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

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Yévan De Busschere

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IRISSE Laboratory
117 rue du Général Ailleret - 97430 - Le Tampon - La Réunion

Supervised by:

Internship Supervisor: Teddy Caderby, teddy.caderby@univ-reunion.fr

School Tutor: Franz Bruckert, franz.bruckert@grenoble-inp.fr

Confidentiality: No

École nationale supérieure de
physique, électronique, matériaux
Grenoble INP - Phelma
3 Parvis Louis Néel – CS 50257
38016 Grenoble Cedex 01
Tél : +33 (0)4 56 52 91 00
Fax : +33 (0)4 56 52 91 03
http://phelma.grenoble-inp.fr

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My thanks go as well to the colleagues from the laboratory who volunteered as participants during the preliminary trials, and to the technical staff for their assistance with the motion capture system, the instrumented treadmill, and the synchronization of all devices.

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1 Introduction

Walking ability often declines with age, and one of the most consistent observations is a reduction in forward propulsion during the push-off phase. This loss of propulsive function has a major impact on mobility, contributing to slower walking speeds, difficulties walking uphill, and, eventually, reduced independence in daily life. In aging, a common gait adaptation is the transfer of mechanical effort from distal joints, such as the ankle, to proximal joints. Older adults tend to use their hip muscles to compensate for reduced ankle push-off, even though the ankle is normally the primary source of forward propulsion. While this strategy may allow them to maintain walking function, it comes at a higher metabolic cost and does not fully replace the efficiency of ankle driven propulsion.

It might be assumed that diminished ankle push-off reflects an inevitable consequence of muscle weakness or sarcopenia. However, several studies, including Franz et al. (2013) [1], suggest otherwise. In that work, older adults with reduced propulsion during level walking were shown to increase their propulsive forces to levels equal to or even greater than those of young adults when provided with real-time biofeedback [1]. This demonstrates that they retain a considerable and underutilized reserve of ankle power. Rather than a limitation of capacity, the reduction in ankle push-off during natural walking appears to be a matter of motor strategy, with older adults favoring hip recruitment over ankle use [1].

Biofeedback, in this context, refers to the process of measuring physiological signals such as muscle activity or ground reaction forces and presenting them back to the individual in real time. By making normally invisible internal processes visible, for example, through visual or auditory cues biofeedback enables participants to consciously adjust their motor output and adopt more effective movement strategies.

The findings from Franz et al. (2013) [1] highlight biofeedback as a promising approach to encourage older adults to re-engage their ankle plantarflexors during gait. By directly providing information on muscle activation or ground reaction forces, biofeedback can shift control strategies back toward the ankle and help restore a more youthful pattern of propulsion. Such interventions may not only improve walking performance but also reduce the metabolic burden associated with compensatory hip use, offering a pathway to maintain mobility and independence in aging populations.

In this context, the present internship focused on the development of a real-time system targeting the *soleus*, a key ankle plantarflexor. The system was designed to provide visual feedback of soleus activation during push-off and to guide participants in adjusting their muscle activity relative to baseline levels. Beyond propulsion, the project also aimed to investigate how different levels of soleus activation influence whole body stability during walking, with the kinetic moment used as the variable to analyze stability.

In this report, the implementation in Python of the real-time EMG biofeedback will be presented, as the coding was carried out entirely by myself. In contrast, the calculation of the whole-body kinetic moment relied on a tool developed by PhD students in the laboratory. The first part of this report will present the general knowledge required to understand this study. Then, the methods and hardware used will be detailed, as well as the Python implementation of the biofeedback. Finally, the results will be presented along with a discussion on the topic.

2 State of the Art

This section aims to provide the general background on biomechanics necessary to understand the remainder of this report. It also presents basic information on EMG and on the motion capture system used to estimate stability during walking.

2.1 Gait cycle fundamentals

The gait cycle is classically divided into stance and swing. The stance phase includes heel strike, loading response, mid-stance, terminal stance, and pre-swing (push-off), followed by the swing phase, which comprises toe-off, mid-swing, and terminal swing as the Figure 1 illustrates. In this study, the focus is only on the stance phase, particularly on the last two phases: terminal stance and pre-swing. These two phases are responsible for forward propulsion.

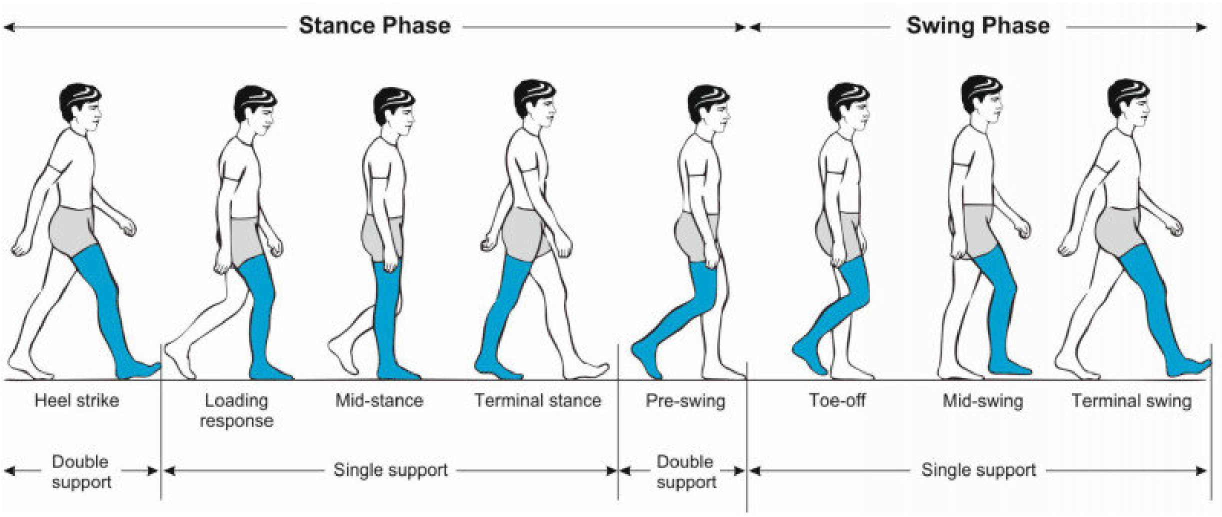

Figure 1: Illustration of the gait cycle [3]

To identify the pre-swing (toe-off) phase during the gait cycle, a study on the groud reaction forces have been conducted. Vertical and anteroposterior (longitudinal) ground reaction forces (GRF) are useful markers for identifying the phases of gait. In the vertical component in Figure 2, the loading peak (first peak) and the push-off (second peak) impulse can be clearly observed, while the anteroposterior (longitudinal) component in Figure 2 shows the transition from braking (negative part of the graph) to propulsion (positive part of the graph). By using these signals, the gait cycle can be segmented with good accuracy. This segmentation is then applied to extract muscle activity specifically during the push-off phase.

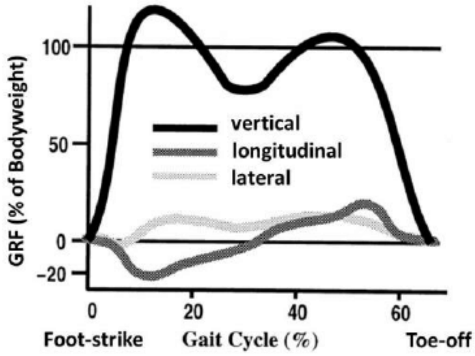

Figure 2: Ground Reaction Force (vertical component) measured under a foot while walking. Adapted from [2]

2.2 Plantarflexor function and the role of the *soleus*

The *soleus* and *gastrocnemius* together form the triceps surae, but they contribute differently depending on the task. During level walking at preferred speeds, *soleus* activation increases progressively throughout stance, reaching its peak during push-off, whereas *gastrocnemius* activity varies more strongly with walking speed and with the position of the knee. The *soleus* is the primary contributor to the ankle plantarflexion moment and to the forward propulsion of the center of mass in steady walking, which makes it an effective target for biofeedback. By contrast, the *gastrocnemius* is more strongly recruited during running or jumping and, although it still plays a role during walking, its contribution is smaller, making it less relevant for the objectives of this study.

2.3 Electromyography (EMG)

Electromyography (*EMG*) is a non-invasive technique used to measure the electrical activity produced by skeletal muscles. Surface EMG electrodes detect voltage fluctuations generated by motor unit action potentials, which reflect the level and timing of muscle activation [6]. In biomechanics, EMG is widely used to study neuromuscular strategies during locomotion, rehabilitation, and sports performance.

For walking tasks, EMG provides valuable information about the timing and intensity of muscle recruitment across the gait cycle. In particular, monitoring the activity of the *soleus* muscle allows direct assessment of plantarflexor contribution to push-off, which is critical for forward propulsion. EMG recordings thus serve as the foundation for building biofeedback systems that guide participants to modulate their muscle activity in real time.

In this study, EMG signals were collected from the *soleus* using a wearable *Cometa* wireless system. EMG raw signals can be very noisy due to powerline interference or movement artifacts (such as heartbeat), as illustrated in Figure 3. These raw signals later underwent digital processing and feature extraction (detailed in Section 3.4) to provide a clear and interpretable feedback metric.

