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Unilateral vs. bilateral hamstring strength assessments: comparing reliability and inter-limb asymmetries in female soccer players

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ABSTRACT
The aims in the present study were to assess reliability for two unilateral and two bilateral field-based hamstring assessments and compare magnitude, direction and agreement of inter-limb asymmetry between tests and sessions. Twenty-nine female soccer players (age: 21.1 ± 4.5 years; height: 169.7 ± 5.8 cm; body mass: 66.2 ± 6.4 kg) performed three repetitions per leg of unilateral isometric 30° and 90° knee flexion (KF) tasks, and three repetitions total for a bilateral 90° isometric KF and Nordic hamstring exercise. Absolute reliability of most methods were acceptable (<10%). Relative reliability within-session was fair to excellent (ICC≥0.784; lower bound 95%CI ≥0.623). Greater variability in between-session relative reliability was observed during the unilateral tests, demonstrating poor to good (ICC = 0.698–0.798; lower bound 95%CI = 0.274–0.638). Bilateral assessments demonstrated similar ranges of poor to excellent (ICC = 0.679–0.963; lower bound 95%CI = 0.231–0.790). Agreement between-session for inter-limb asymmetry identification was slight and fair in the unilateral tests, with moderate to substantial agreement demonstrated in the bilateral. Being the most reliable within- and between-sessions, demonstrating substantial agreement in asymmetry between-sessions, the NHE would be most appropriate to identify inter-limb asymmetry and assess chronic changes in hamstring strength.

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KEYWORDS
Field-based; soccer; nordic hamstring exercise; isometric

1.0 Introduction

Hamstring research has become increasingly common in recent years, predominantly due to the high incidence of hamstring strain injuries (HSI). In soccer alone, HSI represent 12% of all injuries in high-level athletes (Ekstrand et al., 2011b). On average, typical HSI causes athletes to miss 2 weeks of training or match play. Depending on the time of the season and fixture scheduling, this could mean up to 6 fixtures being missed, with professional soccer teams often experiencing 5–6 HSI per season (Ekstrand, Hagglund, Walden et al., 2011a). HSI, therefore, result in a large performance and financial burden, highlighted by Ekstrand (Ekstrand et al., 2016) as costing elite European soccer teams in the region of €500,000, with inflation since 2016 this figure is likely to have increased. Even more alarming is the reported 4% annual increase in HSI occurrence in soccer during a 13-year longitudinal study (Ekstrand et al., 2016). The aforementioned evidence, however, has only been reported in male populations. Although there is evidence to suggest that the overall incidence of HSI is lower in females when compared to males (Cross et al., 2013), Dalton et al. (Dalton et al., 2015) observed that the hamstring injury occurrence rate in female soccer was over twice that of any other female sport, when comparing between athletes across 25 different collegiate sports over a 4-year period. Combining the higher HSI occurrence observed in soccer, with the increasing intensity of the women's game (Bradley & Scott, 2020), highlights the importance of understanding both the possible mechanisms of injury, and methods of identifying athletes at a greater risk of injury in female populations.

Along with other non-contact injuries, HSI have a plethora of modifiable and non-modifiable risk factors that have been shown to contribute to increased injury risk. In an early review by Opar, Williams and Shield (Opar et al., 2012), the authors highlight a range of possible risk factors leading to injury and reinjury of the hamstrings with modifiable risk factors including flexibility, fatigue, but most prominently strength (Worrell & Perrin, 1992). Although results of a more recent meta-analysis has highlighted limited value of flexibility as a standalone risk factor, an appreciation of changes in strength and flexibility over time and in response to fatigue was also recognized (Green et al., 2020). Due to the variable nature of strength, flexibility, and fatigue, the suggestion from Green et al. (Green et al., 2020) is that rather than testing these factors on a single occasion to prospectively identify a players' risk, it is important to continually monitor the changes individuals demonstrate. Although it is important to monitor an individual's hamstrings globally, it may also be necessary to separate observations or measurements of the individual limbs. Zakas (Zakas, 2006) previously proposed that the weaker hamstring may be at an elevated risk of injury compared to the stronger contralateral hamstring. Whilst some authors have found no predictive power of inter-limb asymmetries (Bennell et al., 1998;

