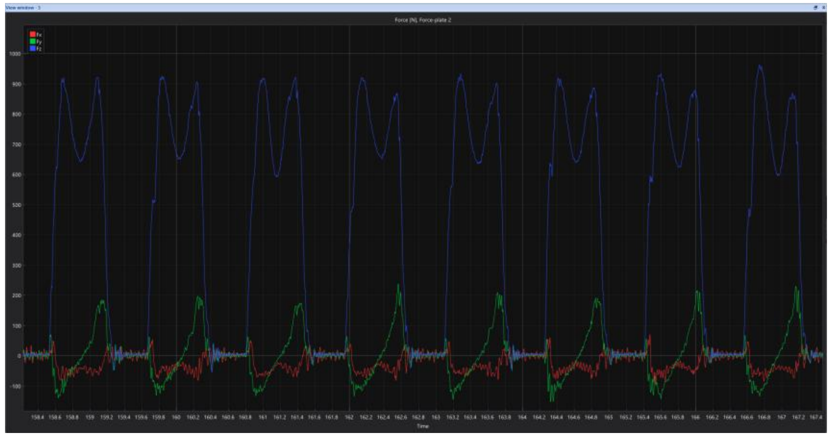

Figure 3: Raw GRF (Ground reactions forces) signal

Now that we have the objective and the background

1. How do we create a biofeedback?
   a) Signal processing pipeline
   b) System implementation (python)
   c) Graphic User Interface

2. How is stability measured?
   a) Motion capture system
   b) Kinematic moment

3. Results

How do we create a biofeedback ?

Figure 5 : Surface EMG

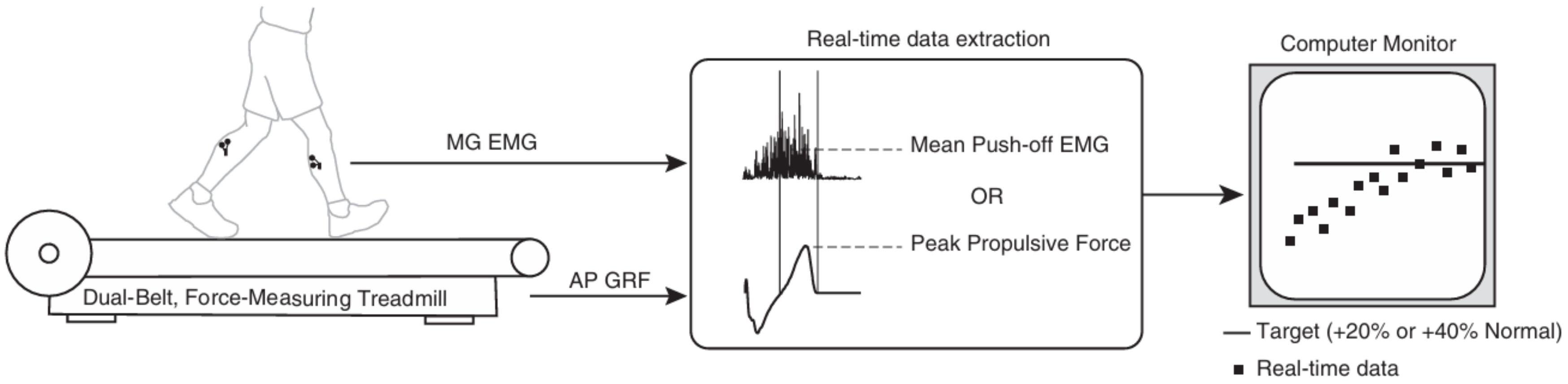

Figure 6 : Biofeedback setup

How do we find the push-off phase?

- 50-Newton threshold in the vertical component → beginning of a stride
- Identify the positive phase of the longitudinal curve → compute mean EMG over that part

