

**Interlimb Asymmetry in Elite Soccer Players During Jumping and Change-of-Direction Tasks:
Emphasizing Chronic Ankle Instability-Induced Contralateral Limb Deficit**

Abstract

Background: Chronic ankle instability (CAI) can induce contralateral limb deficits, influencing inter-limb asymmetry during athletic tasks. Understanding the magnitude, direction, and individual thresholds of these asymmetries is critical for effective rehabilitation and performance monitoring.

Hypothesis: It was hypothesized that CAI-induced contralateral limb deficits would significantly influence the magnitude and direction of inter-limb asymmetry in jumping and change-of-direction-speed (CODS) tasks, with asymmetries consistently favoring the uninjured limb.

Study Design: Cross-sectional study.

Level of Evidence: Level 3.

METHODS: Male elite soccer players with CAI (n=32) and without CAI (n=38) performed single-leg-hop (SLH), triple-hop (SLTH), modified-505 (Mod505), and 90°-changes-of-direction (Cut90°) tests.

RESULTS: Paired-sample t-tests revealed small-to-moderate differences between dominant and non-dominant limbs in both groups ($p < 0.05$), moderate-to-large differences between injured and contralateral uninjured limbs ($p < 0.05$), large differences between injured and matched limbs of healthy players ($p < 0.05$), and small nonsignificant differences between contralateral uninjured and matched limbs of healthy players ($p > 0.05$). Independent-sample t-test revealed asymmetries were significantly higher in all tests ($p < 0.05$) except for SLH ($p > 0.05$) in players with CAI compared to their counterparts. Kappa coefficient showed substantial-to-perfect agreements for players with CAI ($K = 0.71-1.00$), and moderate-to-substantial agreements for healthy players ($K = 0.51-0.73$), indicating asymmetries favored same limb. Agreement percentages for similar identifications of asymmetry patterns based on individual thresholds derived from intralimb variability revealed that injured players adopted similar patterns in CODS (81.25%), while healthy players adopted similar patterns between SLH and mod505 (76.32%).

CONCLUSION: CAI-induced contralateral limb deficits influenced magnitude and direction of asymmetry, potentially underestimating asymmetry. Asymmetry consistently favors the same limb due to injury and functional similarities; and thresholds derived from intralimb variability identify real asymmetry.

27 **Clinical Relevance:** These findings highlight the importance of considering contralateral limb deficits when interpreting
28 inter-limb asymmetries in players with CAI. Rehabilitation programs should address these deficits to optimize performance
29 and reduce injury risk.

30 **Key words:** Soccer, Between-limb differences, Monitoring, Contralateral limb deficits, Athletic performance

INTRODUCTION

Soccer is a high-intensity sport that involves unilateral actions such as jumping and change-of-direction speed (CODS) ^(1, 6), which are interconnected ^(1, 13) and essential for offensive or defensive success, ultimately impacting match outcomes ^(1, 33). However, these high-demand tasks escalate the risk of lower-limb injuries ^(6, 25, 28), particularly lateral ankle sprains, which commonly result from combined inversion and plantarflexion when changing direction and jumping ^(25, 28). Chronic ankle instability (CAI), a common sequela of ankle sprains, affects approximately 32-74% of players across various sports, despite common treatments ^(21, 25). Evidence indicates that CAI can lead to inter-limb asymmetries, defined as performance discrepancies between limbs, in ankle muscle strength, range of motion, proprioception, and functional tasks such as cutting and landing ^(25, 28), which may impair performance and elevate reinjury risk.

Naturally, any assessment method that provides separate limb data enables asymmetry quantification; thus, both laboratory and field-based tests have been used to date ^(6, 17). Field-based tests such as hop and CODS tests are particularly valued for reflecting sport-specific demands while remaining time-efficient ^(14, 17, 36). However, studies have reported equivocal findings regarding the magnitude, direction, and threshold of asymmetry. The asymmetry threshold; a cutoff to determine whether limb differences are real and meaningful, has been calculated by Dos'Santos et al. ⁽¹⁷⁾ using the smallest worthwhile change (SLH=7.25%, SLTH=6.42%, Mod505=-2.74%, Cut90°=-4.93%), yet these thresholds failed to consistently identify team-sport players with real asymmetry; that is, asymmetries large enough to affect function. Fort-Vanmeerhaeghe et al. ⁽¹⁸⁾ and Bishop et al. ⁽¹²⁾ reported that horizontal jump asymmetries of ~6-7% did not impair CODS or sprinting, whereas Bishop et al. ⁽⁵⁾ showed even <10% asymmetry slowed elite male soccer players. Adding complexity, team sport players with faster CODS performance displayed ~12% knee extensor torque asymmetry ⁽³¹⁾. Additionally, from an asymmetry direction viewpoint; whether deficits consistently favor the same limb, Pardos-Mainer et al. ⁽³⁷⁾ observed poor agreement between CODS and hop tasks, while Bishop et al. ⁽⁸⁾ found substantial agreement in vertically directed jumps (Squat Jump vs. Countermovement Jump, K = 0.61). Collectively, no consensus exists on thresholds or directional patterns that define real, performance-limiting asymmetry.

Extending this uncertainty to injury status, few studies have investigated the interaction of inter-limb asymmetries with performance in injured and healthy players. Fort-Vanmeerhaeghe et al. ⁽¹⁹⁾ found no pre-injury asymmetry differences during SLH, CODS, or speed performance between injured and healthy players. From another perspective, it has been reported that patients with CAI do not show asymmetry in any of the hop tests compared to their healthy counterparts ⁽³⁴⁾. Conversely, Vereijken et al. ⁽⁴⁰⁾ demonstrated significant asymmetries across hop tests between injured and healthy players in high-intensity sports. They also reported notable differences between the injured limbs of players and the matched limbs of healthy counterparts (effect size=0.23), whereas differences between the contralateral uninjured limbs of players and

the matched limbs of healthy counterparts were trivial and non-significant⁽⁴⁰⁾. On the other hand, Hiemstra et al.⁽²⁶⁾ suggested that contralateral limb deficits could potentially reduce between-limb differences, and subsequently may mask the real magnitude of asymmetry in injured high-intensity sport players^(26, 40). This uncertainty about injury effects underscores a key gap in understanding how contralateral limb deficits influence inter-limb asymmetry.