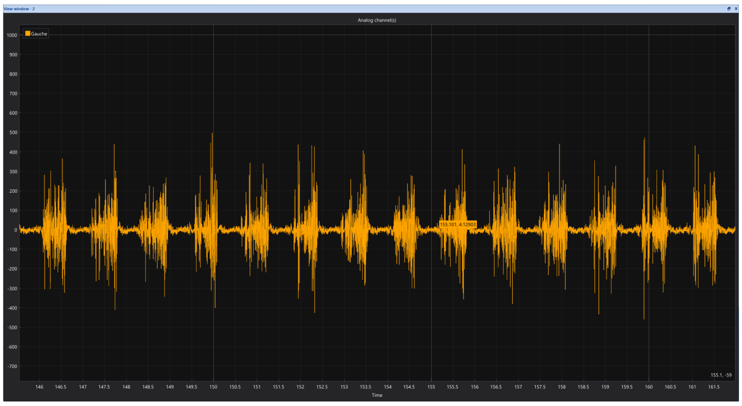

Figure 3: Example of a raw EMG signal acquired from the soleus during walking. This unprocessed signal still contains baseline noise, powerline interference, and movement artifacts.

2.4 Motion capture and instrumented treadmills

The experimental setup relied on a double-belt treadmill with built-in force plates, allowing precise measurement of ground reaction forces (GRF) inside the motion capture area. These force signals were synchronized with the Qualisys Track Manager (QTM) [4], which recorded body kinematics using reflective markers fixed to anatomical landmarks. From the trajectories of these markers, the system reconstructed joint angles, limb movements, and overall body motion.

By combining kinetic data from the treadmill with kinematic data from the markers, gait could be studied in detail and with high accuracy. This integration also made it possible to compute the whole-body kinetic moment, an important measure for assessing balance during walking. The markers were thus essential for linking external forces to body motion and for quantifying postural control.

In this protocol, the treadmill operated in self-paced mode, allowing participants to adjust their speed naturally. This approach avoids the constraints of fixed-speed walking and provides a more realistic evaluation of neuromuscular adjustments and stability.

Summary

In summary, the literature supports the use of *EMG* biofeedback on plantarflexors to study locomotor adaptation. The *soleus* provides a stable and functionally salient target for push-off modulation, while instrumented treadmills and GRF-based segmentation enable robust, low-latency phase detection for real-time applications.

3 Materials and Methods

This section will present the hardware, the exeprimental setup establish in order to conduct this study and the protocole for the test part.

3.1 Environment and hardware

Experiments were conducted in a motion capture space equipped with:

- A double-belt treadmill with integrated force plates, measuring GRF in vertical (Z) and anteroposterior (X) directions.
- An optical motion capture system controlled via Qualisys Track Manager (QTM) for kinematic tracking and device synchronization.
- A *Cometa* [5] wireless surface *EMG* system for muscle activation acquisition.

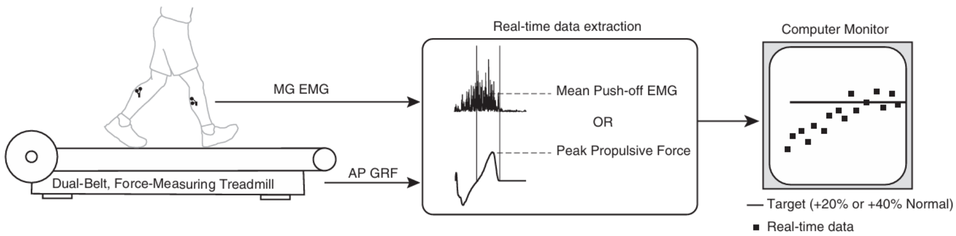

Figure 4: Schematic of the real-time biofeedback system. Surface EMG (here shown on the medial gastrocnemius, as in Franz et al., 2013 [1]) and anteroposterior ground reaction forces are acquired during treadmill walking, processed to extract mean push-off EMG or peak propulsive force, and displayed on a monitor as visual feedback relative to target values

Figure 4 shows the experimental setup used in this study. The EMG signals from the Cometa devices and the ground reaction forces from the treadmill force plates are sent to the PC through the Qualisys software. Python then accesses these data to extract, in real time, the mean push-off activity of the *soleus* while the subject is walking. This mean push-off activity is finally displayed on the screen using a projector.

3.2 Participants and preparation

Healthy adult volunteers from the laboratory participated in pre-tests. Preparation included:

- Skin preparation and electrode placement on the *soleus* following SENIAM recommendations (The electrodes need to be placed at 2/3 of the line between the medial condylis of the femur to the medial malleolus)[7].
- Placement of reflective markers according to a whole-body marker set of Galo Maldonado [8] positioned on anatomical landmarks , enabling robust kinematic model fitting .

Figure 5: Placement of surface EMG electrodes on the soleus muscle.

The *soleus* is a muscle located deep within the calf, which complicates EMG electrode placement since nearby muscles, such as the *gastrocnemius*, can interfere with the signal. SENIAM recommendations [7] must be followed to ensure a high-quality recording.

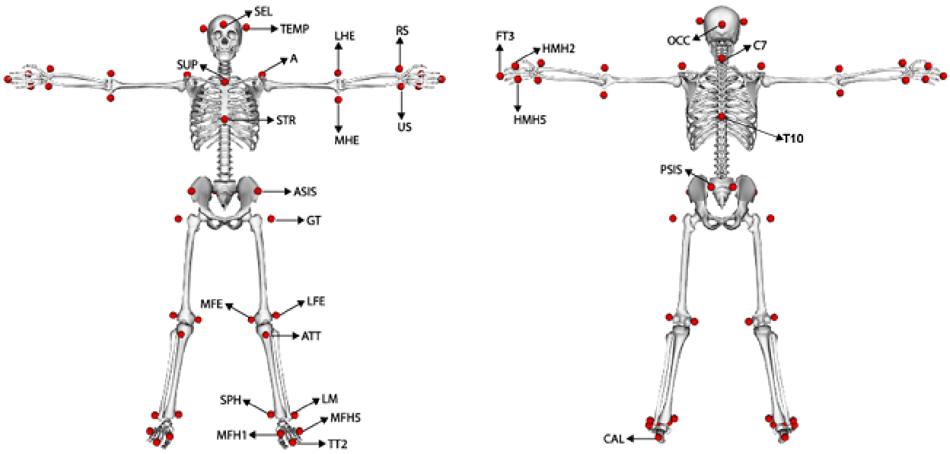

Figure 6: Markerset depicted on the whole body skeletal model [8]

Marker placement considerations. The accuracy of the reconstructed model in Qualisys depends critically on correct marker placement, as shown in Figure 8. Markers shown in Figure 7 must be positioned on bony anatomical landmarks rather than on soft tissue, which can move independently of the underlying bone and introduce artifacts into the kinematic reconstruction. By fixing the markers on stable reference points such as the malleolus, femoral condyles, iliac spines, or calcaneus, the motion capture system can correctly identify each segment and compute joint centers and angles with minimal error. This procedure follows the recommendations of the International Society of Biomechanics (ISB) and ensures that the reconstructed skeletal model reflects true limb motion rather than soft tissue artefacts.

Figure 7: Markers used for the experiment

To ensure accurate modeling of the head, a headset was used, as hair can interfere with reliable marker placement. On the right hand side of Figure 7, the markers used for the model reconstruction are represented.

3.3 Protocol

The experimental protocol comprised four phases:

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Phase 1: **Preparation.** Reflective markers were placed according to the predefined model [8] seen in the section above, and *EMG* electrodes were positioned on the *soleus* according to SENIAM guidelines [7]. System checks confirmed signal quality and synchronization.

Phase 2: **Preferred speed identification (3–5 min).** The treadmill operated in *self-paced* mode. The participant walked naturally to establish preferred speed without external constraints.

Phase 3: **Baseline *soleus* activity (3–5 min).** With the treadmill in *fixed-paced* mode determined in Phase 2, *EMG* and GRF were recorded. The *mean push-off EMG* was computed to define the baseline target for subsequent conditions.

Phase 4: **Randomized conditions.** Three conditions were presented in random order, with real-time biofeedback guiding modulation:

- **+20% condition:** increase *soleus* mean push-off *EMG* by 20% above baseline.
- **–20% condition:** decrease *soleus* mean push-off *EMG* by 20% below baseline.
- **Baseline condition:** maintain *soleus* mean push-off *EMG* at baseline level.

The treadmill remained *fixed-paced* throughout Phase 3 and Phase 4.

The experimental protocol is summarized in Figure 8 below.

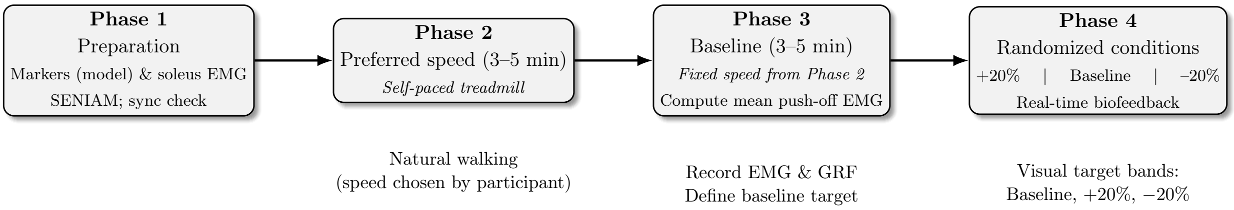


Figure 8: Protocol timeline from preparation to randomized biofeedback conditions.

