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Unilateral jumps in different directions: a novel assessment of soccer-associated power?

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Abstract

Objectives: We aimed to determine whether countermovement jumps (CMJs; unilateral and bilateral) performed in different directions assessed independent lower-limb power qualities, and if unilateral CMJs would better differentiate between elite and non-elite soccer players than the bilateral vertical (BV) CMJ.

Design: Elite (n=23; age, 18.1±1.0yrs) and non-elite (n=20; age, 22.3±2.7yrs) soccer players performed three BV, unilateral vertical (UV), unilateral horizontal-forward (UH) and unilateral medial (UM) CMJs.

Methods: Jump performance (height and projectile range), kinetic and kinematic variables from ground reaction forces, and peak activation levels of the vastus lateralis and biceps femoris (BF) muscles from surface electromyography, were compared between jumps and groups of players.

Results: Peak vertical power (V-power) was greater in BV (220.2±30.1 W/kg) compared to UV (144.1±16.2 W/kg), which was greater than UH (86.7±18.3 W/kg) and UM (85.5±13.5 W/kg) (all, $p<0.05$) but there was no difference between UH and

UM (p=1.000). Peak BF EMG was greater in UH compared to all other CMJs (p≤0.001). V-power was greater in elite than non-elite for all CMJs (p≤0.032) except for BV (p=0.197). Elite achieved greater UH projectile range than non-elite (51.6±15.4 *vs.* 40.4 ± 10.4 cm, p=0.009).

Conclusions: We have shown that UH, UV and UM CMJs assess distinct lower-limb muscular power capabilities in soccer players. Furthermore, as elite players outperformed non-elite players during unilateral but not BV CMJs, unilateral CMJs in different directions should be included in soccer-specific muscular power assessment and talent identification protocols, rather than the BV CMJ.

Keywords: *jump, countermovement, horizontal, mediolateral, vertical, electromyography.*

Introduction

Maximal power is achieved during a sport-specific action when the athlete attempts to maximise velocity at take-off, release or impact [1]. Submaximal running is the predominant activity during soccer match play but powerful efforts often determine the outcome of competitive games [2]. The ability to generate maximal power during complex motor tasks may therefore be considered paramount to successful soccer performance. Nevertheless, a comprehensive assessment battery for evaluating soccer-specific maximal power has not yet been reported.

Maximal lower body power is often assessed in elite soccer players by measuring bilateral vertical countermovement jump (BV CMJ) performance [3, 4]. As part of the Elite Player Performance Plan, which was developed in an attempt to address the apparent shortcomings in the youth player development process in England, all English Soccer Academies are currently required to employ the BV CMJ as a performance assessment for measuring maximal power [5]. During the course of a match, an elite soccer player may perform up to ~119 maximal accelerations, ~35 sprints [6], ~50 forceful changes of direction [7], and ~16 vertical jumps [8]. This activity profile implies that elite soccer match play requires the ability to produce maximal power in the horizontal-anterior, mediolateral and vertical directions. Moreover, whilst elite soccer performance requires both unilateral and bilateral vertical propulsion, the majority of maximal actions are in fact performed unilaterally in the horizontal-anterior and mediolateral directions. The use of unilateral jump assessments in different directions, rather than the BV CMJ, may therefore provide a more specific lower body power profile in elite soccer players.

As the number of competitive matches per season in elite soccer is high (English Premier League players could be required to perform up to 43 competitive games in one season [9], while several Spanish players played 70 competitive games during the 2009-2010 season [10]), the time available for administering lower body power profiling is limited. Therefore, selected tests in a specific lower body power profile should not assess the same capabilities and should provide the greatest relevant information, in the shortest amount of time. Unilateral jump assessments in different directions have previously been shown to measure independent lower-limb power qualities specific to the direction of the jump [11, 12], although this has not yet been established in soccer players. Previous studies have documented that jump direction is controlled by different co-ordination strategies [13, 14] and muscle activation levels [15]. However, no study has compared muscle activation during bilateral and unilateral CMJs directed in the vertical, horizontal-forward and medial directions. Comparing muscle activation during unilateral jumps in different directions would give an insight into whether such assessments evaluate specific muscle activation strategies.

