Relationship Between Interlimb Asymmetries and Speed and Change of Direction Speed in Youth Handball Players

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RELATIONSHIP BETWEEN INTER-LIMB ASYMMETRIES AND SPEED AND CHANGE OF DIRECTION SPEED IN YOUTH HANDBALL PLAYERS

Abstract

The aims of the present study were to quantify inter-limb asymmetry from jumping, change of direction speed (CODS) and iso-inertial tests and to establish the association between those asymmetry scores and performance during speed and CODS tests in youth handball athletes. Twenty-six youth handball players (age: 16.2 ± 0.9 years) volunteered to participate in this study and performed single leg countermovement jumps (SLCMJ), broad jumps (SLBJ), lateral jumps (SLLJ), CODS tests at 180º (CODS180) and 90º (CODS90), change of direction actions with iso-inertial overload (crossover step (CRO) and lateral shuffle step (LSS)) and 20 m sprint test. Excellent ICC values were found for all tests (ICC = 0.96-1.00) with the exception of the dominant limb during the CODS90 test (ICC = 0.69). Inter-limb asymmetry scores ranged from 3.66-12.67%. Iso-inertial asymmetry values were higher than those found during jumping tasks (9.8-12.7% vs. 3.66-8.76%). Spearman's *r* correlations showed significant relationships between CRO asymmetry and CODS90 performance on both limbs ($r = 0.48$-0.51; $p < 0.05$) and CODS180 ($r = 0.41$-0.51; $p < 0.05$) and sprint test ($r = 0.46$; $p < 0.05$). These results show the test-specific nature of asymmetries in youth handball players, with iso-inertial device and CODS deficit presenting the greatest magnitude of asymmetries. Furthermore, inter-limb differences during iso-inertial device (CRO) were associated with reduced CODS and sprint performance. These results suggest that the use of iso-inertial devices for the detection of inter-limb asymmetry may be more effective than total time during traditional CODS tests and

that larger imbalances are associated with reduced athletic performance in youth handball players.

Key Words: iso-inertial; jumping; symmetry; youth athletes

Introduction

Handball is a sport requiring endurance, strength, speed and coordination (37), with several high intensity actions during matches such as jumps, accelerations, decelerations and change of direction speed (CODS), all within the context of attacking and defending (18,31). These situations demand movement proficiency in multiple directions which are underpinned by high levels of plyometric ability (7) and sport-specific skills (31). Of the total distance covered in a match (~3600 m), 18.4% has been suggested to be performed laterally (25). For this reason, displacements in the frontal plane have a critical role in handball performance. Further to this, a specific emphasis has been suggested on the relevance of changing direction during side-stepping movements during matches (25,31). However, empirical studies investigating sport-specific movements in youth handball athletes are scarce; thus, further research in this area is required.

Recently, there has been a rise in the number of studies investigating the association between inter-limb asymmetry and measures of athletic performance. For example, Lockie et al. (20) reported between-limb differences for jump height of 10.4% during the single leg countermovement jump (SLCMJ), and distance of 3.3 and 5.1% during the single leg broad jump (SLBJ) and single leg lateral jump (SLLJ) tests respectively in male collegiate athletes. However, no significant correlations were reported between asymmetry and speed or CODS. Similarly, Dos'Santos et al. (11) reported mean inter-limb differences of 5-6% for jump distance during the single and triple hop tests in male collegiate athletes, and also showed no significant relationships with total time during two CODS tests. In contrast, Bishop et al. (5) showed that jump height asymmetry (12.5%) from the SLCMJ was associated with slower 5 m ($r = 0.49$; $p < 0.05$), 10 m ($r = 0.52$; $p < 0.05$) and 20 m ($r = 0.59$; $p < 0.01$) sprint performance in youth female soccer players. In addition, Bishop et al. (6) showed that drop jump asymmetries were associated with slower acceleration, speed and CODS performance in adult female soccer players. Specifically, drop jump height asymmetry was correlated with 30 m ($r = 0.58$; $p < 0.05$) and 505 on both limbs ($r = 0.52$ - 0.66; $p < 0.05$), and reactive strength index asymmetry was correlated with 10 m ($r = 0.52$; $p < 0.05$) and 505 on both limbs ($r = 0.54$ - 0.55; $p < 0.05$). Thus, with conflicting literature surrounding the association between asymmetry and speed and CODS, further research on this topic is warranted.

As the aforementioned information on asymmetry shows, many studies have quantified side-to-side differences using jump tests. However, owing to the amount of lateral movement patterns in handball, assessing between-limb asymmetries during CODS tests could also be considered a valid test protocol. Hart et al. (15) assessed between-limb deficits during an agility test where the test was completed in 'both directions' using 58 sub-elite Australian rules players. Mean asymmetry was 8.2% for right foot dominant players and 8.0% for left foot dominant players. More recently though, it has been suggested that the measure of total time may actually mask the true ability of an athlete to perform a CODS task (28,29), and that isolating the change of direction itself may be a more useful measure of CODS performance. This can be achieved by subtracting the time taken to complete a linear sprint (e.g., 10 m) from the total time taken to complete a CODS test of equal distance (e.g., 505); a concept known as the "change of direction deficit" (CODD). Where asymmetry is concerned, this notion was supported by Dos'Santos et al. (12) who showed that only 2 out of 43 netball athletes displayed asymmetries > 10% when using total time as the outcome measure during the 505 test. Conversely, 21 athletes showed between-limb differences > 10% when using the CODD. To the authors' knowledge, additional literature relating to asymmetry for both total time and the CODD does not exist; thus, further research in this area is also required.

Recently, iso-inertial devices have been suggested to be a viable method for training athlete populations (13,32,35), and in some instances more so than traditional weight training when aiming to improve velocity, acceleration and eccentric force (30,35). De Hoyo et al. (17) showed squat training on an iso-inertial device improved crossover and side step cutting actions in soccer players and Tous-Fajardo et al. (36) showed positive effects in CODS performance after the introduction of multidirectional training with an iso-inertial pulley in youth soccer players. From an asymmetry perspective, there is a paucity of literature investigating the use of iso-inertial devices to both detect and reduce inter-limb differences. Madruga-Parera et al. (22) showed that isolating specific CODS actions with an iso-inertial device (e.g., crossover and side steps) was a useful tool at detecting asymmetries, especially in comparison to CODS tests (CODS asymmetry = 1.8%; iso-inertial CODS asymmetry = 7.4-11.2%). However, to the authors' knowledge, additional studies pertaining to asymmetry from iso-inertial devices is scarce; thus, further research is again warranted.

Owing to the conflicting results of how asymmetry impacts athletic performance and the prevalence of these between-limb differences during CODS tasks, the aims of the present study were twofold: 1) to utilize a fitness test battery which quantifies inter-limb asymmetry from jumping, CODS and iso-inertial tests and, 2) to establish the association between those asymmetry scores and performance during speed and CODS tests in youth handball athletes.

