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Research article

Establishing the Reliability and Limits of Meaningful Change of Lower Limb Strength and Power Measures during Seated Leg Press in Elite Soccer Players

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Abstract

Measurement of lower limb strength, power and asymmetries of soccer players is important for monitoring physical development and injury risk. The aim of the present study was to establish the reliability and limits of meaningful change of single and double leg maximal strength, power and bilateral imbalance measures in elite soccer players using a pneumatic resistance based seated leg press. Thirteen participants undertook an incremental resistance leg press test on three separate testing days within a seven day period. Paired t-tests established no significant differences (p > 0.156) between consecutive tests, whilst 'good' reliability (intraclass correlation coefficient-ICC >0.762) and acceptable typical percentage errors (< 6.9%) were observed for maximal resistance, velocity and force pushed as well as average and peak power outputs. Imbalance variables accounting for left and right leg average power output across all repetitions were established as the most reliable imbalance variables, with 'good' reliability (ICC > 0.874) and absolute typical error values of 2.1%. Imbalance variables calculated using peak power output or average power output from the last 4 repetitions resulted in weaker reliability (ICC < 0.657) and significant differences between tests, and therefore were considered less suitable for applied use. Subsequently, to better inform the practitioner, limits of meaningful change were calculated for all strength, power and imbalance variables. The current study shows that lower limb strength, and power output variables and average imbalance measures of soccer players assessed through a seated leg press protocol show acceptable levels of reliability, and provides practitioners with limits of meaningful change around parameters to better evaluate test results.

Key words: Football, imbalance, performance, testing.

Introduction

Leg strength and power are important physical attributes for soccer, for competent skill execution (Cabri et al., 1988; Cometti et al., 2001) and injury prevention (Henderson et al., 2010, van Beijsterveldt et al., 2013). In particular, left-right leg strength/power asymmetries are commonly associated with increased injury risk in soccer (Croisier et al., 2002; Knapik et al., 1991). Measurements of leg strength, power and asymmetry can be an important tool to assess an athlete's physical ability, and to monitor changes that occur with training or detraining.

For practitioners to have confidence in any test, results attained from it must be considered reliable and have established ranges of meaningful change (expected natural variation around a test, needed to establish if longitudinal change can be considered 'real').

The reliability of leg strength and power assessment protocols has been reported extensively. Various studies investigating reliability of double leg jumps including unresisted and resisted countermovement jumps (Nuzzo et al., 2011,Young et al., 1997), squat jumps (Ortega et al., 2008) and broad jumps (Ortega et al., 2008, Wiklander and Lysholm, 1987) have reported test-retest coefficients of variations (CV) between 1.8%-6.0% and intraclass correlation coefficient (ICC) values between 0.88-0.93, with all studies suggesting that double leg jump tests show 'good' or 'excellent' test-retest reliability.

As the majority of movements in sport (e.g. running, cutting and kicking) involve single leg loading (Fousekis et al., 2010, Reilly 1996), to improve specificity of testing, single leg jump testing has also been utilised across the literature as a lower limb strength and power assessment protocol. As such, various single leg hop tests such as horizontal distance (Bandy et al., 1994; Paterno and Greenberger, 1996), vertical hop and triple hop for distance (Munro and Herrington, 2011) have also been assessed for reliability. These studies consistently show 'good' reliability, with ICC values between 0.76-0.96 and no significant differences between any repeated tests. Test-retest reliability of left-right leg asymmetries obtained through single leg hops has been reported to be 'good' (ICC > 0.81) in some studies (Hopper et al., 2002; Reid et al., 2007), although Risberg et al (1995) found that a 21% change in performance was needed to establish significance due the variation they found between repeated tests (7.7% coefficient of variation-CV). Differences in findings may be due to large learning effects associated with single leg jumps (Bogla and Keskula, 1997; Booher et al., 1993) suggesting that extensive familiarisation to the movement technique may be required particularly for adolescent athletes. Additionally, due to the necessity to bear load through hip, knee and ankle joints, the use of double and single leg jumps as a measure of lower limb power can be limited with load compromised individuals and alternative offloaded protocols with greater control of movement are useful for testing in the elite environment.

