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Research article

Unilateral or Bilateral Standing Broad Jumps: Which Jump Type Provides Inter-Limb Asymmetries with a Higher Reliability?

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Abstract

This study aimed to compare the between-session reliability of performance and asymmetry variables between unilateral and bilateral standing broad jumps (SBJ). Twenty-four amateur basketball players (12 males and females) completed two identical sessions which consisted of four unilateral SBJs (two with each leg) and two bilateral SBJs. Mean and peak values of force, velocity and power, and impulse were obtained separately for each leg using a dual force platform. Inter-limb asymmetries were computed using the standard percentage difference for the unilateral SBJ, and the bilateral asymmetry index-1 for the bilateral SBJ. All performance variables generally presented an acceptable absolute reliability for both SBJs (CV range = 3.65-9.81%) with some exceptions for mean force, mean power, and peak power obtained with both legs (CV range = 10.00-15.46%). Three out of 14 variables were obtained with higher reliability during the unilateral SBJ ($CV_{ratio} \geq 1.18$), and 5 out of 14 during the bilateral SBJ ($CV_{ratio} \geq 1.27$). Asymmetry variables always showed unacceptable reliability (ICC_{range} = -0.40 to 0.58), and *slight* to *fair* levels of agreement in their direction (Kappa range = -0.12 to 0.40) except for unilateral SBJ peak velocity [Kappa = 0.52] and bilateral SBJ peak power [Kappa = 0.51]) that showed moderate agreement for both SBJs. These results highlight that single-leg performance variables can be generally obtained with acceptable reliability regardless of the SBJ variant, but the reliability of the inter-limb asymmetries in the conditions examined in the present study is unacceptable to track individual changes in performance.

Key words: Direction; force platform; inter-limb differences; variability; horizontal jump.

Introduction

The assessment of inter-limb asymmetries (i.e., difference in performance or function of one limb with respect to the other) has received increasing attention in recent years in the fields of rehabilitation and strength and conditioning (Barber et al., 1990; Impellizzeri et al., 2007; Bishop at al., 2018c). Previous research has suggested that lower inter-limb asymmetries may be associated with a lower injury incidence (Barber et al., 1990) and a safer return to play (Kyritsis et al., 2016). Furthermore, the available literature has also suggested that inter-limb differences may have a detrimental effect on physical and sport-specific performance (Bishop et al., 2018c), although definitive evidence is lacking (Maloney, 2019). Therefore, it has been recommended that clinicians and coaches frequently evaluate inter-limb differences throughout a training cycle in order to ensure that their patients or athletes do not exceed an arbitrary “high risk threshold” (e.g., 10-15%) (Bishop et al., 2018d). However, arbitrary thresholds have been criticized due to the task- and metric-dependent nature of inter-limb asymmetry (Bishop et al., 2018a; Dos’Santos et al., 2020; Bishop, 2021). Since multiple strength and jumping tests have been used to monitor the existence of inter-limb asymmetries (Bishop et al., 2017), of special interest to practitioners should be the identification of the most appropriate test and metric for an accurate diagnosis of inter-limb differences.

The standing broad jump (SBJ) likely is the test most frequently used for detecting inter-limb differences in the ability to apply force in a horizontal direction (Lockie et al., 2014; Bishop et al., 2018a; Madruga-Parera et al., 2020a; 2020b; 2020c). The main goal of any variant of the SBJ is to jump as far as possible (Lockie et al., 2014; Bishop et al., 2018a; Madruga-Parera et al., 2020a; 2020c). The high applicability of the SBJ tests comes from the fact that a simple tape measure can be used to determine the main performance indicator (i.e., jump distance) (Lockie et al., 2014; Madruga-Parera et al., 2020a; 2020b; 2020c).

Jump distance has shown to be a highly reliable metric (intraclass correlation coefficient [ICC] ≥ 0.92) for evaluating both performance and inter-limb asymmetries during the unilateral SBJ (i.e., SBJ performed from a monopodial stance) (Bolgla and Keskula, 1997; Ross et al., 2002; Reid et al., 2007). Although jump distance is considered as a handy, field and useful metric, the use of a force platform could provide more comprehensive information about the underlying biomechanical mechanisms of jumping performance by analyzing additional metrics such as mean and peak values of force, velocity and power, or impulse (McMahon et al., 2018; Chavda et al., 2018). For example, analyzing the vertical ground reaction force (GRF) with a force platform Bishop et al. (2018a) reported generally acceptable reliability for peak force, concentric impulse, and eccentric impulse during the unilateral SBJ variant (coefficient of variation [CV] range = 7.3-11.9%; ICC range = 0.66-0.87).

It is also important to note that practitioners could simultaneously evaluate both legs on the same repetition using a dual force platform (Benjanuvatra et al., 2013;

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Heishman et al., 2019). To that end, the SBJ is performed using a bipodal stance (bilateral SBJ) with each leg positioned on an individual force platform. Although the bilateral SBJ would be a more time-effective alternative, this SBJ variant may mask any deficits given the possibility of dividing the effort between the two lower limbs (Maloney et al., 2018). In this regard, a previous study recommended the unilateral countermovement jump (CMJ) instead of the bilateral CMJ to obtain more accurate measures of impulse asymmetries (Benjanuvatra et al., 2013). Similarly, another study recommended the unilateral drop jump (DJ) to provide a more reliable measure of vertical stiffness (i.e., the ratio between peak GRF to the center-of-mass displacement) when compared to bilateral DJ (Maloney et al., 2018). However, it should be note that there is little similarity in the biomechanical demands of each jumping-based task. For example, Kotsifaki et al. (2021) showed that the hip and ankle joints are predominantly involved during the SBJ, while the knee joint is more involved during the CMJ. Therefore, since each jumping-based task measures different constructs of lower limb function, further research is still needed to exhaustively compare the reliability of single-leg performance and inter-limb asymmetry variables collected with force platforms between the unilateral and bilateral SBJ variants.

