Asymmetry Thresholds for Common Screening Tests and Their Effects on Jump Performance in Professional Soccer Players

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Context: Arbitary asymmetry thresholds are regularly used in professional soccer athletes, notwithstanding the sparse literature available to examine their prevalence.

Objective: To establish normative and positional asymmetry values for commonly used screening tests and investigate their relationships with jumping performance.

Design: Cross-sectional study.

Setting: Elite soccer screening.

Patients or Other Participants: A total of 203 professional male soccer players.

Main Outcome Measure(s): Bilateral and unilateral jumping; range of motion; and hamstrings (HAM), quadriceps (QUAD), and hip-adductor and -abductor strength tests were used to quantify asymmetry. Players were divided into 4 quartiles (Q1–Q4) based on the magnitude of their asymmetry for each test. Single composite scores were also developed to group tests by range of motion and HAM, QUAD, hip-adduction, and hip-abduction strength, and differences in jump performance were examined among players in each quartile.

Results: Large variability (range = 5.2%–14.5%) was evident in asymmetry scores across the different tests and physical qualities. Forwards displayed greater asymmetry in concentric quadriceps and eccentric hip-abduction strength (P < .05). The HAM and QUAD composite scores indicated that Q4 players’ jumps were shorter than those in other quartiles during a single-legged countermovement jump and 10-second hop (P < .05). No decrements in unilateral jump performance were shown among players in each quartile for range of motion or hip-adduction and -abduction strength, and no composite measures of asymmetry affected bilateral jump performance.

Conclusions: No single asymmetry threshold was present for all tests; the outcomes were task, variable, and population specific. Larger asymmetries in HAM and QUAD strength appeared to be detrimental to unilateral jump performance.

Key Words: laterality, variability, assessment

Key Points

- Great variability was evident in asymmetry thresholds measured across the different tests and physical qualities in professional soccer players, and only very large asymmetries in strength appeared to affect jump performance.
- It is likely not possible to apply a single asymmetry threshold when assessing athlete profiles. Instead, task- and variable-specific values should be established. More emphasis may also be placed on reducing asymmetries in strength.
- Our focus was on preparticipation screening, and sport-specific evaluations, including sprinting and changes of direction, were not studied. Future researchers should examine the effects of different asymmetry thresholds on performance using these tasks.

Imbalances between limbs are common in sports such as soccer, in which players are exposed to high volumes of training and competition and preferred limb dominance is evident.1,2 Many of the skills involved in soccer training and competitions require athletes to frequently repeat the execution of unilateral and asymmetric movements (eg, cutting, changing direction, and kicking). Over time, this may lead to between-limbs differences in strength, power, and joint range of motion (ROM) due to unique loading patterns and coordination of movement. Asymmetry is a potential risk factor for injury in soccer players3 that may be the result of additional stresses placed on the soft tissue structures of the nondominant leg.4 Furthermore, researchers5,6 have noted some negative associations between asymmetry and measures of athletic performance. Unilateral testing modes enable practitioners to identify the magnitude of these differences across a range of tasks and physical qualities.

Although some level of asymmetry is expected in professional male soccer players, few investigators have examined the prevalence of asymmetry during commonly used screening tests. Among male youth soccer players,
musculoskeletal imbalances of >10% on at least 1 test were present in most participants tested. More recently, asymmetries of ≥15% during landing tasks were shown in uninjured elite youth players. Before protocols are initiated to reduce these between-limb differences, it is important to first characterize “normal” levels of asymmetry across a range of physical qualities in order to diagnose “abnormal” asymmetry. This will aid in individualizing training and rehabilitation programs for athletic populations, thereby allowing practitioners to more effectively stratify their players using targeted interventions.

One of the purposes of assessing lower limb asymmetry is to evaluate its possible effects on performance. Within the available literature, most researchers have investigated the association between individual factors, such as strength and jump or jump and sprint asymmetry. Asymmetries measured during common screening protocols may also be associated with reductions in jumping performance. Therefore, a holistic examination of multiple physical components (eg, strength and ROM) in various joint segments (ankle, knee, and hip) is important. Further examination of the magnitudes of these asymmetries in professional soccer players and their effects on performance outcomes is required.

