STUDY PROTOCOL

Official Title:

Foot Progression Angle Phenotype Modulates Acute Vastus Medialis Contractile Responses During Leg Press Exercise in Resistance-Trained Athletes

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This document contains the complete study protocol including objectives, design, methods, scientific background, and statistical considerations.

1. SCIENTIFIC BACKGROUND

Initial joint alignment in closed kinetic chain resistance exercises is a determinant factor for load transfer and inter-segmental force transmission (Neumann, 2019; Straub and Powers, 2024). Among these exercises, the leg press is widely used in strength and hypertrophy-oriented programs owing to its capacity to accommodate high mechanical loads while providing external support for trunk stability (Martín-Fuentes et al., 2020). Foot placement on the platform during leg press constitutes an important initial condition that may influence force transmission and joint loading patterns along the lower extremity (Da Silva et al., 2008). Given the natural inter-individual variability in the rotational alignment of the lower extremity, whether standardized foot positions applied during leg press generate equivalent biomechanical conditions across individuals represents an important consideration for the development of individualized training strategies.

One of the key indicators that quantifies these natural rotational differences is the foot progression angle (FPA). The FPA is an important biomechanical parameter that defines the angular relationship between the longitudinal axis of the foot and the direction of progression during gait, reflecting the rotational alignment of the lower extremity in the transverse plane (Caderby et al., 2022; Cibulka et al., 2016). This angle, which may vary among individuals, is regarded not only as a descriptive feature of gait pattern but also as a functional indicator of habitual lower extremity alignment (Caderby et al., 2022; Shen et al., 2026). It has been reported that inter-individual differences in FPA may be associated with tibial rotation and load distribution at the knee joint (Bennour et al., 2017; Cibulka et al., 2016; Qiu et al., 2020), and may also alter lower extremity muscle activation (Rutherford et al., 2010).

The effects of foot placement on lower extremity biomechanics during leg press exercise have been examined in the literature through various manipulations. These studies have focused on the effects of variables such as foot height on the platform, foot width, or fixed internal–external rotation angles on muscle activation and joint loading (Da Silva et al., 2008; Escamilla et al., 2001; Harandi et al., 2013; Martín-Fuentes et al., 2020; Martín-Fuentes et al., 2022; Pereira et al., 2017). However, in these studies, standardized foot positions were applied to all participants and rotational manipulations were performed using fixed angles. The absence of FPA from the initial foot positioning suggests that these studies operated under the assumption that applied foot positions generate similar biomechanical conditions across all individuals.

Furthermore, biomechanical differences associated with foot position in previous research have predominantly been assessed through electromyographic muscle activation and kinematic parameters (Martín-Fuentes et al., 2020; Da Silva et al., 2008; Martín-Fuentes et al., 2022). While electromyography provides information on the neural dimension of muscle activation (Disselhorst-Klug, 2025), tensiomyography enables assessment of contractile properties through the mechanical response of the muscle to electrical stimulation and can provide important information regarding the functional state of the muscle (Rey et al., 2012; Fernández-Baeza et al., 2024). The absence of tensiomyographic methods in the aforementioned studies limits the direct assessment of the effects of initial foot positioning on skeletal muscle contractile properties.

In this context, the existing literature presents a clear gap with respect to both the integration of individual rotational alignment differences (FPA) into exercise starting position and the evaluation of this interaction through muscle contractile properties.

2. STUDY OBJECTIVES AND HYPOTHESES

2.1. Primary Objective

To examine the effects of the interaction between rotational foot positioning during leg press exercise and individuals' habitual foot progression angle (FPA) phenotype on the acute contractile response of the vastus medialis muscle.

2.2. Hypotheses

Primary hypothesis: When the foot rotation position applied during exercise is incongruent with the individual's habitual foot progression angle, the contractile responses of the vastus medialis muscle would be more pronounced.

Secondary hypothesis: A neutral foot position in individuals with a habitually high FPA profile, and an externally rotated foot position in individuals with a normal FPA profile, would be associated with greater contractile responses.

3. STUDY DESIGN

This study was designed as a mixed-design, crossover experimental investigation. In the study design, FPA phenotype (high FPA vs. normal FPA) was defined as the between-subjects factor, while foot rotation protocol (0° neutral vs. 30° toe-out) and time (pre-exercise vs. post-exercise) were defined as within-subjects factors.

