



Investigation of relationships between static postural control, dynamic stabilization, and agility in female handball players: a pilot study

Balance and agility in female handball athletes

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Abstract

Aim: Handball is a high-intensity, multidirectional sport requiring postural control, agility, and lower-limb strength for performance and injury prevention. Relationships among static postural control, dynamic stabilization, and agility remain unclear. This pilot study examined static postural control, dynamic stabilization, and agility in female handball athletes.

Methods: Twelve licensed players (age 26.6 ± 3.4 years; height 173.9 ± 6.1 cm; weight 69.6 ± 7.6 kg; BMI 23.0 ± 1.5 kg/m²) participated. Static postural control was assessed via single-leg stance on a VALD ForceDecks dual force plate, measuring center of pressure (COP) parameters: total excursion, mean velocity, and medio-lateral (ML) and antero-posterior (AP) sway. Dynamic stabilization was evaluated using single-leg landings from a 30 cm box, with peak vertical ground reaction force and time to stabilization recorded. Agility was measured using the Pro-Agility (5 10-5) test with infrared timing gates. Unilateral tests distinguished the jump limb from the contralateral limb.

Results: No significant correlations were found between static COP, dynamic stabilization, and agility ($P > .05$). Significant limb differences were observed in static balance: the jump limb showed lower ML sway ($P = .029$) and mean COP velocity ($P = .017$) with large effect sizes ($r > 0.50$). A moderate positive correlation was observed between peak landing force and AP sway on the contralateral limb ($r = 0.625$, $P = .03$). Dynamic parameters did not differ between limbs.

Conclusion: Although static postural control did not predict dynamic stabilization or agility, unilateral asymmetries highlighted the jump limb's superior stability, while the contralateral limb required greater conscious force production. These results emphasize the use of eccentric and neuromuscular exercises to address limb deficits in female handball players.

Keywords

handball, static postural control, dynamic stabilization, agility, female athletes

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Introduction

Handball is a team sport requiring speed, rapid directional changes, jumping, and short, high-intensity efforts that rely on both aerobic and anaerobic systems. Players perform upper-extremity tasks such as passing and shooting while executing lower-extremity skills like jumping, sudden stops, acceleration, and directional changes on hard surfaces. Sustaining performance and minimizing injury risk under these high-tempo conditions depend largely on effective postural control in both static and dynamic situations.¹

The base of support is the area formed by the body's contact points with the ground. Balance, or postural stability, is the ability to keep the center of mass within this area. Postural control relies on integrating sensory input, selecting appropriate motor responses, and coordinating muscle activity. Static balance refers to maintaining posture on a stable surface, whereas dynamic balance involves preserving stability during movement or changing environmental conditions. Stability limits describe the anterior, posterior, and lateral boundaries within which balance can be maintained without altering the base of support and vary according to the task and environment.²

Most handball movements are performed on one or both legs, making static and dynamic balance essential components of performance. In dynamic sports such as handball, dynamic balance tests are preferred over static ones. Single-leg landing and stabilization time is widely used as a reliable measure of dynamic postural control, as it requires effective force absorption on landing and rapid deceleration to achieve stability.³

Agility is another key determinant of handball performance. It relies not only on speed and directional changes but also on effective force production, maintaining postural control during rapid stop-start actions, and efficient neuromuscular coordination. Tests based on single-leg stance or landing reflect an athlete's ability to control transitions from movement to stationary positions.⁴

Recently, portable force platforms and video-based motion analysis methods have become more common for assessing static balance, dynamic stabilization, and agility in athletes.⁵⁻⁷ However, research examining the relationships among these three motor components—especially in female handball players—remains limited. This pilot study aimed to investigate the associations among static postural control, dynamic stabilization, and agility in female handball players. Understanding these interactions may help identify key motor control factors influencing performance and guide more targeted training and injury risk assessments.

The study hypotheses were as follows

H1: Female handball players with better static balance will achieve single-leg landing stabilization in a shorter time.

H2: Female handball players with better static balance will complete agility tests faster.

H3: The jump limb will demonstrate superior COP sway parameters/mean velocity and shorter time to stabilization compared to the contralateral limb.

Materials and Methods

Study Design and Participants

This cross-sectional pilot study included 12 active, licensed female handball players aged 21–33 years, recruited voluntarily from club teams. Demographic and anthropometric data—including age, height, weight, and BMI—were collected using a standard form. To reduce circadian-related variability, all measurements were performed under similar environmental conditions and at

comparable times of day.