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Yeung et al., 2009), there has also been evidence suggesting that Australian rules football (Orchard et al., 1997), soccer (Croisier et al., 2008) and rugby players (Bourne et al., 2015) with inter-limb asymmetries of at least 8%, 15% and 20%, respectively, are found to be at higher risk of HSI. The contrasting evidence in the role that asymmetries play in HSI could be attributed to the varying methods used to collect and calculate the asymmetry data (Bishop et al., 2016). In addition, due to HSI being multi-factorial, it is not clear if it is the asymmetry that is a contributing risk factor or the fact that the weaker muscle simply lacks the required force-generating capacity for the required tasks.

When continually monitoring an athlete's hamstring strength or strength asymmetry, the measurements used are required to be both reliable and valid within the cohort, population or environment in which the test or exercise is being utilized. Recently, there has been a greater availability of field-based assessment tools that negate the typical drawbacks of isokinetic dynamometry, such as expense, accessibility, and the time-consuming nature of the assessment protocols. Force plates, strain gauges, load cells and hand-held dynamometers are becoming much more affordable solutions for teams to access, which allows for changes in the way hamstring strength can be assessed. Force plates have been used to identify isometric peak force during knee flexion at two different knee angles (30° and 90°) (McCall et al., 2015; Read et al., 2019), and strain gauges used to identify peak force during eccentric knee flexion (NHE) (Opar et al., 2013). Hand-held dynamometers have also been used to assess peak force in both isometric and eccentric knee flexion tasks in both prone (0–15° and 30°), supine (90°) (Van der Made et al., 2019) and seated (30°) positions (Whiteley et al., 2012). Load cells have also been used to assess peak force during isometric knee flexion (0°, 45° and 90°) and various eccentric sliding tasks and hamstring bridges (Hickey et al., 2018). The reliability of these hamstring strength measures have been reported between testing sessions, with all tests on force plates, strain gauges and loading cells demonstrating good to excellent relative reliability for both isometric and NHE exercises (ICC ≥ 0.83) (Hickey et al., 2018; McCall et al., 2015; Opar et al., 2013). The reliability of these measures however only appears to have been carried out with male populations of various team sports, sprinters or as a minimum physically active at least twice a week. Although there may be little to no difference in reliability, it is important to demonstrate within specific populations to inform practitioners of the potential applications of a testing protocol.

Hamstring strength asymmetries or strength imbalances may be a risk factor for HSI, particularly when there is a large magnitude of difference, it is therefore important to understand the agreement in imbalance between testing occasions of a particular test or exercise to identify that same imbalance reliably on each occasion so practitioners can identify when real changes are occurring. Hamstring strength asymmetries have typically been assessed using isokinetic dynamometry during concentric actions (Anastasi & Hamzeh, 2011) or both concentric and eccentric action, as well as hamstring:quadriceps ratios (Bennell et al., 1998; Croisier et al., 2008; Van Dyk et al., 2016; Yeung et al., 2009). Although investigators have looked at similar muscle actions, the range in angular velocities has been demonstrated from as low as 30°/s to as high as 240°/s. Despite such variations in angular velocities, when tracking injuries longitudinally van Dyk et al. (Van Dyk et al., 2016) have only identified meaningful associations between eccentric hamstring peak torque, adjusted for bodyweight, at 60°/s and an increased risk of HSI within a four-year cohort study. Asymmetries have only been reported as a ratio between limbs or percentage difference, however, with no measure of agreement between trials or test sessions.

It is worth highlighting that inter-limb asymmetries have been previously calculated during both bilateral and unilateral strength and jumping-based tasks (Bishop, Lake et al., 2018; Bishop, Pereira et al., 2019; Bishop et al., 2020; Bishop, Read et al., 2019). During the aforementioned tasks, the same side/limb was rarely favoured between tests and variables derived from those tests, with asymmetry changes dependent upon the chosen activity and the variables examined. Inter-limb asymmetry in the hamstrings has been demonstrated to follow a similar pattern, with no correlation of limb-limb strength asymmetries derived from isokinetic dynamometry and the Nordic hamstring exercise (NHE) (Wiesinger et al., 2020), however, this was again only investigated in male athletes.

