Exposé – Master Thesis

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Research Question:

How do motor unit discharge and recruitment patterns in the quadriceps change with acute concentric versus eccentric training interventions in healthy adults?

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Background and State of the Art

The neuromuscular system responds differently to concentric (muscle shortening) and eccentric (muscle lengthening) contractions. Classic work by Bigland-Ritchie & Woods (1976) [1] demonstrated that eccentric contractions produce higher forces with lower integrated EMG activity compared to concentric contractions. Subsequent studies confirmed that during eccentric actions, fewer motor units (MUs) are recruited, and their discharge rates are lower, indicating a more economical neural strategy [2, 3]. Conversely, concentric contractions require higher firing frequencies and recruitment levels to achieve the same torque [4, 5].

Recent studies also show contraction-mode specific fatigability: concentric loading increases MU firing rates more strongly, while eccentric protocols induce less neural drive adjustment but higher mechanical stress [6, 7]. Despite these insights, there is still limited evidence on how MU *modulation* (i.e., changes in firing patterns before vs. after acute training) differs between contraction modes. This project addresses this gap by systematically investigating MU firing behavior before and after standardized concentric and eccentric interventions using high-density surface EMG decomposition.

Objectives and Hypotheses

The primary objective is to examine MU modulation, i.e. how firing patterns of vastus lateralis and medials motor units change as a consequence of acute concentric versus eccentric training interventions in the short term.

Hypotheses (H1):

1. The change in motor unit discharge rate from pre- to post-intervention will be smaller after eccentric training compared to concentric training.

2. Recruitment thresholds will shift to higher force levels after eccentric training, and to lower levels after concentric training.

3. Motor unit conduction velocity will remain stable in both interventions.

4. The change in estimates of persistent inward currents (PIC; via ΔF and Brace methods) from pre- to post-intervention will be larger after eccentric compared to concentric training.

Methods

Design:

Randomized self-controlled feasibility study with repeated measures.

Participants

The initial cohort will consist of six healthy male adults since it has been reported in numerous studies that for sEMG decomposition the decomposition yield and accuracy decrease in female individuals [8, 9, 10]. Each participant will take part in a familiarization session followed by one intervention session. During the intervention session, minimal and non-exhaustive concentric and eccentric training will be performed in a randomized order, separated by an wash-out period to minimize carry-over effects. This self-controlled cross-over design ensures that each participant serves as their own control.

If the extraction and tracking of motor units across the intervention session proves to be feasible, a second cohort of six healthy female participants will be recruited in order to explore potential sex-specific differences in neuromuscular responses. Otherwise, an additional cohort of six new male participants will be recruited instead.

Sample Size and Study Aim

This is a feasibility pilot study with a within-subject cross-over design (initial cohort: $n = 6$ healthy males; optional second cohort: $n = 6$ additional males or females). The methodological benchmarks, expected motor-unit yields, and relevant reference values for decomposition and tracking performance are detailed in the subsequent section *Sample Size and Study Aim*. The primary aims are to (i) establish feasibility, (ii) estimate effect sizes and variance components for motor-unit (MU) modulation after concentric vs. eccentric loading, and (iii) refine measurement and analysis protocols for a subsequent adequately powered study. Accordingly, statistical reporting in this pilot will emphasize effect sizes with 95% confidence intervals and precision estimates. *Before finalizing the confirmatory study protocol, we will conduct an a priori power analysis* using established tools (G*Power for paired/repeated-measures tests [11, 12] and, where appropriate, simulation-based power for linear mixed-effects models [13]).

Motor Unit Extraction and Tracking Performance. Recent studies have demonstrated that high-density surface EMG (HD-sEMG) decomposition can identify approximately 20–30 distinct MUs per muscle under optimal recording conditions [14, 15, 16]. When tracking MUs across experimental conditions (e.g., PRE–POST interventions), tracking success rates between 57–67% have been reported, depending on muscle group and contraction characteristics [15, 8]. Based on these data, a conservative estimate of $\sim$15 MUs per muscle and a 60% tracking yield can be expected.

For recordings of the vastus medialis (VM) and vastus lateralis (VL), this corresponds to approximately 18 tracked MUs per participant. Hence, the initial cohort ($n = 6$) is expected to yield around 108 tracked MU pairs for analysis, while the combined cohorts ($n = 12$) would provide $\sim$216 MU pairs, sufficient for reliable within-subject statistical comparisons.

