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Bilateral and unilateral vertical ground reaction forces and leg asymmetries in soccer players

AUTHORS: Yanci J, Camara J

Department of Physical Education and Sport, Faculty of Education and Sport, University of the Basque Country, UPV/EHU, Vitoria-Gasteiz, Spain

Corresponding author:
Javier Yanci
Faculty of Education and Sport
University of the Basque Country,
UPV/EHU,
Lasarte 71, 01007,
Vitoria-Gasteiz, Spain
E-mail: javier.yanci@ehu.es

ABSTRACT: The purposes of this study were to assess unilateral and bilateral vertical jump performance characteristics, and to compare the vertical ground reaction force characteristics of the impulse and landing phase of a vertical jump between the dominant and non-dominant leg in soccer players. The sample consisted of 20 male soccer players (22.80 ± 2.71 years, 1.88 ± 0.06 m, 76.47 ± 8.80 kg) who competed in the third division of the Spanish football league. Vertical jump performance was determined by testing the impulse and landing phase of a bilateral vertical jump, dominant leg vertical jump and non-dominant leg vertical jump. Significant differences ($p < 0.05$) between dominant and non-dominant legs were found in counter movement jump (CMJ) flight time (LA = -2.38%, d = 0.33), CMJ flight height (LA = -4.55%, d = 0.33) and CMJ speed take-off (LA = -2.91%, d = 0.42). No significant differences were found between the dominant and non-dominant leg in the F1 and F2 magnitudes during the landing phase, the time from the first contact of the foot with the ground to the production of F1, the time from the second contact of the foot with the ground to the production of F2, and the time to stabilization of the landing phase. Although differences were found between the dominant and non-dominant leg in the impulse phase of the jump, no significant differences were found between dominant and non-dominant legs in the landing phase of vertical jump variables.

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INTRODUCTION

Individual technique, tactics and physical resources, such as the energy delivery system, are all important when evaluating performance differences in soccer [1], even though it is difficult to discriminate between the relative importance of each of these elements [1]. The energy delivery system during a soccer game is characterized by a high demand of both aerobic and anaerobic metabolism [2]. Furthermore, since during a soccer game the prevalence of sprints, jumps, tackles and dual plays is very high, the neuromuscular performance [3], the anaerobic metabolism, and specifically, the anaerobic power of the lower extremities, have been pointed out as crucial factors for the match outcome [4].

Anaerobic power evaluation of the lower extremities in soccer players has been frequently performed using free weights [5] and isokinetic dynamometry [6-8]. Although these methods have been widely used, some authors consider that these tests do not reflect the functional aspects of physical demands involved in soccer practice [2]. Nevertheless, since vertical jump (VJ) tests also measure the anaerobic power of the lower legs and have been previously used for talent selection in soccer [4], they seem more appropriate tests for soccer players. Furthermore, counter movement jumps (CMJs) have been related to competitive success in elite-standard soccer teams [5, 9].

Bilateral vertical jumps (i.e. using both legs during the push-off phase) have been widely used in soccer players [9-12]. However, since many jumps and most propulsive forces are generated in a unilateral fashion, unilateral jump assessments would appear to have the advantage of reproducing specific movement patterns [13]. Unilateral jump assessment may therefore be of greater prognostic/diagnostic value to the strength and conditioning practitioner and consequently offer better training information [13]. Furthermore, since some studies suggest that bilateral strength asymmetry can be a risk factor for musculoskeletal injuries [8, 14], unilateral vertical jump assessment may be useful for identifying athletes at increased risk of incurring lower-leg injuries during training and competition [15]. Despite the importance of unilateral actions in soccer, there are few studies examining unilateral vertical jump performance [13, 16].

Considering the relationship between lower leg impacts, such as the impacts produced during the landing phase of a jump and overuse injuries [17, 18], not only the vertical jump capacity should be assessed, but also the landing phase from vertical jumps. It has also been observed that soccer players are prone to developing lower leg injuries [19]. The landing phase is characterized by a vertical ground reaction force (VGRF) that comprises two peaks corresponding to forefoot (F1) and rear foot (F2) contact with the ground [20]. High VGRFs have been identified as the main causes of soccer injury [21, 22], owing to the stress that they place on the musculoskeletal system [23].