Isokinetic dynamometry is also commonly used to assess lower limb strength and power and has consistently been found to elicit 'moderate' to 'excellent' test-retest reliability with ICC values between 0.71-0.99 tested over a range of velocities and muscle actions (Abernethy et al., 1995; Gleeson and Mercer, 1992; Li et al., 1996; Pincivero et al., 1997). However, studies assessing the reliability of left-right leg strength/power asymmetries obtained through isokinetic dynamometry have found weaker reliability with ICC values ranging between 0.29-0.78 and standard error of mean (SEM) between 3.2% to 8.7% (Impellizzeri et al., 2007, Impellizzeri et al., 2008). Isokinetic dynamometry

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also lacks applicability to sporting movement (Cometti et al., 2001) and has low correlation with other sports performance measures (Mognoni et al., 1994). Therefore, isokinetic dynamometry may not be an applicable lower limb assessment tool for soccer players.

The Keiser Air 420 seated leg press (Keiser Corporation, Fresno, CA) is a pneumatic resistance-based seated leg press machine with the left and right footplates that move independently of each other. Movement from a seated position with feet elevated enables offloaded maximal strength and power testing utilising movements that may be considered more applicable to the sporting environment than isokinetic dynamometry, overcoming many of the aforementioned issues. However, to date, there has only been one study investigating the reliability of the Keiser Air 420 (LeBrasseur et al., 2008) which found a non-statistically significant increase in maximum resistance of 1.1% and 'excellent' test-rest reliability (ICC:0.990) between 2 trials. However, reliability was not established for single or double leg power values or for left-right leg asymmetries, and as participants were classified as healthy males (age range: 37-70 y), the findings cannot be generalizable to an elite soccer population.

Therefore, the current study aimed to establish the reliability of double leg maximal strength, single leg and double leg power and left-right power asymmetries in elite soccer players using a seated leg press. Additionally, the study aimed to quantify the magnitude of change between tests that can be confidently established as outside of the range of natural variability of the test.

Methods

Experimental approach to the problem

The current study used a repeated test-retest protocol in which participants undertook an incremental resistance leg press test on three separate occasions to assess for variation between tests. Each test was completed at least 72 hours following and within 192 hours of the individuals' previous test (mean interval of 132±43 hours). Tests took place prior to a training session, occurred at the same time of day, following a day consisting of minimal or no physical stimulus (<4000 m total distance, <50 m high intensity distance and <5 minutes above 85% max heart rate) established through GPS monitoring (Statsports Viper, Statsports Technologies Ltd, N.Ireland) and greater than 60 hours following a competitive match or lower limb strengthening session. The testing period was specifically selected as a period in the season when on-field conditioning was at its most consistent day-to-day and week-to-week.

Subjects

Thirteen elite male professional soccer players (Age: 18.4 ± 0.8 y, height: 1.79 ± 0.09 m, weight: 72.1 ± 6.7 kg, body fat: 9.6 ± 1.4%, VO2 max: 58.1 ± 1.3 ml·kg^{-1}·min^{-1}) volunteered for this study. A small sample size was considered acceptable due to the elite level of participants and is in line with previous research conducted within the research field (Bandy et al., 1994; Li et al., 1996). All participants were playing full time academy soccer for the same premier league football club for a minimum of 9 months prior to testing. Inclusion criteria were that they were injury free (defined as a 'time loss injury' as classified in a consensus statement on injuries within soccer (Fuller et al., 2006)) for the duration of the testing period and that they had previously completed a minimum of three exposures to the testing protocol. All participants were regularly participating in soccer training sessions and lower limb gym strengthening sessions between tests and all were exposed to similar physical stimulus over this period. The study obtained ethical approval from the School of Health Research Ethics Approval Panel at University of Bath and all participants were informed of the potential benefits and risks of the research prior to providing informed consent. For participants under the age of 18 (age range: 16.8-19.5 y), parental informed consent was obtained also.