Despite prior studies, the magnitude and direction of inter-limb asymmetry and a reliable method to quantify real asymmetry in elite soccer players with and without CAI remain unclear. Importantly, contralateral limb deficits may obscure real asymmetry in injured players, limiting accurate assessment for performance and injury risk. Addressing this gap has practical implications for strength and conditioning coaches and rehabilitation specialists by guiding training and return-to-play decisions. Therefore, this study aimed to (a) compare between-limb differences in soccer players with and without CAI during jumping and CODS performance, (b) assess how contralateral deficits affect real asymmetry, (c) compare the magnitude of inter-limb asymmetry between groups, (d) determine whether asymmetries consistently favor the same limb, and (e) establish a method to identify real asymmetry and determine levels of agreement for similar identifications using this method. We hypothesized that the CAI- injured limb would demonstrate performance deficits compared with both the contralateral uninjured limb and matched limbs of healthy players, and that injured players would exhibit greater inter-limb asymmetries, with asymmetry direction consistently favoring the uninjured limb. We further hypothesized that contralateral limb deficits would reduce the injured–uninjured difference, such that the real magnitude of asymmetry (injured vs. healthy reference) would be greater than intra-player asymmetry. Finally, we hypothesized that both the magnitude and direction of inter-limb asymmetries would be task- and population-dependent.

METHODS

Experimental Approach to the Problem

This cross-sectional study assessed the magnitude, direction, and individual thresholds of asymmetry, as well as the effect of contralateral limb deficits during jumping (SLH , SLTH) and change-of-direction (Cut90° , Mod505) tasks in elite soccer players with and without CAI. The study was approved by the Research Ethics Committee of the University of Isfahan (IR.UI.REC.1402.111). Given the task-specific nature of asymmetry reported in previous research, multiple performance tests were implemented to provide a comprehensive assessment of inter-limb asymmetry^(1, 12, 17, 30, 31).

Subjects

An a priori power analysis using G*Power software (Version 3.1, Düsseldorf, Germany) indicated a minimum sample size of 64, based on a moderate effect size, $\alpha < 0.05$, and statistical power=0.80, consistent with previous literature^(6, 24).

Ultimately, 69 male elite soccer players participated in the study and were allocated into two groups: unilateral CAI (n=32; age=21.78±3.18 years; height=1.77±0.07 m; mass= 68.39±8.82 kg) and healthy controls with no lower-limb injuries within the previous year (n=37; age=21.95±2.40 years; height=1.78±0.06 m; mass= 69.84±6.03 kg). All soccer players volunteered, received a detailed explanation of the study, and signed a university-approved informed consent form. Inclusion for CAI group followed International Ankle Consortium recommendations ⁽²²⁾ and required players to meet at least one of the following criteria: 1) ≥ 2 episodes of ankle giving way within the past six months, 2) more than one lateral ankle sprain affecting the same ankle, or 3) unilateral instability, defined as a Cumberland Ankle Instability Tool (CAIT) score ≤ 24/30 ^(22, 25).

Procedures

All testing procedures were conducted between 9 April and 15 June 2023 in two sessions separated by two days, prior to the competition season. On the first day, players' age, height, and body mass were recorded, followed by completion of the CAIT questionnaire to assess perceived ankle instability, after which they underwent familiarization with all functional assessments. On the second day, players performed a standardized progressive warm-up as previously recommended ⁽¹⁷⁾ and were allowed unlimited practice attempts to ensure correct execution of the movement patterns ⁽¹⁾. Dependent variables included distance in SLH and SLTH tests, time in Cut90° and Mod505 tests, and inter-limb asymmetry. All assessments were performed barefoot on an indoor track. Players were instructed to wear appropriate clothing, avoid alcohol for 24 hours and caffeine for 2 hours before testing, maintain their usual diet, and refrain from intensive activities for 48 hours ⁽¹⁷⁾. The dominant (D) limb was defined as the preferred leg used for kicking a ball ⁽¹¹⁾. To calculate the effect of contralateral limb deficits on inter-limb asymmetry, healthy players were matched to those with CAI based on whether the D or non-dominant (ND) limb was injured. Recovery intervals between CODS and jumping trials were 3 minutes and 1 minute, respectively ^(17, 32). Each player completed three trials per limb, with mean values analyzed. Test and participant order were randomized using the "True Random Number Generator" program (www.random.org) ⁽¹⁾.

Jumping tests

Jump performance was measured using single-leg hop (SLH) and single-leg triple hop (SLTH), as previously described ⁽¹⁷⁾. Learning and fatigue effects were controlled by practicing tests and resting between trials, respectively ⁽³⁹⁾. To isolate lower-limb contribution, all hops were performed with hands akimbo ⁽¹⁷⁾. In SLH, players executed a countermovement followed by a maximal forward hop, landing on the same limb ⁽¹⁷⁾. In SLTH, players performed three consecutive maximal hops on one limb, sticking the landing after the final hop ⁽¹⁷⁾. Trials were repeated if the landing position was not maintained for at

least two seconds or if hands left the hips ⁽¹⁷⁾. Distance between starting line and the heel's posterior aspect was measured to the nearest 1 centimeter using a standard tape measure grounded on the floor ⁽¹⁷⁾.