Due to strength asymmetries being viewed as a potential risk factor for HSI, as well as a result of previous hamstring injury, it is important to identify reliable methods of assessing the direction and magnitude of asymmetries to reduce the potential risk for injury and re-injury in all populations. Therefore, the aim of the present study was to 1) assess the reliability of two unilateral and two bilateral field-based hamstring assessment methods in a female population and, 2) compare the magnitude and direction of asymmetry between these methods. It was hypothesized that the unilateral isometric tests would have the least agreement in asymmetries between testing sessions as the actions are performed separately for each leg, therefore individuals would not have feedback in terms of effort from the opposite leg.

2.0 Methods

2.1 Participants

Twenty-nine female soccer players (age: 21.1 ± 4.5 years; height: 169.7 ± 5.8 cm; body mass: 64.7 ± 6.0 kg) playing in the Women's Super League, all of which having a minimum of 2-years resistance training experience, volunteered to participate in the isometric assessments and NHE assessment. Due to player availability, 23 players (age: 20.7 ± 4.7 years; height: 168.7 ± 5.9 cm; body mass: 64.4 ± 6.7 kg) participated in the three isometric assessments and all 29 participated in the NHE assessment. Participants were required to have had no hamstring related injuries for 6 months prior to taking part. Organizational consent was acquired prior to approaching the participants and all participants provided written informed consent, or parental/guardian assent where required, to participate in the study. Ethical approval was granted by the institutional ethics committee in accordance with the declaration of Helsinki.

2.2 Experimental design

A repeated measures cross-sectional design was used to examine the reliability of four field-based hamstring strength assessments and then to compare the asymmetries observed between those assessments. Participants completed the tests prior to their normal training day on two occasions 72 h apart. The familiarization session was carried out 48 h after a competitive fixture, following their recovery day, with the testing session completed three days after familiarization, allowing at least 48 h recovery prior to their next competitive fixture.

2.3 Procedures

2.3.1 Isometric hamstring strength tests

Twenty-three of the participants performed three isometric assessments prior to the eccentric assessment, due to the isometric tests being less fatiguing and creating less metabolic stress (Carroll et al., 2017). The kneeling 90° knee flexion (kneeling ISO) assessment was performed on a NordBord (Vald Performance, Brisbane, QLD, AUS) sampling at the default 50 Hz, whilst the other two, ISO 30° and ISO 90° knee flexion, were tested using a force plate (Kistler Type 9286AA: Kistler Instruments Inc, Amherst, NY, USA) sampling at 1000 Hz and collected using Kistler's BioWare software. For the kneeling ISO test, participants were instructed to position themselves on all four limbs, with a 90° angle of flexion at hip and knee whilst their hands and knees provide stability during the test, participants were then instructed to flex their knees as much as they could for 3–5 seconds, by pulling their heels up against the strain gauges embedded in the ankle attachments. The remaining isometric tests (ISO 30° and ISO 90°) were measured using the force plate mentioned above, placed upon a box at an appropriate height for each participant, this was determined by participants lying in a supine position with their knee at either 90° of flexion or 30° of flexion depending on the test, their heel resting on the box and their hip at an angle appropriate to allow the lower shank to be parallel to the floor (i.e. 90° and 150°, respectively) (figure 1). These two tests were applied unilaterally with the non-testing leg being placed fully extended next to the box. Three trials for each leg were executed with the participants driving their heel down into the force platform for 3–5 s following three submaximal trials, similar to the previous tests. Participants were required to repeat trials if their hips raised off the ground or if a countermovement was performed, the latter of which was detected through inspection of the force trace following each repetition.

2.3.2 Eccentric hamstring strength test

The eccentric hamstring test was assessed using the NordBord also sampling at the default 50 Hz whilst performing the NHE. Participants knelt on a padded board with individual ankle attachment points and integrated uniaxial load cells for force capture (Opar et al., 2013). Participants were asked to execute three maximal bilateral repetitions of the NHE, where they were instructed to lean forwards slowly, whilst maximally resisting this motion with both lower limbs, maintaining an extended hip position with a neutral spine and extending through the knee joint. Force-time data was exported from the NordBord, into an Excel spreadsheet, for further analysis.