In addition to the magnitude of inter-limb asymmetries (i.e., the percentage difference of one limb with respect to the other), another factor that determines the usefulness of the measurement is the consistency in the direction of the asymmetries (Dos'Santos et al., 2020; Virgile and Bishop, 2021). In this regard, Bishop et al. (2020c) found that the levels of agreement for the direction of unilateral CMJ (jump height and concentric impulse) and unilateral DJ asymmetries (jump height and reactive strength) were *poor* to *substantial* (kappa range = -0.10 to 0.78) through the season (pre-session, mid-season, and end of season) in male academy soccer players. More importantly, other studies (Bishop et al., 2019, 2020b) have explored the consistency of inter-limb asymmetry between sessions separated by 2-3 days. Bishop et al. (2019) reported a *fair* to *substantial* (kappa range = 0.29 to 0.64), *substantial* (kappa range = 0.64 to 0.66), and *fair* to *moderate* (kappa range = 0.36 to 0.56) levels of agreement for the direction of unilateral isometric squat asymmetries (peak force and impulse), unilateral CMJ asymmetries (jump height and peak force), and unilateral DJ asymmetries (jump height and reactive strength index), respectively. Bishop et al. (2020b) also observed s*ubstantial* (kappa = 0.72) levels of agreement for asymmetries in unilateral DJ height, but *fair* (kappa range = 0.25 to 29) levels of agreement for the asymmetries in reactive strength during the unilateral DJ and jump height during the unilateral CMJ. Finally, another study (Bishop et al., 2020a) observed *poor* levels of agreement (Kappa range = -0.15 to -0.07) when comparing inter-limb asymmetries (mean force, eccentric impulse, and concentric impulse) between the unilateral and bilateral CMJ variants within the same session. These data indicate that the direction of inter-limb asymmetries seems to be highly variable depending on the metric and exercise evaluated. Therefore, due to the lack of similar studies, it seems reasonable to explore the consistency in the direction of asymmetries between consecutive sessions during the unilateral and bilateral SBJ variants.

To address the existing gaps in the literature, a number of mechanical variables were obtained separately for the left and right legs using a dual force platform during unilateral and bilateral SBJs. Specifically, the aim of this study was to elucidate whether single-leg performance and inter-limb asymmetries can be obtained with a higher reliability during unilateral or bilateral SBJs. Based on previous findings observed on other jumping-based tasks (Benjanuvatra et al., 2013; Maloney et al., 2018), it was hypothesized that the reliability of single-leg performance variables would be higher for the unilateral SBJ compared to the bilateral SBJ. However, given that the consistency of the inter-limb asymmetries has been shown to be affected by the metric and exercise evaluated (Bishop et al., 2019, 2020b), no specific hypothesis was formulated regarding the comparison of the reliability of inter-limb asymmetries between the unilateral and bilateral SBJs.

Methods

Experimental approach to the problem

A repeated-measures design was used to compare the between-session reliability of single-leg performance and inter-limb asymmetry variables between unilateral and bilateral SBJs. Subjects completed two identical sessions separated by seven days. Each testing session consisted of four unilateral SBJ (two trials with each leg) and two bilateral SBJs. The average value of the two trials performed with each SBJ variant was used for statistical analyses (Bishop et al., 2019). All testing sessions were performed at the same facility, under the direct supervision of the same experimenter, and were held between 19:00–21:00 hours. Subjects were asked to refrain from any strenuous physical activity for at least 24 hours prior to testing days.

Subjects

Twenty-four amateur basketball players volunteered to participate in this study. Specifically, the study sample was composed of a senior male (n = 12; age = 18.9 ± 1.8 years [range: 16-22 years]; body mass = 80.2 ± 11.0 kg; body height = 1.88 ± 0.08 m) and female (n = 12; age = 21.1 ± 4.2 years [range: 15-29 years]; body mass = 70.6 ± 7.2 kg; body height = 1.75 ± 0.06 m) team that played in a regional-level Spanish basketball club (data presented as mean ± standard deviation [SD]). All subjects had a minimum basketball experience of five years and they were accustomed to performing the unilateral and bilateral SBJs as part of their habitual strength and conditioning training routines during at least the last two competitive seasons. Subjects were free from health problems and musculoskeletal injuries that could compromise testing. Prior to testing, subjects were informed about the research purpose and procedures, and they or their legal guardians (for subjects younger than 18 years) gave written consent to participate in the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board.

Procedures

Body height and body mass were measured at the beginning of the first session using a wall-mounted stadiometer (Seca 202 Stadiometer; Seca Ltd., Hamburg, Germany) and an eight-electrode system (Tanita BC-418 MA; Tanita Corp., Tokyo, Japan), respectively. The warm-up consisted of 5 minutes jogging, lower-limb dynamic stretching exercises, and three sub-maximal practice trials of each SBJ variant. The jogging pace and lower-limb dynamic stretching exercises were self-selected by the subjects as they commonly do in their usual training. After warming-up, subjects rested 3 minutes and thereafter performed two trials for each SBJ variant. The order of execution of the SBJ variants was randomized in the first session, and the same order was followed in the second session. The rest between trials of the same and different SBJ types was set to 1 and 2 minutes, respectively. Subjects were encouraged to perform all trials with maximal effort. The specific characteristics of the unilateral and bilateral SBJ exercises were the following:

Unilateral SBJ. Subjects began standing in a unilateral stance with the tested leg fully extended on the center of a force platform, the alternate leg flexed to 90º at the hip and knee joints, and the hands placed on the hips (Figure 1). Subsequently, subjects were instructed to jump forward as far as possible and land on the tested leg after performing a countermovement to a self-selected depth. Subjects had to keep their hands on the hips throughout the movement and the swing of the opposite leg prior to the jump was prohibited (Bishop et al., 2017; Madruga-Parera et al., 2020c). An experienced researcher asked the subjects to repeat the trial after 1 minute of rest in case that the jump did not comply with these instructions.