Hence, the aim of our study was to establish normative asymmetry values for a range of commonly used screening tests. The secondary aim was to examine the effects of these different thresholds on jump performance. Jumps occur frequently during match play, whereas asymmetry is a natural by-product of competing in a single sport over time. Increased jumping asymmetry and reductions in change-of-direction performance have also been shown. Understanding if larger asymmetries observed during common screening tasks are associated with a reduction in key performance indicators can provide us with a mechanistic understanding and help identify factors that contribute to decrements in jump performance.

**METHODS**

**Participants**

A total of 203 professional soccer players (age = 24.4 ± 4.7 years, height = 175.7 ± 6.6 cm, body mass = 71.5 ± 9.3 kg) registered at clubs competing in the Qatar Stars League, Qatar, were recruited. Inclusion criteria were current participation in unrestricted soccer training and being asymptomatic and free from severe injury at the time of testing and during the preceding 12-month period. This approach was used to remove the confounding factor of increased asymmetry in professional soccer players who had sustained a previous severe injury (defined as >28 days of time loss) in the prior 12 months compared with those who had not sustained an injury during the same time period. We verified injury status by examining the Aspetar Orthopaedic and Sports Medicine Hospital injury audit that documents all injuries sustained in the Qatar Stars League as part of the work performed by the National Sports Medicine program. Informed consent was obtained before the study, and ethical approval was provided by the Anti-Doping Laboratory, Doha, Qatar (No. E2013000003).

**Design**

Players were tested at the Aspetar Orthopaedic and Sports Medicine Hospital during the preseason or early competition period of the 2017–2018 season. The assessment consisted of a series of ROM, strength, and dynamic screening tests. Upon arrival, explanations of all procedures were provided, and anthropometric information was collected. Players then completed a standardized warm-up consisting of 10 minutes of cycle ergometry and dynamic stretching. A consistent order of testing was followed, ensuring that nonfatiguing tests were performed before more physically demanding modes of assessment; for all strength and jump tests, warm-up trials enabled each participant to become familiar with and demonstrate technical competence on the test.

**Range-of-Motion Assessment**

Hip ROM evaluation involved the supine bent-knee fall-out (BKFO) and prone internal rotation (IR) in 90° of hip flexion, as described previously. Data collected at our center using these tests have indicated strong reliability (intraclass correlation coefficient [ICC] = 0.87–0.93, SEM = 1.1–3.3). The BKFO was measured via a tape measure as the distance between the most distal point at the head of the fibula and the surface of the plinth. Prone IR in 90° of hip flexion was measured using a manual goniometer. The BKFO distance was tested once, and 3 repetitions of the IR assessment were performed, with the average score recorded.

Hamstrings flexibility was measured using a passive knee-extension test as previously described, which has shown acceptable reliability in our center (ICC = 0.96, SEM = 3.3). The athlete positioned the hip in maximal flexion by clutching the thigh to the chest, and the contralateral leg was fixed in place by the assessor. The maximal angle was measured using a handheld inclinometer positioned on the tibia.

Ankle-dorsiflexion ROM was measured using the weight-bearing lunge test as the standing athlete faced a wall.
used a tape measure to determine the maximum distance from the wall that the knee of the lead (testing) leg was able to touch during the forward lunge as the heel remained in contact with the ground. This method has shown strong reliability in previous research (ICC = 0.98–0.99, SEM = 0.4–0.6 cm).21 All testing was completed with the participants barefoot, and measures were recorded with dorsiflexion ROM defined as the maximum distance (to the nearest 0.1 cm) of the big toe from the wall.

**Strength Assessment**

Quadriceps (knee-extension) and hamstrings (knee-flexion) strength profiles were measured via an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) using procedures described earlier.22 A measurement error of 24 Nm for consecutive assessments has been reported from our laboratory.22 Assessment consisted of 5 repetitions of concentric knee flexion and extension at 60°/s and 5 repetitions of eccentric knee extension at 60°/s, with the highest peak torque value recorded. In addition, we calculated the functional hamstrings-to-quadriceps ratio (FUNC: HQ). A minimum of 60 seconds of rest was provided between contraction modes. During testing, the assessors supplied standardized and vigorous oral encouragement.