Power and Precision Considerations. The cross-over design substantially increases statistical efficiency by removing between-subject variability. Assuming typical within-subject effect sizes observed for MU discharge parameters after neuromuscular interventions (Cohen's $d = 0.4$–0.8) [17, 8, 7], the current design provides:

- $n = 6$ **participants:** adequate power ($> 90\%$) to detect medium-to-large effects ($d \geq 0.5$), and
- $n = 12$ **participants:** excellent power ($> 90\%$) to detect smaller effects ($d \geq 0.4$).

Muscles:

Vastus medialis and vastus lateralis of the dominant leg, each recorded using two high-density sEMG grids (64- and 32-channel).

Training Device

All interventions will be performed on an isokinetic dynamometer (Con-Trex system [1]), ensuring standardized concentric and eccentric loading at controlled angular velocities.

HD-sEMG Recording Device and Laboratory Setting

HD-sEMG Recording Device: We use the Novecento+ (OT Bioelettronica, Torino, IT), a modular bioelectrical acquisition system designed for advanced neurophysiological recordings and medical applications. The platform supports simultaneous capture of up to 960 surface EMG (sEMG) channels[2]. Signals are *amplified, filtered, A/D converted*, and transferred to the host PC via Ethernet for real-time monitoring and storage. For multi-device synchronisation and workflow integration, the system provides trigger I/O, one analog output, 14 auxiliary input channels, and two dedicated load-cell inputs.

Laboratory Setting: All measurements are conducted in a motion analysis laboratory equipped with an isokinetic dynamometer (Con-Trex MJ - Physiomed). The measurement environment and cable routing will be optimised to minimise electromagnetic and 50Hz powerline interference, including consistent electrode skin-prep, short shielded cable runs, stable reference placement, and hardware synchronisation between dynamometer and EMG acquisition.

Inclusion and Exclusion Criteria

Inclusion: healthy adults (18–40 y), no current lower-limb injury, able to perform knee extensions, right- or left-leg dominance documented.

[1] https://physiomed.de/en/produkt/con-trex-mj/
[2] https://otbioelettronica.it/en/novecento/

Exclusion: acute illness/fever; recent musculoskeletal injury; uncontrolled cardiovascular/neurological disease; medications substantially affecting neuromuscular function; skin conditions at electrode sites; vigorous lower-limb training within 48 h before testing; alcohol within 24 h; caffeine/nicotine within 3 h.

Acquisition Parameters

HD-sEMG: Monopolar reference with high-density grids placed on Vastus Medialis and Vastus Lateralis. Each muscle will be recorded with 32- and 64-channel grids using inter-electrode distances (IED) of 4 to 10 mm. This results in a total of 96 channels per muscle (192 channels covering a shared motor unit pool). Signals will be sampled at 2000 Hz, with hardware band-pass filtering from 10–500 Hz and a 50 Hz noise reduction applied if required. Reference electrodes at the wrist. Signal Quality Checks before each session will ensure target RMS noise levels below $10\ \mu V$ (upper acceptable limit $15\ \mu V$).

Dynamometer: Isokinetic knee extensions at $45°/\mathrm{s}$; knee angle range $90° \to 30°$ flexion; gravity correction each session; seat/backrest/lever positions fixed and documented between sessions. Analog outputs from the isokinetic dynamometer (torque, joint angle, and movement direction) will be simultaneously recorded with the HD-sEMG signals. Event markers (TTL) will be manually triggered to indicate task onsets (PRE/POST).

Body Composition: Height will be measured using a stadiometer to the nearest 0.5 cm (SECA 213, Seca Vogel&Halke, Hamburg, GER). Weight and body composition will be assessed with a bioelectrical impedance device (SECA mBCA 525, Seca Vogel&Halke, Hamburg, GER). Extracted parameters include:

- body height (m)
- body mass (kg)
- body fat mass (% BW)
- muscle mass (% BW)
- left / right muscle mass (kg)

MU Decomposition, Quality Control, and Tracking

Motor unit discharge times will be extracted using swarm-contrastive blind source separation (SCD) [18]. Quality control will be based on silhouette/stability indices (SIL), interspike interval variability (bootstrapped coefficient of variation), and firing rate plausibility; MUs failing QC thresholds (SIL < 0.85 or unstable ISI patterns) will be excluded a priori (manual review). Decomposed spike trains will be inspected and manually edited using the open-source software *MUedit* [19] and analyzed in *openhdemg* [20]. PRE–POST MU matching will rely on action potential waveform correlations and discharge pattern similarity within muscle and participant. Estimates of persistent inward currents (PIC) will be obtained via the ΔF method [21] (paired MU analysis with anchor/test criteria) and the Brace method [22] (standardized ramp slopes).