2.4 Data analysis

Raw force-time data for each trial was analysed using a customized Microsoft Excel spreadsheet (version 2019, Microsoft Corp., Redmond, WA, USA). Peak force was identified from the net force values (excluding limb weight) for each trial ISO 30° and ISO 90°, and gross force was used for the kneeling ISO and NHE. The mean of the three trials was taken and used for further analysis. Inter-limb asymmetries were quantified using percentage difference between the two limbs as recommended by Bishop et al. (Bishop, Read et al., 2018), with the direction of asymmetries signified with a positive value demonstrating right limb dominance and negative value demonstrating left limb dominance (Bishop, Lake et al., 2018; Bishop, Pereira et al., 2019; Bishop et al., 2020; Bishop, Read et al., 2019). Right and left limbs were used to calculate asymmetries, as opposed to dominant vs non-dominant based on a certain task (such as kicking or jumping), due to objective assessments of limb dominance being highly task-specific with the same applying to subjective assessments of "limb preference" (Virgile & Bishop, 2021). Contextualizing the dominance as either left or right also makes the results comparable between tasks.

2.5 Statistical analyses

All statistical analyses were conducted using SPSS for Windows version 24 (IBM SPSS Inc, Chicago, IL). Data is presented as the mean ± standard deviation (SD), with normality verified using the Shapiro-Wilk's test. An *a priori* alpha level was set at <0.05. Absolute reliability was calculated using coefficient of variance (CV), with acceptable reliability <10% (Cormack et al., 2008). Relative reliability was assessed using intraclass correlation coefficients and interpreted based on the lower bound

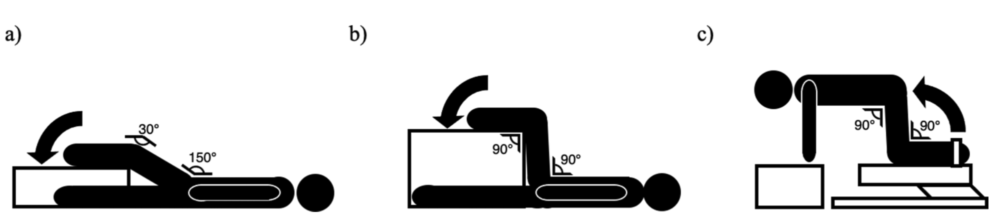

Figure 1. Illustration of the performance of a) ISO 300 (isometric knee flexion at 90) and c) kneeling ISO (isometric knee flexion at 90 prone).

confidence intervals (CI) (ICC; poor <0.39, fair 0.4–0.69, good 0.7–0.89 and excellent >0.9) (Koo & Li, 2016). Differences between testing sessions within- and between-limbs were evaluated using a series of t-tests, with Bonferroni post hoc analysis. The magnitude of differences was also be calculated using Hedges *g* effect sizes and interpreted based on the recommendations of Hopkins (Hopkins, 2010) 0.00–0.19 = trivial; 0.20–-0.59 = small; 0.60–1.19 = moderate; 1.20–1.99 = large; ≥2.00 = very large. Understanding that asymmetries can favour either the left or right limb, a Kappa coefficient was calculated to determine the levels of agreement for how consistently an asymmetry favoured the same limb between testing occasions (Cohen, 1960). Kappa coefficients were interpreted using the scale 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–0.99 = almost perfect, as suggested by Viera and Garrett.(Viera & Garrett, 2005) Additionally, data are presented in Cumming estimation plots, with individual data and paired mean difference is plotted as a bootstrap sampling distribution and 95% CI. Statistical analyses were performed using SPSS (Version 23. IBM, New York, NY), with individual plots and Cumming estimation plots generated via www.estimationstats.com.