3.5 Signal processing and gait segmentation

In this section, the digital signal processing applied on the EMG signal and the ground reaction forces have been detailled.

EMG conditioning. The *EMG* signal from the *soleus* underwent:

(a) **Notch** at 50 Hz to suppress powerline interference.

(b) **Band-pass** (20–400 Hz, 4th-order Butterworth) to remove low-frequency artifacts (e.g., movement, heartbeat) and high-frequency noise.

(c) **Full-wave rectification** (absolute value).

Ground reaction forces. GRF channels were low-pass filtered at 20 Hz (4th-order Butterworth).

Gait segmentation and push-off extraction. Stance and swing phase were delimited using thresholds on F_Z of 50 N. Push-off was identified in late stance when F_X transitions from braking to propulsion and F_Z declines toward toe-off. The *mean push-off EMG* was computed per step as the average rectified *EMG* over the push-off window.

Figure 9 provides an overview of the digital signal processing implemented to extract key component from raw signals.

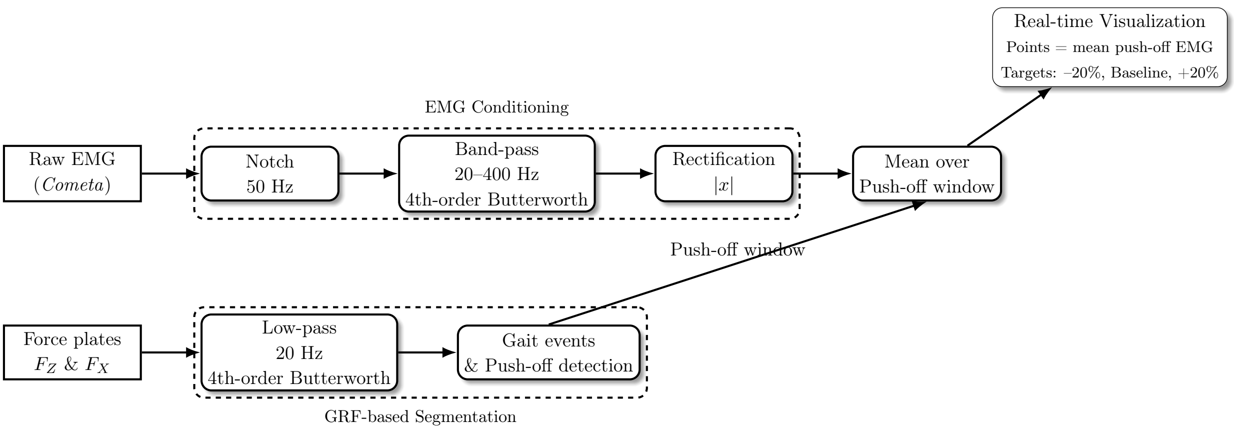


Figure 9: Real-time processing pipeline for *soleus EMG* biofeedback and GRF-based gait segmentation.

4 Implementation of the Real-Time Biofeedback System

In this section, the Python implementation of the real-time EMG biofeedback system is detailed, as it represented a major component of the internship. The goal is to provide a clear overview of how the program was designed and implemented.

The self-paced algorithm allowing the patient to walk at his prefreed speed has been implement by a Phd student of the laboratory.

4.1 Overview

The implementation of the real-time EMG biofeedback system was carried out entirely in Python. The system integrates multiple modules for signal acquisition, processing, visualization, and user interaction. The general architecture consists of three main components:

- **Acquisition and threading:** connection to the Qualisys motion capture system and synchronous reception of EMG and ground reaction force (GRF) signals.
- **Real-time processing and feature extraction:** filtering and segmentation of EMG and GRF to extract the mean push-off EMG value per stride.
- **Graphical user interface (GUI) (Feedback and control):** real-time display of processed signals, thresholds, and biofeedback, with control options for the experimenter.

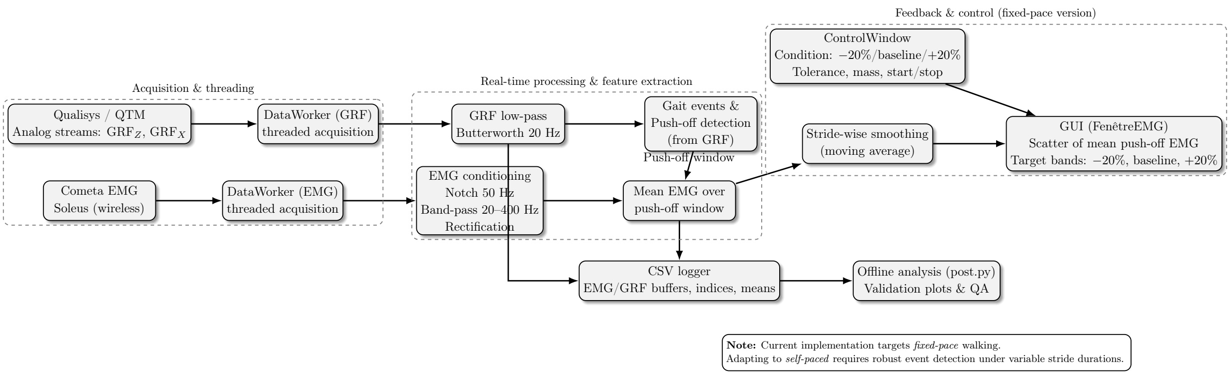


Figure 10: Overview of the real-time EMG biofeedback pipeline: threaded acquisition (QTM/Cometa), real-time filtering and push-off segmentation, feature extraction (mean push-off EMG), smoothing and GUI feedback with condition control, and CSV logging for offline validation.

4.2 Acquisition and Thread Management

Signal acquisition is handled through the `qualisys_data_receiver.py` and `data_worker.py` modules. A connection to Qualisys Track Manager (QTM) is established using the `qtm_rt` library, from which both EMG (via Cometa wireless sensors) and analog GRF channels are streamed.

The acquisition loop runs in a dedicated thread (`DataWorker`, extending `QThread`) to ensure that real-time acquisition does not block the graphical interface. Data are received frame by frame, preprocessed (interpolation, NaN handling), and then pushed into thread safe queues for further processing. Each worker handles specific channels: EMG, anteroposterior GRF, and vertical GRF for left and right legs separately.

Thread management was a crucial step in the implementation. The main challenge of this project was to display information in real time, allowing the subject to adjust muscle activity without delay (for example, data had to be shown on the screen immediately after each step). This was achieved by using separate threads for data acquisition and for the user interface.

4.3 Signal Processing

The processing pipeline is implemented in `traitement_emg.py`. The main steps are:

1. **Notch filtering** at 50 Hz to remove powerline interference.
2. **Band-pass filtering** between 20–400 Hz to isolate muscle activity and suppress low-frequency movement artifacts and high-frequency noise.
3. **Rectification** (absolute value).
4. **Low-pass filtering** of GRF signals (Butterworth, 20 Hz cutoff) to smooth the braking/propulsion curve.

These filters are applied to blocks of incoming data in real-time, with recursive updates of filter states to ensure continuity between frames.

4.3.1 Filtering in Real-Time Applications

In offline processing, it is common to apply the `filtfilt` function to perform zero-phase filtering, which eliminates phase distortions by processing the signal forward and backward. However, this method requires access to the entire dataset and is therefore incompatible with real-time applications, where data must be processed sample by sample as it arrives.

For this reason, the real-time pipeline implemented here uses the `lfilter` function, which applies the filter in a causal, forward-only manner. To avoid initialization artifacts at the start of each update, the filter state is refreshed at every iteration, ensuring continuity and stable filtering across consecutive data windows. While this approach introduces a small phase shift compared to `filtfilt`, it is the only feasible solution for real-time processing and remains sufficient for extracting the relevant EMG features.

4.3.2 Filter design

Filters were implemented as digital IIR Butterworth sections. The band-pass (20–400 Hz) and low-pass (20 Hz) used 4th-order designs . The 50 Hz notch employed a standard second-order notch with quality factor chosen to suppress line noise while preserving adjacent frequencies.

4.4 Detection of Push-Off and EMG Averaging

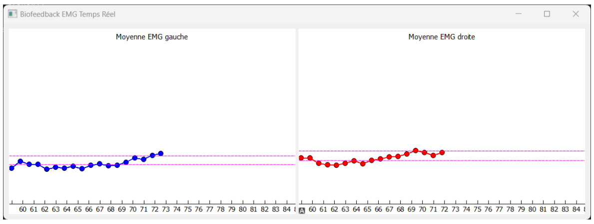
Within the class `FenetreEMG` (in `interface.py`), ground reaction force signals are used to segment the gait cycle. The transition from braking to propulsion in the anteroposterior GRF, combined with vertical GRF thresholds, defines the beginning and end of the push-off phase. For each detected push-off, the mean rectified EMG of the soleus channel is computed. This mean value is then displayed as a single point on a real-time scatter plot, corresponding to the participant's performance in that stride.

A moving average buffer was implemented to smooth fluctuations across strides, making the feedback more stable and interpretable for participants. In practice, the last point displayed on the graph corresponds to the average of the three most recent strides. This approach was introduced to reduce variability, since muscle activity can fluctuate considerably in an unconscious manner. It provides sufficiently stable and meaningful results for the purposes of biofeedback.

