

Sport-Specific Differences in Spinal Mobility, Hamstring Flexibility, and Dynamic Balance in Elite Male Adolescent Athletes

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Abstract

Background

Sport-specific training may shape dynamic balance, spinal mobility, and hamstring flexibility during adolescence, but whether these domains vary coherently across sports within a single cohort remains unclear. This study compared dynamic balance, spinal mobility, and hamstring flexibility among elite adolescent athletes from different sports and aimed to identify independent predictors of Y-Balance Test (YBT) performance.

Methods

This cross-sectional study was conducted at the Athlete Training Center, Adana, Türkiye, and included 125 elite male athletes aged 15–17 years in taekwondo ($n = 35$), sprint kayaking ($n = 29$), wrestling ($n = 31$), or track and field ($n = 30$). Dynamic balance was assessed with the Lower Quarter YBT (normalized composite score, primary outcome), spinal mobility with a digital inclinometer, and hamstring flexibility with the active straight leg raise test. Group differences were compared, and hierarchical regression identified independent predictors of the YBT composite score.

Results

Normalized YBT composite scores differed among sports ($p = 0.025$, $\eta^2=0.074$), with wrestlers scoring higher than track-and-field athletes. Taekwondo athletes showed greater hamstring flexibility than other athletes ($p < 0.001$, $\eta^2=0.353$), and sport-specific differences were also found in spinal mobility (all $p < 0.05$). After FDR correction, only body fat percentage remained inversely associated with YBT score, in wrestlers ($r=-0.536$, $q = 0.036$). Confounders explained 19.2% of YBT variance ($R^2=0.192$); adding secondary outcome measures raised this to 25.9% ($\Delta R^2=0.067$, $p = 0.007$). Wrestling and body fat percentage were independent predictors throughout, and hamstring flexibility emerged as an independent positive predictor once confounders were controlled ($B = 0.21$, 95% CI: 0.05–0.36, $p = 0.009$), despite no significant unadjusted correlation.

Conclusions

Dynamic balance in elite adolescent athletes is shaped less by sport discipline itself than by individual body composition and flexibility. Identifying athletes at risk for balance deficits requires looking beyond sport category: body fat percentage and hamstring flexibility, unlike spinal mobility, stand out as modifiable, individually trackable targets.

INTRODUCTION

Competitive sport participation during adolescence exposes athletes to repeated movement patterns, neuromuscular demands, and biomechanical loads that shape the development of physical function¹. Because these demands differ markedly by discipline, athletes across different sports would be expected to vary in dynamic balance, flexibility, strength, and movement quality^{2,3}, and prior work has indeed documented such differences between athletes in symmetrical versus asymmetrical sports and between individual- versus team-sport athletes^{2,3}. What remains far less clear is whether this sport-specific divergence extends coherently across multiple domains of physical function within a single cohort of adolescent athletes.

Among these domains, dynamic balance occupies a central role, underpinning postural stability during demanding athletic tasks such as landing, cutting, and rapid changes in direction². The Lower Quarter Y-Balance Test (YBT) has become the instrument of choice for quantifying unilateral dynamic postural control, owing to its excellent reliability in athletic populations⁴. Its performance is known to vary with age, competitive level, and sport background, patterns thought to reflect differences in neuromuscular development and cumulative training exposure¹.

Dynamic balance, however, is not a purely lower-extremity phenomenon: it demands coordinated contributions from multiple body segments⁵, with the lumbopelvic region serving as the critical link between trunk and lower-extremity coordination and as a conduit for force transmission throughout the kinetic chain⁶. While core strength and endurance have attracted considerable research attention, the contribution of spinal mobility to dynamic postural tasks remains comparatively uncharted⁶, and direct evidence linking spinal mobility to dynamic balance in athletic populations is scarce⁷.

A parallel gap surrounds hamstring flexibility, another key component of the lumbopelvic kinetic chain: because the hamstrings influence pelvic alignment and lower-extremity biomechanics, reduced extensibility could plausibly alter movement strategies during dynamic tasks⁷. Existing evidence on the relationship between hamstring flexibility and athletic performance is nonetheless inconsistent, suggesting that its functional relevance may be sport-specific rather than universal^{7,8}.