The Nordic hamstrings curl was performed on the NordBord (Valid Performance, Albion, Australia) with the participant kneeling, chest and hips extended, arms across the chest, and ankles secured by individual braces that were attached to uniaxial load cells as previously described.23 The reliability of this assessment has been described (ICC = 0.83–0.90, typical error [TE] = 21.7–27.5).23 Players were instructed to lower the body as slowly as possible to maximum depth or until they achieved a prone position. After catching their fall, each player pushed himself back to the starting position to minimize concentric knee-flexor activity. Three trials were completed with a 30-second rest period between repetitions. The peak force recorded for each limb across the 3 trials was used for subsequent analysis.

Eccentric hip-adduction and -abduction strength was evaluated with the athlete in a side-lying position using a hand-held dynamometer (model PowerTrack II Commander, JTECH Medical, Midvale, UT), adopting the break-test method in accordance with published protocols displaying acceptable reliability at our rehabilitation institute (ICC = 0.83–0.90, typical error [TE] = 21.7–27.5).23 Players were instructed to lower the body as slowly as possible to maximum depth or until they achieved a prone position. After catching their fall, each player pushed himself back to the starting position to minimize concentric knee-flexor activity. Three trials were completed with a 30-second rest period between repetitions. The peak force recorded for each limb across the 3 trials was used for subsequent analysis.

**Jump Performance**

The single-legged countermovement jump (SLCMJ) was performed in accordance with earlier recommendations and showed good to excellent reliability and acceptable variability in a test-retest design (ICC = 0.81–0.93, coefficient of variation [CV] ≤ 5.8%).24 Players began in a unilateral stance on a force plate (model FD4000: Force Decks v1.2.6109; Vald Performance, Newstead, Queensland, Australia) with hands on hips and the opposite hip flexed to 90° to reduce contributions from the contralateral limb. The examiner instructed the participant to perform a countermovement by dropping into an approximate quarter-squat position and then immediately triple extending at the ankle, knee, and hip in an explosive concentric action. For standardization, bending of the knees while airborne was not permitted. Jump height was calculated from the impulse-momentum relationship-derived take-off velocity and the equation of constant acceleration [velocity at take-off squared divided by 2 × 9.81 (To²/2 g)]. Peak propulsive force, defined as the maximum force output during the concentric phase of the jump before take-off, was also calculated. The initiation of the jump was identified by a 20-N change from body weight calculated during the quiet standing period. The eccentric phase was determined as the time from initiation of the jump to the zero center-of-mass velocity. The concentric phase consisted of the period from the zero center-of-mass velocity to the instant of take-off, when the total vertical force dropped below 20 N. All data were recorded at a sampling rate of 1000 Hz. Three trials were completed with a 30-second rest period between repetitions. In addition, a bilateral countermovement jump (CMJ) was assessed for general performance and the procedures replicated those described, albeit with 2 feet on the floor to initiate the jumping and landing actions.

A single-legged 10-second hop test was undertaken that involved a series of repeated single-legged jumps performed for 10 seconds in accordance with previous guidelines.25 The test began with the participant completing a rapid countermovement into a quarter-squat, followed by a maximal vertical jump. This action was replicated across the test period with instructions to jump as high as possible, minimize ground contact time while landing under control, and try to maintain the same footprint while facing forward during the entire test. One trial was completed for each leg. An optical measurement device (model Optojump; Microgate, Bolzano, Italy) was used to quantify the average jump height, and the reactive strength index was derived from flight time/ground contact time.