Change of direction speed tests (CODS)

Change-of-direction performance was assessed using the 90° Cut (Cut90°) and Modified 505 (Mod505) tests, following established protocols ^(17, 32). As mentioned earlier, learning and fatigue effects were controlled ⁽³⁹⁾. Players performed six trials for each CODS task; three trials with D foot planted and three with ND foot planted. A trial was valid only if the change-of-direction occurred on the designated line using the correct foot; otherwise, it was repeated ^(17, 32). Timing was recorded to the nearest millisecond using photocell gates positioned at hip height and linked to a handheld computer (Newtest PowerTimer, Testing System, Finland). In Mod505 test, players started 0.3 m behind the timing gate, sprinted toward a line marked 5 m ahead, planted either the D or ND foot on the line, executed a 180° turn, and quickly returned through the gate ⁽¹⁷⁾. In Cut90° test, players performed two 90° cuts with the same limb over a total distance of 20 m; the first after 6.66 m, the second after another 6.66 m, followed by a final 6.66 m sprint to the finish ⁽³²⁾. Similar to the preceding test, players started 0.3 m behind the timing gate ⁽¹⁷⁾.

Statistical Analyses

Descriptive statistics were calculated to summarize the variables, and the Shapiro-Wilk test confirmed their normality. Within-session reliability was calculated using a two-way random intraclass correlation coefficient (ICC) with absolute agreement (95% confidence interval), and the coefficient of variation (CV). ICC values were interpreted as > 0.90=excellent, 0.75-0.90=good, 0.50-0.75=moderate, and <0.50=poor ⁽²⁹⁾, while CV values were interpreted according to Banyard et al. ⁽²⁾ as <5%=good, 5-10%=moderate, and >10%=poor. Paired-sample t-tests were conducted to calculate between-limb differences, while independent-sample t-tests compared inter-limb asymmetries between CAI and healthy groups. Hedge's g was calculated to estimate effect sizes, interpreted as: <0.20=trivial, 0.21-0.60=small, 0.61-1.20=moderate, 1.21-2.0=large, and >2.0=very large ⁽²⁷⁾.

Inter-limb asymmetry was calculated for all tests using the formula: $100 / \text{maximum value} \times \text{minimum value} \times -1 + 100$, a method recommended for assessing asymmetry in unilateral tests ⁽⁶⁾. Individual asymmetry thresholds were established based on intralimb variability (CV), with the higher CV of the two limbs used as the threshold. Players exceeding this threshold were classified as exhibiting real asymmetry, whereas those below it were considered symmetrical ⁽⁴⁾. To specify the direction of asymmetry, an "IF function" was added to the end of the formula in Microsoft Excel: for time-based test *IF (Dominant<Non-dominant, 1, -1), and for distance-based test *IF (Dominant>Non-dominant, 1, -1). A supplemental

procedure was conducted to determine the direction of asymmetry between uninjured and injured limbs; for time-based test *IF (uninjured<injured, 1, -1), for distance-based test *IF (uninjured>injured, 1, -1) ⁽⁶⁾.

Asymmetries may favor either side depending on which limb scores higher; therefore, a Kappa coefficient was calculated to determine how consistently asymmetries favored the same side across tests ⁽⁶⁾. This method was chosen because the Kappa coefficient quantifies agreement between two methods after removing chance agreement ⁽¹⁶⁾. Kappa values were interpreted according to previous recommendations ^(9, 41): ≤ 0 = poor, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, 0.81–0.99 = almost perfect, and 1 = perfect. The percentage of agreement for similar identification among tests, indicating whether players were above or below the asymmetry threshold (asymmetrical or symmetrical), was calculated as (frequency of similar classification / number of players) $\times$ 100, with values $\geq$ 80% considered good ⁽¹⁷⁾. All statistical analyses were performed using Excel 2019 and SPSS 26.0.

RESULTS

Reliability data for SLH, SLTH, Cut90°, and Mod505 are presented in **TABLE 1**. Almost all tests exhibited good within-session ICC values (0.75-0.90), and good CV values ($\sim$ <5%). In CAI group, CAIT mean $\pm$ SD scores were 17.47 $\pm$ 2.02 for injured limb, 28.72 $\pm$ 1.05 for uninjured limb, 19.59 $\pm$ 5.32 for D limb, and 26.59 $\pm$ 4.11 for ND limb. In healthy group, mean $\pm$ SD scores for D and ND limbs were 28.19 $\pm$ 1.08 and 29.19 $\pm$ 0.84 respectively.

TABLE 2 shows between-limb differences, effect sizes (95% CI), and inter-limb asymmetry magnitudes for all tests. Small to moderate significant differences were observed between D and ND limbs across all tests in both groups ($p<0.05$). Comparisons between CAI players' injured and contralateral uninjured limbs showed moderate significant differences, with effect sizes ranging from 0.73 to 1.00 across all tests, except of the Mod505 test, which showed a large effect size (1.35). Given that out of the total of 32 players in the CAI group, 25 (78%) and 7 (22%) players suffered CAI injuries in D and ND limbs, respectively, significant differences were observed between D and ND limbs ($p<0.05$), as well as between uninjured and injured limbs ($p<0.05$) in jumping and CODS performance (Table 2). When injured limbs were compared with matched limbs of healthy players, differences were more pronounced, with large effect sizes (1.23 to 1.73) in all tests except SLTH test, which showed a moderate effect size (1.00). No significant differences were found between contralateral uninjured limbs of CAI players and matched limbs of healthy players, with only trivial to small effect sizes (0.17-0.42). Regardless of statistical significance, contralateral uninjured limbs of CAI players consistently underperformed compared to matched limbs of healthy players. Differences between injured limbs of CAI players and matched limbs of healthy players were more pronounced than those between injured and uninjured limbs within CAI players, indicating that contralateral limb deficits may mask real magnitude of asymmetry. Inter-limb asymmetry magnitudes in players with CAI were significantly greater

than those of healthy players across all tests ($p < 0.05$; $ES = 0.65-0.74$), except for SLH test, which was not significant ($p > 0.05$; $ES = 0.40$) (**FIGURE 1**).