Taken together, these threads point to a clear gap in the literature: despite growing interest in athletic function, how dynamic balance relates to mobility and flexibility across different sports during adolescence remains poorly understood^{2,6-8}, and, to our knowledge, no study has so far examined these three domains concurrently within a single cohort of elite adolescent athletes spanning contrasting biomechanical demands. This study therefore compared YBT performance, segmental spinal mobility, and hamstring flexibility among elite male adolescent athletes participating in taekwondo, sprint kayaking, wrestling, and track and field, while also examining the anthropometric, training-related, and physical characteristics associated with balance. We hypothesized that these functional profiles would differ across sports and that YBT performance would be associated with selected anthropometric and physical characteristics.

METHODS

Study Design

This cross-sectional comparative study was conducted between December 2025 and March 2026, in accordance with the Declaration of Helsinki. The Non-Interventional Clinical Research Ethics Committee of the Faculty of Health Sciences, Toros University (Mersin, Türkiye) approved the protocol (Decision No. 27, December 4, 2025), and the study was prospectively registered at ClinicalTrials.gov (NCT07395947).

Participants

We consecutively recruited 125 licensed elite male athletes aged 15–17 years from the Athlete Training Center (ATC). During the recruitment period, athletes within the eligible age range participating in taekwondo, sprint kayaking, wrestling, and track and field (sprinting and jumping events) were identified from the center's athlete records, in collaboration with the respective coaches. All potentially eligible athletes were then screened according to the predefined inclusion and exclusion criteria and invited to participate. Athletes who agreed to participate were consecutively enrolled after written informed consent was obtained from both the athlete and a legal guardian.

Elite status was defined as systematic training and regular participation in national- or international-level competitions. Eligibility criteria included ≥ 3 years of continuous participation in licensed sports, active training at the ATC, and participation in official competitions. Athletes were excluded if they had sustained an acute musculoskeletal injury within the previous 3 months, undergone surgery within the previous 6 months, or had a chronic musculoskeletal disorder, pain, or any other condition that could affect test performance.

All participants followed a standardized training program throughout the competitive season, training 6 days/week for a minimum of 20 h/week. Athletes completed two sport-specific sessions per day on 5 days and one session on the remaining training day.

A total of 125 athletes met the eligibility criteria, provided the required informed consent, completed all assessments, and were included in the final analyses. No participants were excluded or lost after enrollment.

We performed an a priori sample size calculation using G*Power (version 3.1.9.7) for a one-way ANOVA (fixed effects, omnibus). Assuming Cohen's $f = 0.50$, $\alpha = 0.05$, and 80% power, the minimum required sample size was determined to be 48 participants. The assumed effect size was based on a previous study investigating physical performance characteristics, including dynamic balance, in adolescent athletes¹. Our final sample of 125 athletes exceeded this requirement.

Measurement Standardization

Our research team performed all assessments under standardized conditions. Participants refrained from vigorous physical activity for 24 h before testing and completed a standardized 10-minute dynamic warm-up. Body composition and anthropometric measurements were obtained in the morning. The same physiotherapist subsequently performed spinal mobility, hamstring flexibility, and dynamic balance assessments in a fixed order under consistent environmental conditions. The normalized Y-Balance Test composite score was predefined as the primary outcome, with spinal mobility and hamstring flexibility considered secondary outcomes.

Outcome Measures

Demographic Characteristics

Age (years), height (cm), body mass (kg), body mass index (BMI; kg/m²), sports experience (years), body fat percentage (%), dominant lower-limb length (cm), and limb dominance were recorded for each athlete. Height, body mass, and body fat percentage were assessed using a multifrequency bioelectrical impedance analyzer (Tanita MC-780 MA, Tanita Corp., Tokyo, Japan) according to a standardized protocol⁹. Sports experience was defined as the total number of years of regular participation as a licensed athlete in the primary sport. We measured dominant lower-limb length as the distance from the anterior superior iliac spine to the medial malleolus, and limb dominance was defined as the lower extremity preferred for kicking a ball.

Dynamic Balance Assessment

The Lower Quarter Y-Balance Test (YBT) was used to assess dynamic balance^{10,11}. Participants performed the test barefoot while standing on the dominant lower limb and were instructed to reach as far as possible in the anterior, posteromedial, and posterolateral directions without losing balance. Participants completed familiarization trials before formal testing. Three valid trials were then recorded in each direction, and the mean reach distance was calculated for each direction. These values were normalized to dominant lower-limb length to calculate the normalized YBT composite score (%), our primary outcome measure. The normalized composite score was calculated as follows:

Normalized composite score (%) = [(anterior + posteromedial + posterolateral reach distances) / (3 × dominant lower-limb length)] × 100.