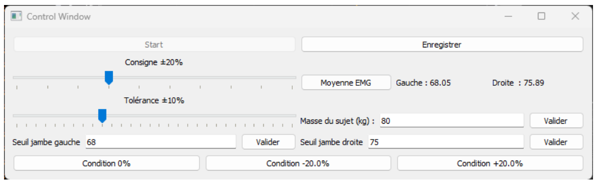
4.5 Graphical User Interface

The user interface consists of two main windows:

- **FenetreEMG:** the main visualization window displaying two real-time plots (left and right leg). Each plot shows the successive mean push-off EMG values as points, with horizontal lines indicating baseline and target zones as illustrated in Figure 11 (a).
- **ControlWindow:** a secondary interface allowing the experimenter to start/stop acquisition, adjust the feedback target (±20% of baseline), set tolerance margins, record the subject's mass, define thresholds, and save recorded data as illustrated in Figure 11 (b).



(a) Main GUI (`FenetreEMG`) displaying real-time EMG biofeedback.



(b) Control interface (`ControlWindow`) used to set conditions and manage data.

Figure 11: Graphical user interface of the real-time EMG biofeedback system. (a) The visualization window shows push-off EMG values and target bands. Each point, in blue for the left leg and in red for the right leg, represents the mean push-off value for one stride. (b) The control window allows the experimenter to adjust conditions, thresholds, and data saving.

The `ControlWindow` also includes dedicated buttons to set the experimental conditions (baseline, −20%, and +20% of normal activation). These adjust the feedback thresholds dynamically by scaling the baseline EMG level and updating the tolerance zone.

A data saving function is available to export all buffers (EMG, GRF, vertical force, stride indices, and computed mean values) into a CSV file. This ensures compatibility with offline analysis scripts.

4.6 Offline Analysis

The script `post.py` was developed to analyze saved data. It enables visualization of EMG, GRF, and vertical force traces alongside the computed push-off means. Functions for smoothing (moving averages across three strides) and threshold calculation are provided. The offline analysis allows validation of the real-time pipeline and comparison of conditions across participants.

4.7 Program Execution

The entry point is `main.py`. It launches both the main visualization window (`FenetreEMG`) and the control interface (`ControlWindow`) simultaneously. The architecture is modular, allowing easy adaptation for future extensions (e.g., additional muscles or different biofeedback strategies).

4.8 Extension to Self-Paced Treadmill Mode

In addition to the fixed-speed implementation described above, the system was also adapted to operate in a self-paced treadmill mode. In this configuration, the treadmill speed continuously adapts to the participant's walking pace, instead of being imposed externally.

The overall EMG acquisition and processing pipeline remains identical, as does the segmentation of the gait cycle and the calculation of mean push-off values. The modifications mainly concern the integration of treadmill speed estimation and control:

- A dedicated `Data_Speed` worker thread (see `data_speed.py`) retrieves instantaneous speed data from Qualisys (index channel 12), applies a forward-fill procedure to handle missing samples, and streams these values to the GUI (`fenetre_vitesse`).
- The treadmill is interfaced through the `treadmill_remote` module, which implements a state estimator (Kalman filter on the center of pressure trajectory) and an LQG controller. This controller computes a target treadmill speed based on step detection, center of pressure displacement, and vertical ground reaction forces. (This has been done by a PhD student from the laboratory)
- A separate GUI (`fenetre_vitesse`) displays both instantaneous and average treadmill speed in real time, allowing the experimenter to monitor and validate the adaptation.

With this extension, participants are free to select their preferred speed during phases 3 of the protocol. The treadmill reacts to their pace in real time, providing a more natural walking environment while maintaining synchronized EMG biofeedback acquisition.

5 Model Reconstruction in Qualisys

Before analyzing the results, the collected motion capture data were processed in Qualisys Track Manager (QTM) to reconstruct the kinematic model of each participant.

Reflective markers placed on anatomical landmarks were tracked by the eight-camera Qualisys system. From these trajectories, a full-body skeletal model was reconstructed according to the predefined marker set. This reconstruction step was essential to obtain joint angles, limb positions, and overall body kinematics synchronized with the kinetic data from the instrumented treadmill.

The reconstructed model also ensured that the center of mass (CoM) trajectory could be reliably extracted. In parallel, the ground reaction forces (GRF) recorded by the treadmill were synchronized with the kinematic data, allowing calculation of the whole-body kinetic moment. This variable is used as the main indicator of stability throughout the study.

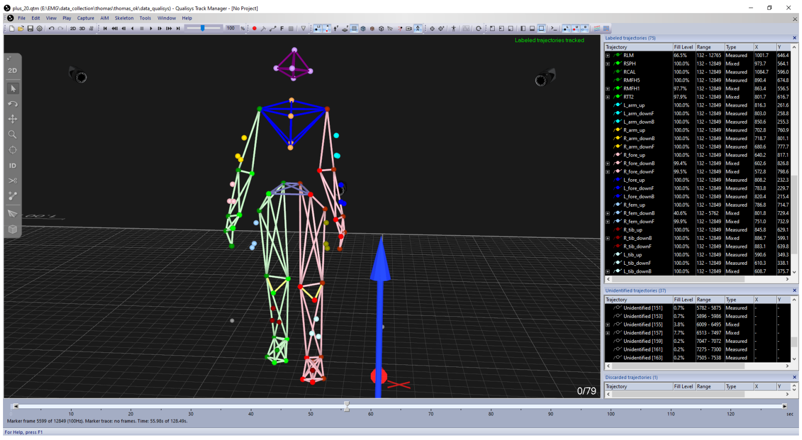


Figure 12: Example of model reconstruction in Qualisys Track Manager based on reflective marker placement.

This process is essential to ensure the reliability of the data. The main objective is to guarantee that all markers are consistently recorded throughout the dataset. In practice, it often happens that some markers are not recognized by the model, which results in them being mislabeled, not labeled at all, or even having their labels switched between two markers. In such cases, each marker must be manually relabeled to restore data integrity. The effectiveness of this step also depends on how well the model has been trained. For example, a model trained primarily on tall subjects may encounter difficulties when applied to smaller participants, leading to inconsistencies in automatic labeling.

Moreover, some markers may not be recorded for a period of time if they are hidden from the cameras by the participant's hands or by the metallic bars on the side of the treadmill. These markers must then be reconstructed manually.

The Figure 12 shows the Qualisys software for model reconstruction. In the Figure 12, every markers are well labelled.

This process can be very time-consuming if the model is not sufficiently trained or if the system calibration is not performed correctly at the beginning of the experiment.

6 Results

This section presents the results of the study. Before doing so, a short explanation is given on how the kinetic moment was obtained from the Qualisys Track Manager recordings.

It is important to note that the calculation of the kinetic moment was not performed on the entire recorded dataset. Each condition of the protocol lasted about five minutes. A program that I developed was used to automatically detect the period during which the participant performed the task most effectively. For example, when the majority of the data points on the graph were within the target zone between the two threshold lines.

The stability analysis was then carried out over this selected period, which lasted about 30 seconds. This approach allowed participants some time to adapt to the requested threshold at the beginning of each trial and ensured that the kinetic analysis was based only on the portion of data where the target level of muscle activity was actually achieved.

Remark. *The results presented in this section do not have statistical significance, as the experiment was conducted on only two subjects due to time limitations during the internship. Nevertheless, they provide a useful indication of the expected outcomes of the protocol. With more time, the study could have been carried out on a larger sample, approximately 15 participants would be needed to obtain meaningful results. In addition, the model used was not sufficiently trained, and the reconstruction process was relatively time-consuming.*

6.1 Processing of QTM Recordings

The motion capture data acquired with Qualisys Track Manager (QTM) were exported in `.c3d` format and processed to obtain the kinematic and dynamic variables of interest. The main steps were as follows:

1. **Model creation and personalization.** A generic base model (Maldonado et al.) [8] was scaled to the subject's anthropometry using anatomical markers and a static trial. Joint centers were refined based on technical markers and functional calibration trials.

2. **Gait cycle identification.** Walking cycles were segmented using the vertical ground reaction force: each new cycle was defined when the right foot vertical force (F_z) exceeded 50 N.

3. **Kinematic reconstruction.** Joint angles were computed using a least-squares optimization that minimized the distance between the experimental markers and the virtual markers of the model.

4. **Joint angular velocities.** Angular velocities were obtained by finite-difference calculation on the joint angle time series.

5. **Whole-body kinetic moment.** The angular momentum of the entire body was computed on the three axes. The results were normalized with respect to the subject's body mass and height according to the following factor:

$$\text{Normalization factor} = m \cdot h \cdot \sqrt{g \cdot h} \tag{1}$$

where m is the body mass (kg), h is the height (m), and g is the gravitational acceleration (m/s^2).

This processing pipeline ensured that gait cycles, kinematics, and stability-related variables (kinetic moments) could be consistently extracted from the QTM recordings.

Remark. *This pipeline has been realized by PhD students from the laboratory prior to this internship.*

6.2 Results on Two Subjects

Rationale for using angular momentum as a stability metric. Whole-body angular momentum, also referred to as the kinetic moment, was selected as the main stability metric in this study. Angular momentum describes how the body rotates around its center of mass, integrating the contributions of all body segments. Maintaining dynamic stability during walking requires the regulation of this quantity: large or uncontrolled fluctuations indicate a reduced ability to stabilize posture, whereas tight regulation reflects efficient balance control. Compared to local measures such as joint kinematics or ground reaction forces alone, angular momentum provides a global indicator of stability that captures the coordinated action of the entire body. In the context of gait, the medio-lateral component (H_y) is particularly informative, as humans are naturally less stable in the frontal plane and rely on fine adjustments to keep angular momentum within safe limits.