Figure 1. Initial position during the unilateral standing broad jump variant.

Bilateral SBJ. Subjects began standing in a comfortable bilateral stance with each leg fully extended on the center of two parallel force platforms, feet positioned hip-width apart, and the hands placed on the hips. The technique execution was identical to the unilateral SBJ but subjects were instructed to jump and land on both legs simultaneously.

Measurement equipment and data analysis

All SBJ tests were performed on two parallel force platforms (Type 9260AA6; Kistler, Winterthur, Switzerland; 0.5 × 0.6 × 0.1 m) embedded in a wooden housing (1.1 × 1.0 × 0.1 m; see Figure 1 for further details). The horizontal GRF data from each force platform were synchronously acquired with the BioWare® software (Kistler, Winterthur, Switzerland) at 1,000 Hz. The force platforms were zeroed before each trial. The horizontal GRF data were exported as text files and analyzed using a customized 2019 Microsoft Excel® spreadsheet (version 16.32, Microsoft Corporations, Redmond, Washington, USA).

Prior to each jump, the subjects were weighed in a bilateral stance for approximately 3 seconds. Since both legs are coordinated to accelerate the center-of-mass forward, 50% of body weight was used to separately analyze the right and left legs during the bilateral SBJs. The push-off started when the horizontal GRF was above 10 N (start of the jump) and finished when the horizontal GRF was below 10 N (end of the jump) (García-Ramos et al., 2018). The impulse-momentum approach was used to calculate the dependent variables of the present study (Linthorne, 2001). Horizontal acceleration was calculated as the horizontal GRF divided by body mass, while horizontal velocity of the center-of-mass was determined by integrating acceleration with respect to time. Horizontal power was calculated as the product of force and velocity at each time point. The mean and peak values of force, velocity, and power, as well as the horizontal impulse (force × push-off time) were determined for each jump.

Statistical analyses

Descriptive data are presented as means, SD, and range. The normal distribution of the data was confirmed using the Shapiro-Wilk test ($P > 0.05$; except for the magnitude of the peak force obtained during the unilateral SBJs and the inter-limb asymmetry in peak force obtained during the bilateral SBJ). Paired samples *t*-tests or Wilcoxon signed-rank tests, in addition to the standardized mean difference (Cohen's *d* effect size [ES]), were used to compare the magnitude of the performance and inter-limb asymmetry variables between both testing sessions. The criteria to interpret the magnitude of the ES was the following: *trivial* (<0.20), *small* (0.20–0.59), *moderate* (0.60–1.19), *large* (1.20–2.00), or very large (>2.00) (Hopkins et al., 2009). Absolute (CV% = standard error of measurement / subjects' mean score × 100) and relative reliability (ICC, model 3.1) were calculated with their corresponding 95% confidence intervals. Acceptable reliability was determined as an ICC > 0.70 and CV < 10% (Cormack et al., 2008). The ratio between two CVs was used to compare the between-session reliability of performance variables between the unilateral and bilateral CMJs. The smallest important ratio between two CVs was considered to be higher than 1.15 (Fulton et al., 2009).

Standard percentage differences (100/[maximum value from right and left leg]*[minimum value from right and left leg]*[-1] + 100) were calculated to assess inter-limb asymmetries during the unilateral SBJ (Bishop et al., 2018b). To determine the direction of asymmetry, an “IF function” (IF*[left leg < right leg, 1, -1]) was added to the end of the asymmetry equation (Bishop et al., 2018a). The bilateral asymmetry index-1 ([dominant leg – nondominant leg]/[dominant leg + nondominant leg]*100) was used to assess inter-limb asymmetries during the bilateral SBJ (Bishop et al., 2018b). Leg-dominance was determined from the self-reported preferred limb via a questionnaire (2 males and 2 female were left leg dominant) (Gonzalo-Skok et al., 2017).

Finally, kappa coefficients were calculated to determine the levels of agreement for the direction of the asymmetries between both testing sessions (Bishop et al., 2019). Therefore, data were firstly coded on a subject-by-subject basis; where the direction of asymmetry was assigned as “1” when favored the right leg (unilateral SBJ)/dominant (bilateral SBJ) or “0” when favored the left leg (unilateral SBJ)/nondominant (bilateral SBJ). The criteria to interpret the kappa values were as follows: *poor* (≤ 0.00), *slight* (0.01-0.20), *fair* (0.21-0.40), *moderate* (0.41-0.60), *substantial* (0.61-0.80), or *almost perfect* (0.81-0.99) (Bishop et al., 2021). All reliability assessments were performed by means of a custom Excel spreadsheet (Hopkins, 2000), while other statistical analyses were performed using the software package SPSS (IBM SPSS version 22.0, Chicago, IL). Alpha was set at 0.05.

Results

Descriptive data of single-leg performance and inter-limb asymmetry variables are presented in Table 1. *Trivial* (ES ≤ 0.19; 23 out of 28 comparisons) or *small* (0.21 ≤ ES ≤ 0.44; 5 out of 28 comparisons) differences were observed for the performance variables between both testing sessions but, with the exception of peak velocity of the right leg during the bilateral SBJ (P = 0.003), were no significant (P ≥ 0.085). Most performance variables presented an acceptable absolute reliability (CV range = 3.65-9.81%) for both SBJ variants, with some exceptions for mean force, mean power, and peak power (CV range = 10.00-15.46%). The relative reliability of the performance variables was generally unacceptable for the unilateral SBJ variant (ICC range = -0.02 to 0.62; except for mean power of the left leg and mean force and impulse of both legs) and acceptable for the bilateral SBJ variant (ICC range = 0.72 to 0.93; except for peak force of the left leg) (Table 2). Regarding the reliability comparison between SBJ variants, the unilateral SBJ variant reported a greater reliability in 3 out of 14 comparisons (CV_{ratio} range = 1.18-1.69 for mean force of the left leg and peak force of both legs), while the bilateral SBJ variant was more reliable in 5 out of 14 comparisons (CV_{ratio} range = 1.27-1.74 for mean power and peak velocity of the right leg, as well as mean velocity, peak velocity, and impulse of the left leg) (Figure 2).