Spinal Mobility Assessment

Spinal mobility was evaluated with a digital inclinometer (Baseline®, Fabrication Enterprises Inc., White Plains, NY, USA), following the standardized protocol recommended by the American Medical Association (AMA). The assessed parameters included lumbosacral and thoracolumbar upright posture angles; lumbar and thoracolumbar flexion and extension; and right and left axial rotation in both spinal regions (Fig. 1). Each measurement was performed twice, and the mean value was used in the statistical

analyses¹². For use as a predictor in the hierarchical regression analysis, a standardized composite of right and left lumbosacral and thoracolumbar axial rotation was computed (Cronbach's $\alpha = 0.81$).

Hamstring Flexibility Assessment

The active straight leg raise (SLR) test was used to assess hamstring flexibility of the dominant lower limb. Participants were positioned supine and instructed to actively raise the dominant lower limb as far as possible while maintaining full knee extension and avoiding compensatory pelvic or trunk movement. At the maximal range achieved without loss of the standardized position, the hip flexion angle was measured in degrees (°) using a standard universal goniometer aligned with established anatomical landmarks. Each measurement was performed twice, and the mean value was used in the statistical analyses¹³.

Measurement Reliability

Before the main study, inter-rater reliability was evaluated in a pilot sample of 10 participants. The principal investigator and an experienced physiotherapist independently assessed hamstring flexibility, the YBT composite score, thoracolumbar upright posture, and right thoracolumbar rotation using the same equipment and standardized measurement protocols. Inter-rater reliability was evaluated using intraclass correlation coefficients (ICCs) and Krippendorff's alpha coefficients. Hamstring flexibility (ICC = 0.971), the YBT composite score (ICC = 0.961), thoracolumbar upright posture (ICC = 0.979), and right thoracolumbar rotation (ICC = 0.917) demonstrated excellent inter-rater reliability, and Krippendorff's alpha coefficients indicated high agreement for hamstring flexibility (0.9693), the YBT composite score (0.9537), and thoracolumbar upright posture (0.9715), and moderate agreement for right thoracolumbar rotation (0.7623).

Statistical Analysis

An independent statistician blinded to sport-group allocation performed statistical analyses using IBM SPSS Statistics version 31.0 (IBM Corp., Armonk, NY, USA). No data were missing. Descriptive statistics are presented as mean $\pm$ SD, median (minimum-maximum), or frequency (%). Normality was assessed via skewness and kurtosis (± 1.5). Between-group differences were analyzed using one-way ANOVA or the Kruskal-Wallis test with Bonferroni-adjusted post hoc comparisons, and categorical variables were compared using the chi-square test. YBT composite scores were compared between dominant sides using the Mann-Whitney U test, overall and within each sport. Associations of the normalized YBT composite score with demographic, sports-experience, hamstring flexibility, and spinal mobility variables were assessed using Pearson's or Spearman's correlations, applying Benjamini-Hochberg false discovery rate (FDR) correction within the overall sample and each sport group. A hierarchical multiple linear regression was then performed to identify independent predictors of the YBT composite score: Block 1 entered demographic and sport-related confounders (age, BMI, body fat percentage, sports experience, and sport), and Block 2 added hamstring flexibility and a standardized spinal rotation composite

(Cronbach's $\alpha = 0.81$) as secondary outcome measures. We computed 95% confidence intervals for all regression coefficients and assessed collinearity via variance inflation factors and tolerance. Inter-rater reliability was assessed using intraclass correlation coefficients and Krippendorff's alpha. Effect sizes were expressed as eta squared (η^2) for ANOVA, epsilon squared (ϵ^2) for Kruskal-Wallis tests, and r for Mann-Whitney U tests. Two-sided $p < 0.05$ was considered significant in unadjusted analyses, and $q < 0.05$ after FDR correction.

RESULTS

We present participant characteristics in Table I ($n = 125$: taekwondo = 35, kayaking = 29, wrestling = 31, track and field = 30); age and limb dominance were comparable across groups ($p > 0.05$). Groups varied in height, body mass, BMI, sports experience, body fat percentage, and dominant leg length (all $p < 0.05$, $\eta^2 = 0.065\text{--}0.251$); taekwondo athletes had greater sports experience, wrestlers greater body mass and fat, and track-and-field athletes greater leg length.