Methods

Experimental approach to the problem

The current study employed eight tests to provide fitness data for youth handball players. These tests measured unilateral jump performance (during vertical, horizontal and lateral directions), CODS performance (inclusive of 90º and 180º turns), muscle power in specific CODS actions: lateral shuffle step (LSS) and crossover step (CRO) performed by iso-inertial resistance, and linear speed (via a 20 m sprint test). Recently, several studies have noted the task-specificity of asymmetry and suggested that more than a single test must be used to profile muscular imbalances (2,3,21); thus, multiple tests were used to profile both physical fitness and inter-limb asymmetry in this youth athlete population. Associative analysis was also conducted enabling a greater understanding of the relationships between asymmetry and CODS and speed performance in youth handball players.

Subjects

Twenty-six male youth handball players volunteered to participate in this study (age: 16.2 ± 0.9 years; post peak height velocity: 2.5 ± 0.8 years; height: 1.76 ± 0.60 m; body mass: 78.2 ± 12.4 kg) Subjects were eligible for inclusion if they had > 5 years of competitive handball experience, 2 years of experience in resistance training and were excluded if they presented any injury (overuse or acute) at the time of testing. All players were actively participating in high level youth handball league, performing 3 sessions per week, each lasting approximately 120 minutes per session and a match per week. All testing was completed during the third month of the competition period (nine month season). Written informed consent and assent were obtained from participants and their parents. This study was approved by the [** DELETED FOR PEER REVIEW **] ethics committee.

Procedures

Subjects arrived at a sports academy prior to the first training session of the week having been instructed not to eat for the preceding 2 hours and avoid caffeine consumption for at least 24 hours before the tests. All athletes were previously familiarized with the testing procedures due to their regular physical assessments throughout the handball season. Subjects were tested in two separate days, each separated by 72 hours.

Day one consisted of three unilateral jump tests and the CODS and sprint tests. On day two, players performed the specific change of direction actions with the iso-inertial device, owing to the likelihood of it impacting the performance of other tests if conducted on the same day. Each subject went through a specific warm up procedure consisting of five minutes of light jogging and dynamic stretches for the lower body (such as multi-directional lunges, inchworms, bodyweight squats, and spidermans). Upon completion, three practice trials were provided for each test where subjects were instructed to perform them at 75, 90 and 100% of their perceived maximal effort. Three minutes rest was given between the last practice trial and the start of the first test. For the change of direction test with iso-inertial resistance, an incremental procedure was performed (33). The researchers involved in this study randomized the use of players´ starting leg in each test. The reliability of all tests is presented in Table 1.

Single leg countermovement jump (SLCMJ). The SLCMJ was conducted on a contact mat (Chronojump, Boscosystem, Barcelona, Spain) measuring jump height in centimetres (cm). Subjects were required to step onto the center of the contact mat with one leg and place their hands on their hips (22). When ready, subjects performed a countermovement to a self-selected depth before accelerating as quickly as possible into a unilateral vertical jump, following the instructions to “jump as high as you can”. The non-jumping leg was slightly flexed at the knee with the foot hovering next to the ankle of the jumping leg. No additional swinging of the non-jumping leg was allowed during the jump and hands were required to remain fixed at the hips. Any deviations from these criteria resulted in a void trial and subsequently retaken. Three trials were performed on each leg with 60-seconds rest provided between each trial. The highest jump on each leg was then used for subsequent data analysis

Single leg lateral jump (SLLJ). The SLLJ measured lateral jump distance (in cm) with a standard measuring tape that was fixed to the floor. Subjects started just behind 0 cm with a selected test leg and performed a countermovement to a self-selected depth before jumping laterally as far as possible along the direction of the tape measure (without landing directly on it). For example, when starting on the left leg, subjects were instructed to jump to the right as far as they could with hands placed on hips throughout the test. Owing to the increased difficulty of this test (by virtue of jumping in the frontal plane), the landing was performed on both limbs to increase the chance of a stable landing. Subjects were required to stick the landing for 2-seconds with the distance measured from the outside edge of the landing foot (part of the foot closest to 0 cm). Three trials were performed on each leg with 60-seconds rest provided between each trial. The trial with the furthest jump on each leg was then used for subsequent data analysis.

Single leg broad jump (SLBJ). The SLBJ measured horizontal jump distance (in cm) with a standard measuring tape that was fixed to the floor. Subjects started with their toes just behind 0 cm with a selected test leg and performed a countermovement to a self-selected depth before jumping as far forward as possible along the direction of the tape measure (without landing directly on it) with hands placed on the hips throughout. Similar to the SLLJ, owing to the increased difficulty of this test, the landing was performed on both limbs to increase the chance of a stable landing. Subjects were required to stick the landing for 2-seconds with the distance measured from the heel of the jumping foot. The non-jumping leg was slightly flexed at the knee with the foot hovering next to the ankle of the jumping leg. No additional swinging of the non-jumping leg was allowed during the jump. Any deviations from these criteria resulted in a void trial and subsequently retaken. Three trials were performed on each leg with 60-seconds rest provided between each trial. The furthest jump on each leg was then used for data analysis.

90º Change of Direction Speed test (CODS90). CODS90 test was previously validated by Maloney et al. (23) who reported intraclass correlation coefficients (ICC) of 0.95 within-session and 0.97 between-sessions (Figure 1). To perform this test, subjects were instructed to conduct two 90º changes of direction with the same leg, for a total distance of 20 m. The first change of direction was performed after a distance of 6.66 m, whereby the subject then sprinted 6.66 m before the second 90º change of direction, and subsequently sprinted another 6.66 m to finish the test. Total time in the CODS test was measured with photocell beams connected to a computer (Chronojump Boscosystem, Barcelona, Spain). The fastest time of the three trials for each leg was used for data analysis and a trial was considered successful if the player performed a clear change of direction action. Each trial was separated by a 180-second recovery period.

** PLEASE INSERT FIGURE 1 ABOUT HERE **

180º Change of Direction Speed test (CODS180).

Subjects performed two 180º changes of direction using the same leg in each trial (dominant or non-dominant leg), for the CODS180-D or CODS180-ND, respectively (Figure 2) (22). The first change of direction was performed after 7.5 m from the start, and the second one was performed after 5 m from the first change of direction. The subjects sprinted a total distance of 20 m. Total time in the CODS test was measured with photocell beams (Chronojump Boscosystem, Barcelona, Spain). The fastest time of the three trials for each leg was used for analysis. A trial was considered successful if the entire foot crossed over the line while changing direction. Each trial was separated by a 180-second recovery period.

** PLEASE INSERT FIGURE 2 ABOUT HERE **

20m sprint test. Total time in the sprint test was measured with photocell beams, placed on the starting line and at 20 m which was connected to a laptop (Chronojump Boscosystem, Barcelona, Spain). The front foot was placed 0.3 m before the first set of photocells to ensure that the beam was not broken until each trial began. The fastest time of the three trials was used for analysis. Each trial was separated by a 180-second recovery period.