Inclusion and Exclusion Criteria

Inclusion criteria were defined as: (i) being between 18 and 35 years of age, (ii) being an active licensed handball player, (iii) having participated in regular training or official matches within the last three months, and (iv) possessing the physical capability to perform test protocols safely and without pain. Exclusion criteria included: (i) a history of acute lower extremity injury (e.g., sprain, muscle-tendon injury, fracture) or surgery within the last six months, (ii) complaints of persistent pain or instability, (iii) neurological or vestibular disorders affecting balance performance, (iv) uncorrected visual impairment, and (v) reporting fatigue or any acute condition preventing protocol completion on the test day.

Assessments

All tests, with the exception of the agility test, were performed unilaterally for both lower extremities; the side preferred by the athletes during jumping was defined as the 'jump limb'. To ensure measurement standardization, all procedures were conducted in a fixed order and by the same researcher. A VALD ForceDecks dual force plate system (VALD Performance, Brisbane, Australia) was used to collect data. It has been reported in the literature that this system exhibits high validity (mean bias < 2 N or 0.1 mm) and reliability (ICC > 0.75) for vertical ground reaction force and Center of Pressure (COP) measurements compared with traditional laboratory-grade platforms.⁷

Static Postural Control

Static balance performance was assessed using the Single-Leg Stance Test performed barefoot on the force plate. Participants stood on the tested limb with hands on hips, torso upright, and eyes focused forward, while the non-weight-bearing leg remained slightly flexed at the knee and elevated. In each trial, they were instructed to maintain maximal stability for 15 seconds.

The protocol consisted of three repetitions per leg, with 30-second rest intervals. Trials were repeated if balance was lost (touching the ground with the free foot, stepping, or removing hands from the hips). Data analysis was based on Center of Pressure (COP) parameters recorded by the ForceDecks system, including total excursion, mean velocity, and medio-lateral and antero-posterior ranges.

Agility Test

Agility performance was assessed using the Pro Agility (5-10-5) test, a widely accepted protocol in team sports. High-precision infrared timing gates (SmartSpeed, VALD Performance, Brisbane, Australia) recorded all measurements. Athletes began at the central gate and, after an auditory signal, sprinted 5 m to their preferred side, touched the line, turned 180°, sprinted 10 m in the opposite direction, and then changed direction once more to complete the final 5 m through the finish gate. Timing was automatically triggered by photocell crossings.

Each athlete completed two trials, starting from each direction once, and the best time was used for analysis. Passive rest periods of 2–3 minutes were provided to reduce fatigue. Timing-gate-based sprint and agility assessments have shown lower error rates (Coefficient of Variation = 1.0–1.54%) and high reliability compared with GPS-based systems.⁸

Single-Leg Landing and Stability

Single-leg landing and stability performance were assessed using a 30 cm box and a force plate. Participants positioned themselves on the box on the limb to be tested, with hands on their hips, torso upright, and gaze directed forward. Athletes were instructed to step off the box forward onto the platform and to achieve stability

(stabilization) as quickly as possible after landing, remaining motionless. Peak Vertical Ground Reaction Force (Peak Force, N) and time to stabilization (s) data were collected during the test. Three repetitions were applied for each leg with 30-second rest intervals.

Ethical Approval

This study was approved by the Ethics Committee of Mudanya University (Date: 04.05.2025, Decision No: 2025-5/4).

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics for continuous variables were presented as mean ± standard deviation (X ± SD) or median (minimum–maximum). Normality was assessed with the Shapiro–Wilk test. Differences between the jump limb (JL) and contralateral limb (CL) were examined using the Paired Samples t-test for normally distributed variables and the Wilcoxon Signed-Rank Test for non-normally distributed variables.

Relationships among static postural control, single-leg landing, and agility performance were analyzed using Pearson or Spearman correlation coefficients, depending on distribution characteristics. Effect sizes were calculated using $r = |Z|/\sqrt{n}$ for Wilcoxon tests and Cohen’s $d_z = t/\sqrt{n}$ for paired t-tests. Effect sizes were interpreted as small (0.10–0.29), medium (0.30–0.49), or large (≥ 0.50).⁹ Correlation strengths were classified as weak (0.00–0.29), moderate (0.30–0.64), strong (0.65–0.84), and very strong (0.85–1.00).¹⁰ Statistical significance was set at $P < .05$ for all analyses.