3.0 Results

3.1 Within- and between-session reliability

Mean ± SD, reliability of peak force during all tests for both testing sessions and between-session data are presented in table 1. In all but the left leg between-sessions during the ISO 90°, acceptable variability was observed both within- and between-session (<10% CV) with fair to excellent reliability within-session (ICC ≥ 0.784, lower bound 95% CI ≥ 0.623). Between-session reliability of the NHE was good to excellent reliability (ICC ≥ 9.01, lower bound 95% CI ≥ 0.790). Between-session reliability of the isometric conditions were less reliable in some cases, with ISO 30° and ISO 90° demonstrating poor to good reliability in the left limb (ICC = ≤0.762, lower bound 95% CI ≥ 0.274), and the right limb during the kneeling ISO demonstrating poor to fair reliability (ICC = 0.679, lower bound 95% CI = 0.231). The right limb during the ISO 30°, ISO 90° and left limb during the kneeling ISO demonstrated fair to excellent reliability (ICC = 0.798–0.909, lower bound 95% CI = 0.530–0.788).

3.2 Between-session differences within- and between-limbs

The only significant difference was demonstrated by the right leg of the ISO 30° which showed a small difference between session one and two (p= 0.029; g= 0.32) (table 2 and figure 2), illustrating the individual differences of the participants, whereby the mean difference (and 95% CI) do not overlap. No significant ($p > 0.05$) differences were observed in the magnitude of asymmetries between session.

Mean ± SD for magnitude of asymmetry during both testing sessions ranges from −2.76 ± 13.94% during the kneeling ISO to 3.94 ± 7.41% observed during the NHE (table 3). The direction of asymmetry between sessions is also highlighted, for individuals, between session one and two (figure 3), with kappa coefficient values demonstrating slight to moderate (k = 0.03–-0.47) agreement within the isometric assessments and substantial agreement (k= 0.62) between the direction of the NHE asymmetries (table 2).

Table 1. Within- and between-session reliability of hamstring strength assessments.

	Session 1			Session 2			Between-Session		
ISO 30°	Mean (± SD)	% CV	ICC (95% CI)	Mean (± SD)	% CV	ICC (95% CI)	Mean (± SD)	% CV	ICC (95% CI)
Left (N)	154.03 ± 27.05	6.77	0.834 (0.658–0.925)	162.91 ± 24.44	5.20	0.855 (0.737–0.930)	158.15 ± 23.32	8.72	0.762 (0.290–0.815)
Right (N)	153.97 ± 25.42	5.66	0.865 (0.752–0.935)	162.02 ± 24.69	4.85	0.881 (0.780–0.943)	158.00 ± 23.65	6.50	0.857 (0.638–0.941)
ISO 90°									
Left (N)	188.88 ± 27.84	5.32	0.824 (0.687–0.914)	189.57 ± 34.46	7.33	0.834 (0.700–0.920)	189.22 ± 27.84	10.23	0.698 (0.274–0.873)
Right (N)	189.70 ± 31.28	5.72	0.842 (0.713–0.923)	195.31 ± 32.22	6.25	0.852 (0.732–0.929)	192.50 ± 28.97	7.52	0.798 (0.530–0.914)
Kneeling ISO									
Left (N)	274.86 ± 45.53	6.67	0.812 (0.666–0.908)	278.79 ± 52.44	6.50	0.864 (0.743–0.936)	276.83 ± 46.98	6.27	0.909 (0.788–0.962)
Right (N)	272.86 ± 44.36	7.30	0.786 (0.627–0.962)	269.52 ± 42.36	6.96	0.784 (0.623–0.893)	270.82 ± 37.62	9.10	0.679 (0.231–0.865)
NHE									
Left (N)	319.10 ± 46.92	4.72	0.871 (0.742–0.937)	322.28 ± 50.19	4.88	0.819 (0.696–0.903)	320.60 ± 46.83	2.89	0.963 (0.790–0.983)
Right (N)	332.07 ± 43.51	4.24	0.869 (0.759–0.934)	326.65 ± 45.64	4.86	0.823 (0.702–0.906)	329.36 ± 42.54	4.01	0.901 (0.790–0.953)

ISO = Isometric; SD = Standard deviation; CV = coefficient of variation; ICC = Intraclass correlation coefficient; CI = Confidence interval; N = Newtons; NHE = Nordic hamstring exercise

Table 2. Differences between-session comparisons within- and between-limb.

