STUDY PROTOCOL

Official Title:

Morton’s Toe Is Associated with Faster Contractile Properties and Greater Reactive Strength in Female Football Players

NCT Number: NCT07588048

Unique Protocol ID: GRU-SBF-NS-06

Document Date: 22.10.2026

Principal Investigator: Asst. Prof. Dr. Nihat Sarıalioğlu

Co-Investigator: Res. Asst. Batuhan Sezen

Institution: Giresun University, Faculty of Sport Sciences

Country: Türkiye

Ethics Approval: Giresun University Social Sciences, Science and Engineering Sciences Research Ethics Committee, decision no. 10/492, November 5, 2025

1. SCIENTIFIC BACKGROUND

Morton's toe is a foot morphology characterized by a second toe that is longer than the first toe (Habib et al., 2026). Although its developmental origin has not been fully explained, it has been suggested to be associated with hereditary characteristics and prenatal processes. Harrison (2010) proposed that a longer second toe may represent a possible anatomical manifestation of prenatal androgenization, based on the overlapping developmental periods of the toes and urogenital structures. Prenatal androgens are thought to exert lasting organizational effects on the musculoskeletal and central nervous systems (Huber et al., 2017; DeChick et al., 2020). A similar approach has been adopted in studies of the 2D:4D digit ratio, which has been considered a developmental marker that may be associated with structural and neuromuscular muscle characteristics rather than a mechanical cause of performance.

Limited studies in athletic populations have reported that athletes have a longer second toe relative to the hallux than non-athletes (Kulthanan et al., 2004; Moorthy et al., 2011). Studies directly examining Morton's toe have reported negative associations with single-leg balance and postural control (Agopyan et al., 2011; Han et al., 2015), whereas another study found no differences between foot types and proposed a potential mechanical advantage for balance (Patel et al., 2019). The association of this morphology with muscle contractile characteristics and stretch-shortening cycle (SSC)-based reactive performance has not yet been evaluated.

The contractile profile of skeletal muscle reflects its structural and physiological properties; contraction time is strongly associated with contraction velocity and muscle typology, whereas the magnitude of radial displacement is related to deformation capacity and stiffness (Macgregor et al., 2018; Šimunič et al., 2011). At the functional level, SSC-based reactive performance reflects the capacity of the neuromuscular system to produce force rapidly and to utilize elastic energy effectively (Southey et al., 2024), which is particularly relevant in football.

2. STUDY OBJECTIVES AND HYPOTHESES

2.1. Primary Objective

To compare the contractile characteristics of the vastus lateralis muscle (contraction time, Tc) and SSC-based reactive performance (reactive strength index, RSI) between female football players with (MF) and without (NMF) Morton's toe morphology.

2.2. Secondary Objective

To compare maximal radial displacement (Dm), jump height (JH), and peak power relative to body mass (RPP) between groups.

2.3. Hypothesis

Female football players with Morton's toe morphology would exhibit faster contractile characteristics and greater reactive performance than those without Morton's toe morphology.

3. STUDY DESIGN

This study was conducted using a cross-sectional, observational, group-comparison design. Participants were divided into two groups according to foot morphology: those with Morton's toe morphology (MF) and those without Morton's toe morphology (NMF). All participants were assessed for contractile

characteristics and reactive performance in a single testing session. All measurements were performed during the off-season and within the same time of day (±1 h).

Participants were instructed to avoid strenuous physical activity that could induce fatigue during the 48 h preceding testing and to refrain from using muscle relaxants or similar pharmacological products. They were also instructed not to consume a heavy meal for at least 3 h before testing, to travel to the laboratory by motor vehicle, and to abstain from caffeine for 12 h and alcohol for 24 h before testing. Compliance was verified based on participant self-report.

The testing sequence was: foot morphology assessment, evaluation of muscle contractile properties, standardized warm-up, and reactive performance testing. Foot morphology assessments and TMG and drop jump measurements were performed by different researchers. The researcher conducting the TMG and drop jump measurements was not informed of the participants' foot morphology classification. Statistical analyses were performed by an independent expert using a coded dataset, with group identities concealed during the analysis.

4. PARTICIPANTS

4.1. Study Population

Female football players actively competing in the Turkish Women's First Football League.