**Statistical Analysis**

We quantified between-limbs asymmetries as the percentage difference between limbs based on the average of all trials on each side using the following formula: \[\text{Percentage difference} = \left(\frac{\text{maximum value} - \text{minimum value}}{\text{maximum value}}\right) \times 100\%\].26 Descriptive statistics (mean ± SD) were calculated for each variable, and positional (goalkeepers, defenders, midfielders, and forwards) differences in the magnitude of asymmetry were analyzed via separate 1-way analysis-of-variance (ANOVA) tests, with the Bonferroni correction applied. The magnitude of these differences was also calculated using Cohen d effect sizes. A sample-size calculation relied on the following assumptions. To detect a moderate effect size of 0.25 with 4 groups, setting power to 0.80 and the α level to .05, we estimated the total sample required at 43 per playing position. Asymmetry thresholds were computed using the entire data sample (all players combined) by ordering all recorded values and dividing the data for each variable into equal quartiles according to their position with 4 cut points (Q1–Q4). Principal component analysis was a means of reducing the number of variables into related factors to assess the effects of asymmetry on jump performance. To determine the number of factors for each component, we first observed the scree plot and
retained all eigenvalues above the “natural bend.” Factors with eigenvalues >1 were subsequently included.27 Three single-composite variables were then created: (1) ROM, (2) isokinetic hamstrings (HAM) and quadriceps (QUAD) strength, and (3) hip-adduction (ADD) and -abduction (ABD) strength. Finally, using these composite scores, we conducted separate ANOVA tests to assess differences in jump performance between players in each grouped asymmetry threshold (Q1–Q4). This analysis was performed on all players combined and not by position. The dependent variables were bilateral CMJ and the average SLCMJ and 10-second hop height using the right and left leg. The level of statistical significance was set at \( P \leq .05 \). All data were computed through Excel (version 2010; Microsoft Corp, Redmond, WA). The ANOVA, asymmetry thresholds, and composite scores were processed using SPSS (version 22; IBM Corp, Armonk, NY).

RESULTS

Descriptive statistics displaying absolute asymmetry scores for all players combined and by playing position showed pronounced variability across the different tests and physical qualities (Table 1). Significant positional differences were identified for concentric quadriceps strength at 60°/s: forwards demonstrated the greatest asymmetry (13.6% ± 10.5%) compared with midfielders (9.1% ± 7.5%) and goalkeepers (7.6% ± 4.9%; \( P < .05 \)), corresponding to moderate effect sizes (d = 0.49–0.73). Forwards also exhibited greater eccentric hip ABD asymmetry (12.9% ± 8.1%) than defenders (8.5% ± 6.9%, d = 0.59) and goalkeepers (7.2% ± 5%, d = 0.85; \( P < .05 \)) with moderate-to-large effect sizes.

Asymmetry thresholds for players in each quartile are provided in Table 2. No performance decrements were evident for bilateral CMJ height between players in any quartile. Players in Q4 of the HAM and QUAD isokinetic strength composite asymmetry score jumped lower than players in the other quartiles during the SLCMJ and 10-second hop (\( P < .05 \); Table 3). No other composite variables showed performance decrements in any jump test (\( P \) values > .05).

DISCUSSION

The aim of our study was to establish normative and positional asymmetry values across a range of commonly used screening tests and to examine their effects on jump performance in a cohort of professional soccer players. The main findings were as follows: (1) large variability was present in asymmetry thresholds, as indicated by the wide spread of the data across the different tests and physical qualities; (2) forwards appeared to have the largest asymmetry values for eccentric hip ABD and concentric QUAD strength compared with other positions, which could indicate adaptation to position-specific sport demands; and (3) higher levels of asymmetry during the different ROM and hip-strength tests did not seem to affect jump performance; however, jump height during the SLCMJ and 10-second hop was negatively affected among players in the upper quartile who displayed very large asymmetry in a principal component variable comprising isokinetic HAM and QUAD strength.