	Session 1 vs Session 2										
	Left			Right			Left – Right Asymmetry				
	p	g	% diff	p	g	% diff	p	g	% diff	Kappa Coefficient	Agreement Descriptor
ISO 30°	0.086	0.31	5.08	0.029a	0.32	4.97	0.386	0.29	21.05	0.03	Slight
ISO 90°	0.915	0.02	0.36	0.312	0.17	2.87	0.064	0.49	30.77	0.31	Fair
Kneeling ISO	0.261	0.08	1.41	0.656	−0.06	−0.96	0.484	0.24	49.36	0.47	Moderate
NHE	0.079	0.06	0.93	0.237	−0.12	−1.66	0.150	−0.21	16.51	0.62	Substantial

% diff = Percentage difference; ISO = Isometric; NHE = Nordic hamstring exercise
a= significant $p < 0.05$

Table 3. The magnitude and direction of asymmetries within-session.

	Left − Right Asymmetry (Mean ± SD)	
	Session 1	Session 2
ISO 30° (%)	0.09 ± 9.43	−0.24 ± 11.36
ISO 90° (%)	0.11 ± 12.84	2.90 ± 16.07
Kneeling ISO (%)	−0.89 ± 10.62	−2.76 ± 13.94
NHE (%)	3.94 ± 7.41	1.49 ± 7.80

SD = Standard deviation; ISO = Isometric; NHE = Nordic hamstring exercise
Note: Positive values demonstrate right limb dominance, negative values demonstrate left limb dominance

4.0 Discussion

This investigation aimed to assess the reliability of two unilateral and bilateral field-based hamstring strength assessment methods within a female population, whilst also comparing the magnitude and direction of asymmetries observed during each method. Absolute reliability of all testing methods within- and between-session were acceptable (<10%) apart from between-session for the left leg during the ISO 90°. Within-session relative reliability was more varied with all tests demonstrating fair to excellent reliability. Between-session relative reliability highlighted greater variability with the unilateral tests, demonstrating poor to good reliability, while the bilateral tests showed greater reliability in comparison. In contrast, the right limb during the kneeling ISO demonstrated a similar range of poor to excellent. Agreement between-session for inter-limb asymmetry identification was slight and fair in the unilateral tests, with moderate to substantial agreement demonstrated in the bilateral tests.

The bilateral tests demonstrated fair to good (ICC = 0.623–0.743) and good (ICC = 0.696–0.759) relative reliability within-session for the kneeling ISO and NHE, respectively, with only the right leg (ICC = 0.311) not demonstrating good to excellent between-session. There is no direct comparative reliability data for the kneeling ISO, however based upon the hip and knee positions (90° and 90°), similar to that of the ISO 90° results from previous studies (Hickey et al., 2018; Van der Made et al., 2019) using load cells and hand-held dynamometers can be used to compare. Hickey et al. (Hickey et al., 2018) used a single leg protocol demonstrating ICC's for both dominant and non-dominant limbs of 0.91 and 0.90, respectively. In comparison the load cells utilized by Hickey et al. (Hickey et al., 2018) demonstrated much greater reliability compared to both the ISO 90° on a force plate and the left limb of the

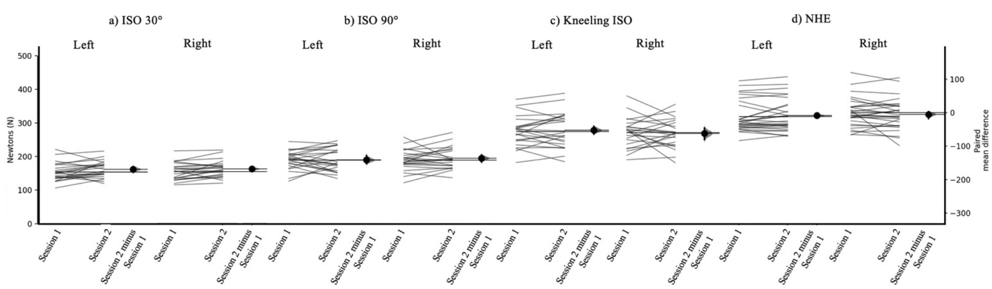

Figure 2. Comparison of peak force of the left and right limb during a) ISO (isometric knee flexion at 30), b) IS) 90 (isometric knee flexion at 90) and c) Kneeling ISO (isometric knee flexion at 90 prone and d) NHE (Nordic hamstring excercise) between testing sessions. Individual data is plotted opn the upper axes. Paired mean difference are plotted as a boopstrap sampling distribution. mean dissference arc depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars.