Change of direction with iso-inertial resistance. Subjects stood beside a conical pulley (CP), an iso-inertial device (Byomedic System SCP, Barcelona, Spain) of a metal flywheel (diameter: 0.42 m) with up to 16 masses (0.421 kg and 0.057 m diameter each one). A fixed axis is located at the center of the beam around which the masses rotate. The moments of inertia were 0.12 kg_m2 and 0.27 kg_m2 for 4 and 16 masses respectively. The modification of the moment of inertia is made by adding any number of the 16 masses on the edge of the flywheel and also by selecting four positions (P1, P2, P3 or P4), changing the location of the pulley that is closest to the cone (26).

Subjects are familiar with the device and the type of tasks, since it is part of their training in the area of strength and performance (2 years of experience, 1 session per week). Subjects were instructed to perform an incremental test to register the maximum power score, set to the maximum point of the power curve, the maximum power test was recorded by (Chronojump Boscosystem, Barcelona, Spain). Every set with a different load was stopped by two possibilities: either by completing eight repetitions or by a decrease of 10% of the maximum value of the set. The test started with 10 masses, and 2 masses were added until that a maximal power outcome was found. For the present sample, only P1 position was necessary to achieve the maximum power. The performed actions were lateral shuffle step (LSS) (Figure 3A), and crossover step (CRO) (Figure 3B). Concentric (C) action is identified by the acceleration phase, while the eccentric (E) one is related to the deceleration phase. Both phases were analyzed.

The attempt was considered valid if the subject located at 1m from the conical pulley and performing the task with maximum effort. In the LSS the subject was instructed to perform a lateral lunge in the frontal plane. The movement began with the feet aligned in this plane and the leg closer to the CP flexed to approximately 100º-120°. Then, repeated lateral shuffle steps of maximum intensity were demanded, without allowing hip rotation. For the CRO test, the movement began with the feet aligned in the frontal plane and the leg closer to the CP flexed to approximately 100°-120°. The action consisted of a crossover step performed at maximum intensity, pivoting on the farthest foot from the CP by a rotation of the whole body. While doing this action, the nearest leg (regarding to the CP) advanced over the pivoting one in the sagittal plane, and keeping the hips and shoulders at the same height during the step. At the end of this acceleration phase, the subject returned to the starting position with the feet aligned in the frontal plane. Each trial was separated by a 180-second recovery period.

** PLEASE INSERT FIGURE 3 ABOUT HERE **

Statistical Analysis

All data was recorded as mean and standard deviations. Data were analyzed by IBM SPSS Statistics for Windows version 22.0 (Armonk, NY: IBM Corp). The Shapiro-Wilk test was used to determine whether data were normally distributed. Data not following a normal distribution were root square-transformed before further analysis. The reliability was tested by a two-way random ICC with absolute agreement and 95% confidence intervals, typical error of the measurement (TEM), and coefficient of variation (CV). For interpretation, acceptable CV values were considered ≤ 10% (9) and intraclass correlation coefficient (ICC) were interpreted in line with Koo and Li

(19), where values > 0.9 = excellent, 0.75 - 0.9 = good, 0.5 - 0.75 = moderate and < 0.5 = poor.

Mann Whitney-U tests were used to examine performance differences between limbs. A one-way analysis of variance (ANOVA) with repeated measures was performed to assess differences in neuromuscular asymmetries between performance tests and Bonferroni post hoc test was used to aid interpretation of the results where significant differences occurred. Statistical significance was set at $p < 0.05$. Cohen's *d* effect sizes were calculated for pairwise comparisons which were computed as the mean difference divided by the pooled standard deviation and defined as: small (< 0.2), moderate (0.2-0.5), and large (> 0.8) mean differences (8).

Spearman's rank correlation coefficients (*r*) were computed to assess the relationship between inter-limb asymmetry scores and performance for all tests. The following criteria were adopted for interpreting the magnitude of correlation between test measures: ≤ 0.1 (trivial); 0.1-0.3 (small); 0.3-0.5 (moderate); 0.5-0.7 (large); 0.7-0.9 (very large) and 0.9-1.0 (almost perfect) (16). CODD was calculated utilizing a similar method from Nimphius et al. (29) to examine if CODS90 and CODS180 times and CODD provided different indications of CODS ability. Z-scores were calculated by the formula: (individual subject score – group mean score)/SD. Worthwhile differences were also calculated (differences in z-scores for 90º and 180º time and CODD) following the methods described by Nimphius et al. (29). Inter-limb asymmetries were calculated for all tasks defining the dominant (D) (the limb with the better score) and non-dominant (ND) limb using the formula: 100/(maximum value)*(minimum value)*-1+100 (4), noting that this has been suggested as an appropriate method for calculating inter-limb differences from unilateral tests.

Results

Asymmetries and test reliability data are presented in Table 1. ICC values were reported *good* to *excellent* for all tests with the exception of the D limb during the CODS90 test (ICC = 0.69). CV values were reported for all tests, some tests such as LSS E-ND did not report an acceptable CV (>10%). Asymmetries during SLBJ, CODS90 and CODS180 were significantly lower ($p < 0.05$) than asymmetries during the CODD90, CRO-C, CRO-E, LSS-C, LSS-E. In addition, CODS180 asymmetry was also significantly lower ($p < 0.05$) than CODD180 asymmetry, whereas SLCMJ asymmetry was significantly greater ($p < 0.05$) than SLBJ, CODS90 and CODS180 asymmetries. While SLLJ asymmetry was significantly lower ($p < 0.05$) than CRO-C asymmetry, it was significantly greater ($p < 0.05$) than CODS180 asymmetry. Furthermore, CODS180 asymmetry was significantly lower ($p < 0.05$) than LSS-E asymmetry. It is worth noting that all iso-inertial asymmetry values were higher than those found during jumping tasks (9.8-12.7% vs. 3.66-8.76%).

** PLEASE INSERT TABLE 1 ABOUT HERE **

Table 2 shows the correlations between asymmetries and speed and CODS performance. CRO-C asymmetry was significantly correlated with both CODS tests (on both limbs) as well as 20m sprint performance ($r = 0.46$; $p < 0.05$). Concentric power asymmetry during the LSS was correlated with CODS90 on the ND limb ($r = 0.44$; $p < 0.05$). Additional significant correlations were present between SLLJ asymmetry and CODS180 on the ND limb ($r = 0.39$; $p < 0.05$), CODS180 asymmetry and CODS180 on the ND limb ($r = 0.42$; $p < 0.05$), and CODD180 asymmetry and CODS180 on the ND limb ($r = 0.46$; $p < 0.05$). Owing to the variable nature of asymmetry, individual data of subjects been included for reported differences during jump, change of direction speed and iso-inertial change of direction tests (Figures 4-6).

** PLEASE INSERT TABLE 2 ABOUT HERE **

** PLEASE INSERT FIGURES 4-6 ABOUT HERE **

Discussion

The aims of the present study were twofold: 1) to utilize a fitness test battery which quantifies inter-limb asymmetry from jumping, CODS and iso-inertial tests and, 2) to establish the association between those asymmetry scores and performance during speed and CODS tests in youth handball athletes. Results showed different magnitudes of asymmetry among tests, with the CODD90 and iso-inertial assessments showing the greater asymmetry values. Larger asymmetry during the iso-inertial CRO was associated with reduced performance during CODS and sprint tests.