The results of lower body power assessments should be used to inform detailed training intervention protocols. Identifying the most important kinetic and kinematic predictors of jump performance allows practitioner to monitor and aim to develop jump-specific performance variables. Although previous research has documented the greatest kinetic and kinematic predictors of unilateral [11] and bilateral [16] jumps in non-elite participants, this has never been investigated in elite soccer players. It is also important that physical training interventions designed for elite soccer players are specific for improving qualities related to high-level soccer performance. It is therefore imperative that physical assessments measure capabilities that are important for elite soccer performance. A specific performance capability is indirectly considered important if elite players have greater capacity than non-elite players [17]. It is currently unknown, however, whether bilateral and unilateral jump abilities in different directions are important determinants of elite soccer performance.

Knowledge of which maximal power assessments may predict soccer performance at the elite level could inform the specificity of future training intervention and talent identification criteria. Given the limited research in this area, the aims of our study were to: (1) determine whether differences existed in the kinetic and kinematic performance variables, and vastus lateralis (VL) and biceps femoris (BF) muscle activation levels, between BV, unilateral vertical (UV), unilateral horizontal-forward (UH) and unilateral medial (UM) CMJs; (2) establish the best kinetic predictors of jump performance; (3) investigate differences in direction-specific power between elite and non-elite soccer players.

Methods

Forty-three male soccer players volunteered to take part in our study, which was approved by Liverpool John Moores University Ethics Committee and complied with the Declaration of Helsinki. Participants provided written informed consent prior to being assigned to two groups according to their level of competition. The elite group (n=23; age, 18.1 ± 1.0 yrs; height, 182.5 ± 7.3 cm; weight, 77.2 ± 10.1 kg) included one goalkeeper, nine defenders, five midfielders and eight forwards from an English Premier League football academy, who regularly participated at U18 and U21 level. The non-elite group (n=20; age, 22.3 ± 2.7 yrs; height, 175.0 ± 5.8 cm; weight, 72.9 ± 7.3 kg) included one goalkeeper, five defenders, six midfielders and eight forwards, who participated in at least one hour per week of competitive soccer (11-a-side or five-a-side), and one hour per week of soccer-specific or fitness-based training. Non-elite participants were excluded if they did not meet these inclusion criteria or had previously played soccer at academy, semi-professional, or professional level. All participants had been free of any injury to the lower body within the previous three months and had not previously sustained a serious knee or ankle injury which may be aggravated during testing procedures, or cause an adverse effect on performance. Participants were fully familiarised with all testing procedures in a separate session and were asked to complete a physical activity and health questionnaire prior to the study for screening purposes.

All participants attended the laboratory on two separate occasions with at least 72 hours between each session. In order to minimise the influence of previous activity, the testing was performed following a period of at least 48 h without any high intensity multi-directional exercise which included any form of soccer match-play activity. All participants confirmed they had not partaken this form of exercise by completing a questionnaire before each session. The fitness coach for the elite soccer players was also contacted to verify this. The first session enabled the participants to be familiarised with the assessment protocol, and was also used to determine the superior jumping leg [defined as the limb that produced the highest ground reaction force during a unilateral vertical countermovement jump (UV CMJ)]. During the second session, the participants performed all CMJ and maximal voluntary isometric contraction (iMVC) assessments.

On arrival at the laboratory for the second session, all participants had their height and body mass measured. Prior to the CMJ assessment protocol, a 10 min standardized warm-up consisting of 5 min of jogging at 13 $km \cdot h^{-1}$ on a motorised treadmill (LOKO S55, Woodway GmbH, Steinackerstraße, Germany) set at a 0° incline, followed by one practice of each CMJ. Participants performed three trials of each CMJ (with 60 seconds recovery between trials within a single CMJ type, and 180 s between jump types), thus performing a total of 21 CMJs (3 bilateral jumps and 9 unilateral jumps on each leg). During each CMJ, participants were instructed to keep their arms akimbo. Prior to each unilateral CMJ, participants were instructed to flex their alternate contralateral hanging leg to 90 degrees at the hip and knee joints (Hewitt et al., 2012). Participants were instructed to jump as far as possible in the designated direction (upwards, forwards or sidewards medial) landing on their jumping leg but allowing the contralateral limb to touch the ground to provide balance after the initial landing. A successful unilateral CMJ was registered if the participant performed the jump without allowing their knees to cross (i.e. the femur of the alternate hanging leg was not allowed to cross beyond parallel relative to the femur of the jumping leg). Unilateral CMJs in different directions have previously been shown to have acceptable test-retest reliability [11]. All CMJs were visually demonstrated to the participants by the investigator.