Procedures

Prior to testing, participants completed a 5-minute standardised warm up at approximately 60-75 Watts on a cycle ergometer (Keiser M3+, Keiser Corporation, California) followed by ten controlled bodyweight squats and three countermovement jumps. The testing procedure, outlined in Table 1 using example resistances, involved completing an incremental leg press test from a seated position (approximately 90º knee flexion) with feet flat on each footplate beginning at low resistance and continuing until failure, with 'max resistance' pushed defined as the final load that could be moved to full knee extension with both legs whilst maintaining proper seating position (McDonagh and Davies, 1984). Resistance reached on the 10th repetition and resistance increments in-between each repetition were set dependent on participant's results from previous exposure tests and remained the same for all three trials. However, as participants were encouraged to work until max resistance was reached, total number of repetitions completed differed between participants. Participants were asked to complete each repetition through extending both legs together with maximum velocity and instruction to 'push as fast and as evenly as possible'. For each effort, peak force, velocity and power were recorded for each leg.

Table 1. Keiser Air 420 example 10 repetition maximal power test protocol.

Repetition Number	1st Warm Up	2nd Warm Up	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	All Subsequent Reps
Resistance (kg) based on 250kg 1RM	41**	41	41	64	87	110	133	157	180	203	226	250	Previous rep+23.2*
Subsequent Rest Period (s)	3.0	3.0	3.0	4.2	5.8	8.1	11.4	15.8	22.1	30.8	43.0	60.0	60.0

*Rep to rep Resistance Increase = (Maximal Resistance[1] selected-18.14)/10. ** Starting Resistance = Resistance Increase + 18.14

[1] Maximal Resistance selected based on max strength attained in familiarisation trails

Power output calculated for each repetition is a product of force and velocity registered in the air cylinders of the device as footplates are moved. As the footplates of the device move, air pressure increases within the air cylinders with force measured as the highest air pressure value detected for each repetition. Velocity is measured as the highest rate of displacement of the piston within the cylinder for each repetition. During rest periods between reps, participants were allowed, but not instructed, to remove their feet from the foot plates, but remained seated at all times. Participants knew the resistance that they were attempting next and received an instantaneous average power feedback following each repetition but at no point were encouraged to use this feedback to affect their results. All trials completed in the study were conducted by the same investigator.

Regardless of the number of repetitions in each test (Mean±SD: 11.2 ± 0.9), peak power (the highest power output from each test for each leg), average power (the average of all power outputs for each leg) and last 4 repetition average power (the average of the power output from the last 4 repetitions of each test for each leg) variables were recorded for each test. A linear trend line plotted through all force-velocity data points extrapolated to 0N force and to 0m/s calculated velocity max variable and force max variable respectively (Figure 1).

Peak power combined, average power combined, last 4 repetition average power combined, force max combined and velocity max combined variables were then calculated by taking the sum of the left and right leg values for each respective variable.

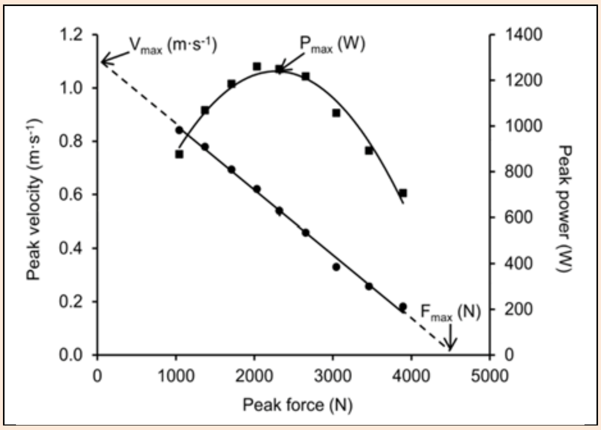

Figure 1. An example single leg force-velocity and power output relationship. Square markers: Power output data points, circle markers: force-velocity data points. Solid lines: line of best fit through each respective data point, dashed line: extrapolation to calculate velocity max and force max.