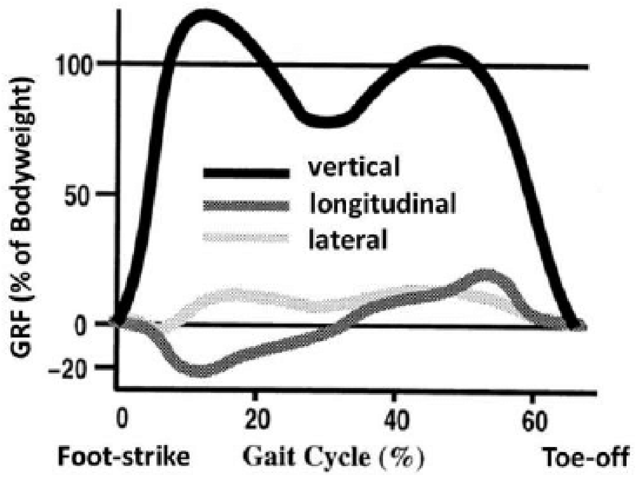

Figure 7 : Ground reactions forces

Signal processing pipeline

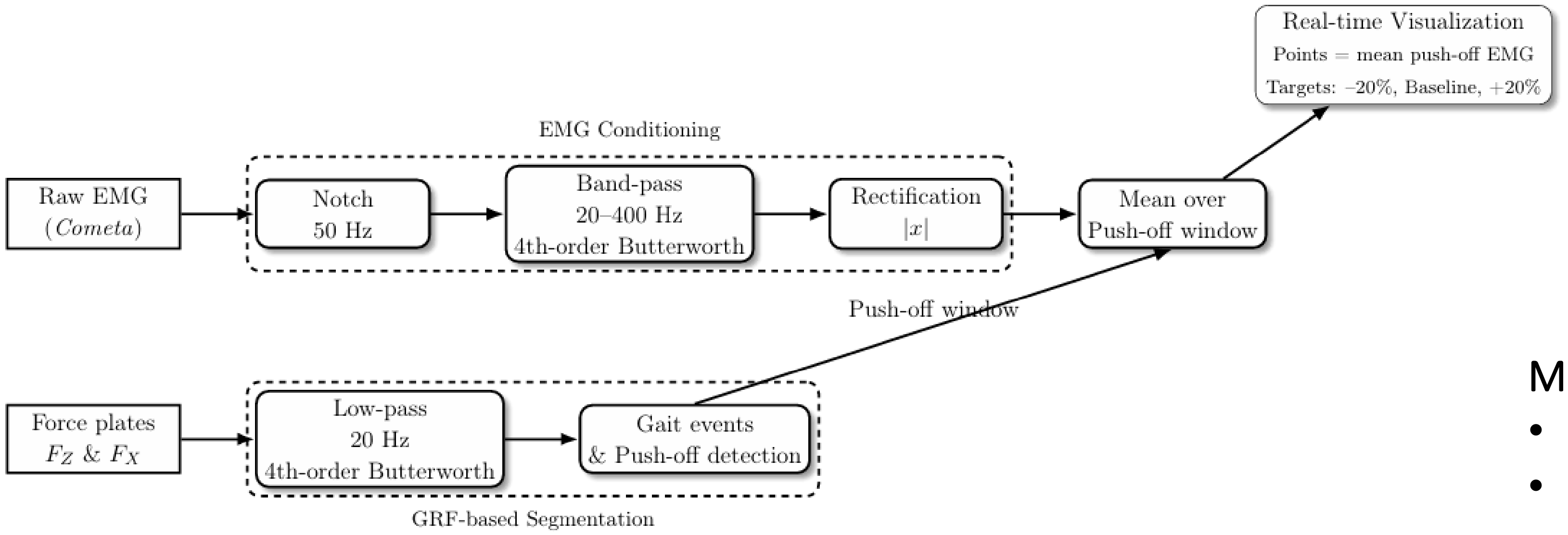

Figure 8 : Signal processing pipeline

Main Challenges :

- Achieve minimal delay in feedback
- Ensure real-time processing → *use lfilter instead of filtfilt*
- Maintain synchronization between signals