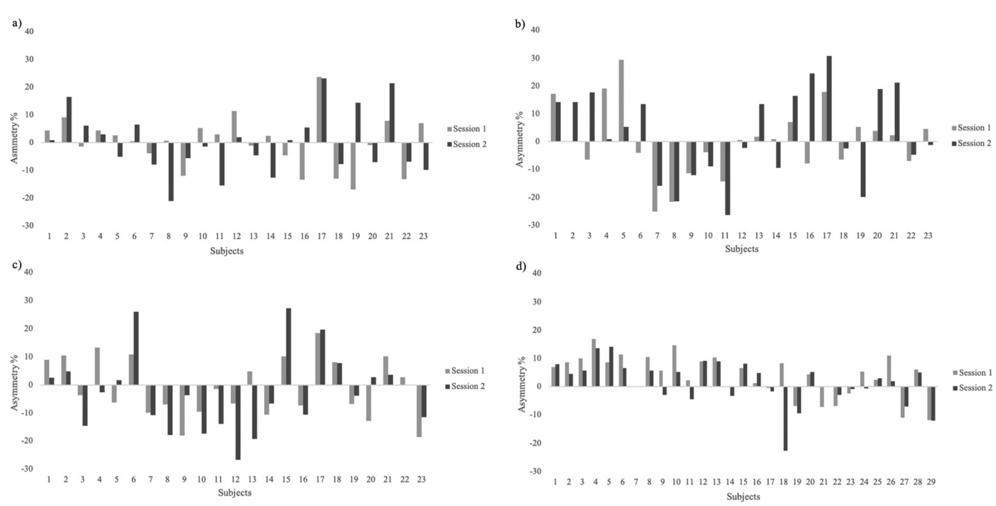

Figure 3. Individual asymmetry data for peak force during a0 ISO 30 (isometric knee flexion at 30), b) ISO 90 (isometric knee flexion at 90) and c) Kneeling ISO (isometric knee flexion at 90 prone) and d) NHE (Nordic hamstring excercise). Above the x axis signifies right limb dominance, below signifies left limb dominance.

kneeling ISO on the NordBord in the present study, whereas the right limb during the kneeling ISO was comparable. Van de Made et al. (Van der Made et al., 2019) only appeared to test a single limb when assessing between-tester reliability of the hand-held dynamometer however they have reported ICC's with slightly greater variation (ICC 95% CI = 0.31–0.95) then observed with the load cells, which is more representative of what has been reported within the current study. When comparing the NHE reliability against that of the original conceptual investigation (ICC = 0.83 and 0.90 for left and right leg, respectively) (Opar et al., 2013), the relative reliability of this group was higher between session in the current study. The comparative reliability demonstrates that for slow eccentric exercises, the reliability of peak force within- and between-session is enough to be confident in the continued monitoring of hamstring strength. The unilateral tests also demonstrated fair to good (ICC = 0.658–0.780) relative reliability for the ISO 30° and the ISO 90° (ICC = 0.647–0.733), within-session based upon the lower bound CI. There was however, a small and significant difference (g= 0.32; p= 0.029) in the right leg for the ISO 30° between session 1 and session 2 (table 2), which almost certainly had an effect on the relative reliability between-session. A statistical difference between-sessions could be one of the reasons why the ICC values in this study are lower than that reported by McCall et al. (McCall et al., 2015) who observed good to excellent reliability between-session (ICC ≥ 0.86). It is clear when inspecting figure 2 that the bilateral tests (kneeling ISO and NHE) had a much greater range of results within the testing group than the unilateral tests on both testing occasions. The reduced range in test scores between participants could be one possible reason for the lower relative reliability. Due to the homogenous sample (and excluding the significant differences between the right ISO 90°), it is likely that there would be changes in the rank order of samples between-session, reducing the ICC which is a measure of rank order consistency. Despite the variation described in relative reliability of the tests, the absolute reliability (CV) was acceptable (<10%) in all but one of the tests (Left ISO 90° = 10.23%) which may be more appropriate for the homogenous sample seen in this study.