Imbalance calculations

Left-right power imbalance scores were also calculated for peak, average and last 4 repetition average power in three different ways- absolute differences, percentage differences and symmetry angle. Absolute differences were calculated using the following equation:

Right Leg-Left Leg

Percentage differences were calculated similar to previous research (Impellizzeri et al., 2007) but with adjustment of numerator to account for critique by Bishop et al (2016). Percentage difference was calculated using the following equation:

$$\left(\frac{RIGHT\ LEG - LEFT\ LEG}{MAXIMUM\ VALUES\ PRODUCED\ BY\ RIGHT\ OR\ LEFT\ LEG}\right) \times 100$$

Symmetry angles were calculated similar to previous research (Zifchock et al., 2008) using the following equation:

$$\left\{\frac{\left(45-\arctan\left[\frac{left}{right}\right]\right)}{90}\right\} \times 100$$

For all calculations, any positive results denoted right dominance and negative results denote left dominance.

Statistical analyses

Data were analysed using Microsoft Excel (Microsoft, Redmond, WA) and statistical package SPSS (Version 17.0; Chicago, IL) and all data are presented as mean ± standard deviation. Paired samples t-tests were used to determine if significant differences existed between consecutive tests (Test 1-Test 2 and Test 2-Test 3). Within subject reliability was assessed with the use of a two way mixed model ICC (3,1) and typical error, which was expressed as both a percentage (TPE) and as an absolute value (TE) for raw data values. Only TE was used for imbalance values as taking a percentage error value of a small percentage value produces values that may mislead and therefore were considered inappropriate. The strength of relationships for ICC coefficients was classified as: $0.3 \leq r < 0.5$ was 'poor', $0.5 \leq r < 0.75$ was 'moderate', $0.75 \leq r < 0.9$ was 'good' and $0.9 \leq r < 1.0$ was 'excellent' (Koo and Li, 2016).

To establish the limits for meaningful change around data, the mean of the outcome variable across all three tests ±1.75 x TE for the outcome variable was used (Hopkins, 2000).

The data were considered for heteroscedasticity by plotting difference between consecutive tests results (Test 1-Test 2 and Test 2-Test 3) against averaged results from the respective tests. A moderate trend towards heteroscedasticity was found for last 4 repetition power variables (r^2 = 0.002-0.479) and therefore, for TPE calculations for these variables, data was log transformed.

Results

Lower limb strength and power

To establish reliability, change in strength and power variables (Mean ± SD) across all three tests was calculated. No significant differences were found between Test 1-Test 2 or between Test 2-Test 3 for any variables ($p > 0.156$) (Table 2).

Between Test 1-Test 2, all variables showed TPE values < 7.1% and ICC > 0.806, and between Test 2-Test 3, all variables showed TPE <7.0% and ICC > 0.849. When establishing reliability across all three tests, all variables showed TPE values <6.9% with ICC values > 0.762 (Table 3).

Table 2. Mean (±SD) for various strength and power variables for Test 1, Test 2 and Test 3 and the change between pairs of trials.