The following figure presents the averaged whole-body angular momentum profiles obtained for the two subjects across the three experimental conditions (baseline, +20% and –20% soleus activation). The data from both participants are gathered in the same plots.

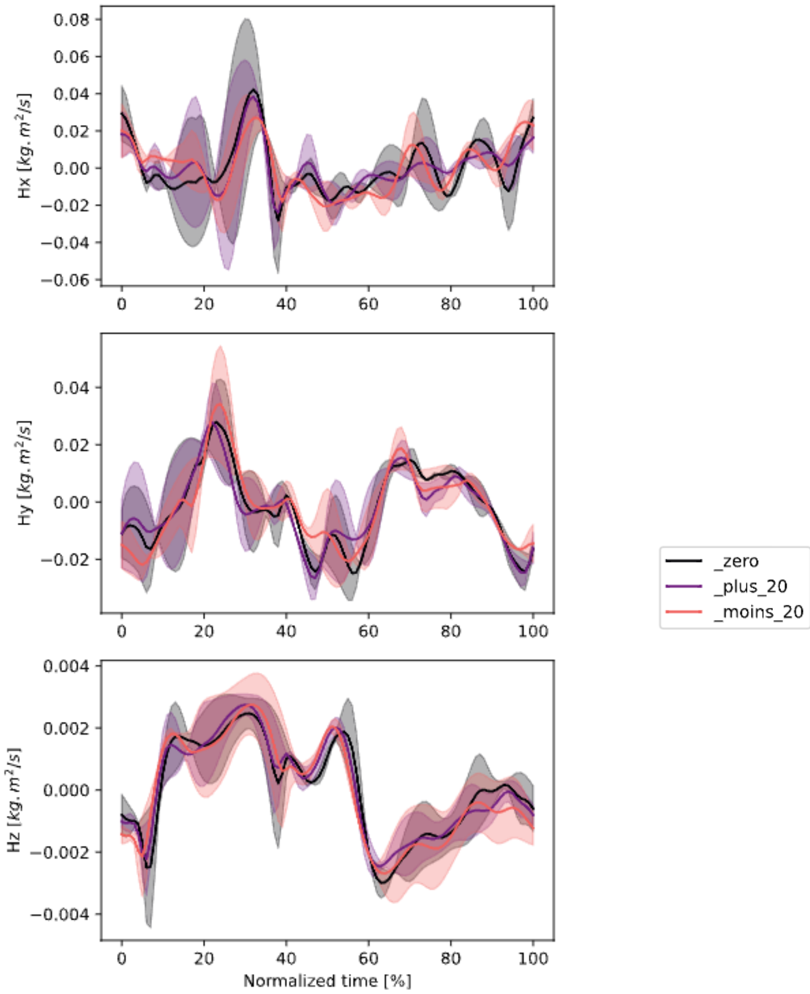


Figure 13: Whole-body angular momentum along the three axes (Hx, Hy, Hz) over the normalized gait cycle for two subjects. Shaded areas represent stride-to-stride variability.

As shown in Figure 13, the overall shape of the angular momentum curves was similar across conditions. No major differences were observed in the sagittal (H_x) or vertical (H_z) components. However, slightly larger variability appeared in the medio-lateral component (H_y), particularly in the –20% condition, which may reflect a subtle decrease in frontal-plane stability. Given that the experiment involved only two participants, the dataset is too small to allow reliable statistical testing. As a result, the observations reported here should be regarded as preliminary trends that illustrate possible effects, rather than as statistically validated findings.

7 Discussion

7.1 Main findings

This project showed that it is possible to compute and display real-time, phase-specific *EMG* feedback during walking. The pipeline in Python was able to acquire the soleus signal, detect gait phases with ground reaction forces, and calculate the average push-off activity with only a small delay. The feedback was simple enough to be understood by the participant and stable enough to follow stride by stride. Adding a moving average helped smooth the signal, which made it easier to interpret during continuous walking. This confirms that the idea of muscle-specific feedback during gait is technically feasible.

7.2 Interpretation and relation to other work

Choosing the soleus as the main target was important. It is a single-joint plantarflexor that is always active during stance and reaches its maximum at push-off, which makes it a reliable indicator of ankle effort. The gastrocnemius, in contrast, changes more with knee movement and speed, so it would have been harder to use as a stable feedback source.

Biofeedback using *EMG* has been used before, especially in rehabilitation or training, but it is often applied to general muscle activity or co-contraction. What makes this project different is that the signal was tied to a specific part of the gait cycle and directly linked to propulsion. The combination with motion capture and treadmill forces also gave a way to link the muscle activity to whole-body mechanics, which is not often done in such systems.

7.3 Implications for stability

The larger goal of this work was to see whether adjusting soleus activity could influence overall stability. Local measures like joint angles do not always show this clearly, so the study looked instead at whole-body angular momentum. This measure reflects how all body parts contribute to motion around the center of mass. In the two subjects tested here, the general pattern of angular momentum was similar across all conditions. Only the medio-lateral direction (H_y) showed small changes in Figure 13, with slightly more variability in the -20% condition. This axis is known to be critical for balance because humans are naturally less stable from side to side. The results are too limited to draw conclusions, but they suggest that changes in soleus activity could, in theory, affect balance if tested with more people.

7.4 Limitations

The main limitation is the very small number of participants. With only two subjects, no statistics can be applied, and the observations should be seen as early indications only. Treadmill walking is another limitation since it is not identical to overground walking. Even with self-paced control, the belt changes the way people walk compared to natural conditions. In addition, the presence of the double belt on the treadmill required participants to maintain a minimum step width, which may have felt less natural for individuals with a smaller height.

There were also technical challenges. Surface *EMG* depends strongly on electrode placement and skin preparation, and it can pick up noise from nearby muscles. The *soleus* lies beneath the *gastrocnemius*, which makes electrode placement even more challenging. The detection of gait phases relied on thresholds in the force signals, which may not always be perfect and can shift the timing of the push-off window. Finally, the motion capture model required a lot of manual relabeling of markers, which was slow and could add errors if not done carefully.

7.5 Future directions

Future studies should include more participants, ideally around fifteen or more, to provide enough data for statistical testing. Longer practice sessions would also allow participants to get used to the feedback, which may make the effect stronger. The feedback design itself can be improved. For example, the target could adapt step by step rather than stay fixed, or multiple muscles could be combined to reflect co-activation patterns. Audio or richer visual cues could also be added to increase engagement.

Including *EMG* measurements at the hip would have made it possible to investigate whether, in the -20% condition, the hip compensates for the reduced ankle power—similar to the compensatory strategy often observed in elderly individuals.

From a technical side, the system could be adapted to use wearable sensors, such as inertial units, so that it works outside of a lab and without an instrumented treadmill. This would make it possible to test in real overground walking or in clinics.

By linking muscle activity directly to global stability, this approach could open new ways to study and improve human locomotion.

8 Conclusion

The aim of this internship was to design and test a real-time biofeedback system based on the soleus muscle during walking. The system was able to acquire EMG, process it online, and provide the participant with a clear visual feedback of push-off activity. This shows that such an approach is technically possible and can be used to guide changes in muscle activation while walking.

Preliminary tests with two subjects did not show strong differences across conditions, but the data gave useful insight into the feasibility of the method. The use of whole-body angular momentum as a measure of stability was explored, and small changes were observed, especially in the medio-lateral direction. These early results need to be confirmed with more participants before drawing firm conclusions.

The project also highlighted some technical challenges, such as electrode placement, gait segmentation, and the need for manual correction in the motion capture model. Despite these limits, the work provided a solid basis for future studies. With more time and a larger sample, this method could help to better understand the link between muscle activity and stability, and it could find applications in rehabilitation, fall prevention, and performance training.

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Abstract

This internship focused on the development of a real-time biofeedback system based on surface *electromyography* (*EMG*) of the *soleus* muscle during walking. The goal was to provide participants with visual feedback of their push-off activation and to explore how modulating this activity could affect whole-body stability.

The experimental setup combined a double-belt instrumented treadmill with synchronized ground reaction forces (GRF) and a Qualisys motion capture system. *Cometa* wireless electrodes recorded the *soleus* signal, which was processed in real time using a 50 Hz notch filter, a 20–400 Hz band-pass, rectification. The push-off phase was identified from GRF data, and the mean *EMG* amplitude during this phase was displayed on screen as a point, together with target zones at +20% and –20% relative to baseline activation.

The experimental protocol included familiarization trials at self-selected speed, a baseline recording, and three randomized feedback conditions (baseline, increased, and decreased activation). Whole-body stability was assessed through the kinetic moment derived from the reconstructed motion capture model, with a particular focus on medio-lateral control.

Preliminary results obtained from a small number of healthy volunteers confirmed the technical feasibility of the system and provided early indications of how changes in soleus activity may influence stability. While the dataset is too limited to draw strong conclusions, the work establishes a foundation for future studies with larger cohorts and opens perspectives for clinical and rehabilitation applications.