System Implementation

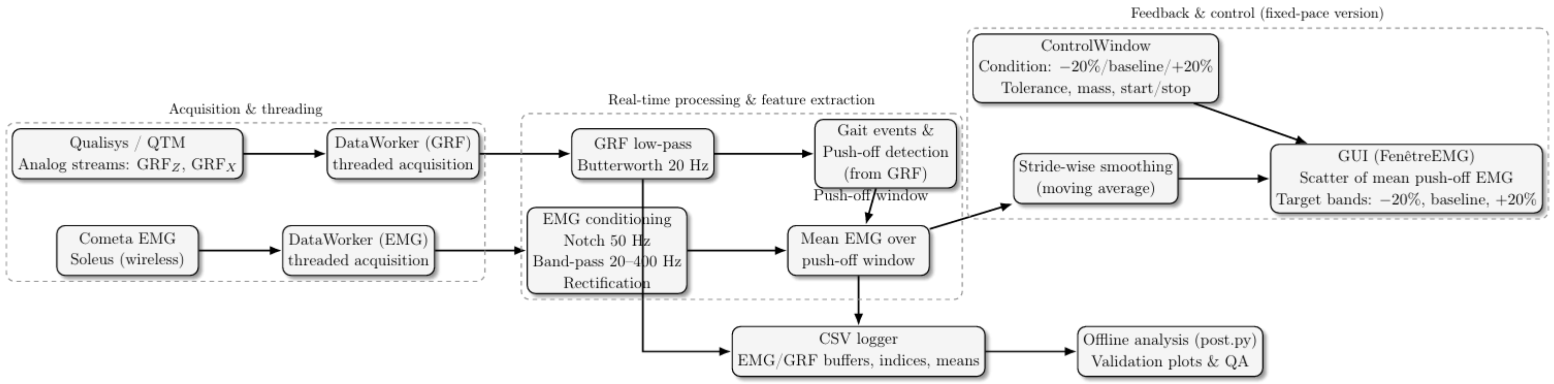

Figure 9 : ¨Python pipeline

- **Language:** Python (PyQt5 + qtm_rt).
- **Multithreading** : separate threads for acquisition & GUI → ensure low latency.

Graphic User Interface

- Main GUI : real time scatter of mean push-off EMG
- Feedback refreshes every stride
- Smoothed over 3 steps

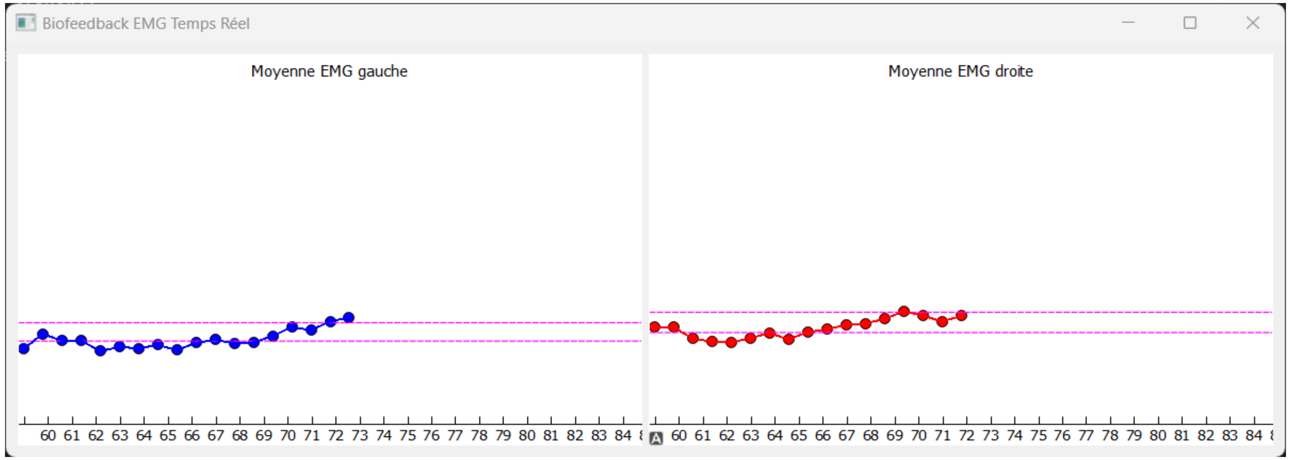

Figure 10 : Main GUI

- Control window : Select condition (+/- 20%, 0%, define tolerance and save data)