Reporting Guidelines

This study was reported in accordance with the STROBE guideline.

Results

Descriptive statistics regarding age, body weight, height, body mass index (BMI), and jump limb preference for the 12 female handball players included in the study are presented in Table 1. The majority of participants (75%) preferred the left extremity as their jump limb (JL).

When examining the relationships between the single-leg landing and hold test and the 5-10-5 agility test parameters, no statistically significant correlations were identified ($P > .05$). The single-leg landing peak force values for the jump limb and contralateral side demonstrated weak negative associations with agility performance (JL: $r = -0.105$; $P = .746$; CL: $r = -0.133$; $P = .681$). Similarly, the time-to-stabilization parameters showed weak to moderate negative correlations with agility performance on both sides (JL: $r = -0.232$; $P = .467$; CL: $r = -0.312$; $P = .324$); however, these relationships were not statistically significant

Table 1. Demographic and Anthropometric Characteristics of Participants

Variable	Mean ± SD	Median (Min - max)
Age, y	26.58 ± 3.4	26.6 (21 - 33)
Body weight, kg	69.62 ± 7.6	69.6 (54 - 81)
Height, cm	173.92 ± 6.07	173.9 (165 - 183)
BMI, kg/m ²	22.96 ± 1.52	23 (19.9 - 25.9)
Jump-Limb, n (%)	Right	3 (25)
	Left	9 (75)

kg, kilogram; kg/m², kilogram per square meter; BMI, body mass index; cm, centimeter; SD, standard deviation; Min, minimum; Max, maximum; n, number of participants; %, percentage.

($P > .05$).

The relationships between COP-based static postural control parameters and agility performance were examined, and no significant correlations were found with the 5-10-5 test ($P > .05$). The jump limb showed moderate but non-significant associations for medio-lateral ($r = -0.334$; $P = .289$) and antero-posterior ($r = 0.312$; $P = .323$) sway. On the contralateral limb, correlations between medio-lateral, antero-posterior, mean velocity, and total excursion values and agility were weak and non-significant. Although contralateral mean velocity ($r = 0.357$; $P = .254$) and total excursion ($r = 0.371$; $P = .236$) showed moderate positive associations, these also did not reach statistical significance.

Correlations between Single-Leg Landing and stabilization performance and static balance (COP) parameters are presented in Supplementary Table S1 (JL-CL). No significant correlations were found among variables for the jump limb ($P > .05$). However, a moderate, positive, and statistically significant relationship was identified between Peak Force and static Antero-Posterior (AP) sway on the contralateral limb ($r = 0.625$; $P = .03$). Other relationships remained weak to moderate and non-significant.

The comparison between the Jump Limb (JL) and Contralateral Limb (CL) is shown in Supplementary Table S2. No statistically significant differences were found between limbs regarding dynamic parameters, specifically Peak Landing Force and Time to Stabilization (TTS) ($P > .05$). Conversely, significant differences were observed in static balance parameters: Medio-Lateral (ML) sway ($P = .029$) and Mean Velocity ($P = .017$). In both parameters, the JL demonstrated significantly lower values (indicating better stability), with large effect sizes ($r > 0.50$). The difference in Total Excursion approached statistical significance ($P = .055$), with the CL showing higher values.

Discussion

In this pilot study, no statistically significant relationships were found between static postural control parameters (COP medio-lateral and antero-posterior sway, mean velocity, total excursion) and dynamic stabilization time or agility performance. This finding does not support the first two hypotheses of the study but confirms the third hypothesis regarding the superior static balance of the jump limb. The lack of significant associations between static and dynamic balance is consistent with findings from similar studies in the literature and suggests that these performance components are governed by distinct neuromuscular control mechanisms.^{11–13} Steib et al. reported that neuromuscular warm-up programs significantly improved dynamic balance while having limited effects on static balance.¹³ Similarly, Zech et al. found that single-leg sway velocity increased following fatigue, yet dynamic balance measures did not change significantly.¹² These results indicate that laboratory-based static balance assessments may be insufficient for predicting functional performance in sports such as handball, which require high-speed changes of direction and eccentric control.