Appendix

.1 Marker Set

Marker	Name	Location
SEL	Selenius	Between the eyebrows and above the nose.
OCC	Occipital	Back and lower part of the skull.
TEMP	Temporal	On the sides and base of the skull.
STR	Sternum	On the center of the chest.
A	Acromion process	Located on the lateral part of the shoulder, right above the shoulder joint.
C7	Seventh cervical vertebrae	Cervical area of the spinal cord.
T10	Tenth thoracic vertebrae	Thoracic area of the spinal cord.
SUP	Clavicle	Center of the clavicle.
LHE	Lateral humerus	Palpated on lateral sides of distal end of humerus.
MHE	Medial humerus	Palpated on medial sides of distal end of humerus.
US	Ulna	Long protuberance on lateral aspect of elbow.
RS	Radius	Long protuberance on medial aspect of elbow.
MH5	Fifth metacarpal	Long protuberance on proximal end of little finger metacarpal.
MH2	Second metacarpal	Long protuberance on proximal end of index finger metacarpal.
FT3	Middle finger	Over the tip of the medial finger.
ASIS	Antero superior ilac spine	Over the antero superior ilac spine.
PSIS	Posterior superior ilac spine	Over the posterior superior ilac spine.
GT	Greater trochanger	Lateral aspect of thigh just distal to hip joint.
LFE	Lateral femoral condyle	Lateral aspect on distal end of femur.
MFE	Medial femoral condyle	Medial aspect on distal end of femur.
ATT	Antero tibial tuberosity	Long protuberance on proximal end of femur.
SPH	Sphiron	Large protuberance on medial aspect of ankle.
LM	Lateral malleolus	Large protuberance on lateral aspect of ankle.
CAL	Calcaneus	Over the heel bone.
MFH1	Firs foot metatarsal	Long protuberance on proximal end of first toe metatarsal.
TT2	Second Toe	Long protuberance on second distal interphalangeal joint.
MFH5	Fifth foot metatarsal	Long protuberance on proximal end of first toe metatarsal.

Figure 14: Marker set used for motion capture, showing marker names, anatomical landmarks, and placement locations.

Compétence C1: Concevoir ou réaliser des solutions d'ingénierie permettant de répondre à un cahier des charges– Niveau 1 (N1): Suivre une démarche ou un protocole établi

Dans le cadre de ma première année à Phelma, j'ai participé à un bureau d'études de vingt heures, réparties en cinq séances. Le projet avait pour but de concevoir et réaliser un micro espion, un petit montage électronique capable de transmettre un signal sonore capté par un microphone. Un cahier des charges détaillé proposait plusieurs niveaux : le premier pour une transmission basique, les suivants pour améliorer la qualité et réduire le bruit.

J'ai commencé par analyser ce cahier des charges afin d'identifier les contraintes et organiser ma démarche. Ensuite, j'ai recherché les valeurs des composants nécessaires (résistances, condensateurs), en appliquant les notions vues en cours d'électronique. La réalisation a demandé plusieurs ajustements entre calculs, essais et corrections : par exemple, modifier certaines résistances pour obtenir un signal amplifié sans saturation. Cette étape m'a montré la nécessité d'adapter la théorie aux réalités expérimentales.

Compte tenu du temps disponible et de mon niveau de connaissances, je me suis arrêté au niveau 2, qui assurait déjà un montage fonctionnel et conforme aux attentes. J'ai préféré livrer une solution stable plutôt que de viser un niveau 3 plus ambitieux mais incertain, ce qui illustre une gestion raisonnée des ressources et du délai.

En complément de la partie pratique, j'ai dû rédiger un rapport détaillé du projet. Ce document avait pour objectif de présenter la démarche suivie, de justifier les choix techniques réalisés et d'exposer clairement les résultats obtenus. Il m'a permis de prendre du recul sur le travail accompli et de structurer mes idées, tout en développant des compétences de communication scientifique indispensables à l'ingénieur.

Ce bureau d'études m'a permis de développer une démarche complète allant de l'analyse théorique à la validation pratique. Même si je ne suis pas allé jusqu'au niveau 3, avoir respecté les objectifs, obtenu un montage opérationnel et présenté des résultats clairs dans un rapport structuré confirme l'acquisition du niveau 1 de la compétence C1.

Cette expérience m'a aussi appris l'importance de la rigueur, de la gestion du temps et de l'équilibre entre ambition et faisabilité, des points essentiels pour la suite de mon parcours d'ingénieur.

En conclusion, cette expérience valide pleinement ma capacité à mettre en œuvre une solution technique simple conformément à un cahier des charges, ce qui correspond à l'obtention du niveau 1 de la compétence C1.

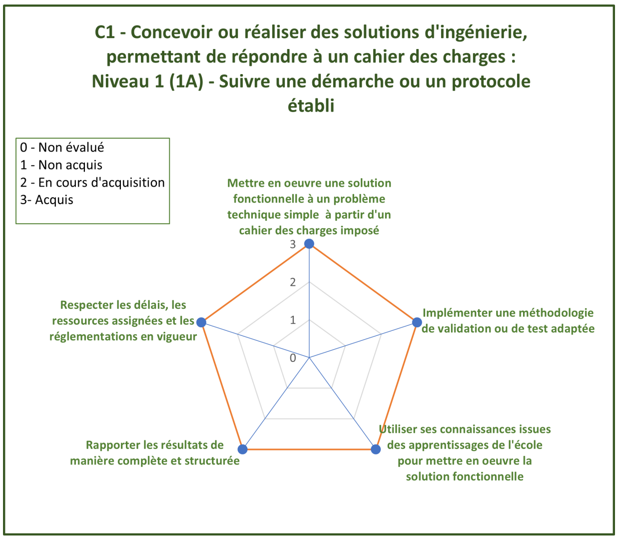

Figure 15: Radar des compétences – validation du niveau 1 de la compétence C1.

Compétence C1: Concevoir ou réaliser des solutions d'ingénierie permettant de répondre à un cahier des charges– Niveau 2 (N2): Proposer une démarche ou un protocole

Durant mon stage de deuxième année à l'Université de La Réunion, j'ai participé à un projet de recherche appliquée visant à développer un système de biofeedback en temps réel basé sur l'activité électromyographique (*EMG*) du muscle soléaire. L'objectif était de concevoir un protocole expérimental et une interface capable de fournir au participant un retour visuel sur son activation musculaire lors de la marche, afin d'étudier l'impact de cette modulation sur la stabilité du corps.

Pour atteindre cet objectif, j'ai mis en œuvre une démarche d'innovation appliquée en plusieurs étapes : (i) analyse des besoins expérimentaux (sélection du muscle cible, définition des phases du cycle de marche pertinentes), (ii) conception et codage en Python d'un pipeline de traitement temps réel (filtrage du signal, détection de la poussée, et affichage dynamique), (iii) mise en place et test d'un protocole expérimental permettant de comparer plusieurs conditions de marche avec modulation du soléaire. À travers cette démarche, j'ai dû mobiliser à la fois des compétences techniques (traitement du signal, synchronisation multi-capteurs, programmation, biomécanique) et une réflexion scientifique (choix des indicateurs pertinents pour l'analyse de la stabilité via le moment cinétique).

Ce travail m'a permis d'appliquer concrètement une démarche de recherche appliquée : partir d'un besoin scientifique, développer un outil expérimental, puis le tester dans un contexte réel. Même si l'échantillon de participants était réduit, la méthodologie mise en place ouvre la voie à des analyses plus approfondies et démontre ma capacité à utiliser une démarche d'innovation dans un projet de recherche. Le niveau 1 de cette compétence est ainsi validé, car j'ai su analyser un problème, concevoir une solution adaptée et la mettre en œuvre dans un cadre expérimental.