4.2. Inclusion Criteria

- Female football players aged 18–30 years actively competing in the Turkish Women's First Football League
- Regular natural menstrual cycles
- Not using hormonal contraceptives
- Bilateral MF or bilateral NMF classification as defined in Section 5.3
- Written informed consent

4.3. Exclusion Criteria

- Not bilaterally meeting the MF or NMF classification criteria, including a first–second toe length difference within ±2 mm in either foot
- Musculoskeletal injury affecting the lower extremity within the previous 12 months that prevented full participation in training and/or competition for more than 28 days (Fuller et al., 2006)
- Body mass index <18.5 or ≥ 30.0 kg/m²
- Very high or very low medial longitudinal arch in at least one foot, defined as an arch index $<7\%$ or $>35\%$, respectively

4.4. Standardization of Menstrual Cycle Phase

To standardize menstrual-cycle phase, all assessments were performed between days 2 and 5 of the cycle, with the first day of menstrual bleeding defined as day 1 (Pojskić et al., 2025). Menstrual cycle length and the onset date of the most recent menstrual bleeding were recorded based on participant self-report, and cycle regularity was confirmed.

4.5. Sample Size Calculation

The sample size was calculated a priori based on Tc. Loturco et al. (2015) reported rectus femoris Tc values of 18.3 ± 2.8 ms and 22.9 ± 4.0 ms in power and endurance athletes, respectively, yielding a Cohen's d of 1.33. Using G*Power (two-sided t-test for two independent groups, $\alpha = 0.05$, $1-\beta = 0.95$, equal allocation), a minimum of 16 participants per group (total 32) was required. To account for potential data loss, the target sample size was set at a minimum of 18 participants per group.

4.6. Screening and Enrollment (as conducted)

A total of 97 female football players were assessed for eligibility. Of these, 10 were excluded for not meeting the BMI criteria, 14 for not meeting the medial longitudinal arch criteria, and 26 for not bilaterally meeting the MF or NMF classification criteria. The remaining 47 players were classified into the MF (n = 24) and NMF (n = 23) groups.

5. METHODS

5.1. Demographic and Physical Characteristics

Standing height was measured to the nearest 0.1 cm using a stadiometer (Seca, Hamburg, Germany). Body mass, body fat percentage, and BMI were determined using a segmental multi-frequency bioelectrical impedance analyzer (Tanita MC-780 MA, Tanita Corp., Tokyo, Japan), with the measured height entered manually. Measurements were taken with participants barefoot and wearing light clothing. Training age was recorded.

5.2. Medial Longitudinal Arch Structure

MLA structure was assessed using a baropodometry system (BTS, S.p.A., Italy). Participants were positioned in the anatomical position according to the reference points indicated on the device, and static plantar pressure data were recorded. The arch index (AI) was automatically calculated by the device software. AI <7% was considered a very high arch and AI >35% a very low arch.

5.3. Determination of Morton's Toe Morphology

Morton's toe morphology was determined using the method described by Davidson et al. (2007), based on measurement of the relative length difference between the distal ends of the first and second toes. The posterior midline of the calcaneus and the midline of the second toenail were marked. The calcaneal midline was established by connecting two points identified at the base of the heel and 5 cm proximal to this point. The participant stood with the heel in contact with the edge of a ruler aligned with a horizontal line on graph paper, and the foot was positioned so that the calcaneal and second-toe midlines were aligned along the same axis.

A right-angle square was placed perpendicular to the distal end of the first toe and parallel to the lines on the graph paper, and the level of the toe tip was marked. The same procedure was repeated for the second toe. The distance between the parallel lines representing the distal ends of the first and second toes was measured and recorded in millimeters.

Martínez-Cepa et al. (2014) reported high test–retest reliability for this measurement (ICC = 0.97; 95% CI: 0.97–0.99; SEM = 0.07 mm; MDC = 0.21 mm). To reduce potential misclassification due to measurement error, a ±2 mm threshold was used. Feet with a difference within ±2 mm were considered to have equal toe length (square foot) and were excluded. Feet in which the second toe was >2 mm longer than the first toe were classified as MF, and feet in which the first toe was >2 mm longer than the second toe were classified as NMF.

5.4. Assessment of Contractile Characteristics (Tensiomyography)

Contractile characteristics were assessed in the vastus lateralis muscle of the dominant limb using tensiomyography (TMG; TMG-BMC Ltd., Ljubljana, Slovenia) (Martín-Rodríguez et al., 2017; Šimunič et al., 2011). Limb dominance was determined by asking participants which leg they would use to kick a ball toward a target (van Melick et al., 2017).

Before testing, participants rested for 10 min in a room maintained at 22 ± 1°C. Participants lay supine with a triangular wedge beneath the knee to maintain approximately 30° of knee flexion. The most prominent point of the muscle belly was identified by palpation, and the probe was positioned perpendicular (90°) to the skin over this point. Surface electrodes were placed proximal and distal to the probe along the longitudinal axis of the muscle, with an interelectrode distance of 5 cm. Participants were instructed to keep the muscle completely relaxed. Electrical stimulation was initiated at 20 mA and increased by 10 mA with each stimulus until maximal radial displacement was achieved, with a 30-s rest interval between stimuli (Macgregor et al., 2018; Šimunič, 2012; Wilson et al., 2018).