The first point to consider from these results is that significant differences between D and ND limbs were evident in all tests (ES range: 0.26-0.84). These results show that in youth handball, limb dominance can be expected and may lead to notable differences in performance between limbs during jumping and CODS tasks. Given the significance of these differences, practitioners are advised to monitor individual limb differences in line with previous suggestions (2), to ensure that deficits do not become too apparent, given they have previously been shown to be a by-product of competing in a single sport over time (14).

When handball demands are considered, jumping is one of the most common athletic actions (31); thus, represents an ecologically valid method of assessment for both performance monitoring and the detection of inter-limb asymmetries. In the present study, results showed that the SLCMJ was able to detect larger between-limb differences (8.76%) than the SLBJ (3.66%) and SLLJ (5.97%) tests, which agrees with previous research reporting jumping asymmetries (5,20). Therefore, if practitioners wish to profile an athlete's existing side-to-side imbalances, it appears that the SLCMJ may offer a useful method when unilateral jump tests are considered.

Another interesting finding of the present study is the magnitude of asymmetry for CODS and the CODD. Previous literature has described the CODD as a way of isolating the actual CODS action (12,29); however, little is known about the prevalence of asymmetries using this metric. Significantly larger asymmetries were shown when using the CODD compared to the total time in the equivalent CODS test. For example, inter-limb differences for the CODS90 were 3.39%, but 10.52% for the CODD90. Likewise, the CODS180 test showed differences of 2.12%, but the CODD180 highlighted imbalances of 5.48%. These values are comparable to Dos'Santos et al. (12), who reported mean asymmetries of -2.3% for the 505 test, but -11.9% for the 505 CODD. Further to this, the importance of angles in CODS actions has been previously indicated by Dos'Santos et al. (10), highlighting the requirement for greater braking strategies during CODS angles > 135°. However, in the present study, larger between-limb differences were actually seen during the CODS90 test. Given the paucity of literature comparing CODD at different angles, this is challenging to fully explain. However, it is possible that because of the smaller change of direction during 90°, that discrepancies in limb dominance were more evident due to the requirement for reduced braking strategies compared to 180° (10). In essence, when turning 180°, athletes have no option but to brake effectively because of the maximal angles required when changing direction. In contrast, less braking is required during 90° which may highlight larger between-limb differences. However, it is worth noting that more in-depth analysis of CODS performance is required to fully corroborate this theory.

Where iso-inertial tests are concerned, results from the present study showed notable asymmetries ranging from 9.80-12.67%, which were significantly greater than the differences in the CODS90 and CODS180 tests. Literature reporting between-limb differences from iso-inertial methods is scarce; however, Madruga-Parera et al. (22) evaluated CODS asymmetries from an iso-inertial device in young tennis players, and reported values ranging 7.35-9.82% in the LSS and 9.31-11.18% in the CRO. These figures represent similar values to those shown in the present study and highlight the suitability of this method to detect asymmetries in both youth tennis and handball populations in comparison to CODS tests. In addition, given the significantly larger asymmetries of iso-inertial and CODD (isolated CODS actions) comparing to CODS tests (non-isolated CODS action), it is plausible to suggest that total time during CODS tests is not a very sensitive metric at detecting existing side-to-side asymmetries. According to our results, iso-inertial tests could be added to the CODD registered by Dos'Santos et al. (12) in order to acquire more specific information about isolated CODS asymmetries. Thus, if targeted training interventions are deemed necessary, then it is likely that specific training drills focusing on these movements are required to show technical proficiency on both limbs. Consequently, iso-inertial training has been described as a useful method to improve strength and performance (13,30), especially when multidirectional tasks with eccentric overload are designed (13). Furthermore, previous studies have shown the importance of the trunk activation by virtue of improved throwing velocity in handball players (24,34). Thus, although not investigated in the present study, it seems apparent that improved trunk strength may enhance throwing performance, most likely due to greater sequential force transference through the kinetic chain during the action of throwing.

Another important finding of the present study is the significant correlation between the concentric phase asymmetry of CRO test and reduced performance in 20 m sprint, CODS90 and CODS180 on both limbs (Table 2). Firstly, all significant correlations are positive, indicating that larger asymmetries are associated with slower times during speed and CODS tests. Again, although challenging to fully explain, this is in agreement with numerous studies on the topic of asymmetry and athletic performance. Recent work has shown that larger asymmetries are also associated with reduced speed (1,3,5,6) and CODS performance (1,6,23). This adds further evidence that inter-limb asymmetries may be detrimental to measures of athletic performance, which practitioners may wish to consider when designing training programmes for athletes that are required to be proficient in multiple planes of movement (e.g., team and court sport athletes).

Significant correlations were also established between concentric phase asymmetry of the LSS and CODS90 on the ND limb ($r = 0.44$; $p < 0.05$) test, but not in the CODS180 assessment. This represents an important finding given that only asymmetry during the concentric actions of the CRO and LSS movements showed significant associations with reduced speed and CODS performance. As such, if practitioners wish to profile their athletes' side-to-side differences using iso-inertial tests, concentric-based movements may be the most appropriate to monitor (22). Additional significant correlations were also shown between SLLJ asymmetry and CODS180 on the ND limb ($r = 0.39$; $p < 0.05$), CODS180 asymmetry and CODS180 on the ND limb ($r = 0.42$; $p < 0.05$) and CODD180 asymmetry and CODS180 on the ND limb ($r = 0.46$; $p < 0.05$). Thus, given the volume of correlations associated with slower speed and CODS performance in the present study, it is suggested that youth handball players may wish to reduce existing side-to-side imbalances to optimize athletic performance.

Despite the usefulness of these findings, this study presents some limitations. There is a lack of knowledge of the 'most suitable' iso-inertial load to achieve the most representative CODS action in sport. Related to this limitation, future research is needed combining the use of force platform both with CODS iso-inertial and CODS tests at different speeds (to obtain a scale of force values), since ground reaction forces could be an adequate parameter to link the intensity of both tests. Moreover, multi-axial force platforms would detect the horizontal force vector in an isolated way, and this parameter is a fundamental factor when aiming to optimize acceleration and speed abilities (21,27).

Practical Applications

This study offers the possibility to apply functional and specific assessments for youth handball players in order to identify the nature of inter-limb asymmetries. In addition, it is important to highlight the importance to isolate the change of direction action to highlight existing asymmetries of this motor skill. Practitioners should consider the iso-inertial tests considered in this research and the CODD in order to inform training programs and aim to optimize CODS performance. Furthermore, according to the asymmetries shown in this study, and the established relationships with performance, it is suggested that training programs should consider the reduction of inter-limb asymmetries in youth handball populations.

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Table 1. Mean test scores, effect sizes, inter-limb asymmetry values and test reliability data.