The purposes of this study were to assess unilateral and bilateral vertical jump performance characteristics, and to compare the vertical ground reaction force characteristics of the impulse and landing phase of a vertical jump between the dominant and non-dominant leg in soccer players.

MATERIALS AND METHODS

The sample consisted of 20 male amateur soccer players (22.80 ± 2.71 years, 1.88 ± 0.06 m, 76.47 ± 8.80 kg, 22.58 ± 2.08 $kg \cdot m^{-2}$) competing in the third division of the Spanish soccer league. They had performed physical training (endurance, sprint and specific soccer skills) during 3-4 days per week, for more than 8 years. Written informed consent was obtained from each of the participants after a detailed written and oral explanation of the potential risks and benefits resulting from their participation. Participants were also informed that they had the option to voluntarily withdraw from the study at any time. The study was conducted according to the Declaration of Helsinki and with the consent of the club to which participants belonged. The study was approved by the local Ethics Committee.

Procedures

This study was designed to assess vertical jump performance during bilateral and unilateral jumps. A cross-sectional design was implemented using male soccer players as participants. Additionally, functional leg asymmetries between dominant and non-dominant legs during unilateral vertical jumping were assessed. Tests were carried out in the in-season (May). Participants were required to attend the exercise testing on two occasions. During the first visit, participants carried out familiarization tests after signing the informed consent, and their anthropometric characteristics were recorded. During the second visit, two days after the first visit, vertical jump tests were performed after a standardized warm-up consisting of 7 min of self-paced low-intensity running and two 15 m sprints. Bilateral and unilateral countermovement jumps were also performed during the warm-up.

Physical characteristics

Height (m), body mass (kg) and body mass index ($kg \cdot m^{-2}$) were measured in each participant. Height was measured to the nearest 0.001 m using a stadiometer (Holtain Ltd, Crymych, United Kingdom). Body mass was obtained to the nearest 0.1 kg using an electronic scale (Seca Instruments Ltd, Hamburg, Germany). Body mass index (BMI) was calculated using body weight and height ($kg \cdot m^{-2}$).

Vertical counter movement jump (CMJ) tests

According to the procedures proposed by Maulder and Cronin [24], participants performed 9 CMJs: 3 bilateral jumps where both legs were used during the push-off phase (CMJ), 3 unilateral jumps where the dominant leg (CMJD) was used during the push-off phase and 3 unilateral jumps where the non-dominant leg was used during the push-off phase (CMJND). Jumps were interspersed with a 20 s recovery time. Both legs were used during the landing phase. A force platform (Quattro Jump, Kistler, Switzerland), at a sampling frequency of 500 Hz, was used to obtain the vertical ground reaction force data on the push-off and landing phases. The leg that each player naturally used for striking the ball was considered as the dominant leg [25]. During the jumps the hands were placed on the hips and a minimal flexion of the trunk during take-off was permitted. Jumps not meeting these requirements were repeated. The obtained parameters were; i) the maximum speed of the centre of gravity during the take-off, ii) the maximum height of the centre of gravity during the flight phase, iii) the flight time, iv) the F1 magnitude, corresponding to forefoot force peak, v) the time from the first contact of the foot with the ground until the production of F1, vi) the F2 magnitude, corresponding to rear foot force peak, and vii) the time from the second contact of the foot with the ground until the production of F2, and viii) the time to stabilization (TTS). The time to stabilization was determined during the landing phase beginning with the first contact of the feet with the ground and ending when the subjects reached and remained within 5% of their body weight [26].