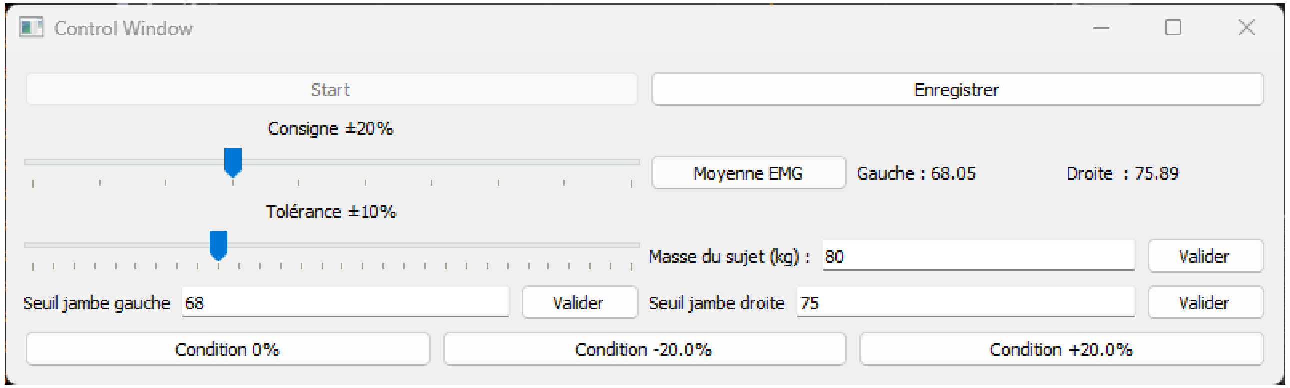

Figure 11 : Control window

How is stability measured?

How is stability measured?

Using whole-body **kinetic moment**

- Reflects how the body controls rotation around its center of mass.
- Stable gait = small, controlled angular momentum variations.

How do we measure the kinematic moment ?

How is stability measured?

- Motion capture system (marker + infrared cameras)
- Markers placed on the body to capture movement

Figure 12 : Treadmill of the lab

Figure 13 : Example of markers

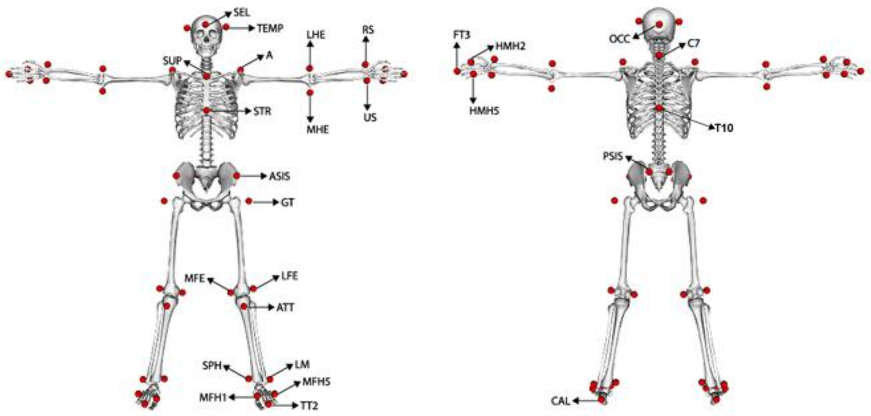

Figure 14 : Marker set – positions of each markers (Maldonado et al.)

How do we assess the stability?