Performance Test	Mean ± SD	Effect Size	Asymmetry (%)	TEM (95% CI)	CV (%)	ICC (95%CI)
SLCMJ-D (cm)	19.05 ± 3.78*	0.48	8.76 ± 4.80	0.52 (0.41-0.72)	2.4 (1.9-3.3)	0.98 (0.96-0.99)
SLCMJ-ND (cm)	17.39 ± 3.65			0.38 (0.30-0.52)	2.3 (1.8-3.2)	0.99 (0.98-1.00)
SLBJ-D (cm)	168.77 ± 24.12*	0.26	3.66 ± 2.55	0.90 (0.70-1.24)	0.6 (0.4-0.8)	0.99 (0.98-1.00)
SLBJ-ND (cm)	162.58 ± 23.51			0.75 (0.58-1.03)	0.4 (0.4-0.6)	0.99 (0.98-1.00)
SLLJ-D (cm)	150.32 ± 22.86*	0.42	5.97 ± 5.05	1.40 (1.10-1.43)	1.0 (0.8-1.3)	0.98 (0.97-0.99)
SLLJ-ND (cm)	141.10 ± 20.76			3.30 (2.59-4.56)	2.2 (1.7-3.0)	0.98 (0.95-0.99)
CODS 90-D (s)	4.41 ± 0.29*	0.56	3.39 ± 2.72	0.13 (0.10-0.19)	2.7 (2.1-3.8)	0.69 (0.42-0.85)
CODS 90-ND (s)	4.57 ± 0.28			0.03 (0.03-0.05)	0.8 (0.6-1.1)	0.99 (0.97-0.99)
CODD 90-D (s)	1.28 ± 0.18*	0.84	10.52 ± 7.94	-	-	-
CODD 90-ND (s)	1.44 ± 0.20			-	-	-
CODS 180-D (s)	4.91 ± 0.27*	0.37	2.12 ±2.50	0.05 (0.04-0.07)	1.1 (0.9-1.6)	0.96 (0.92-0.98)
CODS 180-ND (s)	5.02 ± 0.31			0.04 (0.04-0.06)	0.9 (0.7-1.3)	0.98 (0.96-0.99)
CODD 180-D (s)	1.78 ± 0.14*	0.62	5.48 ± 6.21	-	-	-
CODD 180-ND (s)	1.88 ± 0.18			-	-	-
20m (s)	3.13 ± 0.25	-	-	0.04 (0.03-0.06)	1.3 (1.0-1.7)	0.98 (0.95-0.99)
LSS C-D (W)	467.47 ±140.45*	0.36	10.72 ± 8.35	56.6 (42.1-86.1)	12.9 (9.5-20.3)	0.70 (0.46-0.84)
LSS C-ND (W)	418.17 ± 130.60			48.5 (36.1-73.8)	13.0 (9.6-20.5)	0.72 (0.49-0.85)
LSS E-D (W)	504.54 ± 119.45*	0.57	12.67 ± 9.91	39.1 (29.1-59.5)	10.3 (7.5-16.0)	0.81 (0.54-0.93)
LSS E-ND (W)	438.11 ± 112.69			59.7 (44.4-90.9)	17.5 (12.8-27.8)	0.72 (0.49-0.85)
CRO C-D (W)	541.38 ± 189.11*	0.34	11.79 ± 7.24	40.0 (30.9-56.7)	9.9 (7.6-14.3)	0.87 (0.72-0.94)
CRO C-ND (W)	479.43 ± 167.36			49.4 (38.2-69.9)	11.1 (8.5-16.1)	0.79 (0.57-0.91)
CRO E-D (W)	463.01 ± 140.50*	0.35	9.80 ± 8.77	37.8 (29.2-53.5)	11.8 (9.0-17.1)	0.77 (0.58-0.88)
CRO E-ND (W)	415.36 ± 129.36			35.9 (27.7-50.8)	11.4 (8.7-16.5)	0.70 (0.46-0.84)

* = significantly different to non-dominant leg ($p < 0.001$)

SD = standard deviation; TEM = typical error of measurement; CI = confidence intervals; CV = coefficient of variation; ICC = intraclass correlation coefficient; cm = centimetres; W = watts; s = seconds; CODS = change of direction speed; SLCMJ = single leg countermovement jump; SLBJ = single leg broad jump; SLLJ = single leg lateral jump; LSS = lateral shuffle step with iso-inertial device; CRO = crossover step with iso-inertial device; C = concentric; E = eccentric; D = dominant leg; ND = non-dominant leg.

Table 2. Correlations between inter-limb asymmetries and change of direction (on both limbs) and 20 m sprint performance.

Asymmetry Tests	**CODS90**		**CODS180**		**20 m**
	Dominant	*Non-dominant*	*Dominant*	*Non-dominant*	
SLCMJ	-0.06	-0.16	0.18	0.21	0.18
SLLJ	0.21	0.29	0.28	0.39*	0.27
SLBJ	0.16	0.21	0.28	0.17	0.22
CODS90	-0.33	0.10	-0.20	-0.04	-0.21
CODD90	-0.35	0.07	-0.19	-0.02	-0.15
CODS180	-0.11	0.02	-0.01	0.42*	0.09
CODD180	-0.06	0.06	0.03	0.46*	0.15
CRO-C	0.48*	0.51**	0.51**	0.41*	0.46*
CRO-E	-0.16	-0.02	-0.08	-0.03	0.03
LSS-C	0.29	0.44*	0.28	0.31	0.27
LSS-E	-0.16	0.01	-0.06	0.18	-0.02

** significant correlation at $p < 0.01$; * significant correlation at $p < 0.05$

CODS: Change of direction speed; CODD: Change of direction deficit; SLCMJ: Single leg countermovement jump; SLBJ: Single leg broad jump; SLLJ: Single leg lateral jump; LSS: Lateral shuffle step with iso-inertial device; CRO: crossover with iso-inertial device; C: Concentric; E: Eccentric; D: Dominant leg; ND: Non-dominant leg