Statistical analysis

The results are presented as mean ± standard deviation (SD). All the variables were normal and satisfied the equality of variances according to the Shapiro-Wilk and Levene tests respectively. The reliability of the jump assessment procedures was calculated using the coefficient of variation (CV). The CV was calculated for all test variables to determine the stability of measurement among trials (CV = (SD/mean) x 100) [27]. Paired t-tests were used to determine if any significant differences existed between the dominant and non-dominant leg jump performance during the impulse and landing phases. Dominant to non-dominant leg asymmetry (LA) was determined using the following formula: dominant leg - non-dominant leg/dominant leg · 100 (as previously reported by Newton et al. [28]). Only the maximum score of each test was included in the data analysis [29]. Practical significance was assessed by calculating effect size [30]. Effect sizes (d) were classified as trivial ($d < 0.2$), small ($0.2 < d < 0.6$), moderate ($0.6 < d < 1.2$), large ($1.2 < d < 2.0$), very large ($2.0 < d < 4.0$), nearly perfect ($d > 4.0$), and perfect (d = infinite). Statistical significance was set at $p < 0.05$. Data analysis was performed using the Statistical Package for Social Sciences (version 20.0 for Windows, SPSS Inc, Chicago, IL, USA).

TABLE 1. Results of the impulse and landing phase of the bilateral CMJ (n = 20).

	Min.	Max.	Mean ± SD	CV (%)
CMJ flight time (s)	0.44	0.63	0.56 ± 0.04	3.76
CMJ flight height (m)	0.24	0.49	0.39 ± 0.06	2.91
CMJ speed take-off ($m \cdot s^{-1}$)	2.18	3.10	2.74 ± 0.21	4.59
F1 (BW)	0.69	4.38	2.43 ± 1.03	5.03
F2 (BW)	2.69	8.41	5.50 ± 1.78	6.73
T1 (s)	0.02	0.06	0.03 ± 0.01	4.86
T2 (s)	0.03	0.08	0.05 ± 0.01	5.67
TTS (s)	0.01	0.89	0.44 ± 0.17	3.25

Note: SD = standard deviation, CV = coefficient of variation; CMJ = counter movement jump; F1 = magnitude of the first peak of the vertical ground reaction force, F2 = magnitude of the second peak of the vertical ground reaction force; T1 = time from the first contact of the foot with the ground until the production of the first peak, T2 = time from the first contact of the foot with the ground until the production of the second peak; TTS = time to stabilization.

RESULTS

The impulse and landing phase of bilateral CMJ test values of the soccer players are presented in Table 1. The coefficients of variation (CV) for tests ranged from 2.91% to 6.73%.

The results of the unilateral CMJs of the impulse and flight phases are presented in Table 2. Significant differences were found between dominant and non-dominant legs in CMJ flight time (LA = -2.38%, d = 0.33), CMJ flight height (LA = -4.55%, d = 0.33) and CMJ speed take-off (LA = -2.91%, d = 0.42) values.

No significant differences (Table 3) between the dominant and non-dominant leg in any of the variables of the landing phase were found (F1, F2, T1, T2, TTS).

DISCUSSION

This study assessed CMJ performance and asymmetries between the dominant and non-dominant leg in amateur soccer players. To our knowledge no scientific articles have determined the characteristics of the CMJ parameters and the one leg vertical jump and the bilateral asymmetries in the landing phase in soccer players. The main novelty of this study is that no significant differences were found in the VGRF pattern between the dominant and non-dominant legs. However, the dominant leg showed a shorter flight time than the non-dominant leg.

Because lower extremity bilateral asymmetries are suspected to increase the risk of injury, jeopardizing performance [15, 31], it is considered relevant to ascertain the lower leg bilateral asymmetries of one of the most repetitive actions in soccer, such as jumping. In the present study, significant differences between dominant and non-dominant legs were found in the impulse and flight variables of the CMJ variables (flight time LA = -2.38%, flight height LA = -4.55%, speed take-off LA = -2.91%). Similarly, Menzel et al. [32] found a 6.77% difference between the right and left leg in vertical jump values in CMJs in Brazilian professional soccer players. However, these results contrast with those obtained by Impellizzeri et al. [15] in athletes and Maulder and Cronin [24] in non-athletes, where the average lower-leg strength asymmetry value was 0.8%, and 1%, respectively. The absence of lower extremity asymmetry found in non-soccer players could lead us to think that actions performed in this sport, the competition and training methods used may be one of the reasons for these asymmetries. Therefore, it would be interesting to investigate the effects of different types of strength training programmes on soccer players in order to reduce these asymmetries.