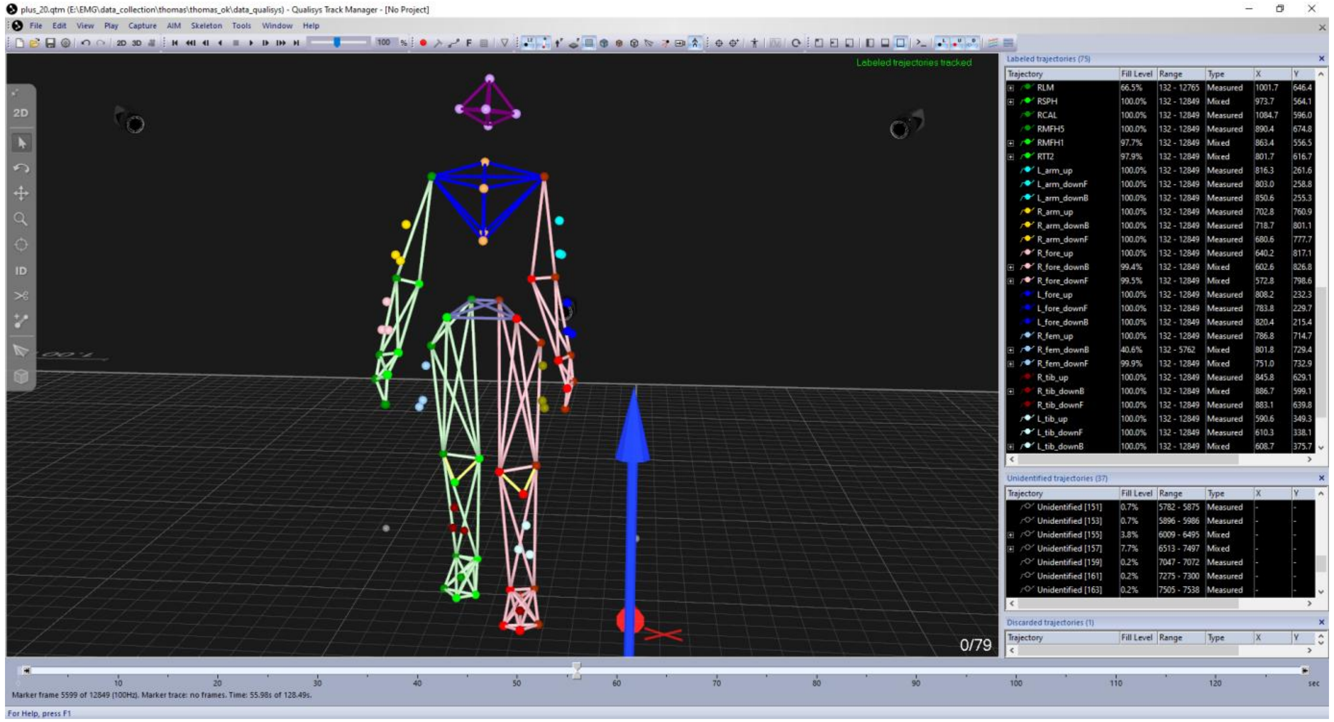

Figure 15 : Qualisys software window

- Model reconstruction
- Extract data into a c3d file

Kinematic moment calculated using a Python program developed by PhD students

Now that we've seen how the biofeedback was created and how stability is assessed,
let's go through the experimental protocol and the main results.