	Test 1	Test 2	Test 3	Change Test 1-Test 2	Change Test 2-Test 3
Max Resistance (kg)	315 ± 41	328 ± 55	329 ± 53	-11.8 ± 28.1	-1.9 ± 22.0
Velocity Max Combined (m/s)	3.66 ± .51	3.57 ± .47	3.55 ± .48	.09 ± .30	.02 ± .24
Velocity Max Left (m/s)	1.82 ± .26	1.76 ± .23	1.77 ± .24	.58 ± .17	-.09 ± .13
Velocity Max Right (m/s)	1.84 ± .25	1.81 ± .25	1.79 ± .25	.03 ± .14	.02 ± .12
Force Max Combined (N)	3211 ± 438	3308 ± 460	3256 ± 546	-97 ± 163	52 ± 195
Force Max Left (N)	1614 ± 207	1665 ± 215	1636 ± 260	-51 ± 104	29 ± 105
Force Max Right (N)	1597 ± 242	1643 ± 254	1620 ± 291	-46 ± 77	23 ± 98
Peak Power Combined (W)	2276 ± 315	2321 ± 307	2287 ± 407	-45.6 ± 142.6	34.8 ± 179.9
Peak Power Left (W)	1123 ± 154	1149 ± 163	1138 ± 196	-25.2 ± 88.5	10.8 ± 92.9
Peak Power Right (W)	1152 ± 171	1173 ± 151	1149 ± 217	-20.4 ± 68.0	24.0 ± 96.7
Average Power Combined (W)	1879 ± 270	1884 ± 260	1847 ± 281	-5.1 ± 157.5	37.1 ± 112.4
Average Power Left (W)	925 ± 136	931 ± 128	913 ± 134	-5.8 ± 80.5	17.5 ± 63.9
Average Power Right (W)	954 ± 139	953 ± 138	933 ± 152	.7 ± 78.7	19.6 ± 52.7
Last 4 Rep Ave Power Comb (W)	2015 ± 341	2010 ± 306	1944 ± 354	5.1 ± 196.3	65.9 ± 164.7
Last 4 Rep Ave Power Left (W)	984 ± 170	991 ± 158	957 ± 171	-6.9 ± 91.0	34.4 ± 90.7
Last 4 Rep Ave Power Right (W)	1031± 183	1019 ± 161	987 ± 196	12.0 ± 107.2	31.5 ± 85.1

Table 3. Test 1-Test 2- Test 3 average typical error values and combined ICC values.

	Average Typical Error		
	Absolute	Relative	ICC (95% CI)
Max Resistance (kg)	17.7	5.9%	0.893 (0.755-0.963)
Velocity Max Combined (m/s)	0.19	5.4%	0.792 (0.564-0.924)
Velocity Max Left (m/s)	0.1	5.8%	0.762 (0.513-0.912)
Velocity Max Right (m/s)	0.09	5.2%	0.815 (0.605-0.933)
Force Max Combined (N)	127	4.2%	0.914 (0.799-0.970)
Force Max Left (N)	74	5.1%	0.881 (0.731-0.959)
Force Max Right (N)	62	3.9%	0.928 (0.830-0.975)
Peak Power Combined (W)	114.1	5.2%	0.886 (0.740-0.960)
Peak Power Left (W)	64.1	5.8%	0.851 (0.671-0.947)
Peak Power Right (W)	58.2	5.3%	0.898 (0.765-0.965)
Average Power Combined (W)	95.4	5.4%	0.866 (0.701-0.953)
Average Power Left (W)	51.1	6.0%	0.846 (0.663-0.945)
Average Power Right (W)	46.5	5.0%	0.884 (0.737-0.960)
Last 4 Rep Ave Power Combined (W)	127.1	6.4%	0.867 (0.702-0.953)
Last 4 Rep Ave Power Left (W)	64.3	6.9%	0.867 (0.703-0.953)
Last 4 Rep Ave Power Right (W)	68.0	6.5%	0.864 (0.696-0.952)

Table 4. Mean (±SD) for left-right leg power imbalance variables for Test 1, Test 2 and Test 3 and the change between pairs of trials.