FIGURES 2 to 4 display individual asymmetry magnitudes and directions, along with CV-based thresholds, across all tests for both CAI and healthy groups (uninjured/injured and dominant/non-dominant modes). As depicted in Figure 2, among 32 players with CAI, 20 (62.50%), 20 (62.50%), 25 (78.13%), and 21 (65.63%) exhibited real asymmetries in SLH, SLTH, Cut90°, and Mod505, respectively. Notably, four CAI players exhibited superior performance on their injured limb compared to their uninjured limb, indicating asymmetry direction favoring the injured limb. Figure 3 illustrates the direction of asymmetry between D and ND limbs in CAI players, showing that asymmetry is favored towards the ND limb due to a higher incidence of injuries in the D limb. Among, 38 healthy players, 27 (71.05%) exhibited real asymmetries in SLH test, 24 (63.16%) in SLTH test, 26 (68.42%) in Cut90° test, and 24 (63.16%) in Mod505 test (**FIGURE 4**). Positive values indicate superiority of the uninjured or D limb, while negative values indicate superiority of the injured or ND limb.

TABLE 3 indicates Kappa coefficients and descriptive agreement. In the CAI group, agreement levels ranged from substantial to perfect ($Kappa = 0.71-1.00$) across all comparisons, whereas the healthy group showed moderate to substantial agreement ($Kappa = 0.51-0.73$). This findings indicates that, compared with healthy players, asymmetries in injured players consistently favored the same direction due to the incidence of injury.

TABLES 4 and 5 display the percentage agreement for similar identifications of asymmetry (asymmetrical or symmetrical) based on individual thresholds in CAI and healthy groups. Agreements for similar identification of players above or below the thresholds ranged from 65.63% to 81.25% in the CAI group, and from 65.79% to 76.32% in the healthy group. Table 4 pertains to similar identification of symmetrical/asymmetrical CAI players and shows that SLH test had agreement levels of 68.75%, 71.88%, and 71.88% with SLTH, Cut90°, and Mod505 tests, respectively. Likewise, SLTH test showed agreement levels of 65.63% with both Cut90° and Mod505 tests. Furthermore, Cut90° and Mod505 tests demonstrated an agreement of 81.25%. Table 5 focuses on similar identification of symmetrical/asymmetrical healthy players and indicates that SLH test had agreement levels of 71.05%, 65.79%, and 76.32% with SLTH, Cut90°, and Mod505 tests, respectively. Likewise, the SLTH test showed agreement levels of 68.42% with both Cut90° and Mod505 tests. Furthermore, Cut90° and Mod505 tests demonstrated an agreement of 68.42%.

DISCUSSION

This study examined inter-limb asymmetry in elite male soccer players with and without CAI during single-leg jumping and change-of-direction speed tasks, with particular attention to contralateral limb deficits. Three principal observations

emerged. First, small-to-moderate significant differences were observed between D and ND limbs in both groups. Second, moderate-to-large significant differences were evident between injured and contralateral uninjured limbs, whereas large significant differences were found in almost all tests between injured limbs and matched limbs of healthy players; by contrast, only small, nonsignificant differences were observed between contralateral uninjured limbs and matched limbs of healthy players. Notably, within the CAI group, 78% of players sustained injuries to their D limb, while 22% experienced injuries to their ND limb. Third, inter-limb asymmetries were significantly greater in CAI players across all tests except SLH, and asymmetry direction consistently favored the same limb across unilateral jumping and CODS tasks. When expressed as individualized real asymmetry (values exceeding each player's intralimb variability), CODS tasks identified a larger proportion of injured players as asymmetric, whereas jumping tasks identified a larger proportion of healthy players. Agreement for similar identifications based on these thresholds ranged from 65.63–81.25% in the CAI group and 65.79–76.32% in the healthy group.

In healthy players, between-limb differences (D>ND) likely reflect sport-specific exposure, as the preferred kicking limb undergoes more repetitions in ball striking and stance transitions, which may enhance its coordination and functional capacity^(1, 20). This likely contributes to the development of functional asymmetries. Consistent with our findings, Bishop et al.⁽⁶⁾ reported differences between D and ND limbs among soccer players, reinforcing that sport-specific practice can lead to limb-specific adaptations. Conversely, among players with CAI, the pattern often shifted (D<ND in many cases), with the dominant limb more frequently injured. These findings are supported by Beynnon et al.⁽³⁾, who reported larger between-limb differences, often characterized by poorer performance of the dominant limb, which is typically more affected by instability. We emphasize that, given the cross-sectional design, we cannot infer that dominance caused injury or that injury caused differences; rather, injury status and limb dominance appear related to the observed asymmetry patterns. Moreover, comparisons between injured and contralateral uninjured limbs in CAI players revealed that injured limbs performed significantly worse. Several non-exclusive mechanisms may contribute, including neuromuscular inhibition after recurrent sprains, localized weakness, altered sensorimotor control, or protective movement strategies that reduce ankle force and velocity^(23, 25). These findings are consistent with those of Sharma et al.⁽³⁸⁾ and Gribble et al.⁽²³⁾, who reported movement deficits and lower-limb muscle weakness in individuals with CAI.

A salient finding was that contralateral uninjured limbs in the CAI group tended to perform slightly worse than matched limbs of healthy controls (trivial-to-small effect size), despite being clinically uninjured. This pattern supports the notion of contralateral limb deficits, inter-system changes that extend beyond the injured side. Possible contributors include cross-over neural inhibition, reduced global training exposure during rehabilitation periods, protective inter-limb coordination strategies, or subtle bilateral changes in proprioception and stiffness regulation⁽²⁶⁾. Importantly, these contralateral effects

can compress the apparent between-limb gap within the injured player, making injured versus uninjured limbs appear less different, while the injured limb shows a much larger deficit relative to matched limb of healthy players. These results are consistent with previous findings ⁽²⁶⁾, which reported an average difference of 20.60% between the contralateral uninjured limb and the matched limb of healthy players, compared with 24.80% between the injured limb and the matched limb. Consequently, rely solely on the within-player comparisons may lead clinicians to underestimate the functional deficits associated with CAI. Practically, benchmarking against healthy norms or at minimum acknowledging contralateral limb deficits when interpreting inter-limb asymmetry, may prevent premature clearance or under-dosage of rehabilitation.