Asymmetries are task, variable, and physical quality specific. Therefore, practitioners should not expect to see the same between-limbs differences across different screening tests.13,14 Variability in asymmetry scores among different modes of strength and jump tests has also been shown previously28 and for a range of variables measured using the same task.13,14 This is consistent with our results: mean interlimb differences for all players combined across the various tests were almost 3-fold (4.9%–14.5%). This

Table 1. Asymmetry Characteristics for All Players Combined and by Playing Positiona

| Variables                        | All (N = 203) | Goalkeepers (n = 20) | Defenders (n = 63) | Midfielders (n = 80) | Forwards (n = 40) |
|----------------------------------|---------------|---------------------|--------------------|----------------------|-------------------|
| Range of motion                  |               |                     |                    |                      |                   |
| Bent knee fall-out               | 13.8 ± 9.4   | 12.2 ± 11.8         | 13.7 ± 9.9         | 14.8 ± 10.7          | 12.3 ± 9.7        |
| Hip internal rotation, 90°       | 11.3 ± 8.6   | 11.1 ± 9.1          | 10.9 ± 9.1         | 11.0 ± 8.3           | 12.7 ± 11.4       |
| HAM peak knee extension          | 4.9 ± 2.1    | 5.1 ± 4.3           | 4.5 ± 3.4          | 4.7 ± 3.2            | 5.6 ± 4.7         |
| Ankle dorsiflexion               | 12.7 ± 9.8   | 12.5 ± 9.4          | 11.8 ± 10.6        | 12.4 ± 11.4          | 14.8 ± 13.2       |
| Strength                         |               |                     |                    |                      |                   |
| Q UAD: Concentric, 60°/s         | 10.1 ± 7.5   | 7.6 ± 4.9           | 9.7 ± 8.4          | 9.1 ± 7.5            | 13.6 ± 10.5b      |
| HAM: Concentric, 60°/s           | 9.7 ± 7.0    | 10.9 ± 9.6          | 8.9 ± 7.5          | 9.5 ± 7.1            | 10.4 ± 8.9        |
| HAM: Eccentric, 60°/s            | 10.5 ± 7.8   | 12.0 ± 9.6          | 9.3 ± 6.8          | 10.4 ± 7.3           | 11.9 ± 8.8        |
| Functional HAM/QUAD              | 13.4 ± 9.3   | 13.7 ± 8.5          | 12.5 ± 10.7        | 12.8 ± 9.3           | 15.8 ± 12.0       |
| Adduction: abduction             | 10.1 ± 7.5   | 15.6 ± 9.0          | 12.5 ± 8.1         | 14.0 ± 10.5          | 16.5 ± 11.4       |
| NordBord                         | 6.6 ± 4.4    | 5.9 ± 4.9           | 7.1 ± 5.1          | 6.1 ± 5.6            | 6.8 ± 4.3         |
| Eccentric hip adduction          | 9.8 ± 6.8    | 11.7 ± 9.6          | 9.2 ± 7.2          | 9.6 ± 7.3            | 10.1 ± 8.6        |
| Eccentric hip abduction          | 10.1 ± 7.5   | 7.2 ± 5.0           | 8.5 ± 6.9          | 10.6 ± 8.2           | 12.9 ± 8.0c       |
| Jump                             |               |                     |                    |                      |                   |
| Single-legged countermovement jump, height, cm | 10.1 ± 7.9   | 8.9 ± 7.7           | 10.1 ± 7.9         | 9.5 ± 8.7            | 11.7 ± 11.0       |
| Single-legged countermovement jump, peak force, N  | 5.2 ± 3.1   | 4.5 ± 3.5           | 5.1 ± 4.6          | 5.7 ± 8.2            | 4.4 ± 3.3         |
| 10-s Hop height, cm              | 12.5 ± 9.1   | 12.4 ± 8.0          | 11.8 ± 8.2         | 12.2 ± 11.0          | 12.4 ± 10.0       |
| 10-s Hop reactive strength index  | 14.5 ± 11.2  | 15.9 ± 14.0         | 13.5 ± 10.4        | 13.8 ± 12.1          | 16.8 ± 13.8       |

Abbreviations: HAM, hamstrings; NordBord, Nordic hamstrings curl (Valid Performance, Albion, Australia); QUAD, quadriceps.

a Values are mean ± SD.

b Greater than midfielders and goalkeepers (\( P < .05 \)).