	Test 1	Test 2	Test 3	Change Test 1-Test 2	Change Test 2-Test 3
% Difference Peak	2.3 ± 6.5	2.1 ± 5.4	.6 ± 6.0	.1 ± 5.2	1.5 ± 4.9
% Difference Average	2.9 ± 5.7	2.1 ± 5.7	1.8 ± 6.0	.7 ± 2.3	.4 ± 3.6
% Difference Last 4 Repetitions	4.3 ± 8.2	2.6 ± 8.3	2.5 ± 9.9	1.64 ± 2.46 *	.1 ± 6.1
Difference Peak (W)	29.0 ± 79.8	24.3 ± 68.0	11.1 ± 72.1	4.73 ± 67.58	13.19 ± 59.80
Difference Average (W)	28.6 ± 55.4	22.1 ± 57.4	19.9 ± 57.68	6.49 ± 23.21	2.19 ± 33.30
Difference Last 4 Repetitions (W)	46.3 ± 90.2	27.4 ± 89.6	30.3 ± 100.8	18.92 ± 32.08	-2.91 ± 61.81
Symmetry Angle Peak (%)	.766 ± 2.17	.707 ± 1.78	.215 ± 1.99	.06 ± 1.73	.49 ± 1.63
Symmetry Angle Ave (%)	.970 ± 1.93	.706 ± 1.91	.608 ± 2.03	.26 ± .78	.01 ± 1.17
Symmetry Angle Last 4 Repetitions (%)	1.44 ± 2.85	.85 ± 2.85	.88 ± 3.42	.58 ± .86 *	-.21 ± 2.05

*Statistical difference (p < 0.05) between test 1 and test 2

Left-right limb power imbalance

To establish reliability of lower limb imbalance variables, mean change across all 3 tests was calculated (Table 4). Between Test 1 and Test 2, significant differences were found for % difference last 4 repetitions and symmetry angle last 4 repetitions ($p < 0.033$) whilst all other imbalance variables were not significantly different ($p > 0.055$). No significant differences were found for any imbalance variables between Test 2 and Test 3 ($p > 0.288$).

Comparing Test 1-Test 2 and Test 2-Test 3, average power and last 4 repetition power imbalance values established ICC values >0.780 and peak power imbalance variables established ICC values <0.768. Combining all three tests (Table 5) average power and last 4 repetition power imbalance values established ICC values >0.843 with peak power imbalance variables established ICC values <0.647.

TE values show % difference variations between 2.07-3.56, symmetry angle variations between 0.69-1.19

and absolute difference variations between 20.0-45.04 (Table 5). Across all calculations, average power imbalance values (% difference average, difference average and symmetry angle average) establishing the narrowest TE values.

Limits of meaningful change

To establish the smallest significant change between tests, ranges of meaningful change for each variable were calculated from their respective TE values (Table 6). Alongside this, lower and upper limits of non-meaningful change placed around mean values have been calculated as an example. For imbalance calculations, due to large TE values, peak imbalance variables (% difference Peak, difference peak and symmetry angle peak) established the largest range of non-meaningful change whilst average imbalance variables established the narrowest range.

Table 5. Test 1-Test 2- Test 3 average absolute typical error values and combined ICC values.

	Average Absolute Typical Error	ICC (95% CI)
% Difference Peak	3.56	0.653 (0.350-0.864)
% Difference Average	2.07	0.874 (0.717-0.956)
% Difference Last 4 Repetitions	3.01	0.843 (0.656-0.944)
Difference Peak (W)	45.04	0.647 (0.342-0.861)
Difference Average (W)	20.0	0.881 (0.731-0.958)
Difference Last 4 Repetitions (W)	33.19	0.848 (0.666-0.946)
Symmetry Angle Peak (%)	1.19	0.657 (0.355-0.866)
Symmetry Angle Ave (%)	0.69	0.878 (0.725-0.957)
Symmetry Angle Last 4 Repetitions (%)	1.03	0.851 (0.671-0.947)

Table 6. Range of meaningful change for all variables and example lower and upper limits based on mean values.