Inter-limb asymmetry comparisons showed that players with CAI exhibited significantly greater asymmetry than healthy players in all tests except SLH. Although differences in SLH were not statistically significant, CAI players still demonstrated larger asymmetry magnitudes. Notably, asymmetry magnitudes may have been underestimated because contralateral limb deficits can mask actual between-limb differences. Nevertheless, these findings are consistent with previous studies reporting greater asymmetries in injured players compared with healthy players ^(19, 40).

Yet relying solely on absolute asymmetry magnitude can mislead clinical decisions if direction is ignored. We observed cases where the injured limb outperformed the contralateral limb on certain tasks. For example, Figure 2 shows injured player 11 with a 16% asymmetry in Mod505 test. Interpreting only the absolute magnitude could suggest the injured limb is 16% weaker, whereas it actually performed better. Several interpretations are plausible. First, limb dominance may interact with task demands; if the injured limb is dominant limb, extensive lifetime practice and a stronger motor schema could help sustain performance despite residual deficits ^(15, 42). Second, rehabilitation may be applied asymmetrically; targeted training of the injured limb can produce task-specific improvements that temporarily surpass performance of the less-trained uninjured limb ^(35, 42). Therefore, for informed clinical decision-making, clinicians should consider both the direction and magnitude of asymmetry.

When considering real asymmetry, we operationalized it by requiring that asymmetry magnitudes exceed each player's own intralimb variability (CV). This method helps distinguish intralimb variability (noise) from real asymmetry (signal). For instance, Player 15 in Figure 2 displays an asymmetry of ~14% in SLH test, surpassing the pre-set threshold of 10%, and should be considered asymmetric. However, due to the player's high variability (CV=~15%), the side-to-side limb difference cannot be considered a real asymmetry. Using individualized thresholds is defensible because asymmetry is metric-specific (e.g., time vs. distance), task-specific (jump vs. cut), and population-specific (healthy vs. CAI) ⁽⁴⁾. These findings align with Bishop et al. ⁽⁷⁾, who reported that asymmetry can vary across different metrics during a specific task, such as the single-leg countermovement jump, where a player may exhibit asymmetries of ~12% in concentric impulse and

20% in eccentric impulse. Simply put, it is preferable to establish task, metric, and population-specific thresholds for asymmetry, rather than relying on a universal pre-set threshold, such as 10% ^(4, 7).

Our findings on the consistency of asymmetry direction across tasks showed moderate-to-substantial agreement in the healthy group and substantial-to-perfect agreement in the CAI group, indicating that asymmetries consistently favored the same side during unilateral jumping and CODS tests. These agreements are more pronounced in the CAI group, such that if an injured player exhibited an asymmetry favoring the ND limb in the SLTH test, they were likely to display a similar asymmetry in the Cut90° test, which may be attributed to the high frequency of injuries in the D limbs (78%) among these players. To date, evidence on asymmetry direction in injured populations is lacking; however, our findings in healthy players contrast with those of Pardos-Mainer et al. ⁽³⁷⁾, who reported poor-to-fair consistency between SLH and Mod505 tests. Conversely, our results align with Bishop et al. ^(7, 8) and Arboix-Alio et al. ⁽¹⁾, who reported substantial consistency, likely reflecting functional similarities across these tests. Lockie et al. ⁽³⁰⁾ noted numerous similarities between CODS and horizontal jump tasks, which may be explained by several non-exclusive interpretations that reflect shared mechanical and neuromuscular demands: first, strong horizontal force orientation in both CODS and horizontal jumps; second, reliance on the stretch-shortening cycle and rapid force development; and finally, ankle stiffness regulation that stabilizes the distal segment during high-demand tasks such as jumping and CODS ^(17, 30, 43). Overall, these findings suggest that asymmetry direction follows consistent neuromechanical patterns, resulting from injury status and sport-specific demands rather than occurring by chance.

Between-test agreement for classifying players as asymmetrical or symmetrical, based on individual thresholds, revealed distinct patterns. Players were classified as really asymmetrical when inter-limb asymmetry exceeded intralimb variability, with more injured players displaying asymmetry in complex, multiplanar CODS tasks (Cut90°=25, Mod505=21, SLTH=20, SLH=20). Of note, agreement was highest between CODS tasks (81.25%), indicating consistent asymmetry patterns and supporting their reliability for symmetry classification. In contrast, healthy players showed the highest agreement between SLH-Mod505 (76.32%) and SLH-SLTH (71.05%), consistent with Dos'Santos et al. ⁽¹⁷⁾, who reported similar patterns. Although conclusions for healthy players are less definitive, these patterns align with the neuromechanical principles described above, reflecting adaptation to soccer-specific demands such as jumping and changes of direction.

This study has several limitations that should be considered when interpreting the findings. First, the sample included only male elite soccer players with and without CAI, limiting the generalizability of the results to other populations. Second, inter-limb asymmetries are time-specific and may fluctuate throughout the season ⁽¹⁰⁾; thus, these findings apply only to the end-of-season assessment. Finally, although categorizing limbs as 'D' and 'ND' based on the preferred kicking limb may

aid practitioners, this approach does not necessarily reflect true differences. Consequently, direct examination of raw performance scores is essential to accurately identify the weaker limb. Despite these limitations, the study provides valuable insights into between-limb differences, contralateral limb deficits and their impact on interpreting asymmetry, the magnitude and direction of asymmetry, task- and population-specific asymmetry thresholds, and between-test agreement for identifying asymmetry patterns in soccer players with and without CAI.

CONCLUSION

This study demonstrates that inter-limb asymmetry in elite male soccer players is influenced by both CAI and limb dominance, with contralateral deficits complicating interpretation. Injured limbs consistently underperformed compared with both contralateral and matched healthy limbs, while contralateral uninjured limbs also showed subtle impairments, underscoring the need to benchmark against healthy norms rather than rely solely on within-player comparisons. Asymmetry magnitude, direction, and individualized thresholds all proved critical; direction depended on task and population, while individualized thresholds distinguished real asymmetry from normal variability. CODS tasks identified more injured players as asymmetric, and asymmetry direction remained consistent across tasks, reflecting shared neuromechanical demands. High agreement among CODS measures supports their utility for detecting clinically relevant asymmetries. Collectively, these findings highlight the importance of comprehensive, task-specific assessment strategies to guide rehabilitation, reduce premature clearance, and inform return-to-play decisions in competitive soccer.