c Greater than goalkeepers and defenders (\( P < .05 \)).
could have been due to task complexity and the sensitivity of the variables measured\textsuperscript{14} and may preclude the use of a single test when examining the magnitude of asymmetry. Furthermore, eccentric HAM strength was measured via 2 assessment modes. Using the isokinetic dynamometer (the athlete was positioned seated with the hip flexed to $90^\circ$), we recorded mean asymmetry of 10.5%. Conversely, between-limbs peak-force differences of 6.6% occurred during the Nordic hamstrings curl, further supporting the notion that asymmetry is task dependent. Specifically, it should be noted that when comparing these tests, we found that one was bilateral and the other was unilateral. It is possible that bilateral testing masks some of the asymmetry, as has been previously indicated.\textsuperscript{29}

Earlier researchers\textsuperscript{8,15} provided guidelines using a single arbitrary criterion value applied to any asymmetry variable to determine adequate symmetry that, if increased, may heighten the injury risk. This approach has also been used to guide decision making for a “safe” return to play.\textsuperscript{11,12} Yet before clinical recommendations can be provided regarding an acceptable threshold, a clearer understanding of normal asymmetry is required. Our findings demonstrated substantial variability across common screening tests and various physical qualities (Table 2). A minimum symmetry target of $\leq 10\%$ has been suggested for assessment and rehabilitation protocols\textsuperscript{10} and for clearance to return to play after anterior cruciate ligament reconstruction.\textsuperscript{11,12} Our classification for very large asymmetry in some tests (for example, SLCMJ peak concentric force and

### Table 2. Asymmetry Thresholds for Players in Each Quartile

| Test Variable                        | Absolute Asymmetry (%) | Small (Q1) | Moderate (Q2) | Large (Q3) | Very Large (Q4) |
|--------------------------------------|------------------------|------------|---------------|------------|-----------------|
| Range of motion                      |                        |            |               |            |                 |
| Bent-knee fall-out                   | $\leq 5.7$             | 5.8–12.5   | 12.6–20.9     | $\geq 21$  |
| Hip internal rotation, $90^\circ$    | $\leq 3.5$             | 3.6–8.9    | 9.0–16.3      | $\geq 16.4$|
| HAM peak knee extension              | $\leq 1.3$             | 1.4–3.3    | 3.4–6.1       | $\geq 6.2$ |
| Ankle dorsiflexion                   | $\leq 3.8$             | 3.9–9.1    | 9.2–18.1      | $\geq 18.2$|
| Strength                             |                        |            |               |            |                 |
| QUAD: Concentric, 60/s               | $\leq 4.4$             | 4.5–7.4    | 7.5–13.4      | $\geq 13.5$|
| HAM: Concentric, 60/s                | $\leq 4.3$             | 4.4–7.3    | 7.4–13.8      | $\geq 13.9$|
| HAM: Eccentric, 60/s                 | $\leq 4.3$             | 4.4–8.4    | 8.5–16.7      | $\geq 16.8$|
| Functional HAM:QUAD                  | $\leq 5.2$             | 5.3–11.0   | 11.1–20.1     | $\geq 20.2$|
| Adduction: abduction                 | $\leq 6.2$             | 6.3–12.7   | 12.8–19.8     | $\geq 19.9$|
| NordBord                             | $\leq 2.8$             | 2.9–5.1    | 5.2–8.9       | $\geq 9$   |
| Eccentric hip adduction              | $\leq 3.8$             | 3.9–8.1    | 8.2–14.1      | $\geq 14.2$|
| Eccentric hip abduction              | $\leq 3.7$             | 3.8–8.7    | 8.9–14.5      | $\geq 14.6$|
| Jump                                 |                        |            |               |            |                 |
| Single-legged countermovement jump, height, cm | $\leq 3.3$             | 3.4–8.7    | 8.8–14.9      | $\geq 15.0$|
| Single-legged countermovement jump, peak force, N | $\leq 1.8$             | 1.9–3.8    | 3.9–6.3       | $\geq 6.4$ |
| 10-s Hop height, cm                  | $\leq 4.6$             | 4.7–10.3   | 10.4–18.0     | $\geq 18.1$|
| 10-s Hop reactive strength index     | $\leq 5.5$             | 5.6–11.7   | 11.8–20.4     | $\geq 20.5$|

Abbreviations: HAM, hamstrings; NordBord, Nordic hamstrings curl (Vald Performance, Albion, Australia); QUAD, quadriceps.