Randomization and Standardization

Participants will be randomized (1:1) to session order (concentric first vs. eccentric first) using a reproducible list generated before recruitment. To reduce circadian and nutritional confounding, both intervention visits are scheduled at the same time of day (±1 h) with standardized pre-visit instructions (sleep, caffeine, alcohol, activity). Delayed-onset muscle soreness (DOMS) will be recorded (0–10 scale) at visit start; if DOMS $>$ 5/10 or residual weakness is present, the session is rescheduled to preserve washout (target 5–7 days).

Statistical Analysis Plan

Primary endpoint: change in MU discharge rate (POST–PRE) between modes (concentric vs. eccentric).
Key secondary: Changes in recruitment threshold, conduction velocity, pooled neural drive, and PIC indices (ΔF, Brace).

While the vastus medialis (VM) and vastus lateralis (VL) are often described as sharing a substantial portion of common synaptic input [23], recent evidence indicates that selective recruitment of distinct motor unit populations between these muscles can occur [24]. Therefore, before pooling motor units across muscles, we will assess whether cumulative spike trains (CSTs) of VM and VL exhibit shared or independent components using cross-correlation and coherence analyses. Depending on these results, VM and VL data may be analyzed separately or jointly at the pooled level.

Data are hierarchical, with MUs nested within participants. Linear mixed-effects models will be fitted with fixed effects for *Mode* (concentric vs. eccentric), *Time* (PRE vs. POST), and their interaction, and random intercepts for *Participant* and *MU* (as applicable). Effect sizes (estimated marginal means and contrasts) will be reported with 95% confidence intervals. Model diagnostics will evaluate normality and heteroscedasticity; robust standard errors will be applied if required. Multiplicity will be controlled within endpoint families.

Protocol

- *Day 1 (Familiarization):* Health and training questionnaire, MVC determination (highest of three attempts), and a short non-fatiguing warm-up on a stationary bike to activate the musculature and ensure proper circulation. This is followed by a familiarization phase including warm-up practice of the force-tracking (FT) tasks. These submaximal tasks at 30–40% MVC (Constant Hold, Trapezoid, and Pyramid) are intended to help participants develop a feeling for the target force and prepare them for the actual FT tasks performed during the intervention sessions on subsequent days:

  - **Trapezoid:** 7 s at 0% MVC, 5 s ramp up to 30% MVC (6% MVC/s), hold 5 s at 30% MVC, 5 s ramp down (-6% MVC/s), 5 s at 0% MVC. *Optimal for PIC estimation while maintaining good motor unit yield* [25]
  - **Pyramid:** 7 s at 0% MVC, 6,25 s ramp up to 50% MVC (8% MVC/s), 6,25 s ramp down (-8% MVC/s), 5 s at 0% MVC. *Ensures* ≥ 4 *seconds above trapezoid maximum. [26]*
  - **Constant hold:** 30% MVC for 60 s (matches trapezoid level).

- *Day 2 (Intervention Session):* The session begins with the same warm-up procedure as performed on *Day 1*, followed by an MVC re-test and pre-intervention force-tracking (FT) tasks. Subsequently, participants complete a no-intervention rest block (FT tasks without loading), after which they perform the first randomized training block (**concentric** or **eccentric**). This is followed by a short post-exercise rest block (FT tasks without loading) and a washout period of 5-7 minutes, after which the second training block with the **other** contraction mode is conducted. This washout duration is based on evidence showing that after brief, high-intensity exercise, central fatigue typically recovers within 2 minutes, while peripheral fatigue associated with excitation-contraction coupling and muscle reperfusion recovers within 3–5 minutes [27]. Finally, post-intervention FT tasks and a concluding MVC test are performed. During all rest periods, the restraint straps should be loosened but the legs must remain within the apparatus to preserve consistent joint positioning and moment arms, which is critical for accurate recruitment threshold analysis. If necessary for participant comfort, minimal passive movements (i.e., slow leg motion performed by the Con-Trex) may be applied during rest periods to reduce stiffness.