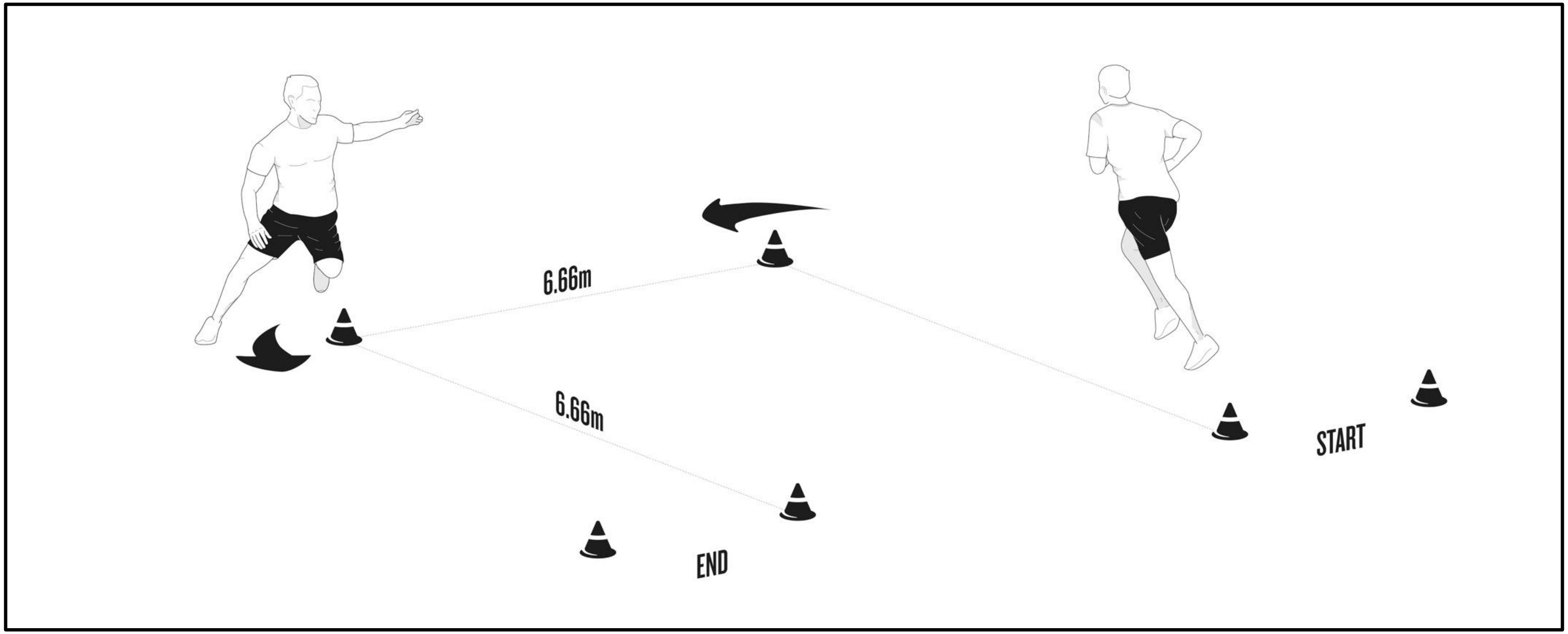

Figure 1. Schematic of the double 90º change of direction speed test (CODS90)

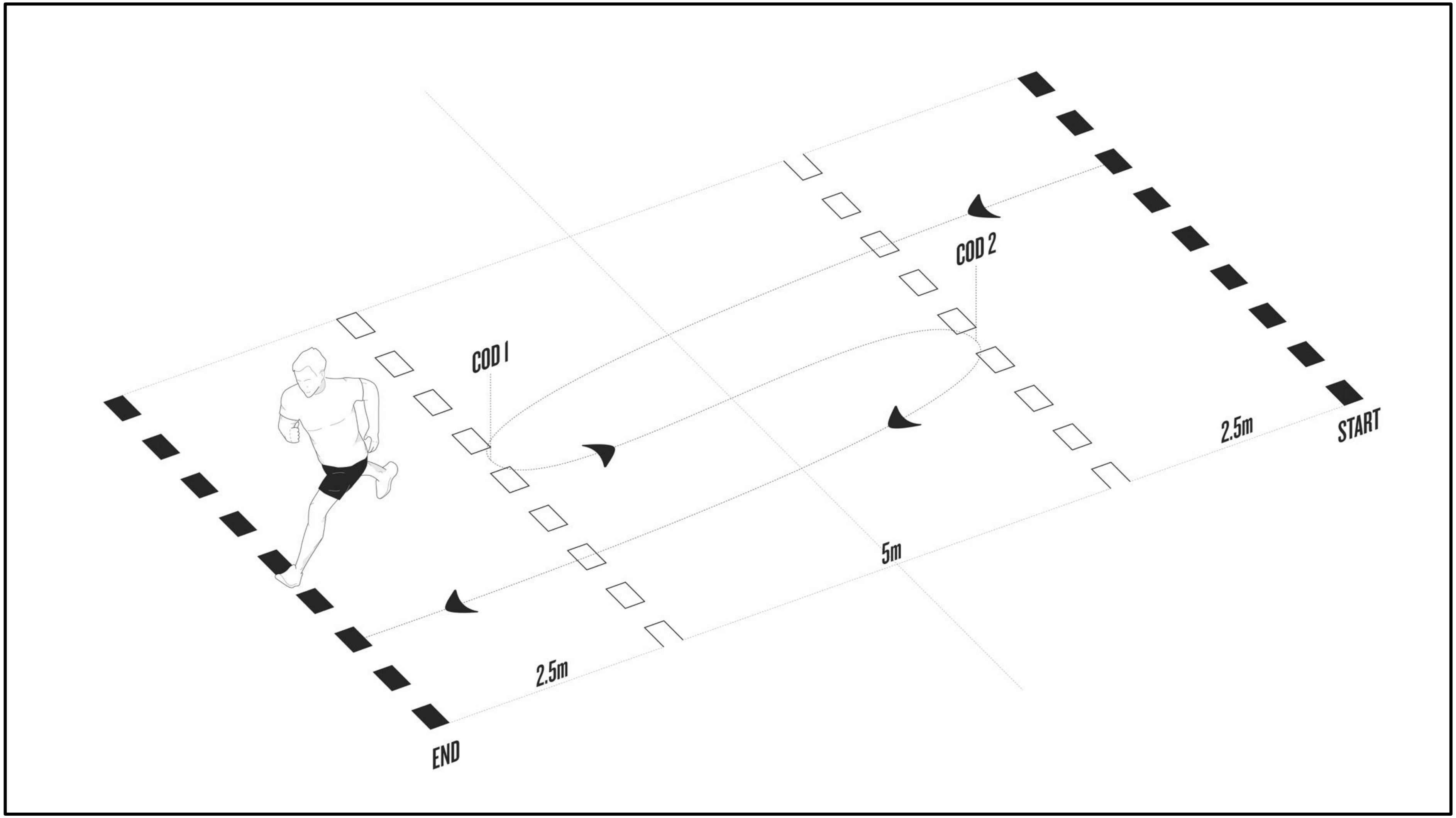

Figure 2. Schematic of the double 180º change of direction speed test (CODS180)