Regarding the inter-limb asymmetry variables, no significant differences were observed between both testing sessions (p ≥ 0.189) with the magnitude of the differences being either *trivial* (ES ≤ 0.17; 8 out of 14 comparisons) or *small* (0.20 ≤ ES ≤ 0.32; 6 out of 14 comparisons). None of the asymmetry variables met the criterion for acceptable relative reliability during any SBJ variant (ICC range = -0.40 to 0.58). Finally, the level of agreement for the direction of inter-limb asymmetries between sessions were *slight* in 8 out of 14 comparisons (Kappa range = -0.12 to 0.19), *fair* in 4 out of 14 comparisons (Kappa range = 0.20 to 0.40), and *moderate* for the unilateral SBJ peak velocity (Kappa = 0.52) and bilateral SBJ peak power (Kappa = 0.51). Individual comparisons between testing sessions for the inter-limb asymmetry scores are presented in Figures 3 and 4.

Table 1. Descriptive data of performance and inter-limb asymmetry variables obtained during the unilateral and bilateral standing broad jump (SBJ) variants. Data are presented as means ± standard deviations.

Variable	Session	Unilateral SBJ			Bilateral SBJ		
		Right leg	Left leg	Asymmetry (%)	Right leg	Left leg	Asymmetry (%)
Mean force(N)	1	131.6 ± 24.4	134.4 ± 26.3	-1.7 ± 18.7	93.7 ± 17.3	94.4 ± 15.8	1.4 ± 6.2
	2	134.2 ± 26.5	137.3 ± 25.4	-2.0 ± 14.5	97.2 ± 19.1	91.6 ± 19.3	3.4 ± 6.8
Mean velocity ($m \cdot s^{-1}$)	1	0.57 ± 0.09	0.57 ± 0.08	-0.8 ± 13.2	0.66 ± 0.11	0.68 ± 0.10	-0.6 ± 6.2
	2	0.57 ± 0.08	0.58 ± 0.09	-1.7 ± 12.5	0.64 ± 0.11	0.66 ± 0.10	-2.0 ± 7.6
Mean power (W)	1	107.3 ± 26.4	109.9 ± 24.7	-2.3 ± 20.1	93.6 ± 24.1	102.0 ± 23.9	-1.9 ± 9.1
	2	107.3 ± 26.0	114.7 ± 274	-5.5 ± 18.8	94.4 ± 26.7	96.9 ± 25.4	-1.7 ± 8.7
Peak force (N)	1	242.1 ± 11.7	244.8 ± 10.1	-1.1 ± 6.2	204.4 ± 24.2	217.3 ± 21.5	-2.2 ± 4.8
	2	242.6 ± 10.5	247.3 ± 9.7	-1.9 ± 5.5	215.2 ± 25.2	221.0 ± 22.6	-0.8 ± 3.6
Peak velocity ($m \cdot s^{-1}$)	1	1.61 ± 0.21	1.63 ± 0.22	-1.5 ± 6.6	1.97 ± 0.28	2.14 ± 0.30	-3.7 ± 7.6
	2	1.59 ± 0.14	1.65 ± 0.17	-3.3 ± 10.0	1.95 ± 0.26	2.12 ± 0.24	-4.7 ± 5.4
Peak power (W)	1	358.1 ± 61.1	377.3 ± 55.7	-5.0 ± 12.5	370.0 ± 79.5	405.0 ± 65.5	-4.2 ± 10.3
	2	353.1 ± 44.7	386.1 ± 50.5	-8.0 ± 12.5	380.2 ± 82.4	413.4 ± 66.3	-4.7 ± 8.4
Impulse (N·s)	1	116.6 ± 15.9	118.7 ± 17.8	-1.5 ± 6.6	72.2 ± 13.1	76.7 ± 12.5	-2.7 ± 6.8
	2	115.5 ± 16.3	120.4 ± 15.5	-4.0 ± 9.6	71.1 ± 12.3	75.9 ± 12.1	-3.8 ± 6.3

Table 2. Reliability of performance and inter-limb asymmetry variables obtained during the unilateral and bilateral standing broad jump (SBJ) variants.