All participants were assessed in two separate sessions, each involving one of the two foot rotation protocols, with a 48-hour washout period applied between sessions to minimize potential fatigue and carry-over effects. Within the crossover design, protocol order was fixed on a group-specific basis to minimize learning effects. Accordingly, each group performed the condition congruent with their habitual foot progression angle in the first session and the incongruent condition in the second session.

Pre-exercise TMG values obtained prior to the second session were compared with baseline measurements to confirm return to baseline levels. All experimental procedures were conducted under controlled environmental conditions (24°C) and within the same time-of-day window for each participant (±1 hour). Participants were instructed to avoid strenuous physical activity and caffeine consumption for 48 hours prior to each measurement.

To minimize measurement bias, the researcher conducting TMG assessments was blinded to participants' phenotype group and the exercise condition applied (single-blind). Exercise administration and data analysis were performed by different researchers, and group codes were anonymized during the analysis process.

4. PARTICIPANTS

4.1. Study Population

A total of 24 male athletes (age: 27.5 ± 3.76 years) who were licensed and actively competing in bodybuilding with a minimum of five years of regular resistance training experience volunteered to participate. Prior to the study, participants were provided with detailed information regarding the research protocol and written informed consent was obtained.

4.2. Inclusion Criteria

(a) Aged between 20 and 35 years; (b) a minimum of five years of regular resistance training experience; (c) currently active participation in training; (d) measurements from both feet required to meet the established threshold values for FPA classification.

4.3. Exclusion Criteria

(a) A history of lower extremity surgery or serious musculoskeletal injury within the past year; (b) the presence of congenital or acquired foot deformity; (c) a history of neurological, cardiovascular, or metabolic disease.

4.4. Group Classification

Participants were divided into two groups based on FPA values measured during gait analysis. Participants with a mean FPA exceeding 13° for both feet were classified as the high FPA (HFPA) group (n=12), while those with values between 0° and 13° were classified as the normal FPA (NFPA) group (n=12). This threshold was established in accordance with reference values recommended in the literature (Cibulka et al., 2016).

4.5. Sample Size Calculation

Sample size was calculated using G*Power 3.1.9.7 software based on a repeated measures mixed-design ANOVA model (within–between interaction). Effect size estimation was based on tensiomyographic changes reported in the lower extremity muscles following acute resistance exercise. Previous studies have reported large effect sizes (Cohen's d ≈ 1.0–1.9) particularly for Tc and Td parameters (Beato et al., 2021). Adopting a more conservative approach, a medium-to-large effect size ($f = 0.40$) was assumed. With a significance level of $\alpha = 0.05$, statistical power of $(1-\beta) = 0.80$, and a correlation between repeated measures of $r = 0.50$, the minimum total sample size was calculated as 20 (n = 10 per group). Considering the within-subject comparison advantage of the crossover design and to compensate for potential data loss, 12 participants were included in each group.

5. METHODS

5.1. Assessment of Demographic and Physical Characteristics

A personal information form was used to obtain demographic data. Body height and mass were measured using standard procedures.

5.2. Assessment of Muscle Contractile Properties (TMG)

Muscle contractile properties were assessed using tensiomyography (TMG-BMC Ltd., Ljubljana, Slovenia) on the vastus medialis muscle of the dominant leg. Participants were positioned in supine with the knee supported at approximately 30° of flexion. The muscle belly was identified by palpation, and surface electrodes were placed proximal and distal to the motor point. The measurement probe was positioned perpendicular (90°) to the skin surface. Electrical stimulation was incrementally increased until maximal radial displacement of the muscle was obtained. Participants were instructed to keep their muscles fully relaxed throughout the measurements (Macgregor et al., 2018; Rey et al., 2012; Šimunič, 2012).

The following TMG parameters reflecting muscle contractile properties were analyzed: maximal radial deformation (Dm), contraction time (Tc), and delay time (Td). These parameters have been reported to demonstrate high relative reliability, with intraclass correlation coefficients of 0.97 for Dm, 0.92 for Tc, and 0.86 for Td, along with low measurement error (CV ≈ 2.7–4.7%) (Loturco et al., 2016; Tous-Fajardo et al., 2010). All measurements were performed before the exercise protocol and within 90 seconds following completion of the final repetition.