[TABLE I]

Sport groups showed distinct profiles in dynamic balance, hamstring flexibility, and spinal mobility (Table II). The YBT composite score varied among groups ($p = 0.025$, $\eta^2 = 0.074$), with wrestlers scoring higher than track-and-field athletes. Taekwondo athletes showed markedly greater hamstring flexibility than the other groups ($p < 0.001$, $\eta^2 = 0.353$). Four spinal mobility parameters also distinguished the groups (upright lumbosacral posture, thoracolumbar flexion, lumbosacral extension, right thoracolumbar rotation; all $p < 0.05$, $\eta^2 = 0.044\text{--}0.138$); the remaining measures were comparable across groups (all $p > 0.05$).

[TABLE II]

Our correlation analyses (Table III) identified several nominal associations with YBT performance before FDR correction; only body fat percentage in wrestlers remained significant after correction ($r = -0.536$, $q = 0.036$), with no other correlations surviving in the overall sample or any sport group (all $q > 0.05$).

[TABLE III]

YBT scores did not vary by limb dominance overall or in most sports (Table IV [Comparison of YBT Composite Score According to Dominant Side], all $p > 0.05$), except among wrestlers, where right-dominant athletes scored higher (108.20 ± 11.35 vs. 91.49 ± 13.18 ; $Z = -2.406$, $p = 0.016$, $r = -0.432$).

[TABLE IV]

Our hierarchical regression predicting the YBT composite score (Table V [Hierarchical Multiple Regression Analysis Predicting the Normalized YBT Composite Score]) showed that confounders explained 19.2% of the variance ($R^2 = 0.192$, $p = 0.001$), with wrestling remaining a significant positive predictor ($B = 9.98$, 95% CI: 3.88–16.08). Adding hamstring flexibility and spinal mobility significantly improved the model ($\Delta R^2 = 0.067$, $p = 0.007$; total $R^2 = 0.259$). Hamstring flexibility was an independent

positive predictor ($B = 0.21$, 95% CI: 0.05–0.36, $p = 0.009$), whereas spinal mobility was not ($p = 0.098$); body fat percentage remained an independent negative predictor throughout ($B = -0.73$, 95% CI: -1.15, -0.30). VIFs were low (maximum 2.37), indicating no meaningful multicollinearity.

[TABLE V]

DISCUSSION

We examined sport-specific differences in dynamic balance, spinal mobility, and hamstring flexibility among elite male adolescent athletes from four disciplines with contrasting biomechanical demands, while evaluating the independent contributions of flexibility and spinal mobility to balance. Hamstring flexibility and several spinal mobility measures differed across sports, whereas normalized YBT performance showed more limited between-sport variation, with wrestlers outperforming track-and-field athletes. The covariate model explained 19.2% of the variance in YBT performance, rising to 25.9% with the addition of hamstring flexibility and spinal mobility. Hamstring flexibility and body fat percentage were independently associated with balance, whereas spinal mobility was not – indicating that distinct sport-specific mobility profiles do not necessarily translate into corresponding differences in dynamic postural control.

Differences in flexibility and spinal mobility likely reflect each sport's distinct movement demands^{1,3}. Taekwondo athletes showed the greatest hamstring flexibility and thoracolumbar rotation, consistent with the hip excursion required during kicking¹⁴. Wrestlers showed greater thoracolumbar flexion and lumbosacral extension, consistent with repeated trunk flexion, extension, and resistance demands^{15–17}. Kayakers showed no consistent advantage, possibly reflecting coordinated rather than maximal trunk motion^{18,19}, while sprinting and jumping emphasize lumbopelvic control over large spinal ranges^{6,20}. Despite these profiles, between-sport differences in normalized balance were comparatively limited, suggesting athletes can achieve comparable YBT performance through different movement strategies rather than superior mobility itself.

Dynamic balance reflects the integration of proprioceptive input, neuromuscular coordination, and task-specific motor strategies rather than any single mobility characteristic^{21,22}. Wrestlers were the exception, outperforming track-and-field athletes – plausibly reflecting the frequent perturbations and postural adjustments inherent to wrestling^{23,24}, versus the forward-directed locomotor demands of sprinting and jumping²⁰. These interpretations remain mechanistic hypotheses, as the cross-sectional design cannot attribute the differences directly to training.