	Range for meaningful change	Mean of all tests	Lower Limit of mean	Upper Limit of mean
Max Resistance (kg)	±31	324	293	355
Velocity Max Combined (m/s)	±0.33	3.59	3.26	3.92
Velocity Max Left (m/s)	±0.18	1.78	1.60	1.96
Velocity Max Right (m/s)	±0.16	1.81	1.65	1.97
Force Max Combined (N)	±222	3258	3036	3480
Force Max Left (N)	±130	1638	1508	1768
Force Max Right (N)	±109	1620	1511	1729
Peak Power Combined (W)	±200	2295	2095	2495
Peak Power Left (W)	±112	1137	1025	1249
Peak Power Right (W)	±102	1158	1056	1260
Average Power Combined (W)	+167	1870	1703	2037
Average Power Left (W)	±89	923	834	1012
Average Power Right (W)	±81	947	866	1028
Last 4 Rep Ave Power Combined (W)	±222	1990	1768	2212
Last 4 Rep Ave Power Left (W)	±113	977	864	1090
Last 4 Rep Ave Power Right (W)	±119	1012	893	1131
% Difference Peak	±6.2	1.7%	-4.5	7.9
% Difference Average	±3.6	2.3%	-1.3	5.9
% Difference Last 4 Repetitions	±5.3	3.0%	-2.3	8.3
Difference Peak (W)	±78.8	21.5	-57.3	100.3
Difference Average (W)	±35	23.5	-11.5	58.5
Difference Last 4 Repetitions (W)	±58.1	34.7	-23.4	92.8
Symmetry Angle Peak (%)	±2.1	0.6%	-1.5	2.7
Symmetry Angle Ave (%)	±1.2	0.8%	-0.4	2.0
Symmetry Angle Last 4 Reps (%)	±1.8	1.1%	-0.7	2.9

Discussion

The primary aim of the current study was to determine the reliability of lower limb strength, power and asymmetry obtained through seated leg press in elite soccer players. No significant differences were observed between consecutive tests for all lower limb strength and power variables, with the ICC values >0.866 suggesting 'good' reliability. Average imbalance variables (% difference average, difference average and symmetry angle average) also showed no significant differences between tests, moderate TE values and high ICC values > 0.874 suggesting 'good' test-retest reliability. Peak imbalance variables were found to have the lowest ICC values (<0.657) and the highest TE values whilst last 4 repetition imbalance variables showed significant differences between Tests 1 and 2, limiting their reliability as applicable imbalance measures. The current study also established ranges of non-meaningful change for all variables, to more accurately evaluate magnitude of change between tests. Peak imbalance variables established the largest range (±6.2%) whilst average imbalance variables established the narrowest range (±3.6%) of non-meaningful change.

In the current study, all lower limb strength and power variables showed 'good' reliability with no significant differences across any tests and therefore can be used with confidence in future research. In particular, maximum resistance showed 'good' reliability with an ICC value of

0.893 and TPE of 5.9%. This corresponds well with the only other published research on the reliability of the Keiser seated leg press, which found ‘excellent’ reliability (ICC: 0.990) of maximum resistance values and non-significant increases of 1.1% between test 1 and test 2 (LeBrasseur et al., 2008). In the current study, all between-tests error values for single leg measurements ranged between 5.3-6.9%, similar to values seen in single leg hop (Risberg et al., 1995) and isokinetic dynamometry (Pincivero et al., 1997) reliability studies. Similarly, ICC results found in the current study for all strength and power variables (ICC: 0.846-0.898) correlate well with single leg hop (Bandy et al. 1994; Paterno and Greenberger, 1996) and isokinetic dynamometry (Gleeson and Mercer, 1992) reliability studies, showing ‘good’ reliability.

Average power imbalance variables (% difference average, difference average and symmetry angle average) were not significantly different between any tests, with ICC values >0.874, and the lowest TE values in comparison to all other imbalance variables. Therefore, all average difference variables can be considered the most reliable imbalance measures and most applicable to be used in future research. Results found with average difference variables in the current study are similar to that found in other studies assessing left-right leg imbalance reliability through single leg hops (Hopper et al., 2002, Reid et al., 2007) and isokinetic dynamometry (Impellizzeri et al., 2008). Although different error calculations were used between studies, 2.1% TE seen in the current study is similar to SEM values seen for single leg hop tests of 3.0-5.6% (Reid et al., 2007) and for single leg isokinetic dynamometry of 3.2-8.7% (Impellizzeri et al., 2008).