Variable	Right leg				Left leg				Asymmetry (%)		
	P	ES	CV (%) (95% CI)	ICC (95% CI)	*P*	ES	CV (%) (95% CI)	ICC (95% CI)	*P*	ES	ICC (95% CI)
Unilateral SBJ											
Mean force	.530	.10	**10.86 (8.44, 15.24)**	.70 (.41, .86)	.411	.11	8.78 (6.83, 12.32)	.80 (.59, .91)	.939	-.02	**.35 (-.06, .65)**
Mean velocity	.830	.04	9.81 (7.63, 13.76)	**.59 (.26, .80)**	.424	.15	9.72 (7.56, 13.64)	**.58 (.24, .80)**	.763	-.07	**.30 (-.11, .62)**
Mean power	.997	.00	**15.46 (12.02, 21.69)**	**.62 (.29, .81)**	.247	.18	**12.16 (9.53, 17.20)**	.74 (.48, .88)	.495	-.17	**.31 (-.10, .63)**
Peak force	.627	.05	4.63 (3.60, 6.49)	**-.02 (-.41, .38)**	.278	.26	3.65 (2.84, 5.12)	**.18 (-.23, .54)**	.703	-.13	**-.40 (-.69, -.01)**
Peak velocity	.578	-.12	8.06 (6.27, 11.31)	**.49 (.11, .74)**	.701	.07	7.47 (5.80, 10.48)	**.62 (.30, .82)**	.373	-.22	**.32 (-.09. .64)**
Peak power	.675	-.09	**11.29 (8.78, 15.84)**	**.45 (.07, .72)**	.419	.16	9.63 (7.49, 13.51)	**.54 (.18, .77)**	.353	-.24	**.27 (-.15, .60)**
Impulse	.657	-.07	7.62 (5.93, 10.70)	.72 (.45, .87)	.509	.11	7.68 (5.97, 10.77)	.71 (.44, .87)	.215	-.31	**.30 (-.11, .62)**
Bilateral SBJ											
Mean force	.210	.19	**10.00 (7.77, 14.03)**	.74 (.49, .88)	.323	-.16	**10.32 (8.02, 14.48)**	.72 (.46, .87)	.208	.31	**.32 (-.09, .63)**
Mean velocity	.141	-.22	8.61 (6.69, 12.08)	.76 (.53, .89)	.085	-.27	7.63 (5.93, 10.70)	.75 (.50, .88)	.310	-.20	**.56 (.22, .79)**
Mean power	.805	.03	**12.18 (9.47, 17.08)**	.81 (.61, .91)	.174	-.21	**12.61 (9.80, 17.68)**	.76 (.51, .89)	.898	.03	**.41 (.02, .70)**
Peak force	.649	-.07	7.42 (5.76, 10.40)	.73 (.46, .87)	.353	.17	6.18 (4.81, 8.67)	**.64 (.33, .83)**	.189	.32	**.37 (-.03, .67)**
Peak velocity	.003	.44	5.45 (4.23, 7.64)	.80 (.59, .91)	.472	-.08	4.65 (3.61, 6.52)	.88 (.74, .94)	.430	-.15	**.58 (.24, .79)**
Peak power	.410	.13	**11.21 (8.72, 15.73)**	.75 (.50, .88)	.406	.13	8.40 (6.53, 11.78)	.74 (.49, .88)	.816	-.05	**.54 (.18, .77)**
Impulse	.515	-.08	7.83 (6.09, 10.99)	.82 (.62, .92)	.421	-.06	4.42 (3.43, 6.19)	.93 (.85, .97)	.419	-.17	**.52 (.16, .76)**

P, *P*-value obtained through a paired samples *t*-test or Wilcoxon signed-rank test between the sessions 1 and 2; ES = Cohen's *d* effect size ([Session 2 – Session 1/*SD* both]); CV = coefficient of variation; ICC = intraclass correlation coefficient; 95% CI = 95% confidence interval. Bold numbers indicate an unacceptable reliability (CV > 10% or ICC < 0.70).

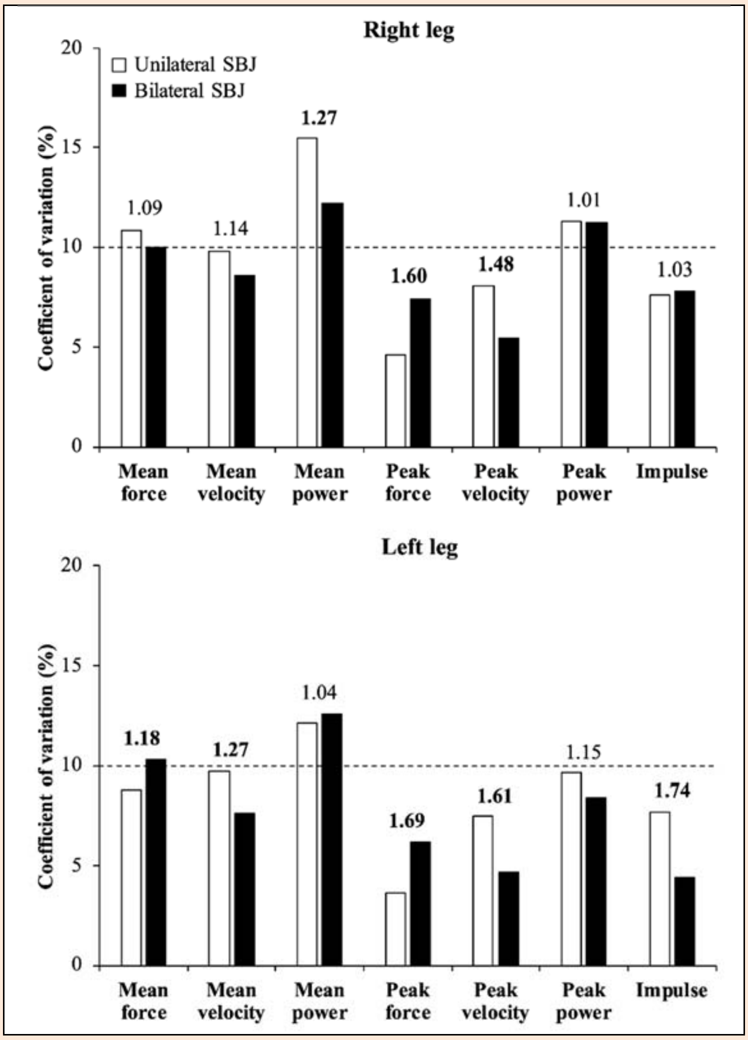

Figure 2. Comparison of the absolute reliability of the different performance variables obtained with the right (upper panel) and left (lower panel) legs between the unilateral (white bars) and bilateral (black bars) standing broad jump (SBJ) variants. Numbers indicate the ratio between two coefficients of variation (CV_{ratio} = higher CV value / lower CV value), while meaningful differences in reliability are indicated in bold (CV_{ratio} > 1.15).