Research on the VALD ForceDecks system used in our study supports the validity of our measurement methods. Collings et al. reported high agreement between the system and gold-standard force platforms for ground reaction forces, COP parameters, and jump measurements.⁷ Therefore, the observed differences in our study are likely due to intrinsic sensorimotor variations among performance components rather than measurement device limitations.^{7,14}

The jump limb demonstrated significantly lower medio-lateral sway

and COP velocity compared to the contralateral limb, consistent with the unilateral loading characteristics of handball.^{15,16} Ozkamci et al. reported superior AP COP velocity in the dominant limb, while Bojić et al. observed a significant increase in countermovement jump performance over the season only in the dominant leg.^{15,16} These findings support the notion that unilateral motor demands induce asymmetric adaptations in the postural control system.

The only significant correlation in this study was a moderate-to-high positive relationship between peak landing force and static AP sway on the contralateral limb. This suggests that the contralateral leg requires greater conscious muscle activation and force production to maintain balance, whereas the jump limb may rely more on automatic postural control. This finding emphasizes the importance of prioritizing unilateral eccentric strength, reactive stabilization, and dynamic neuromuscular control training, particularly for the contralateral limb in female handball players.

The lack of significant associations between agility performance and landing forces or COP parameters can be explained by the multidimensional nature of agility. Agility is a complex motor skill determined by the interaction of multiple components, including change-of-direction speed, linear acceleration, neuromuscular coordination, reaction time, technical execution, and cognitive processing.¹⁷ Okano et al. reported that agility tests discriminated competitive levels in handball players, while Bayraktar found moderate-to-high correlations between change-of-direction speed and reactive agility performance, supporting the multifactorial nature of agility.^{18,19}

Other studies indicate that regular training can significantly improve postural control and agility. Fristrup et al. reported improvements in single-leg COP parameters after 12 weeks of small-sided handball training, demonstrating the trainability of static balance.²⁰ Karadenizli showed positive effects of plyometric training on static balance, long jump, and anaerobic power in young handball players.²¹ Daneshjoo et al. reported a 35–45% improvement in dynamic balance following an 8-week handball-specific warm-up program.²² Similarly, Forster et al. highlighted significant improvements in pro-agility performance following combined sprint, plyometric, and resistance training, indicating that integrated training protocols are most effective for agility development.²³

In this context, the lack of significant relationships between static balance measures and agility or dynamic stabilization in the present study is unsurprising, as the literature consistently emphasizes that these performance components rely on distinct physical and neurological substrates. However, the pronounced inter-limb asymmetry in static balance clearly reflects the impact of handball's unilateral loading on the sensorimotor system.

Overall, due to the small sample size, findings should not be generalized; however, the results highlight the limited predictive value of static balance measures for dynamic performance and agility in female handball players while emphasizing unilateral balance asymmetries. Future studies with larger sample sizes using sport-specific protocols that simultaneously assess static and dynamic postural control could provide more detailed insights.

Limitations

This study has several limitations. First, its cross-sectional design prevents causal inferences. Second, the small sample size typical of pilot studies (*n* = 12) may have limited the statistical power to detect weak or moderate correlations. Third, the study was

conducted only in female athletes, limiting the generalizability of the findings to male players.

Conclusion

This pilot study (*n* = 12 female handball players) found no significant relationships between static postural control parameters and dynamic stabilization time or agility performance. The most notable finding was the pronounced inter-limb asymmetry in static balance. The jump limb demonstrated significantly better performance in medio-lateral sway and COP mean velocity compared to the contralateral limb. Additionally, a moderate-to-high positive correlation was observed between peak landing force and static AP sway on the contralateral limb, suggesting that the contralateral leg requires greater conscious force production and may have lower automatic stabilization capacity. In conclusion, while static balance measures have limited predictive value for dynamic performance and agility, they provide important clinical and training insights by revealing unilateral balance asymmetries. Therefore, training programs should prioritize exercises targeting eccentric strength, reactive stabilization, and neuromuscular control of the contralateral limb.

Declarations

Animal and Human Rights Statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments, or comparable ethical standards.

Informed Consent

Written informed consent was obtained from all participants.

Data Availability

The datasets used and/or analyzed in the current study are not publicly available due to participant confidentiality concerns but are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare no conflict of interest.

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Author Contributions (CRediT Taxonomy)

Conceptualization: A.Ö., S.E.G.
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Data Curation: A.Ö., G.A.
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Supervision: S.E.G.

AI Usage Disclosure

The authors declare that no AI-assisted technologies were used.

Abbreviations

AP: Antero-posterior
BMI: Body mass index
CL: Contralateral limb
COP: Center of pressure
ICC: Intraclass correlation coefficient
JL: Jump limb
ML: Medio-lateral
SD: Standard deviation
TTS: Time to stabilization

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