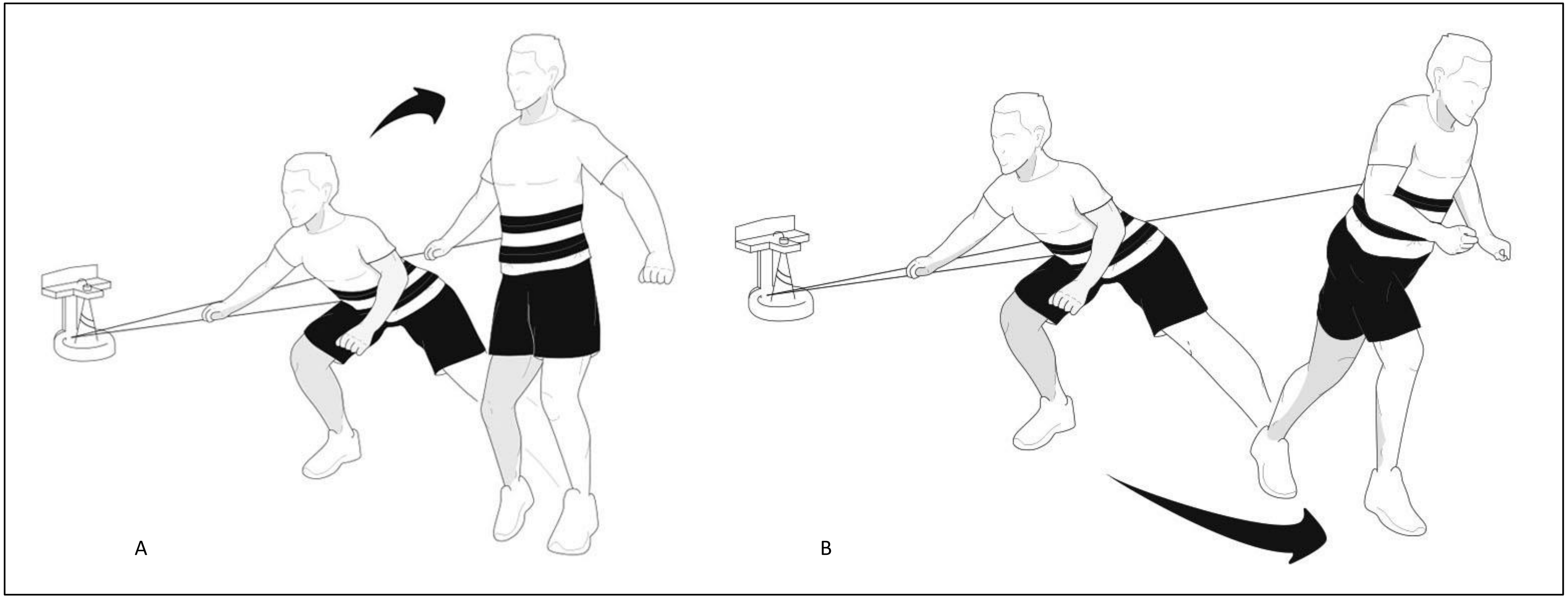

Figure 3. Testing conducted on the iso-inertial device. A = lateral shuffle step (LSS), phase start and brake; B = Crossover step (CRO), phase start and brake with the right leg.

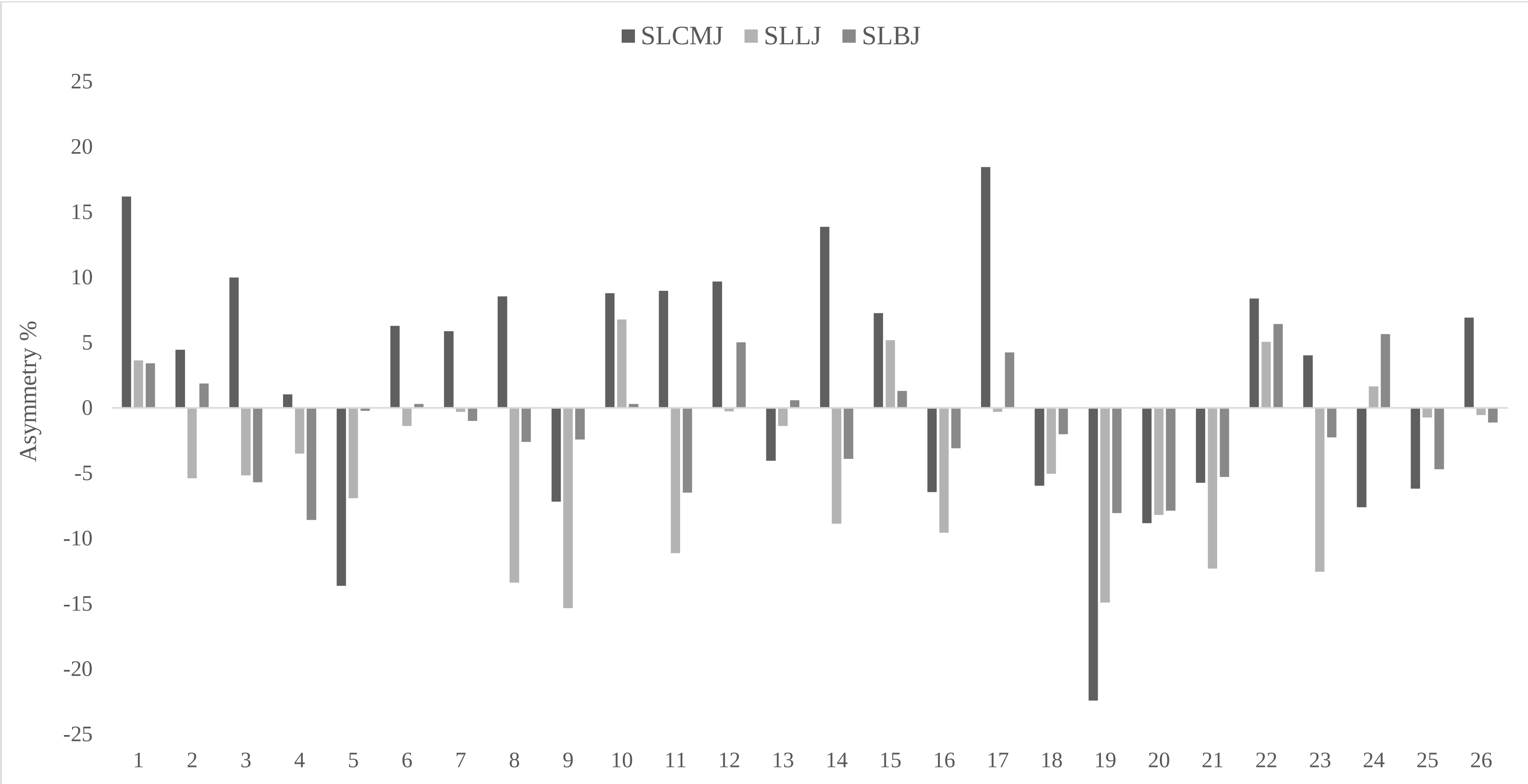

Figure 4. Individual asymmetry scores for the SLCMJ (jump height), SLLJ (distance) and SLBJ (distance) tests. Above 0 line means asymmetry favours the dominant leg and below 0 line means asymmetry favours the non-dominant limb.