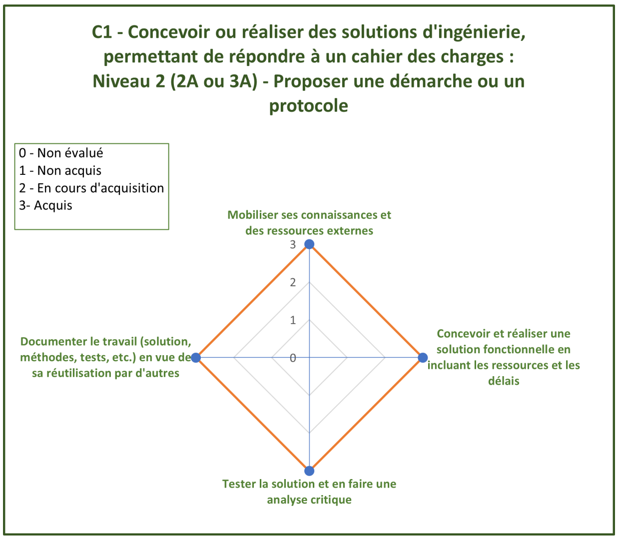

Figure 16: Radar des compétences – validation du niveau 2 de la compétence C1.

```python
class Filter:
    def __init__(
        self,fs,f_notch=50,q_notch=30,low_bp=20,high_bp=400,
        order_bp=2,cutoff_env=5,order_env=4,cut_off_pb=20,order_pb=4,
    ):
        # Notch 50 Hz
        self.b_notch, self.a_notch = iirnotch(f_notch, q_notch, fs)
        self.zi_notch = lfilter_zi(self.b_notch, self.a_notch) * 0.0

        # Band-pass 20-400 Hz
        nyq = fs / 2
        bp_norm = [low_bp / nyq, high_bp / nyq]
        self.b_bp, self.a_bp = butter(order_bp, bp_norm, btype="band")
        self.zi_bp = lfilter_zi(self.b_bp, self.a_bp) * 0.0

        # Passe-bas pour enveloppe (5 Hz)
        env_norm = cutoff_env / nyq
        self.b_env, self.a_env = butter(order_env, env_norm, btype="low")
        self.zi_env = lfilter_zi(self.b_env, self.a_env) * 0.0

        # passe bas butter worth 4th order 20 Hz
        pb_norm = cut_off_pb / nyq
        self.b_pb, self.a_pb = butter(order_pb, pb_norm, btype="low")
        self.zi_pb_grf = lfilter_zi(self.b_pb, self.a_pb) * 0.0

    def process_block_emg(self, signal):

        s_notch, self.zi_notch = lfilter(
            self.b_notch, self.a_notch, signal, zi=self.zi_notch
        )

        s_bp, self.zi_bp = lfilter(self.b_bp, self.a_bp, s_notch, zi=self.zi_bp)

        s_rect = np.abs(s_bp)

        # s_env, self.zi_env = lfilter(self.b_env, self.a_env, s_rect, zi=self.zi_env)

        return s_rect
```

Figure 17: Code permettant le traitement digitaux des signaux EMG

Compétence C2 : Mettre en œuvre une démarche de recherche fondamentale ou une démarche appliquée à des fins d'innovation : Niveau 1 (N1)- Analyser et utiliser une démarche d'innovation ou de recherche

Dans le cadre d'un projet réalisé au deuxième semestre de la filière BIOMED à Phelma, mon groupe et moi avons travaillé sur la conception d'une colle adhésive utilisable en médecine à partir de collagène. La première étape du projet consistait en une recherche bibliographique afin d'établir un état de l'art. Cette phase s'est révélée essentielle, puisqu'il nous fallait identifier des informations fiables et surtout des protocoles expérimentaux réalisables dans les conditions du laboratoire du CIME. L'objectif était de trouver une méthode pouvant être mise en œuvre en moins d'une semaine, délai imposé pour la réalisation pratique.

À première vue, ce temps pouvait sembler suffisant. Cependant, la plupart des protocoles décrits pour la fabrication d'une colle à base de collagène nécessitaient des durées de séchage très longues. À cela s'ajoutait une contrainte supplémentaire : l'accès au laboratoire n'était possible que certains jours, ce qui nous obligeait à prendre en compte les périodes de repos au réfrigérateur entre deux séances et à sélectionner un protocole compatible avec notre emploi du temps.

Malgré ces contraintes, nous avons identifié deux protocoles réalisables dans le délai imparti. Toutefois, l'un d'eux nécessitait l'utilisation de produits chimiques particulièrement coûteux, qui n'ont finalement pas pu nous être fournis. Nous avons donc dû nous adapter une nouvelle fois. Après des recherches complémentaires, nous avons trouvé un protocole alternatif à base de peau de poisson, qui répondait à nos attentes et respectait l'ensemble des conditions fixées, ainsi qu'un deuxième protocole qui utilisait de la gélatine.

Nous avons pu mettre en place ces deux protocoles qui ont mené à l'obtention d'une colle.

De plus, afin de tester notre colle, nous n'avions pas à notre disposition de machine de traction. Nous avons donc dû réaliser notre propre machine artisanale pour effectuer nos tests. Nous avons ainsi dû innover pour mener ce projet jusqu'à sa fin.

Durant ce projet, nous avons analysé les éventuels problèmes de protocoles liés au temps et au budget, mais nous devions aussi identifier tous les problèmes qui auraient pu survenir durant les heures au laboratoire, car celles-ci étaient comptées et ne pouvaient pas être dépassées. Une gestion du temps était obligatoire pour le bon déroulement de ce projet.

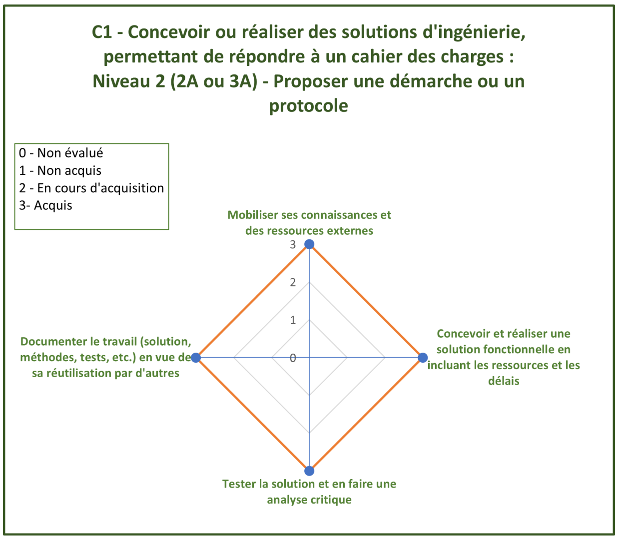

Figure 18: Radar des compétences – validation du niveau 2 de la compétence C1.

Compétence C3 : Coopérer dans une équipe et en mode projet : Niveau 1 (N1)- Participer à une équipe

Pendant mon stage ouvrier chez Schneider Electric, dans leur usine de Moirans qui fabrique des disjoncteurs, j'ai travaillé comme opérateur sur l'une des chaînes d'assemblage de l'usine. C'était ma première expérience en milieu industriel, et je n'avais donc aucune expérience préalable dans ce domaine. La chaîne sur laquelle je travaillais devait produire à un rythme soutenu de 15 pièces par heure et par personne, ce qui exigeait une coordination efficace entre tous les opérateurs. Mon rôle ne consistait pas à assembler directement les disjoncteurs, mais à monter une pièce spécifique qui serait ensuite intégrée dans le disjoncteur sur une autre ligne d'assemblage.

Mon travail impliquait de passer par différents postes sur la ligne de production. J'ai été formé sur 4 des 6 postes disponibles. Les deux postes restants demandaient plus d'expérience et de maîtrise, et comme le stage ne durait qu'un mois, le responsable de la ligne a préféré ne pas me former sur ces postes plus complexes. Je savais que, sans expérience préalable, je devais m'adapter rapidement et trouver ma place au sein de l'équipe pour atteindre les objectifs de production.

Dès le début, j'ai adopté une attitude d'apprentissage. Plutôt que d'essayer de tout comprendre tout seul, j'ai observé mes collègues, écouté leurs conseils, et posé des questions pour réussir à suivre le rythme. Je me suis concentré sur l'amélioration de ma propre vitesse et précision, tout en restant ouvert aux remarques pour m'ajuster aux besoins de l'équipe. Quand je ne pouvais pas aider directement sur les machines, je m'assurais que toutes les pièces nécessaires étaient à portée de main et que notre espace de travail restait bien organisé, ce qui a facilité le travail de tout le monde.

Grâce à cette approche, je me suis rapidement intégré à l'équipe et j'ai pu suivre le rythme de production exigé. En collaborant avec mes collègues, nous avons non seulement respecté l'objectif de production, mais nous avons aussi travaillé dans une bonne ambiance où chacun se sentait soutenu. Ce stage m'a vraiment appris l'importance de la coopération et de la communication au sein d'une équipe, même lorsque l'on est débutant.

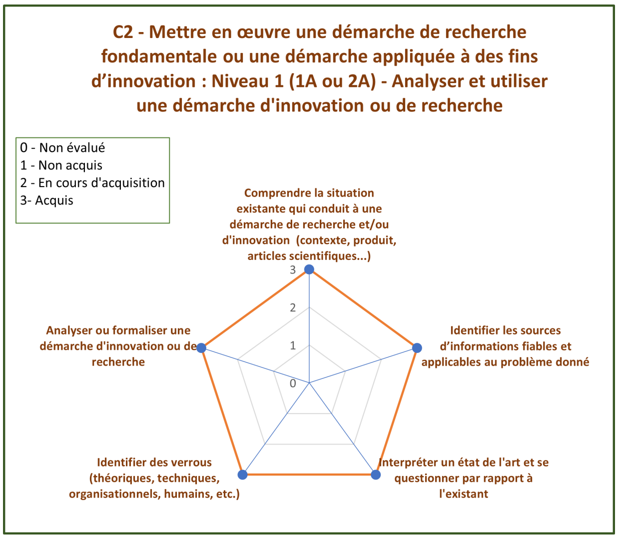

Figure 19: Radar des compétences – validation du niveau 1 de la compétence C3.

Compétence C3: Coopérer dans une équipe et en mode projet : Niveau 2 (N2)- Animer un projet

Lors de mon stage de deuxième année au laboratoire IRISSE (Université de La Réunion, du 19 mai au 25 juillet 2025), j'ai intégré une équipe composée de doctorants et d'enseignants-chercheurs. Le projet portait sur l'étude de l'effet de différents niveaux d'activation du muscle soléaire sur la stabilité lors de la marche, à l'aide d'un système de biofeedback en temps réel basé sur l'EMG.

Afin d'assurer le bon déroulement du stage, le projet a été découpé en plusieurs sous-tâches : une phase de recherche bibliographique pour identifier les travaux existants, une phase de développement et d'implémentation du biofeedback, une phase de tests techniques, puis une étape finale de validation par les responsables scientifiques.