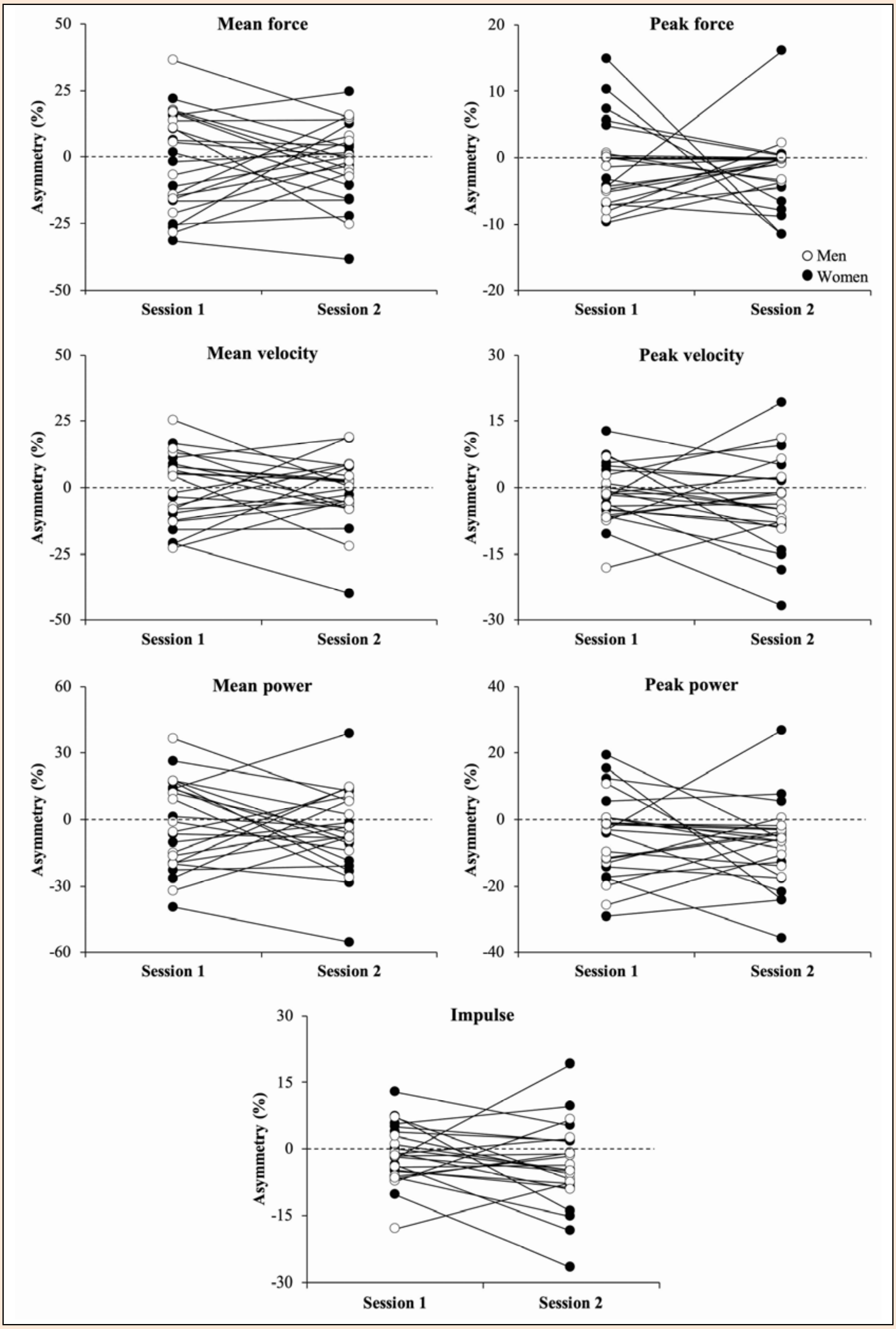

Figure 3. Individual comparisons between testing sessions for the inter-limb asymmetry scores obtained for men (white circles) and women (black circles) during the unilateral standing broad jump variant.

Discussion

This study was designed to compare the between-session reliability of single-leg performance and inter-limb asymmetry variables between unilateral and bilateral SBJ variants. The main findings revealed that (I) most single-leg performance variables presented an acceptable absolute reliability for both SBJ variants (II) the relative reliability of single-leg performance variables was generally unacceptable for the unilateral SBJ variant, but acceptable for the bilateral SBJ variant; (III) the unilateral SBJ variant reported higher absolute reliability in 3 out of 14 comparisons, while the bilateral SBJ variant was more reliable in 5 out of 14 comparisons; and (IV) the asymmetry variables generally showed unacceptable relative reliability and lack of agreement in their direction for both SBJ variants. These results highlight that most single-leg performance variables can be obtained with acceptable absolute reliability regardless of the SBJ variant. However, the low reliability and lack of agreement observed for the inter-limb asymmetries question their usefulness to classify healthy athletes as asymmetrical during both variants of the SBJ.