In contrast, peak imbalance variables (difference peak, % difference peak and symmetry angle peak) resulted the lowest ICC values across all tests (ICC < 0.657) and the largest TE across all imbalance variables, showing that peak imbalance variables have the weakest reliability of all imbalance variables. Similarly, % difference last 4 repetitions and symmetry angle last 4 repetitions were shown to have significant differences between 1st and 2nd tests, suggesting low reliability of these imbalance variables also. However, as no significant differences were found between 2nd and 3rd tests for either variables, it may be the case that greater familiarisation to heavier loads is needed to improve the reliability of last 4 repetition imbalance values. Indeed, whilst reliability is yet to be confidently established, the current study shows that larger differences between left and right leg power are seen over the last 4 repetitions in comparison to all other imbalance variables (Table 4), and it may be the case that power near maximal loads highlights a dominance that power at lighter loads does not. Despite differences in calculations between absolute difference, percentage difference and symmetry angle imbalance values, no differences were seen between test-retest results in the current study for any of the imbalance calculations. Therefore, for clarity, any one of the calculation methods in the current study can be used to represent left-right leg power imbalance with selection of the most appropriate calculation based on what is considered most appropriate to the individual practitioner in the applied environment.

To accurately evaluate the magnitude of change between tests for future research, the current study also aimed to establish the range of non-meaningful change around each variable to quantify the natural variability of the participants and of the testing equipment. These values were calculated by multiplying the TE across all 3 tests for each variable by 1.75 (Hopkins, 2000). For instance, for an individual with an average power of 2000W, values beyond the range of 1833W-2167W (2000±167W) are likely a meaningful change and are not due to variability in the individual or the testing equipment/protocol.

A limitation of the current study may be that the Keiser incremental resistance leg press protocol, which increases resistance in block increments dependent on the pre-determined maximum resistance (see Table 1) and therefore may be unable to identify subtle variations in an individual’s strength and power. For example, a 10-repetition test with max resistance set at 300 kg will increase from 300 kg to 328 kg between repetitions. It is possible that this ~9% increase may be too great and result in failure even though improvements may be apparent between tests. However, in the context of the applied environment, the magnitude of this limitation of the testing protocol is not considered great enough to employ an alternative method with greater sensitivity, which would introduce time efficiency and practicality limitations of its own. Additionally, although movement completed in the testing modality is multiarticular in nature, as movements are completed in a seated position with a fixed trunk direct specificity in relation to soccer could be questioned.

The current study established the reliability of single and double leg strength and power output of elite soccer players over varying resistances as well as bilateral left-right leg power imbalances obtained through the Keiser Air 420 incremental resistance leg press protocol. There were no significant differences between 3 test-retest trials for all strength and power variables. Results from imbalance calculations showed that average power imbalance variables (% difference average, difference average and symmetry angle average) offer a reliable form of calculating left-right leg imbalance values with no significant differences across all trials, ‘good’ ICC values, and the lowest TE of all imbalance calculations. However, due to weaker test-retest results, peak power and last 4 repetition imbalances variables cannot be considered as reliable imbalance measures. TE values found in the current study were also used to establish appropriate ranges of meaningful change for all variables to better inform future testing.

Conclusions

The current study has established that maximal strength, single and double leg power output and average bilateral imbalance of soccer players results obtained through a seated leg press protocol can show an acceptable level of reliability and therefore gives practitioners greater confidence in any results obtained through the current testing protocol. Additionally, establishing the limits of meaningful change ranges for all variables allows practitioners to derive a greater detailed, accurate evaluation on the magnitude of changes between repeated tests in soccer players.

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Key points

- Paired tests found no significant differences between consecutive tests and 'very strong' reliability for all strength and power variables.
- Imbalance variables accounting for the average power output across all repetitions for left and right legs were found as the most reliable with 'very strong' reliability.
- Despite establishing 'strong' reliability, imbalance variables accounting for peak power output and average power output from the last 4 repetitions had the poorer reliability, limiting their application as a reliable marker of imbalance.
- Limits of meaningful change established for each strength, power and imbalance variable provide practitioners with parameters to better evaluate test results.

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