5.3. TMG Measurement Reliability

Prior to the main experimental sessions, test–retest measurements were performed on 12 participants with a 48-hour interval. Reliability was assessed using the intraclass correlation coefficient [ICC(3,1)] calculated with a two-way mixed-effects model. ICC values for TMG parameters were 0.91 for Dm, 0.88 for Tc, and 0.83 for Td, indicating high reliability. The standard error of measurement (SEM) and minimal detectable change (MDC95) were calculated to quantify measurement error. SEM and MDC95 values were 0.31 mm and 0.86 mm for Dm, 0.49 ms and 1.36 ms for Tc, and 1.17 ms and 3.24 ms for Td, respectively.

5.4. Assessment of Foot Progression Angle

Habitual FPA values were assessed during dynamic gait analysis using a baropodometric walkway platform (BTS P-Walk, BTS Bioengineering, Italy; 2.4 m). Measurements were performed under standardized laboratory conditions. Participants were instructed to walk across the platform at their natural walking speed, and data collection was initiated without prior notification to preserve the naturalness of the gait pattern. FPA values were automatically calculated by the device's integrated software as the angle between the longitudinal axis of the foot and the direction of progression during gait. FPA values for both feet were obtained separately. A minimum of three valid walking trials were collected per participant, and mean FPA values across trials were used in analyses (Caravaggi et al., 2017; Kawai et al., 2019).

5.5. FPA Measurement Reliability

Test–retest reliability of FPA measurements was assessed in 12 participants with a 48-hour interval. The two-way mixed model intraclass correlation coefficient (ICC 3,1) was 0.92. The minimal detectable change (MDC95) was calculated as 1.8°.

5.6. Leg Press Foot Positioning and Exercise Protocol

In the neutral protocol, participants' feet were placed on the platform at shoulder-width apart with foot rotation in a neutral (0°) position. In the toe-out protocol (30°), feet were placed at the same shoulder-width distance with the forefoot rotated 30° outward. Foot positions were measured using a standard goniometer at each session and verified by angle markings drawn on the footplate (Da Silva et al., 2008; Escamilla et al., 2001; Martín-Fuentes et al., 2020).

All procedures were performed on a 45° inclined leg press machine (Technogym, Italy). Range of motion was restricted from 90° of knee flexion to full extension. One-repetition maximum (1RM) values were determined 48 hours prior to the experimental sessions.

In the experimental session, participants performed the leg press exercise following a standardized general warm-up. The exercise protocol consisted of 2 × 15 repetitions at 40% 1RM followed by 4 × 10 repetitions at 75–80% 1RM. Inter-set rest was standardized at 2 minutes. Tempo was controlled using a metronome with a 2-second eccentric phase and 1-second concentric phase, and technical compliance was monitored by an experienced coach (Ratamess et al., 2009; Nuzzo et al., 2024).

5.7. Outcome Variables

All outcome variables were determined from tensiomyographic (TMG) parameters obtained from the vastus medialis muscle of the dominant leg before the leg press exercise protocol and within 90 seconds following completion of the final repetition. Pre- and post-exercise measurements were analyzed using raw data within a repeated measures model. Outcome variables were defined a priori.

Primary Outcomes: Changes in Dm and Tc. It was hypothesized that the acute effect of the potential interaction between foot rotation position and habitual FPA phenotype on muscle contractile dynamics would be most evident through Dm and Tc parameters. Accordingly, the Protocol × Time interaction was evaluated primarily in terms of changes in Dm and Tc.

Secondary Outcomes: Change in the Td parameter.

6. STATISTICAL CONSIDERATIONS

Statistical analyses were performed using SPSS software (Version 27, IBM Corp., Armonk, NY, USA). Descriptive statistics are presented as mean ± standard deviation (mean ± SD) and the significance level was set at $\alpha = 0.05$. Normality of continuous variables was assessed using the Shapiro–Wilk test and homogeneity of variance was evaluated with Levene's test.

To assess potential carry-over effects associated with the crossover design, pre-exercise measurements obtained prior to the second session were compared using paired samples t-tests within each group; no significant carry-over effect was observed (all $p > 0.05$).

A 2 (Group: HFPA vs. NFPA) × 2 (Protocol: congruent vs. incongruent) × 2 (Time: pre vs. post) factorial repeated measures ANOVA were applied to examine changes in muscle contractile parameters. Group was included as a between-subjects factor, while protocol and time were included as within-subjects factors. Main effects and all two-way (Group × Protocol, Group × Time, Protocol × Time) and three-way (Group × Protocol × Time) interactions were evaluated. As each within-subject factor had two levels, the sphericity assumption was automatically satisfied and no correction was applied.