KEY POINTS:

Findings: Elite male soccer players with CAI exhibit greater inter-limb asymmetry than healthy counterparts, particularly in injured limbs, while contralateral uninjured limbs also show subtle deficits. Asymmetry magnitude, direction, and individualized thresholds reveal task- and population-specific patterns, with CODS tasks detecting more clinically relevant asymmetries than jumping tasks. Asymmetry direction is consistent across tasks, reflecting neuromechanical and sport-specific demands.

Implications: Assessment of inter-limb asymmetry should integrate magnitude, direction, and individualized thresholds, and benchmark injured players against healthy norms. CODS tasks provide reliable detection of functional deficits, informing targeted rehabilitation and preventing premature return to play. Recognition of contralateral deficits ensures more accurate interpretation of limb performance and rehabilitation progress.

316 **Caution:** Findings are specific to male elite soccer players and end-of-season assessments; asymmetry may fluctuate across
317 the season and between populations. Limb categorization as dominant or non-dominant should be interpreted carefully,
318 and conclusions may not generalize to female players or other sports.

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TABLE 1. Reliability measures using the coefficient of variation (CV) and intraclass correlation coefficient (ICC) with 95% confidence intervals (CI) for all tests in chronic ankle instability (CAI) and healthy groups.

	Variables	Limb	CV	Descriptor	ICC (95%CI)	Descriptor
CAI (n=32)	SLH	Dominant	3.89 (3.08-4.70)	Good	0.74 (0.53-0.86)	Moderate
		Non-dominant	5.68 (4.64-6.72)	Moderate	0.82 (0.68-0.91)	Good
	SLTH	Dominant	4.39 (3.43-5.35)	Good	0.76 (0.57-0.88)	Good
		Non-dominant	5.11 (4.11-6.12)	Moderate	0.86 (0.74-0.92)	Good
	90°Cut	Dominant	3.86 (2.80-4.92)	Good	0.77 (0.58-0.88)	Good
		Non-dominant	4.89 (3.88-5.91)	Good	0.84 (0.71-0.91)	Good
	Mod505	Dominant	5.22 (4.35-6.09)	Moderate	0.86 (0.76-0.93)	Good
		Non-dominant	5.44 (4.59-6.29)	Moderate	0.85 (0.74-0.92)	Good
	SLH	Dominant	3.89 (3.12-4.66)	Good	0.77 (0.61-0.87)	Good
		Non-dominant	3.44 (2.84-4.04)	Good	0.77 (0.60-0.87)	Good
Healthy (38)	SLTH	Dominant	2.85 (2.20-3.50)	Good	0.81 (0.68-0.90)	Good
		Non-dominant	2.38 (1.78-2.98)	Good	0.88 (0.80-0.93)	Good
	90°Cut	Dominant	2.67 (1.94-3.40)	Good	0.79 (0.60-0.89)	Good
		Non-dominant	3.07 (2.32-3.82)	Good	0.78 (0.62-0.88)	Good
	Mod505	Dominant	4.00 (3.19-4.81)	Good	0.83 (0.71-0.91)	Good
		Non-dominant	3.58 (2.88-4.28)	Good	0.88 (0.79-0.93)	Good

SLH= Single-leg hop; SLTH= Single-leg triple hop; Cut90°= 90° changes of direction; Mod505= modified505.

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TABLE 2. Comparisons between limbs (Mean ± standard deviation) for Jumping and CODS tests, Hedges *g* effect sizes (with descriptor) with 95% confidence intervals (CI); Magnitudes of asymmetry for each test in CAI and healthy groups.

CAI group					Healthy group			
Variable	SLH(cm)	SLTH(cm)	90°Cut(ms)	Mod505(ms)	SLH(cm)	SLTH(cm)	90°Cut(ms)	Mod505(ms)
D	141.24±9.93	436.90±33.03	5409.30±421.22	3208.18±192.74	157.07±8.61	474.83±21.46	4921.23±178.62	2880.36±124.03
ND	146.97±10.94	462.68±32.11	5144.76±349.15	3002.17±202.99	150.72±7.04	463.30±23.65	5115.25±240.36	2974.83±135.69
<i>g</i> ES (CI)	0.54 (0.02-1.06)	0.78 (0.25-1.31)	0.68 (0.15-1.20)	1.03 (0.48-1.57)	0.80 (0.31-1.29)	0.51 (0.03-0.98)	0.91 (0.41-1.40)	0.72 (0.24-1.20)
<i>g</i> descriptor	small	moderate	moderate	moderate	moderate	small	moderate	moderate
Asymmetry	8.92±3.81	7.47±2.45	8.44±3.55	9.43±4.79	7.17±4.76	5.36±3.51	6.05±3.73	5.87±4.71
<i>g</i> ES (95% CI) with descriptor								
Variable	Injured limb	Contralaterl uninjured	Matched control limb	Inj vs Contra	Inj vs Matched	Contra vs Matched		
SLH(cm)	139.23±8.68	148.98±10.52	153.24±9.40	1.00 (0.46-1.54) moderate	1.53 (0.95-2.11) large	0.42(-0.94-0.09) small		
SLTH(cm)	437.67±34.04	461.91±31.67	468.21±25.86	0.73 (0.20-1.26) moderate	1.00 (0.46-1.54) moderate	0.22(-0.73-0.30) small		
90°Cut(ms)	5452.01±390.37	5102.05±346.19	5049.77±239.74	0.94 (0.40-1.48) moderate	1.23 (0.67-1.78) large	0.17(-0.34-0.68) trivial		
Mod505(ms)	3230.61±199.29	2979.73±167.50	2933.33±134.11	1.35 (0.78-1.91) large	1.73 (1.13-2.33) large	0.30(-0.21-0.81) small		

SLH= Single-leg hop; SLTH= Single-leg triple hop; Cut90°= 90° changes of direction; Mod505= modified505; CAI=chronic ankle instability. *Note:* Effects sizes in bold indicate significant difference between limbs (p < 0.05).