Experimental protocol

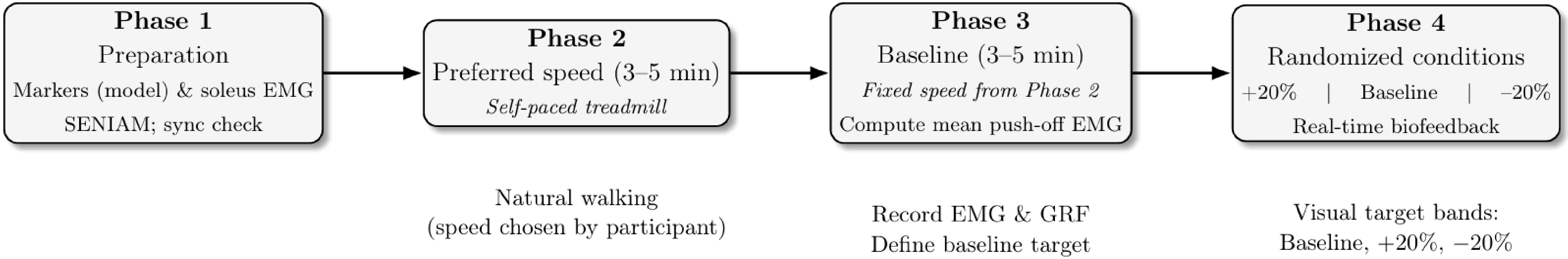

Figure 16 : Experimental protocol

Results

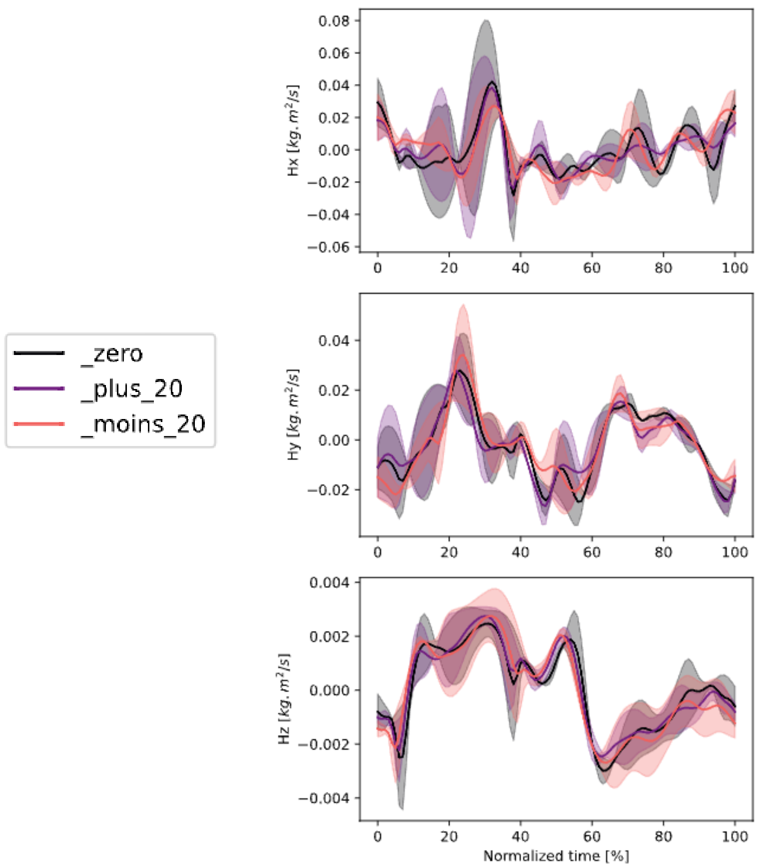

Figure 17 : Kinetic moment along three axes with respect to normalized time

- Only 2 subjects only due to a lack of time → results not conclusive
- Slight increase in medio-lateral variability (Hy) in −20% condition → Possible link between reduced ankle activity and balance control.
- Kinetic moment calculated over the period where the condition was best respected (majority of points within the tolerance line)

Discussion

- Real-time soleus feedback was technically feasible (stable in real time)
- Soleus = reliable feedback muscle for propulsion
- Preliminary data: modulating ankle activation may influence stability
- Limitations: small sample (n=2), treadmill vs. natural gait
- Future directions : EMG hip measurement, inertial units

Competence Phelma

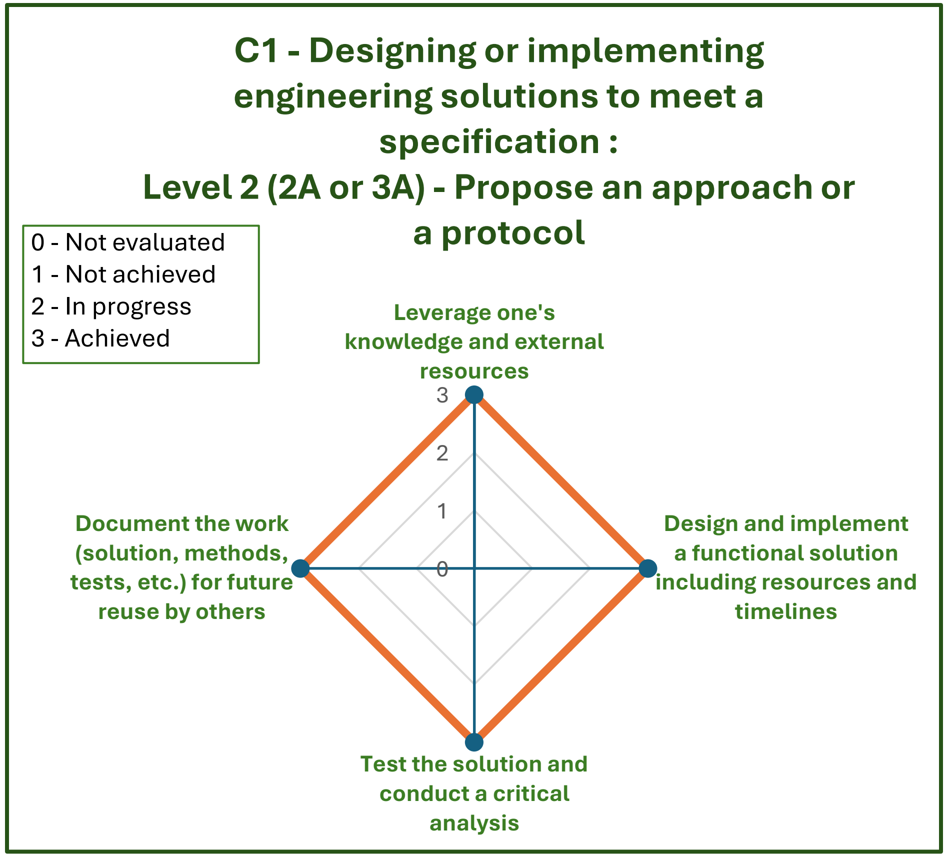

Figure 17 : Competence Radar – C1- Level 2

- Realization of the EMG biofeedback in real time
- Applied class knowledge for signal processing and Python implementation
- Used external resources to gain new skills in biomechanics, programming, and QTM
- Tested multiple system versions to achieve a functional setup
- Work documented through a detailed report and well-structured code