Primary Outcomes (motor-unit modulation before vs. after training):

- Recruitment thresholds (**tracked MUs**)
- Discharge rates (mean, ISI variability; **tracked MUs**)
- MU conduction velocity (**tracked MUs**)
- Neural drive (estimated from the low-pass filtered cumulative spike train [CST]; quantified as the trapezoid–plateau mean of the CST derived from the **overall MU pool**)
- Persistent inward currents (PIC) estimated via ΔF and Brace methods (**tracked MUs**)
- Force-tracking performance (error metrics during tracking tasks; task-level measure)
- Maximal voluntary MVC torque (control variable)

Secondary Outcomes:

- Body composition, age, and sex
- Global EMG amplitude/frequency measures (RMS, MDF, MNF; **overall MU pool**)
- Spatial activation features (spatial entropy and activation barycenter derived from HD-sEMG maps)
- Temporal activation features (temporal entropy across contraction phases)
- Subjective exertion (Borg CR10 scale)

Parameters derived from **tracked MUs** reflect direct within-unit adaptations across conditions. Metrics related to the **overall MU pool** capture global neuromuscular modulation and coordination changes independent of unit identity.

Detailed Measurement Schedule

Day 1 – Familiarization (60–75 min), on-site, C.E.17

00:00–00:10 Consent, anthropometrics (height, body mass, dominant leg), baseline soreness (0–10).

00:10–00:20 Seat/lever adjustment, ROM definition, gravity correction; skin prep & electrode landmarking.

00:20–00:30 Warm-up: 5 min light cycling or unloaded extensions, 2–3 submaximal trials.

00:30–00:40 MVC familiarization (3–4 s efforts, best of three).

00:40–00:55 Practice force-tracking:

- **Trapezoid:** 7 s at 0% MVC, 5 s ramp up to 30% MVC (6% MVC/s), hold 5 s at 30% MVC, 5 s ramp down (-6% MVC/s), 5 s at 0% MVC.
- **Pyramid:** 7 s at 0% MVC, 6,25 s ramp up to 50% MVC (8% MVC/s), 6,25 s ramp down (-8% MVC/s), 5 s at 0% MVC.
- **Constant hold:** 30% MVC for 60 s.

00:55–01:15 Rehearsal of concentric/eccentric contractions without load.

Day 2 – Cross-Over Reliability and Intervention Sessions (180–200 min each), on-site, C.E.17

Each participant completes one extended intervention visit comprising both contraction modes (concentric and eccentric) in a randomized order within the same session. This **cross-over reliability protocol** allows for direct intra-session comparison and repeatability assessment of motor unit parameters across identical task conditions.

Session structure (schematic overview):

Step	Block	Description / Notes
1. MVC (Pre)		Initial maximal voluntary contractions (3 trials, best of three). Used to normalize all subsequent force levels.
2. Force-Tracking Block 1	TRAP / TRI_{rand}	Baseline force-tracking tasks at 30–40% MVC (trapezoid and triangular ramps, random order). Establishes pre-training reliability.
3. REST		Passive rest (2–3 min) before pre-intervention reference tracking.
4. Force-Tracking Block 2	TRAP / TRI_{rand}	Pre-intervention tracking after rest. Serves as immediate baseline before the first loading block.
5. Training Block 1	CON or ECC	First loading phase (4 × 10 repetitions @ 45°/s). Contraction mode (concentric or eccentric) randomized between participants.
6. Force-Tracking Block 3	TRAP / TRI_{rand}	Immediate post-training tracking to evaluate short-term MU modulation following the first loading phase.
7. WASHOUT		Active recovery (5–7 min pause with some light muscle movements) before switching contraction mode.
8. Force-Tracking Block 4	TRAP / TRI_{rand}	Tracking immediately after washout to capture transient recovery effects prior to the second intervention.
9. Training Block 2	CON or ECC (opposite mode)	Second loading phase (same volume and intensity) with the opposite contraction mode, counter-balanced order.
10. Force-Tracking Block 5	TRAP / TRI_{rand}	Post-training tracking following both contraction modes to assess cumulative adaptation and reliability.
11. REST		Short recovery (2–3 min) before final MVC test.
12. Force-Tracking Block 6	TRAP / TRI_{rand}	Final tracking task after rest, ensuring stable post-intervention conditions before maximal testing.
13. MVC (Post)		Final MVC series (3 trials). Determines post-intervention maximal strength and neural drive changes.

Table 1: Vertical overview of the cross-over reliability session. Each row represents one experimental step; color codes correspond to MVC (red), force-tracking (blue), training (orange), and rest/washout (green). TRAP and TRI_{rand} tasks alternate randomly.