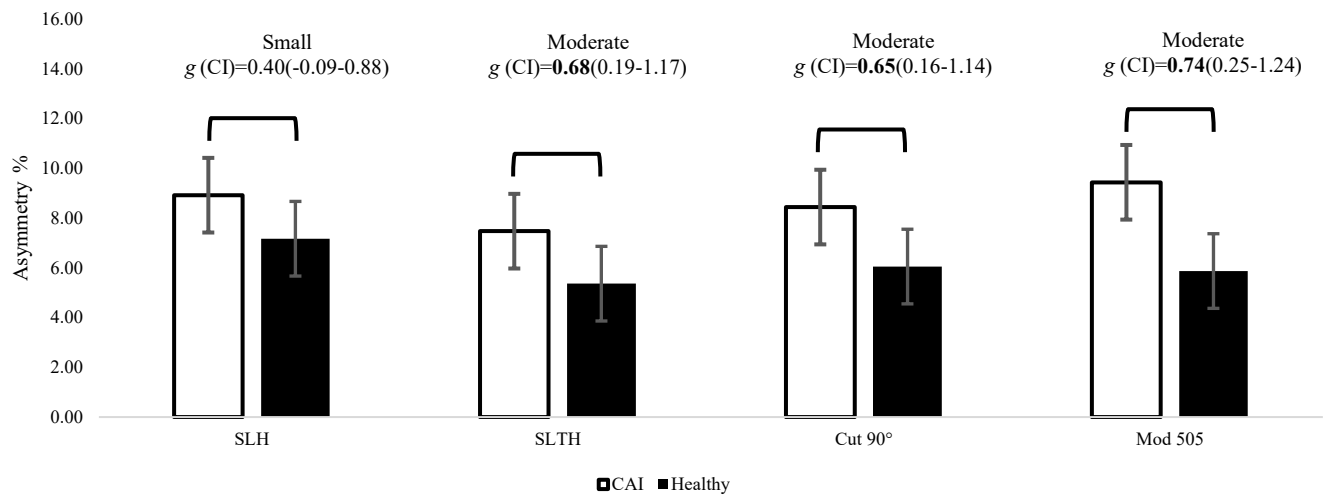


FIGURE 1: Comparisons of inter-limb asymmetry (Mean $\pm$ SD (error bar)) during all tests between CAI and healthy groups. (Cohen's d effect sizes (with descriptor) with 95% confidence intervals (CI) in bold indicate significant differences between groups ($p < 0.05$).

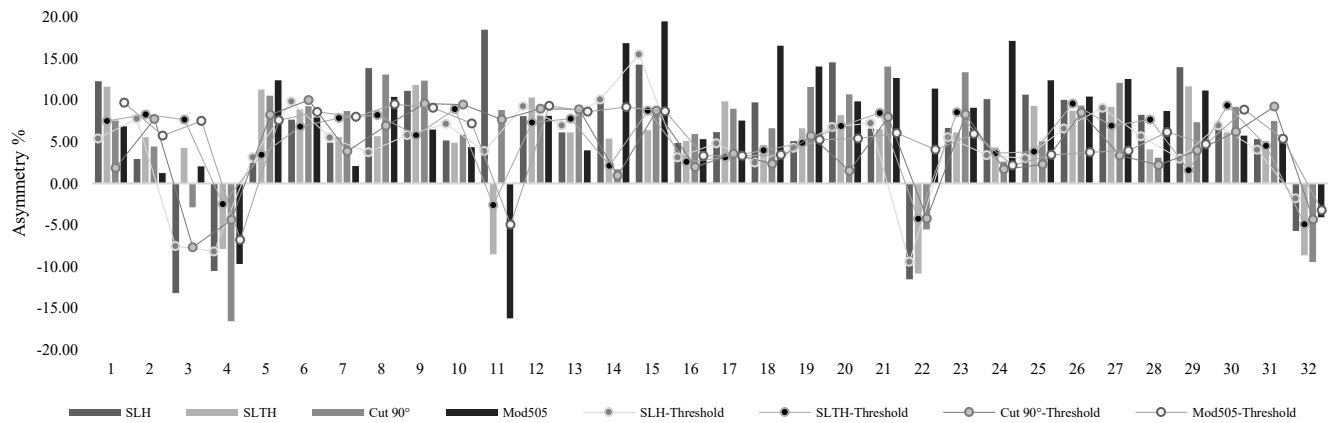


FIGURE 2: Individual uninjured/injured asymmetry during SLH, SLTH, Cut90°, and Modified 505 tests in CAI group (Positive value indicates asymmetry favors the uninjured limb and negative value indicates asymmetry favors the injured limb).