Contraction time (Tc) was defined as the time from 10% to 90% of maximal radial displacement (ms), and maximal radial displacement (Dm) as the peak radial displacement of the muscle belly (mm).

5.5. Warm-Up

Before the performance assessments, participants completed a 15-min active warm-up consisting of 5 min of light running, short-distance accelerations, and dynamic stretching exercises.

5.6. Assessment of Reactive Performance (Drop Jump)

Reactive performance was assessed using the drop jump test performed barefoot on a dual force platform (ForceDecks FD Mini, VALD Performance, Australia) (Collings et al., 2024; González-García et al., 2024). Participants completed a standardized familiarization protocol in which the test technique was demonstrated and practice trials were performed, followed by a 5-min rest. Participants were instructed to drop from the 40-cm box with their hands on their hips and, immediately after ground contact, jump as high as possible in the shortest possible time. The device was calibrated before measurement for each participant. Drop jumps were performed from a custom-made 40-cm box positioned behind the force platform. Trials that did not comply with the protocol or for which the device did not produce a valid score were considered invalid. Each participant completed three valid trials with a 1-min rest interval, and the trial with the highest RSI was included in the analysis (Hook et al., 2024).

- Reactive Strength Index (RSI): jump height calculated from flight time divided by contact time (m/s)
- Jump Height (JH): vertical displacement derived from flight time (cm)
- Peak Power Relative to Body Mass (RPP): peak power during the jump normalized to body mass (W/kg)

6. OUTCOME VARIABLES

Co-primary outcomes: Tc (ms) and RSI (m/s)

Secondary outcomes: Dm (mm), JH (cm), and RPP (W/kg)

All outcomes were assessed in a single measurement session.

7. STATISTICAL ANALYSIS

Normality was assessed using the Shapiro–Wilk test and homogeneity of variance using Levene's test. Normally distributed variables are presented as mean ± standard deviation and non-normally distributed variables as median [25th–75th percentile]. Between-group comparisons were performed using the independent-samples t-test or the Mann–Whitney U test, as appropriate. Mean differences are reported with 95% confidence intervals for t-tests. Effect sizes were expressed as Hedges' g for t-tests and rank-biserial correlation (r_rb) for Mann–Whitney U tests, with 95% confidence intervals; confidence intervals for r_rb were calculated using bias-corrected and accelerated (BCa) bootstrap resampling with 5,000 resamples.

Support for the main hypothesis required a statistically significant between-group difference in both co-primary outcomes (Tc and RSI); therefore, no additional multiple-comparison correction was applied to Tc and RSI. For the secondary outcomes (Dm, JH, RPP), p-values were adjusted using the Holm–Bonferroni method.

Group differences in all outcome variables were also examined using multiple linear regression models including group (NMF = 0, MF = 1), training age, BMI, and body fat percentage. Results are presented as unstandardized coefficients (B) with 95% confidence intervals. Model assumptions were examined with respect to linearity, normality of residuals, homoscedasticity, and multicollinearity.

Group comparisons, Holm–Bonferroni adjustment, and regression analyses were performed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Hedges' g and r_rb with 95% confidence intervals were calculated in R (R Foundation for Statistical Computing, Vienna, Austria). All tests were two-sided, with statistical significance set at $p < 0.05$.

8. ETHICAL CONSIDERATIONS

Ethical approval was obtained from the Giresun University Social Sciences, Science and Engineering Sciences Research Ethics Committee (decision no. 10/492, November 5, 2025). The study was conducted in accordance with the Declaration of Helsinki, and written informed consent was obtained from all participants before participation.

9. REFERENCES

Agopyan, A., Ersöz, A., & Topsakal, N. (2011). Effects of Morton's foot on vertical jump, static and dynamic balance performances of modern dancers. Medicina dello Sport, 64(2), 137–150.

Collings, T. J., Lima, Y. L., Dutaillis, B., & Bourne, M. N. (2024). Concurrent validity and test–retest reliability of VALD ForceDecks' strength, balance, and movement assessment tests. Journal of Science and Medicine in Sport, 27(8), 572–580.

Davidson, G., Pizzari, T., & Mayes, S. (2007). Reliability of measuring first and second metatarsal and toe length. The Foot, 17(1), 32–37.

DeChick, A., Hetz, R., Lee, J., & Speelman, D. L. (2020). Increased skeletal muscle fiber cross-sectional area, muscle phenotype shift, and altered insulin signaling in rat hindlimb muscles in a prenatally androgenized rat model for polycystic ovary syndrome. International Journal of Molecular Sciences, 21(21), 7918.

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., Hägglund, M., McCrory, P., & Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Scandinavian Journal of Medicine & Science in Sports, 16(2), 83–92.