### Table 3. Performance Scores for Players in Each Quartile of Absolute Asymmetry

| Composite Absolute Asymmetry Scores | Q1      | Q2      | Q3      | Q4      |
|-------------------------------------|---------|---------|---------|---------|
| Isokinetic strength                 |         |         |         |         |
| CMJ\textsuperscript{a}             | 34.8 ± 4.8 | 34.9 ± 4.3 | 35.6 ± 4.6 | 33.7 ± 4.8 |
| SLCMJ                               | 17.5 ± 2.3 | 18.0 ± 3.0 | 17.9 ± 3.0 | 16.0 ± 2.8\textsuperscript{b} |
| 10-s Hop                            | 13.4 ± 2.6 | 13.7 ± 3.3 | 13.4 ± 2.9 | 12.0 ± 2.7\textsuperscript{c} |
| Hip strength                        |         |         |         |         |
| CMJ                                 | 34.2 ± 4.0 | 34.7 ± 4.7 | 35.8 ± 4.5 | 34.3 ± 5.2 |
| SLCMJ                               | 17.0 ± 2.7 | 17.9 ± 2.7 | 17.6 ± 2.6 | 16.8 ± 3.3 |
| 10-s Hop                            | 13.1 ± 3.1 | 13.6 ± 2.6 | 13.1 ± 3.1 | 12.7 ± 3.0 |
| Range of motion                     |         |         |         |         |
| CMJ                                 | 33.9 ± 4.7 | 35.5 ± 4.0 | 34.5 ± 4.8 | 35.1 ± 4.8 |
| SLCMJ                               | 17.0 ± 2.8 | 18.0 ± 2.5 | 17.3 ± 3.2 | 17.1 ± 2.8 |
| 10-s Hop                            | 13.3 ± 2.8 | 13.3 ± 2.5 | 13.0 ± 3.5 | 12.9 ± 2.9 |

Abbreviations: CMJ, countermovement jump; SLCMJ, single-legged countermovement jump.

\textsuperscript{a} Height (cm) was the measure for all variables.

\textsuperscript{b} Lower than all other asymmetry thresholds ($P < .05$).

\textsuperscript{c} Lower than players in the moderate asymmetry threshold (Q2; $P < .05$).
HAM ROM measured via passive knee extension) was >6%, which is below these suggested arbitrary thresholds. Therefore, this approach would have been inappropriate in this cohort. Using a 10% threshold, we expect that comparing eccentric HAM strength during the isokinetic unilateral and NordBord assessment would also lead to a different classification of asymmetry. Furthermore, different values were present for each quartile on the same test, with SLCMJ concentric peak force and jump height Q4 asymmetry recorded as 6.4% and 15%, respectively. Thus, tests should be examined separately and may require a specific threshold that is population, task, and metric specific to more accurately identify abnormal asymmetry. In addition, the aim of the current study was to examine only the absolute magnitude of asymmetry, as this is most commonly applied in practice. Investigators24 suggested that the direction of asymmetry (right or left dominance) should also be considered, as this may vary across different tasks. Establishing clearer guidelines will assist practitioners in making more effective and evidence-based decisions about training programs to target these between-limbs deficits.

Positional differences in asymmetry were also identified, with forwards displaying a trend toward greater asymmetry in concentric QUAD peak torque and eccentric hip ABD strength. This may reflect the specific demands of match play with forwards expected to perform more short-duration, high-intensity actions than other positions.1 In a large sample of professional soccer players, Wik et al10 recently reported positional differences for anthropometry and isokinetic strength but did not examine asymmetry. Costa Silva et al31 showed no differences between positions in isokinetic peak torque asymmetry of the knee and ankle, but a critical examination of their data may suggest that the sample size was too small to conduct any meaningful analysis. Ruas et al12 noted greater between-limbs values in isokinetic concentric QUAD peak torque among strikers; however, these differences were not statistically significant. Carvalho and Cabri33 also reported increased QUAD strength in the dominant (kicking) limb of goalkeepers and forwards. Cumulatively, these data indicate that screening programs for soccer players should specifically target forwards, as they may be predisposed to greater between-limbs differences. Still, given the previously stated task-specific nature of asymmetry, it is important for practitioners to examine players across a range of assessments and physical constructs and not assume that the dominant limb is the kicking limb, thereby enabling a more valid decision-making process.