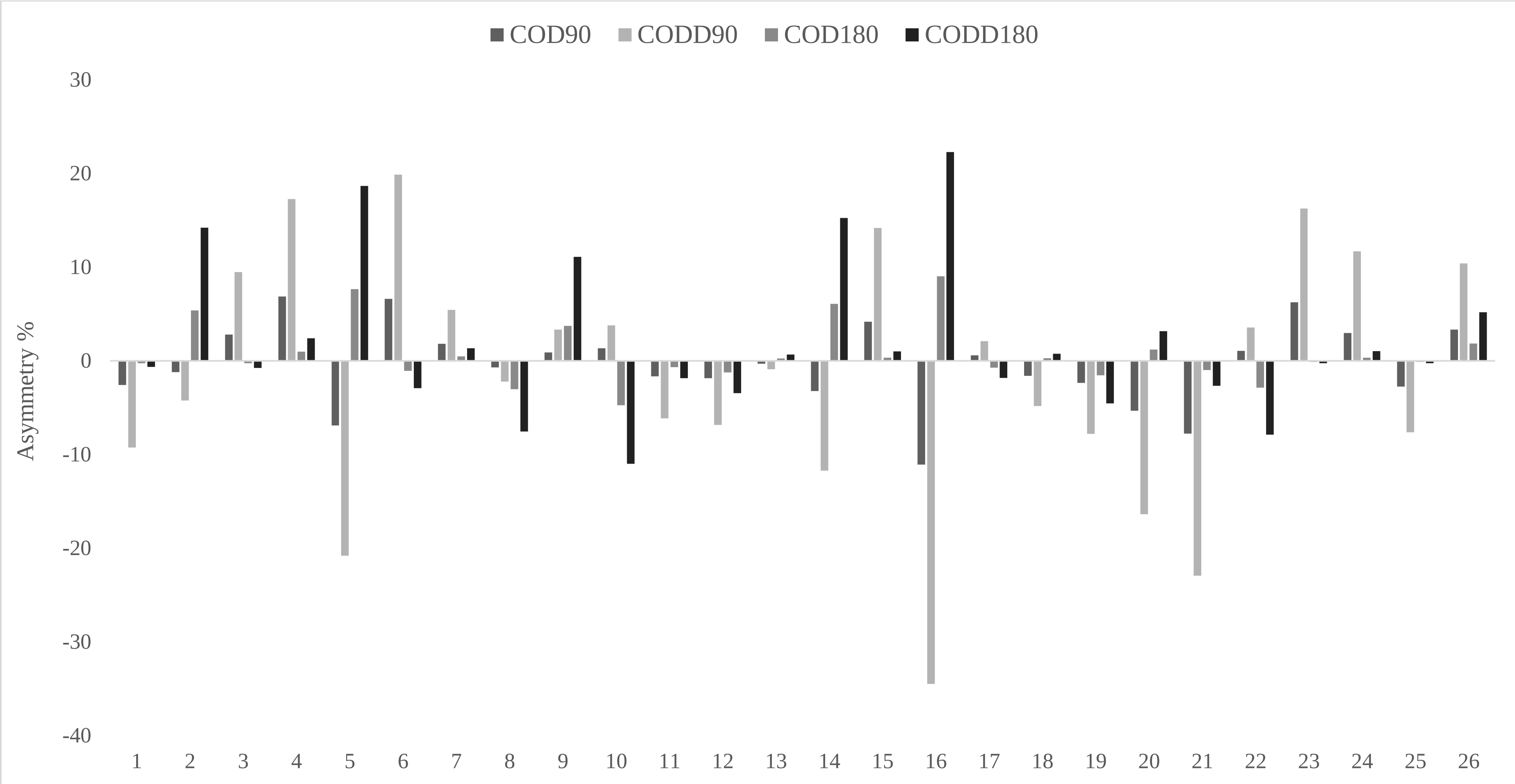

Figure 5. Individual asymmetry scores for the CODS90, CODD90, CODS180, CODD180 (time) tests. Above 0 line means asymmetry favours the dominant leg and below 0 line means asymmetry favours the non-dominant limb.

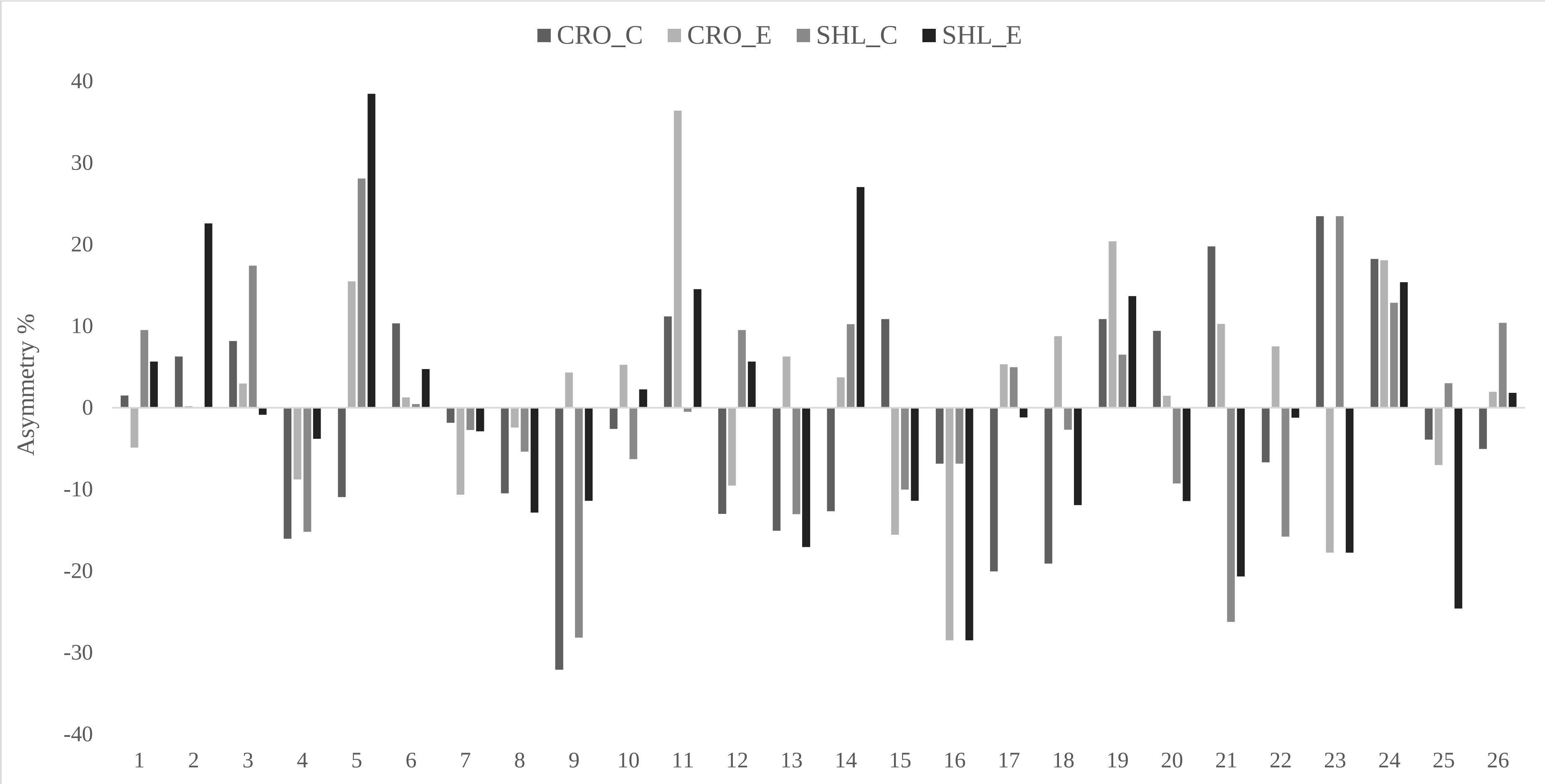

Figure 6. Individual asymmetry scores for the CRO_C, CRO_E, LSS_C, LSS_E (power) tests. Above 0 line means asymmetry favours the dominant leg and below 0 line means asymmetry favours the non-dominant limb.