González-García, J., Conejero, M., & Gutiérrez-Hellín, J. (2024). Assessing jump performance: Intra- and interday reliability and minimum difference of countermovement jump and drop jump outcomes, kinetics, kinematics, and jump strategy. Applied Sciences, 14(6), 2662.

Habib, Z. M. H., Al-Qaed, A. N., Yahya, A. A., Al-Balushi, M. A., Almarabheh, A., Nasr El-Din, W. A., & Potu, B. K. (2026). Prevalence of Morton's toe: A systematic review and meta-analysis. F1000Research, 15, 664.

Han, J.-T., Go, M.-J., Kim, Y.-J., Choi, Y.-S., & Ryu, H.-N. (2015). The effect of Morton's foot on static balance ability. Journal of the Korean Society of Physical Medicine, 10(2), 81–87.

Harrison, M. A. (2010). An exploratory study of the relationship between second toe length and androgen-linked behaviors. Journal of Social, Evolutionary, and Cultural Psychology, 4(4), 241–253.

Hook, A., Stephens, J., Mason, B., Warmenhoven, J., & Ball, N. (2024). Exploring peak concentric force and zero velocity synchronization in the drop jump. Scandinavian Journal of Medicine & Science in Sports, 34(11), e14761.

Huber, S. E., Lenz, B., Kornhuber, J., & Müller, C. P. (2017). Prenatal androgen-receptor activity has organizational morphological effects in mice. PLOS ONE, 12(11), e0188752.

Kulthanan, T., Techakampuch, S., & Donphongam, N. D. (2004). A study of footprints in athletes and non-athletic people. Journal of the Medical Association of Thailand, 87(7), 788–793.

Loturco, I., Gil, S., Laurino, C. F. S., Roschel, H., Kobal, R., Abad, C. C. C., & Nakamura, F. Y. (2015). Differences in muscle mechanical properties between elite power and endurance athletes: A comparative study. Journal of Strength and Conditioning Research, 29(6), 1723–1728.

Macgregor, L. J., Hunter, A. M., Orizio, C., Fairweather, M. M., & Ditroilo, M. (2018). Assessment of skeletal muscle contractile properties by radial displacement: The case for tensiomyography. Sports Medicine, 48(7), 1607–1620.

Martín-Rodríguez, S., Loturco, I., Hunter, A. M., Rodríguez-Ruiz, D., & Munguia-Izquierdo, D. (2017). Reliability and measurement error of tensiomyography to assess mechanical muscle function: A systematic review. Journal of Strength and Conditioning Research, 31(12), 3524–3536.

Martínez-Cepa, C. B., Zuil-Escobar, J. C., Chillón-Martínez, R., Jiménez-Rejano, J. J., & Palomo-Toucedo, I. C. (2014). Intra-observer reliability for measuring first and second toe and metatarsal protrusion distance using palpation-based tests: A test-retest study. Journal of Foot and Ankle Research, 7(1), 37.

Moorthy, T. N., Samsudin, W. N. Z. W. M., & Ismail, M. S. (2011). A study on footprints of Malaysian athletes and non-athletes for application during forensic comparison. Malaysian Journal of Forensic Sciences, 2(1), 29–35.

Patel, V., Vanani, N., Patel, M., & Vagh, K. (2019). Comparison of balance among asymptomatic population with Egyptian and Greek foot: A cross-sectional study. Russian Journal of Physical Education and Sport, 14(2), 131–137.

Pojskić, H., Schiller, J., Pagels, P., Ragnarsson, T., & Melin, A. K. (2025). Are counter movement jump and isometric mid-thigh pull tests reliable, valid, and sensitive measurement instruments when performed after maximal cardiopulmonary exercise testing? A sex-based analysis in elite athletes. Frontiers in Physiology, 16, 1663590.

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.

Šimunič, B., Degens, H., Rittweger, J., Narici, M., Mekjavic, I., & Pisot, R. (2011). Noninvasive estimation of myosin heavy chain composition in human skeletal muscle. Medicine and Science in Sports and Exercise, 43(9), 1619–1625.

Southey, B., Willshire, M., Connick, M. J., Austin, D., Spits, D., & Beckman, E. (2024). Reactive strength index as a key performance indicator in different athlete populations: A systematic review. Science & Sports, 39(2), 129–143.

van Melick, N., Meddeler, B. M., Hoogeboom, T. J., Nijhuis-van der Sanden, M. W. G., & van Cingel, R. E. H. (2017). How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults. PLOS ONE, 12(12), e0189876.

Wilson, H. V., Johnson, M. I., & Francis, P. (2018). Repeated stimulation, inter-stimulus interval and inter-electrode distance alters muscle contractile properties as measured by tensiomyography. PLoS ONE, 13(2), e0191965.