Primary outcome variables were defined a priori as Dm and Tc. In line with the primary hypothesis of the study, the Protocol × Time interaction was prioritized during analysis and interpretation.

Where significant main effects or interactions were identified, pairwise comparisons were conducted with Bonferroni correction. Additionally, 95% confidence intervals for mean differences were calculated and reported for all post-hoc comparisons.

Effect sizes were reported as partial eta squared (ηp^2) and interpreted as small (0.01), medium (0.06), and large (0.14) (Richardson, 2011). The Td parameter was treated as a secondary outcome variable and only significant effects are reported.

7. ETHICAL CONSIDERATIONS

The research protocol was approved by the relevant ethics committee and the study was conducted in accordance with the Declaration of Helsinki. Prior to the study, participants were provided with detailed information regarding the research protocol and written informed consent was obtained from all participants.

8. REFERENCES

Beato, M., Madruga-Parera, M., Piqueras-Sanchiz, F., Moreno-Pérez, V., & Romero-Rodriguez, D. (2021). Acute effect of eccentric overload exercises on change of direction performance and lower-limb muscle contractile function. The Journal of Strength & Conditioning Research, 35(12), 3327-3333.

Bennour, S., Ulrich, B., Legrand, T., Jolles, B., & Favre, J. (2017). Effects of foot progression angle on knee biomechanics during gait modification. Computer Methods in Biomechanics and Biomedical Engineering, 20(sup1), 17-18.

Caderby, T., Begue, J., Dalleau, G., & Peyrot, N. (2022). Measuring foot progression angle during walking using force-plate data. Applied Mechanics, 3(1), 174-181.

Caravaggi, P., et al. (2017). Effect of age and gender on the main baropodometric parameters. Gait & Posture, 57, 10-11.

Cibulka, M. T., et al. (2016). Predicting foot progression angle during gait using two clinical measures in healthy adults. International Journal of Sports Physical Therapy, 11(3), 400.

Čular, D., et al. (2023). Tensiomyography: from muscle assessment to talent identification tool. Frontiers in Physiology, 14, 1163078.

Da Silva, E. M., et al. (2008). Analysis of muscle activation during different leg press exercises at submaximum effort levels. The Journal of Strength & Conditioning Research, 22(4), 1059-1065.

de Paula Simola, R. Á., et al. (2015). Assessment of neuromuscular function after different strength training protocols using tensiomyography. The Journal of Strength & Conditioning Research, 29(5), 1339-1348.

Disselhorst-Klug, C. (2025). What are my muscles up to? Journal of Electromyography and Kinesiology, 81, 102988.

Escamilla, R. F., et al. (2001). Effects of technique variations on knee biomechanics during the squat and leg press. Medicine & Science in Sports & Exercise, 33(9), 1552-1566.

Fernández-Baeza, D., Díaz-Ureña, G., & González-Millán, C. (2024). Contractile and Mechanical Properties of Quadriceps Muscles Measured by TMG in Professional Soccer Players. Bioengineering, 11(12), 1295.

García-Manso, J. M., et al. (2011). Assessment of muscle fatigue after an ultra-endurance triathlon using tensiomyography (TMG). Journal of Sports Sciences, 29(6), 619-625.

Harandi, V. J., Ehsani, H., & Rostami, M. (2013). Investigating the role of foot placement on the muscular forces of knee extensors in horizontal leg press. In 2013 20th Iranian Conference on Biomedical Engineering (ICBME) (pp. 59-64). IEEE.

Kalc, M., et al. (2023). Diagnostic accuracy of Tensiomyography parameters for monitoring peripheral neuromuscular fatigue. Journal of Electromyography and Kinesiology, 70, 102775.

Kawai, H., et al. (2019). Reference values of gait parameters measured with a plantar pressure platform. Clinical Interventions in Aging, 1265-1276.

Lohr, C., et al. (2019). Diagnostic accuracy, validity, and reliability of Tensiomyography to assess muscle function and exercise-induced fatigue. Journal of Electromyography and Kinesiology, 47, 65-87.