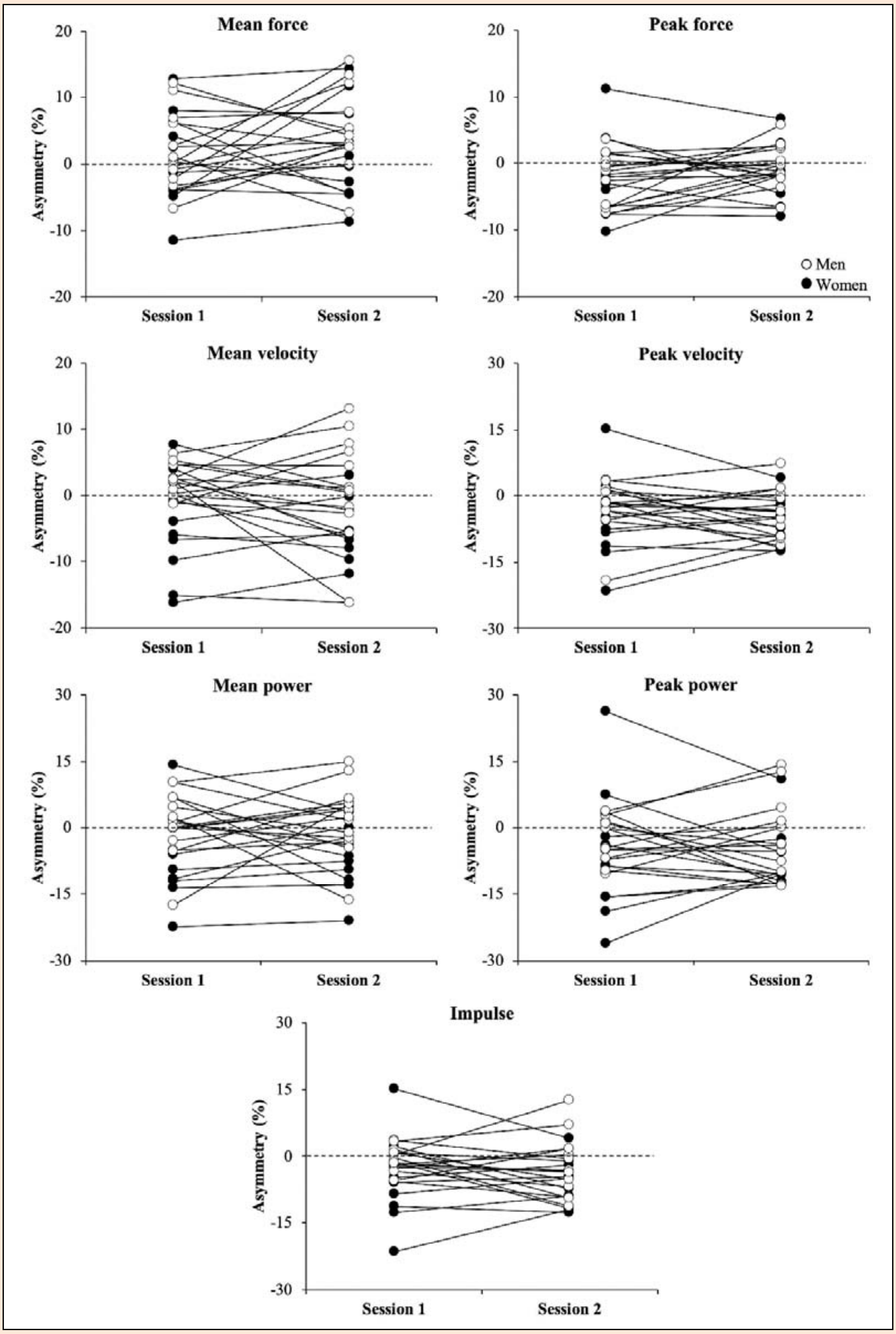

Figure 4. Individual comparisons between both testing sessions for the inter-limb asymmetry scores obtained for men (white circles) and women (black circles) during the bilateral standing broad jump variant.

Reliability is a basic requirement in the selection of any physical test to guarantee that there is an adequate precision in the outcomes measured to quantify the inter-limb asymmetries (Bishop et al., 2017). To our knowledge, this is the first study to provide in-depth insight into the between-session reliability of various single-leg performance variables obtained with force platforms during the unilateral and bilateral SBJ variants. The present study demonstrated that the different single-leg performance variables have an acceptable absolute reliability for both SBJ variants with some exceptions for mean force, mean power, and peak power. It is plausible that the consistency of mean force values are influenced by the variability in jumping strategy (i.e., force-time characteristics from the initiation of the jump to the take-off) (Pérez-Castilla et al., 2019), while the consistency of power values may be affected by the greater manipulation of the GRF data (i.e., power is the last variable obtained using the forward dynamics approach) (Cormie et al., 2007). On the other hand, the relative reliability of the single-leg performance variables was generally unacceptable for the unilateral SBJ variant (except for mean power of the left leg and mean force and impulse of both legs), but acceptable for the bilateral SBJ variant (except for peak force of the left leg). It is important to note that the relative reliability refers to the stability in the position of an individual within a group (Weir, 2005). Therefore, lower ICCs values may be attributed to a low heterogeneity in the examined variables. These results are in line with the findings reported by Bishop et al. (2018a) for peak force (CV range = 8.7-9.3%; ICC = 0.75-0.80) and concentric impulse (CV range = 7.3-8.8%; ICC = 0.66-0.69) obtained from vertical GRF data analysis during the unilateral SBJ variant. In particular, the horizontal impulse could be recommended for an accurate evaluation of single-leg performance since it was the only variable with acceptable relative and absolute reliability for both SBJ variants.