Regarding the bilateral landings, in our results F1 and F2 were higher (1.59 and 1.75 times, respectively), and the time to the

TABLE 2. Results of the parameters characterizing the impulse and flight phases of the unilateral jumps.

	Dominant leg	Non dominant leg	LA (%)	d
CMJ flight time (s)	0.42 ± 0.03	0.43 ± 0.03*	-2.38	0.33
CMJ jump height (m)	0.22 ± 0.03	0.23 ± 0.03*	-4.55	0.33
CMJ speed off ($m \cdot s^{-1}$)	2.06 ± 0.14	2.12 ± 0.14*	-2.91	0.42

Note: CMJ = counter movement jump; LA = asymmetry between the dominant and non-dominant leg; d = Hopkins effect size. * Significant differences ($p < 0.05$) between dominant and non-dominant leg.

TABLE 3. Results of the parameters characterizing the landing phase during the unilateral counter movement jumps.

	Dominant leg	CV (%)	Non dominant leg	CV (%)	LA (%)	d
F1 (BW)	1.29 ± 0.50	4.52	1.23 ± 0.40	5.09	4.71	0.12
F2 (BW)	3.55 ± 7.66	3.46	3.64 ± 0.73	2.87	-2.50	0.11
T1 (s)	0.03 ± 0.01	2.02	0.03 ± 0.01	3.64	0.00	0.00
T2 (s)	0.05 ± 0.02	1.96	0.05 ± 0.02	1.87	0.00	0.00
TTS (s)	0.45 ± 0.41	4.93	0.44 ± 0.26	3.91	2.22	0.02

Note: SD = standard deviation, CV = coefficient of variation; LA = leg asymmetry; d = Hopkins effect size; F1 = magnitude of the first peak, F2 = magnitude of the second peak; T1 = time from the first contact of the foot with the ground until the production of the first peak, T2 = time from the second contact of the foot with the ground until the production of the second peak; TTS = time to stabilization.

production of these peaks (T1 and T2) shorter (3.01 and 7.13 times, respectively) compared to the magnitudes reported by previous authors in recreational athletes [33]. Nevertheless, when compared to semi-professional soccer players, even though the magnitude of F2 was smaller (44.55%), the magnitude of F1 was similar (5.81%). In spite of the fact that high magnitudes of VGRF have been related to injuries [34], it has been hypothesized that the unilateral development of overuse injuries may be due to the bilaterally asymmetrical function of the lower extremities [35]. Considering on the one hand that most soccer players are forced to use one particular leg for ball kicking and cutting skills [36] and on the other, the relationship between CMJs and competitive success in elite soccer teams [5, 9], it is important to ascertain whether soccer players show an asymmetry between the legs during the landing phase of CMJs. Previous studies have suggested that there are differences in behaviour between the dominant and non-dominant legs in landings [37], with the non-dominant leg sustaining a higher VGRF than the dominant leg. Nevertheless, in the present study the magnitude of the forces related to the production of injuries (F1 and F2) [20] and the time to the production of these forces (T1 and F2) did not show significant differences between the legs. These results coincide with a previous study [38] where it was shown that during the landing phase of running the dominant and non-dominant legs did not show significant differences in the kinetic pattern. Because a similar VGRF pattern was found in both legs and because previous studies have shown differences in the kinematic pattern during landings [39], it is hypothesized that the unilateral development of overuse injuries might be due to a bilaterally asymmetrical kinematic pattern of the lower extremities.

CONCLUSIONS

The results of this study revealed significant differences between dominant and non-dominant legs in CMJ flight time, flight height and speed take-off values. However, these differences were not observed in any of the landing phase variables (F1, F2, T1, T2, TTS). This aspect may lead us to consider the need to implement specific strength training programmes in order to reduce asymmetric differences in the impulse phase.

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