The magnitude of asymmetry was calculated to quantify the inter-limb differences to compare between the tests and testing sessions, with mean asymmetry values all relatively low ≤ 3.94% in either direction (table 3). There was large individual variability of magnitude within the groups as seen in the SD (also evident in table 3 and the individual plots in figure 3). The largest asymmetry values during the isometric tasks was observed during the ISO 90°, however this also showed the greatest range in reliability overall considering the lower bound CI for both limbs. The kneeling ISO showed a similar mean ± SD of asymmetry as the ISO 90° but in the opposite direction, so although the kneeling ISO is coupled with the slightly greater relative reliability particularly in the left limb and similar absolute reliability between-session, there is no definitive answer as to which test could show a slightly superior level of detecting asymmetries.

The reliability of inter-limb asymmetry is not only the ability to get similar magnitudes of asymmetry with each test but there also needs to be a strong level of agreement in the direction of asymmetry, whereby the test can repeatedly identify the same limb as being dominant and non-dominant between testing sessions. The level of agreement in the direction of asymmetry between-session was calculated using a kappa coefficient and descriptors were used to show that there was a range across the different tests (see table 3). The lowest level of agreement was demonstrated by the ISO 30° whereby only slight agreement was present (Kappa = 0.03), which then increased to fair during the ISO 90° (Kappa = 0.31), moderate for the kneeling ISO (Kappa = 0.47). In contrast, the greatest level of agreement was the NHE that presented substantial levels of agreement (Kappa = 0.62). Of note, levels of agreement were greatest during the bilateral tests, with the isometric (kneeling ISO) test being slightly more variable than the eccentric. One possible reason for the bilateral tests showing a greater level of agreement could potentially be due to a common neural drive whereby the dominant limb receives focused attention from the movement-related cortical potentials and the non-dominant limb receives subsidiary attention (Oda & Moritani, 1996). However, during unilateral tasks, where it is understood that one side of the body is controlled by the contralateral cerebral hemisphere (Ohtsuki, 1983), there is clearly no need for interhemispheric interaction as seen during bilateral tasks, which may serve as a potential reason why the between-limb difference is more likely to change between testing sessions. Another potential explanation for the differences between unilateral and bilateral assessments could be due to sampling frequency, with the NordBord sampling at the default 50 Hz potentially reducing the sensitivity of the assessment when compared to the force plate assessments which sampled at 1000 Hz.

The data from this study gives a representation of reliability of both unilateral and bilateral hamstring tests and the ability to detect interlimb hamstring strength asymmetry during those tests within a female soccer population. One limitation, however, is that this may not apply to other groups without further investigation as the present sample is too homogenous to be able to generalize the results across sports and sexes. An area for future research would be to understand if any of these tests were to be completed much more frequently throughout a season, whether the reliability would increase and subsequently would any of the tests be appropriate to assess hamstring fatigue, or at least be appropriate for continued monitoring of hamstring strength, as this is thought to be a possible risk factor for HSI (Green et al., 2020; Opar et al., 2012). Another area for future research would be to investigate the effect sampling frequency has on these assessments, due to the NordBord now having the capacity to sample at 400 Hz and the force plate potentially sampling at too high or low a rate.

5.0 Conclusion

The NHE was the most reliable test within- and between-session whilst also demonstrating substantial agreement in identifying inter-limb asymmetry between-session, suggesting that the NHE is the most appropriate method for assessing of hamstring strength and inter-limb asymmetry over time. There are reservations with some practitioners around this exercise due to its supramaximal nature and the fatigue it may cause, however, this study does demonstrate that only 3 repetitions are required which should not be fatiguing for athletes who are familiar with the tasks during their normal training and monitoring procedures. If the NHE is still a concern the kneeling ISO would be the best isometric alternative when wanting to identify both strength and inter-limb asymmetry.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the corresponding author.

Disclosure statement

No potential conflict of interest was reported by the authors.

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