Mon rôle principal a été de concevoir et de programmer l'outil de biofeedback en Python. J'ai travaillé en interaction régulière avec les doctorants, qui apportaient leur expertise sur les aspects biomécaniques et méthodologiques. Ces échanges m'ont permis de mieux comprendre les besoins du projet et d'adapter le développement logiciel en conséquence.

Au cours du stage, j'ai dû suivre l'avancée des différentes étapes et adapter mon travail aux contraintes rencontrées. Par exemple, certaines difficultés techniques liées au traitement en temps réel ont nécessité des ajustements rapides du code. J'ai également dû préparer et présenter un dispositif fonctionnel pour la phase de validation finale.

Lors de la présentation interne au laboratoire, j'ai présenté le système de biofeedback à la direction du projet. Cette présentation a permis de valider le dispositif et d'ouvrir des perspectives pour de futures expérimentations.

Ce stage m'a permis de développer des compétences de coopération en mode projet : structurer une démarche collective, interagir efficacement avec des professionnels, suivre l'évolution d'un projet de recherche appliquée, et communiquer des résultats à des décideurs scientifiques.

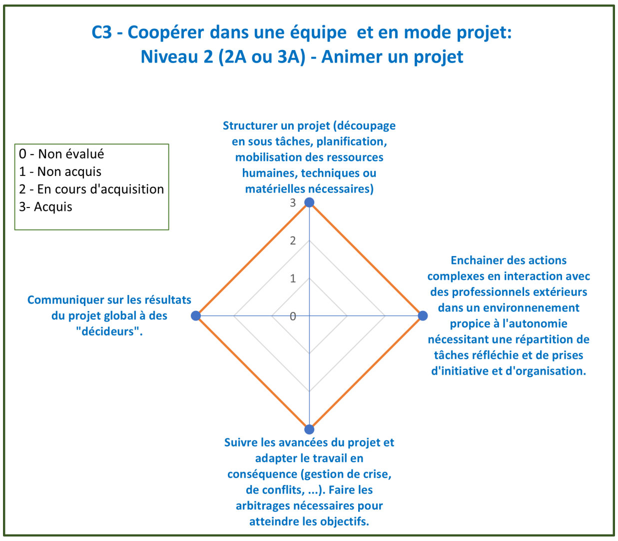

Figure 20: Radar des compétences – validation du niveau 2 de la compétence C3.

Compétence C5 : Tenir compte des transitions technologiques, environnementales, sociétales : Niveau 1 (N1)- Analyser un existan

J'ai effectué mon stage de deuxième année au laboratoire IRISSE de l'univerisité de la Réunion au Tampon. Ce stage avait pour but la réalisation d'un biofeed back du soléaire (muscle situé dans le mollet) à fin d'étudier la stabilité du patient lors de la locomotion.

I. Analyse de l'impact environnemental et sociétal du projet

L'impact environnemental de mon stage peut être analysé à travers différents aspects, en commençant par les déplacements nécessaires pour me rendre sur mon lieu de stage. Le trajet en avion pour rejoindre La Réunion, en passant par Paris, a représenté une part importante de mon empreinte carbone, avec plus d'une tonne de CO_2 émise pour un aller-retour. Une fois sur place, mes trajets quotidiens domicile-laboratoire s'élevaient à environ 10 km par jour, soit environ 500 km sur la totalité du stage. En prenant comme base un facteur d'émission de 0,2 kg CO_2/km, cela représente environ 100 kg CO_2, ramené à 50 kg grâce au covoiturage pratiqué avec un autre stagiaire.

L'autre poste important concerne l'utilisation des équipements nécessaires aux expérimentations. Le fonctionnement du tapis de course instrumenté, des systèmes de capture de mouvement et des dispositifs EMG a constitué la source principale de consommation électrique. Même si la consommation exacte n'est pas connue, il est évident que ce matériel spécialisé est plus énergivore que l'usage d'un simple poste informatique.

Pour limiter mon impact, j'ai adopté certaines habitudes : j'ai systématiquement éteint les appareils après utilisation, évité de faire tourner inutilement le tapis de course et privilégié le travail numérique afin de réduire l'usage du papier. Ces gestes simples, mais constants, m'ont permis de limiter mon impact au quotidien. De plus, le fait que mon logement à La Réunion soit partiellement alimenté par des panneaux solaires a contribué indirectement à réduire mon empreinte carbone. De plus, j'ai effectué du covoiturage durant toute la durée de mon stage, cela m'a permis de diviser par deux mes émmissions. Ces éléments montrent que même dans un cadre où les équipements de recherche sont imposés, il reste possible d'agir à son échelle pour limiter l'impact global.

Le laboratoire met en place différentes actions pour limiter son empreinte carbone au quotidien. Tout d'abord, l'utilisation des équipements expérimentaux les plus énergivores est optimisée en regroupant les essais, ce qui évite des cycles répétés de mise en route et permet de réduire la consommation électrique. Les appareils sont systématiquement éteints après usage et leur maintenance est assurée pour prolonger leur durée de vie. Dans les bureaux, la communication interne est presque entièrement dématérialisée, ce qui limite fortement l'usage du papier. Le laboratoire accorde également une attention particulière à la gestion de l'éclairage et de la climatisation : dans un contexte tropical, la ventilation naturelle est privilégiée et l'usage de la climatisation est limité aux moments nécessaires. Enfin, les étudiants et chercheurs sont encouragés à pratiquer le covoiturage ou à utiliser des modes de transport plus écologiques, ce qui contribue à réduire les émissions liées aux trajets domicile-travail. Ces initiatives traduisent une volonté collective de réduire nos émissions.

L'analyse de l'impact ne se limite pas aux aspects énergétiques : elle inclut aussi des dimensions sociales et éthiques. Durant mon stage à l'Université de La Réunion, j'ai pu constater une forte diversité culturelle au sein du laboratoire, avec des échanges entre chercheurs et étudiants venus d'horizons variés. Ce climat international, ouvert et inclusif, favorise la richesse scientifique et la confrontation de points de vue différents. L'égalité hommes-femmes est également bien représentée dans les équipes de recherche, et la répartition des tâches se fait de manière équitable. Ce cadre de travail contribue à créer une dynamique collaborative et motivante, essentielle pour mener à bien un projet scientifique.

Enfin, il convient de considérer l'utilité du projet. Le développement d'un système de biofeedback EMG en temps réel centré sur le soléaire possède une forte dimension clinique, puisqu'il peut être appliqué à la rééducation et à l'amélioration de la mobilité chez les personnes âgées ou en réhabilitation. Le fait de donner un retour direct au patient sur son activité musculaire constitue une avancée prometteuse pour le suivi et la personnalisation des exercices. Au-delà de l'application clinique, ce travail contribue aussi à la recherche fondamentale en améliorant la compréhension des mécanismes liés à la stabilité et à la propulsion lors de la marche.

En résumé, les bénéfices sociétaux et scientifiques de ce projet sont réels, mais ils s'accompagnent d'un coût énergétique et matériel qu'il convient de garder en tête. Le matériel utilisé reste coûteux et réservé à des laboratoires spécialisés, ce qui limite pour l'instant la diffusion de ce type de solution à grande échelle. Les deux grands défis à relever seraient donc, d'une part, de concevoir des dispositifs de recherche moins consommateurs d'énergie et, d'autre part, de rendre ce type d'outils plus accessibles, afin de permettre un transfert plus rapide vers des applications cliniques concrètes.

II. Proposer des solutions d'ingénierie durable

Le principal défi environnemental et sociétal de ce projet réside dans l'usage d'équipements de recherche coûteux et énergivores (tapis de course instrumenté, système de capture de mouvement, EMG sans fil). Indispensables pour la validation scientifique, ils limitent toutefois l'accessibilité et augmentent la consommation énergétique. Une solution durable consisterait à développer des dispositifs plus sobres et transportables. Un biofeedback portable pourrait ainsi être utilisé en rééducation, voire à domicile, avec un traitement local des données réduisant la dépendance aux ordinateurs. L'efficacité énergétique des équipements existants pourrait aussi être améliorée, par exemple via des tapis instrumentés moins gourmands ou des systèmes d'arrêt automatique. Enfin, la généralisation de ces technologies doit anticiper les effets rebond, comme une surconsommation énergétique ou une production accrue de déchets électroniques. La conception Le recyclage des capteurs apparaissent alors comme une action essentiel pour une ingénierie à la fois durable.

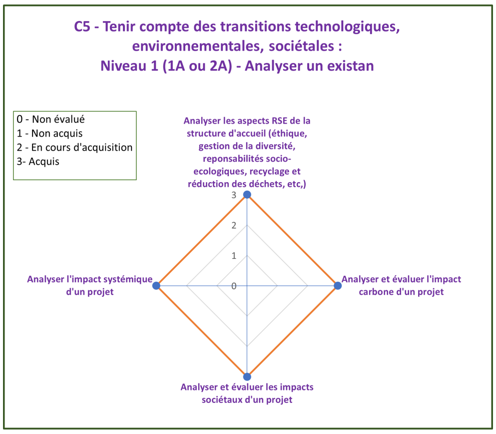

Figure 21: Radar des compétences – validation du niveau 1 de la compétence C5.