Rejecting our hypothesis, the unilateral SBJ variant was more reliable in 3 out of 14 comparisons (mean force of the left leg and peak force of both legs), while the bilateral SBJ variable was more reliable in 5 out of 14 comparisons (mean power and peak velocity of the right leg, as well as mean velocity, peak velocity, and impulse of the left leg). Our results for the unilateral SBJ variant are in agreement with the findings of Maloney et al. (2018) who found that the vertical GRF used to determine the vertical stiffness was more reliable for the unilateral DJ (CV = 2.5% for left leg and 2.6% for right leg)compared to the bilateral DJ (CV = 5.5% for both legs). These findings provide additional evidence that unilateral jumping-based tasks are more appropriate to quantify the force production because it places a greater emphasis on one leg, in addition to reducing the athlete's base of support, which is a more representative position for most sports actions such as in basketball (Benjanuvatra et al., 2013). Note also that inter-limb differences during bilateral tasks can be primarily driven by mechanical factors rather than biomechanical factors (Simon and Ferris, 2008). Instead, our results for the bilateral SBJ variant are in disagreement with the findings of Benjanuvatra et al. (2013) who recommended the unilateral CMJ to determine impulse asymmetries due to the inaccuracy in the determination the weight of each limb during the bilateral CMJ. However, while Benjanuvatra et al. (2013) adjusted the vertical GRF of each limb to 50% of total body weight to preserve the possible variations in bilateral vertical GRF during the weighing phase (i.e., slight shifts of the center-of-mass toward one side), the horizontal GRF data were not adjusted in the present study for the bilateral SBJ variant. Collectively, these results suggest that the reliability of the single-leg performance variables seems to be dependent on the SBJ variant. In general, the unilateral SBJ variant could be more reliable option to quantify the single-leg force production, while the bilateral SBJ variant is a more reliable alternative to measure the single-leg performance of velocity, power, or impulse. It should be also noted that the unilateral SBJ variant represents a more robust measure of the capacity of each limb, while the bilateral SBJ variant may provide a more comprehensive view of compensatory strategies between limbs (Cohen et al., 2020). However, practitioners should take into consideration other aspects such as the necessary equipment (one or two force platforms) or time available when selecting the most appropriate SBJ variant for routine testing procedures.

It is important for practitioners to confirm the acceptable between-session reliability for inter-limb asymmetries in order to make correct decisions when prescribing resistance training programs or deciding whether athletes should return to competition based on inter-limb asymmetry scores (Bishop et al., 2017; Dos'Santos et al., 2020). Our results revealed that the different inter-limb asymmetry variables obtained from both the unilateral and bilateral SBJ variants reported poor between-sessions reliability not only due to the differences in the magnitude of asymmetry, but also due to the high inconsistency in the direction of asymmetry (see Figure 3 and 4). These results are partially in line with the findings of Bishop et al. (2020b) who found *fair* levels of agreement for the reactive strength unilateral DJ asymmetries (kappa = 0.25) and jump height unilateral CMJ asymmetries (kappa = 0.29), but s*ubstantial* levels of agreement for the jump height unilateral DJ asymmetries (kappa = 0.72). At the same time, our results are in disagreement with another study of Bishop et al. (2019) who observed *fair* to *substantial* levels of agreement for the unilateral isometric squat asymmetries (kappa range = 0.29 to 0.64), *substantial* levels of agreement for the unilateral CMJ asymmetries (kappa range = 0.64 to 0.66), and *fair* to *moderate* levels of agreement for the unilateral DJ asymmetries (kappa range = 0.36 to 0.56). Therefore, the present study adds evidence to the variable nature of inter-limb asymmetries not only depending on the metrics and tasks (Bishop et al., 2017; 2018a; 2020a), but also for the same metric and task when the measurement is repeated a week apart (Bishop et al., 2019, 2020b). Practitioners are encouraged to establish the between-session reliability of inter-limb asymmetries over repeated sessions, in order to identify any consistency in the direction and magnitude of the asymmetry, before classifying the athlete's profile as asymmetrical (Virgile and Bishop, 2021).

Finally, this study is not without limitations. First, the jumping strategy was not strictly controlled and can greatly vary depending on sex (McMahon et al., 2017).

Therefore, since our sample consists of male and female basketball players, it is possible that the variability in the jumping strategy between sessions and sexes may have influenced the reliability outcomes for some performance variables (Pérez-Castilla et al., 2019). Secondly, the arm swing has been shown to provide greater balance and control throughout the jumping motion which contributes to improve SBJ performance (Ashby and Heegaard, 2002). In addition, although the study sample was accustomed to performing the unilateral and bilateral SBJ variants, the ecological validity is compromised by eliminating the arm swing during the SBJ execution. Future studies should explore the effect of the arm swing on inter-limb asymmetries. Third, although the subjects were encouraged to perform each trial with maximal effort, the fact of not providing any feedback on jumping performance (e.g., jump distance) may have compromised the consistency of the different mechanical outputs. Finally, since both legs are coordinated to accelerate the center-of-mass forward, 50% of body weight was used for forward dynamics procedures during the bilateral SBJ variant but, unlike the Benjanuvatra's study (2013), the horizontal GRF data obtained from each leg was not adjusted to avoid preserving variations in bilateral GRF. Future studies are necessary to elucidate which analysis procedure is more appropriate to determine the magnitude of the single-leg performance variables obtained using a dual force platform during jumping-based tasks.

Conclusion

The between-session reliability of the different single-leg performance variables obtained from the SBJ exercise seems to be variant-dependent. In general, the unilateral SBJ variant could be more reliable test to quantify the single-leg force production, while the bilateral SBJ variant is a more reliable alternative to measure the single-leg performance of velocity, power, or impulse. In addition, when deciding the best option, practitioners must take into consideration the greater versatility and lower cost of the unilateral SBJ variant (only a single force platform is required) or the greater time efficiency of the bilateral SBJ variant (the performance of both legs is evaluated simultaneously within the same repetition). On the other hand, the asymmetry variables present poor reliability during both the unilateral and bilateral SBJ variants due to the nature variability of asymmetry direction. As such, practitioners are encouraged to examine the reliability over repeated sessions to ensure that the magnitude and direction is consistent before making decisions regarding the athlete's asymmetry profile.

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Key points

- The between-session reliability of the different single-leg performance variables obtained from the standing broad jump seems to be variant-dependent.
- The unilateral standing broad jump variant could be more reliable test to quantify the single-leg force production, while the bilateral standing broad jump variant is a more reliable alternative to measure the single-leg performance of velocity, power, or impulse.
- The asymmetry variables present poor reliability during both the unilateral and bilateral standing broad jump variants due to the nature variability of asymmetry direction.

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