Loturco, I., et al. (2016). Muscle contraction velocity: a suitable approach to analyze the functional adaptations in elite soccer players. Journal of Sports Science & Medicine, 15(3), 483.

Macgregor, L. J., et al. (2018). Assessment of skeletal muscle contractile properties by radial displacement: the case for tensiomyography. Sports Medicine, 48(7), 1607-1620.

Martín-Fuentes, I., Oliva-Lozano, J. M., & Muyor, J. M. (2020). Muscle activation and kinematic analysis during the inclined leg press exercise. International Journal of Environmental Research and Public Health, 17(22), 8698.

Martín-Fuentes, I., Oliva-Lozano, J. M., & Muyor, J. M. (2022). Influence of feet position and execution velocity on muscle activation and kinematic parameters during the inclined leg press exercise. Sports Health, 14(3), 317-327.

Martín-Rodríguez, S., et al. (2017). Reliability and measurement error of tensiomyography to assess mechanical muscle function. The Journal of Strength & Conditioning Research, 31(12), 3524-3536.

Mohammad, W. S., & Elsais, W. M. (2020). Association between hip rotation and activation of the quadriceps and gluteus maximus in male runners. Orthopaedic Journal of Sports Medicine, 8(11), 2325967120962802.

Muñoz-López, A., et al. (2022). Using tensiomyography to assess changes in knee muscle contraction properties after concentric and eccentric fatiguing muscle actions. The Journal of Strength & Conditioning Research, 36(4), 935-940.

Neumann, D. A. (2019). Kinesiology of the musculoskeletal system (Vol. 124). Mosby.

Nuzzo, J. L., et al. (2024). Maximal number of repetitions at percentages of the one repetition maximum. Sports Medicine, 54(2), 303-321.

Pereira, R. S., et al. (2017). Does feet position alter triceps surae EMG record during heel-raise exercises in leg press machine? Manual Therapy, Posturology & Rehabilitation Journal, 1-4.

Powers, C. M. (2010). The influence of abnormal hip mechanics on knee injury. Journal of Orthopaedic & Sports Physical Therapy, 40(2), 42-51.

Qiu, R., et al. (2020). The effect of modifying foot progression angle on the knee loading parameters. Gait & Posture, 81, 7-13.

Ratamess, N. A., et al. (2009). Progression models in resistance training for healthy adults. Medicine & Science in Sports & Exercise, 41(3), 687-708.

Rey, E., Lago-Penas, C., & Lago-Ballesteros, J. (2012). Tensiomyography of selected lower-limb muscles in professional soccer players. Journal of Electromyography and Kinesiology, 22(6), 866-872.

Richardson, J. T. (2011). Eta squared and partial eta squared as measures of effect size in educational research. Educational Research Review, 6(2), 135-147.

Rojas-Valverde, D., et al. (2021). Detection of neuromechanical acute fatigue-related responses during a duathlon simulation. Proceedings of the Institution of Mechanical Engineers, Part P, 235(1), 53-61.

Rusu, L. D., et al. (2013). Tensiomyography method used for neuromuscular assessment of muscle training. Journal of Neuroengineering and Rehabilitation, 10(1), 67.

Rutherford, D. J., Hubley-Kozey, C. L., & Stanish, W. D. (2010). The neuromuscular demands of altering foot progression angle during gait. Osteoarthritis and Cartilage, 18(5), 654-661.

Shen, L., et al. (2026). Foot Progression Angle Modulates Three-Dimensional Lower-Limb Biomechanics in Flexible Flatfoot. Journal of Foot and Ankle Research, 19(1), e70126.

Šimunič, B. (2012). Between-day reliability of a method for non-invasive estimation of muscle composition. Journal of Electromyography and Kinesiology, 22(4), 527-530.

Sousa, A., & Macedo, R. (2010). Effect of the contraction of medial rotators of the tibia on the electromyographic activity of vastus medialis and vastus lateralis. Journal of Electromyography and Kinesiology, 20(5), 967-972.

Straub, R. K., & Powers, C. M. (2024). A biomechanical review of the squat exercise. International Journal of Sports Physical Therapy, 19(4), 490.

Tous-Fajardo, J., et al. (2010). Inter-rater reliability of muscle contractile property measurements using non-invasive tensiomyography. Journal of Electromyography and Kinesiology, 20(4), 761-766.

van Melick, N., et al. (2017). How to determine leg dominance. PloS One, 12(12), e0189876.