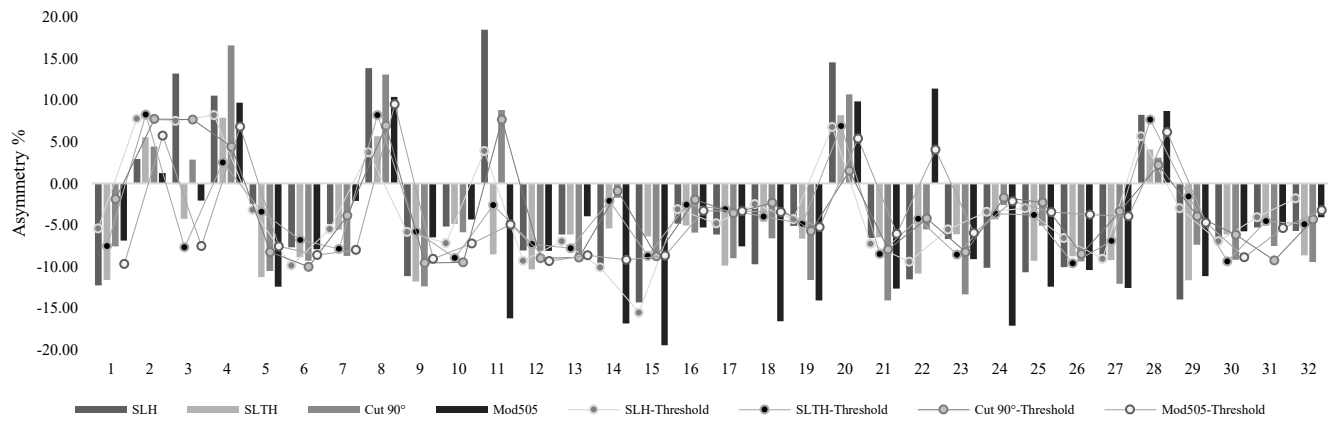


FIGURE 3: Individual dominant/non-dominant asymmetry during SLH, SLTH, Cut90°, and Modified 505 tests in CAI group (Positive value indicates asymmetry favors the dominant limb and negative value indicates asymmetry favors the non-dominant limb).

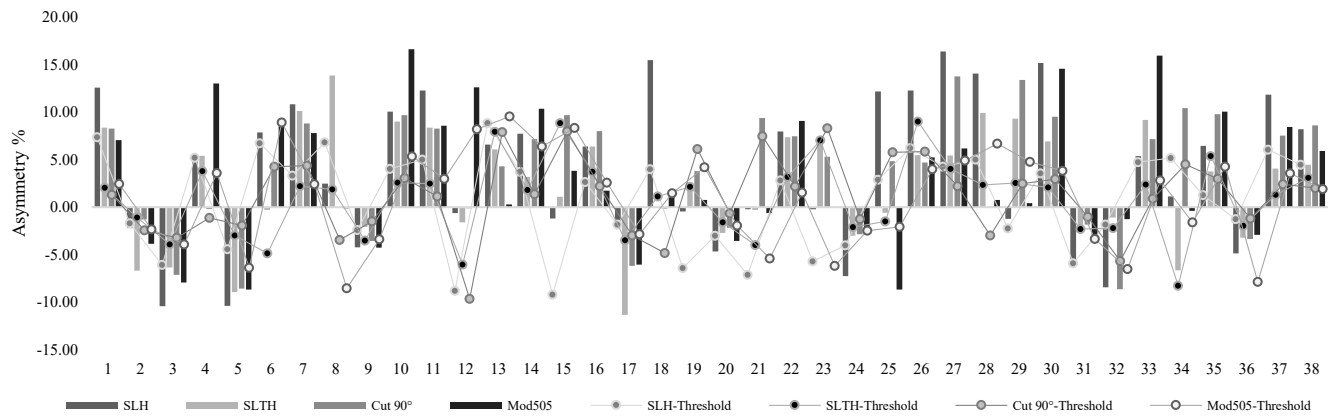


FIGURE 4: Individual dominant/non-dominant asymmetry during SLH, SLTH, Cut90°, and Modified 505 tests in healthy group (Positive value indicates asymmetry favors the dominant limb and negative value indicates asymmetry favors the non-dominant limb).

TABLE 3. Kappa coefficients indicate levels of agreement (with descriptor) for the direction of asymmetry in chronic ankle instability and healthy groups.

Test comparison	Chronic ankle instability group		Healthy group	
	Kappa Coefficient	Descriptor	Kappa Coefficient	Descriptor
SLH vs SLTH	0.80 (0.000)	substantial	0.57 (0.000)	Moderate
SLH vs Cut90°	1.00 (0.000)	perfect	0.51 (0.002)	Moderate
SLH vs Mod 505	0.71 (0.000)	substantial	0.62 (0.000)	substantial
SLTH vs Cut90°	0.80 (0.000)	substantial	0.62 (0.000)	substantial
SLTH vs Mod 505	0.89 (0.000)	almost perfect	0.73 (0.000)	substantial
Cut90° vs Mod 505	0.71 (0.000)	substantial	0.56 (0.001)	Moderate

SLH= Single-leg hop; SLTH= Single-leg triple hop; Cut90°= 90° changes of direction; Mod505= modified505.

TABLE 4. Agreements for similar identification of soccer players with CAI who were either above or below asymmetry thresholds.

		SLH	SLTH	90°Cut	Mod505
Frequency (n=32)	Symmetry	12	12	7	11
	Asymmetries favor D	6	2	5	5
	Asymmetries favor ND	14	18	20	16
% agreement with SLTH performance (similar identification)		22 (68.75 %)		21 (65.63 %)	21 (65.63 %)
% agreement with cutting performance (similar identification)		23 (71.88 %)	21 (65.63 %)		26 (81.25 %)
% agreement with mod505 performance (similar identification)		23 (71.88 %)	21 (65.63 %)	26 (81.25 %)	

SLH= Single-leg hop; SLTH= Single-leg triple hop; Cut90°= 90° changes of direction; Mod505= modified505; D= dominant; ND= non-dominant.

TABLE 5. Agreements for similar identification of healthy soccer players who were either above or below asymmetry thresholds.

		SLH	SLTH	90°Cut	Mod505
Frequency (n=38)	Symmetry	11	14	12	14
	Asymmetries favor D	19	17	17	15
	Asymmetries favor ND	8	7	9	9
% agreement with SLTH performance (similar identification)		27 (71.05 %)		26 (68.42 %)	26 (68.42 %)
% agreement with cutting performance (similar identification)		25 (65.79 %)	26 (68.42 %)		26 (68.42 %)
% agreement with mod505 performance (similar identification)		29 (76.32 %)	26 (68.42 %)	26 (68.42 %)	

SLH= Single-leg hop; SLTH= Single-leg triple hop; Cut90°= 90° changes of direction; Mod505= modified505; D= dominant; ND= non-dominant.