Using quartiles to classify players based on their magnitude of asymmetry, we found that players in Q4 who displayed larger asymmetries in the HAM and QUAD strength principal component factor jumped lower than players in the other quartiles who recorded lower asymmetry values during the SLCMJ and 10-second hop. Greater asymmetry is detrimental to sport performance; however, this finding has not been consistent across all tasks and physical qualities,5 which supports our results. Previous researchers34 showed that greater asymmetry in isometric force production was detrimental to bilateral vertical jumping in collegiate athletes. In the current study, we did not observe any differences in performance for the bilateral CMJ across the range of asymmetry thresholds or physical qualities for each quartile. Bailey et al35 measured asymmetry during an isometric midthigh pull with a dual force-plate system, which is a bilateral task. We assessed strength using a unilateral mode, which further indicates that specificity is a key component in relating surrogate measures of asymmetry to performance-oriented tasks. Lower limb strength was highly correlated with jump height in soccer players;35 increases in strength achieved through targeted training programs elicited favorable changes in jump height.36 Therefore, it is logical to assume that asymmetry in this physical quality could be expected to reduce jump height. In addition, we should consider that although no decrements in performance were evident despite asymmetry in single-joint tasks and bilateral jumping, phase-related variables (for example, eccentric and concentric impulse) during each jump may be more affected by asymmetries, and this topic warrants further investigation.

Correlational studies are the most common experimental design for examining relationships between asymmetry and performance measures.2,14,37,38 However, this approach does not identify the magnitude of asymmetry that is detrimental to the measured outcome variable. Earlier researchers37,38 used thresholds to classify individuals as asymmetric via the mean imbalance + (0.2 × standard deviation). Dos Santos et al37 used this method to determine the prevalence of asymmetry but did not relate these classifications to performance. Lockie et al38 applied the same classification to split the group into lesser and greater asymmetry, with cut-off points for the vertical jump (12.6%), standing broad jump (3.9%), and lateral jump (5.8%). No differences in sprint or change-of-direction performance were reported between groups; thus, a dichotomous approach may not be sensitive enough to demonstrate decrements in performance. Here, we used 4 cut points to examine the effects of a broader range of asymmetry scores during single-joint tasks on jump performance. Players in Q4 who displayed larger asymmetries in QUAD and HAM strength showed reductions in unilateral jump height, which suggests that asymmetry in the higher ranges may be required to translate into greater decrements in jump performance. Future authors should investigate this topic across a wider variety of performance tasks and among athletes in other sports.

When interpreting the results of our study, important limitations should be considered. The use of quartiles to compute asymmetry thresholds is a novel approach, and to our knowledge, this is the first time it has been applied in an asymmetry context. Consequently, it is not possible to compare our findings with those of previous researchers. The cross-sectional design provided only a single time-point measurement for capturing player performance. In addition, sport-specific assessments including sprint and change-of-direction performance were not included due to the design of the study, which instead focused on preparticipation screening. Finally, the sample size we recruited was insufficient to achieve the required power when comparing goalkeepers with other positions. However, unlike other investigators32 whose aim was to provide normative values, we were able to recruit a larger sample. Also, given that the players were high-level professionals and the difficulties in recruiting many goalkeepers due to the smaller number of such positions on a squad, we feel
the sample recruited in our study was adequate based on the aforementioned limitations.

CONCLUSIONS

Wide variability was present in asymmetry thresholds across common screening tests and different physical qualities in professional soccer players. Although larger asymmetries in QUAD and HAM strength may be detrimental to specific aspects of soccer performance, they did not appear to affect unilateral and bilateral jumping tasks. Furthermore, greater asymmetries in ROM and hip strength did not appear to affect jump performance.

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