After FDR correction, the only sport-specific correlation that remained significant was the inverse association between body fat percentage and YBT performance among wrestlers ($r = -0.536$, $q = 0.036$). This emerged as a post-hoc finding rather than a pre-specified hypothesis and should be interpreted as hypothesis-generating; replication in an independent cohort is warranted. Wrestlers also showed greater adiposity than track-and-field athletes²⁵, and greater adiposity may increase the mechanical demands of

controlling body mass during unilateral reaching^{26,27}. Body fat percentage also remained independently and negatively associated with YBT performance in the pooled multivariable analysis ($B = -0.73$, 95% CI: -1.15 to -0.30). A 10% increase in body fat corresponded to a 7.3-point decrease in normalized YBT score — a magnitude approaching clinical relevance — indicating the association was not confined to the wrestling subgroup. Notably, wrestlers still scored higher overall than track-and-field athletes despite their greater adiposity, underscoring that body composition is only one component of balance performance.

Hamstring flexibility showed a different pattern: though its unadjusted association did not survive FDR correction, active SLR was independently and positively associated with YBT performance after adjustment ($B = 0.21$, 95% CI: 0.05 to 0.36 , $p = 0.009$). A 10° increase in SLR corresponded to only a 2.1-point increase in YBT score — considerably smaller than the effect of body fat. Greater hamstring extensibility may facilitate hip motion during reaching while maintaining postural control, though the modest magnitude does not support a causal interpretation. In contrast, the spinal rotation composite was not independently associated with balance ($B = -1.88$, 95% CI: -4.12 to 0.36 , $p = 0.098$), consistent with evidence that dynamic reaching depends on coordinated trunk-hip-knee-ankle contribution rather than spinal range of motion alone^{28–30}. Together, these findings suggest range of motion itself should not be treated as a proxy for dynamic postural control.

Several methodological features strengthen the interpretation of these findings, including standardized testing procedures, normalization of YBT performance to limb length, excellent inter-rater reliability for the principal outcome measures, FDR adjustment for multiple correlations, and multivariable analysis accounting for relevant demographic, anthropometric, training-related, and sport factors. Nevertheless, several limitations should be acknowledged. The cross-sectional design precludes causal inference and cannot determine whether the observed characteristics developed in response to sport-specific training or contributed to athletes' selection or continued participation in particular disciplines. Although the total sample exceeded the a priori requirement for the primary between-sport analysis, individual sport groups were relatively small ($n = 29–35$ per sport), which may have limited the ability to detect modest within-sport associations, particularly after correction for multiple comparisons. Assessment was restricted to the dominant limb, and the exclusively male adolescent elite sample limits generalizability.

Anthropometric and training characteristics also differed among sport groups, though several were incorporated into the multivariable model. Longitudinal studies with bilateral assessment and more diverse populations are needed.

CONCLUSIONS

From a practical perspective, sport discipline alone does not fully characterize dynamic balance in elite adolescent athletes. Hamstring flexibility and body composition provided additional information beyond sport, whereas spinal mobility did not contribute independently. The final model explained only about one-quarter of the variance in balance; the remainder likely reflects factors not captured here, such as neuromuscular reaction time, proprioceptive acuity, core stabilization strategy, and training age. These

characteristics should therefore be considered within a broader athlete assessment rather than as isolated determinants of balance.

Declarations

Ethics approval and consent to participate:

The study protocol was approved by the Non-Interventional Clinical Research Ethics Committee of the Faculty of Health Sciences, Toros University, Mersin, Türkiye (Decision No. 27; approval date: December 4, 2025). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants and their legal guardians before enrollment.

Consent for publication:

Written informed consent for publication of identifiable images was obtained from the participant shown in Fig. 1 and from his parent/legal guardian, and from the assisting physiotherapist shown in Fig. 1. The other examiner shown in Fig. 1 is an author of this study and consented to the publication of her image.

Competing interests:

The authors certify that they have no conflict of interest with any financial organization regarding the material discussed in this manuscript.

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Author Contribution

BU conceptualized the study and contributed to methodology, investigation, and formal analysis. BU and IEU contributed to methodology, investigation, writing of the original draft, and writing review and editing, and both authors supervised the project and contributed to project administration. All authors read and approved the final version of the manuscript.

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Data Availability

The datasets generated and/or analysed during the current study are not publicly available due to [participant privacy / institutional data protection policy], but are available from the corresponding author on reasonable request.

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Tables

Table 1 to 5 are available in the Supplementary Files section.

Figures



Figure 1

Digital inclinometer positioning for assessment of thoracolumbar and lumbosacral axial rotation. Right and left rotation angles were measured separately at each spinal level and combined into a standardized composite score, in accordance with the standardized AMA protocol described in the Methods section.

Supplementary Files

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