Timing overview

- Arrival/setup: 20–25 min
- Initial MVC + first FT blocks: 25–30 min

- CON/ECC training and interleaved FT blocks: 90–100 min
- Final MVC + closing FT blocks: 20–25 min
- Debrief & electrode removal: 10 min
- **Total:** $\sim$180–200 min

Notes: Task order within each FT block (TRAP vs. TRI) is randomized (*rand*) to avoid sequence bias. This design provides both PRE–POST and repeated-measure reliability information within a single experimental visit.

Standardization & Quality Control

- **Electrodes:** Identical grid models/IED, reproducible placement, landmarks photographed pre/post.
- **Signal QC:** RMS noise target $< 10\ \mu V$ (max $15\ \mu V$); re-seat if poor channels $>$10%.
- **Dynamometer:** Same seat/lever settings, ROM, and angular velocity fixed; gravity correction each session.
- **Task replication:** Visual feedback, gains, order, and timing identical across sessions.
- **Safety criteria:** Pain $>$5/10, dizziness, or adverse signs $\Rightarrow$ stop and assess.

Expected Results and Relevance

It is expected that concentric training induces stronger increases in MU discharge rates and shifts recruitment thresholds downward, reflecting enhanced neural drive, whereas eccentric training produces more economical activation with altered thresholds and increased PIC indicators. Because each participant performs both contraction types on separate days, intra-individual comparisons will reveal mode-specific MU modulation. A subsequent female cohort will allow for exploratory sex-specific analyses. These findings will provide novel insights into acute MU plasticity and inform training and rehabilitation strategies in healthy and clinical populations.

Planned Timeline and Milestones

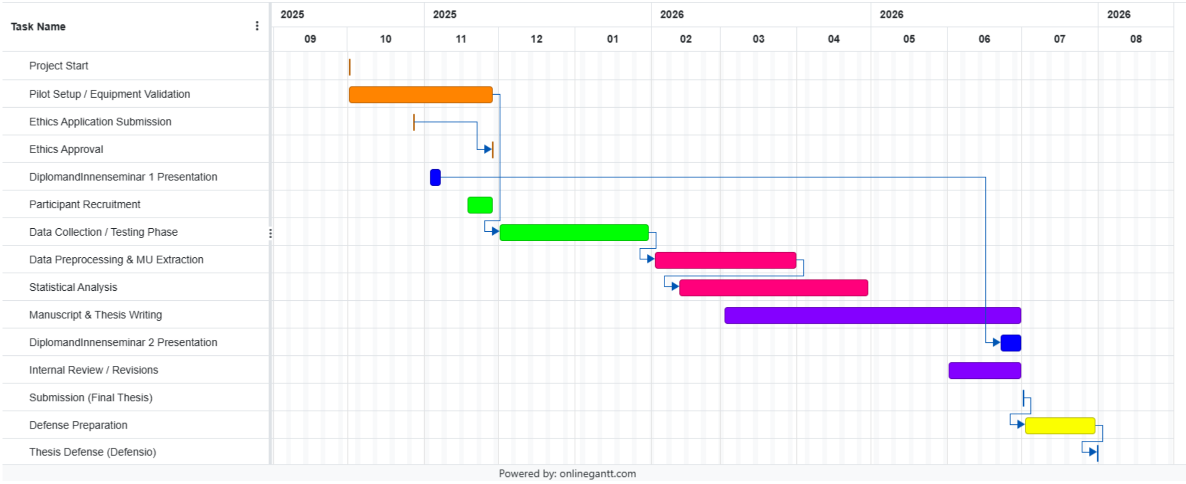

Figure 1: Planned Gantt chart of the master's thesis timeline (October 2025 – July 2026).

Data Protection

All collected data are processed in accordance with the EU General Data Protection Regulation (GDPR) and institutional policies of the University of Applied Sciences Campus Wien. Personal information (e.g., contact details) is stored separately from pseudonymized measurement data and used solely for organizational purposes. The assignment key linking personal identifiers to participant codes is securely locked in a separate location accessible only to the study lead and supervisor. Measurement data (HD-sEMG, torque, and metadata) are pseudonymized and stored on the encrypted internal university drive for a maximum of ten years after completion of the thesis. Weekly automated backups minimize data-loss risk. After the retention period, all personal identifiers are irreversibly deleted and physical documents shredded in accordance with institutional data-disposal procedures.

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