Vertical ground reaction force (VGRF), horizontal anterior-posterior ground reaction force (HGRF), and mediolateral ground reaction force (MGRF) data were collected using an in-ground 0.9×0.6 m^2 force platform (9287C, Kistler Instruments Ltd., Winterhur, Switzerland), at a sampling rate of 1000 Hz. Using procedures explained in detail elsewhere [11], a custom-designed macro analysis programme [18] was used to calculate the jump height, vertical take-off velocity, peak vertical power (V-power) and peak vertical ground reaction force (VGRF) for all vertical jumps; and the resultant take-off velocity, peak VGRF, V-power, peak HGRF/MGRF and peak horizontal-forward/medial power (H-power/M-power) for UH and UM CMJ. Unilateral horizontal-forward and UM CMJ projectile range (PR) were calculated using equations of constant acceleration [19]. This variable was used as the criterion performance measure for these jumps as unlike when measuring jump distance using a measuring tape, PR is not affected by airborne and landing technique and better represents the propulsive phase of the jump [20]. To reduce statistical analysis to a meaningful data set and allow comparisons with other research, only performance variables measured in the superior jumping leg were analysed. The jump trial with the best performance (greatest height or PR) was used for subsequent analysis. All kinetic variables were allometrically scaled to body mass ($BM^{0.67}$).

In order to normalize EMG data collected during CMJs, knee extension (KE) and knee flexion (KF) iMVCs were assessed after the CMJs on an isokinetic dynamometer (Biodex 3, Medical Systems, Shirley, NY, USA), according to procedures documented previously [21]. Data were analysed using AcqKnowledge data acquisition software (Biopac Systems Inc., Goleta, CA, USA). All measurements were performed in the superior jumping leg only.

During all CMJ and iMVC assessments, surface EMG activity was recorded from the VL and BF muscles of the superior jumping leg using self-adhesive Ag/AgCl bipolar surface electrodes (10 elite and 9 non-elite participants; 2-cm inter-electrode distance, 1-cm circular conductive area; product 72000-S/25, Neuroline 720, Ambu, Denmark) placed in accordance with SENIAM guidelines [22] for application, location, and orientation**.** Reference electrodes were placed on the patella (Biopac Systems EMG transmitter) or on the cervical vertebra 7 (Motion Lab Clinical EMG Systems). To reduce skin impedance, the site of electrode placement was shaved, abraded with fine sandpaper and cleansed with alcohol wipes. The EMG signal was sampled simultaneously with ground reaction force data at a rate of 1000 Hz, and was transmitted in real time via a wired transmitter (Biopac TEL100M-C 4-CH

Transmitter, Biopac Systems Inc., Goletta, USA); or via Motion Lab clinical EMG System with built-in wired surface electrodes (13 elite and 11 non-elite participants; MA-300 EMG System, Motion Lab Systems, Inc., Los Angeles, USA).

All original raw EMG signals were band-pass filtered (20-500 Hz), then digitally processed using a centred root mean square algorithm with a 50 ms time constant. The peak EMG signal amplitude measured over a 500 ms time epoch centred upon the peak force level during the highest of the 3 KE and KF iMVC trials for each muscle was recorded. These data were used to normalize the EMG data during soccer specific assessments of power. For the CMJ assessments, the EMG signals digitally processed using a centred root mean square algorithm with a 50 ms time constant. Muscle activity was reported as the peak EMG amplitude during the downward and upward phases. Peak amplitudes were normalized to each participant's peak RMS EMG value obtained during the iMVC trials and are reported as a percentage of the iMVC.

The mean and standard deviation (*s*) were calculated for all variables. All data was tested for normality using the Shapiro Wilks normality test. Main effects for CMJ type or muscle activation, and athlete status, and an interaction between the two, were investigated using two separate 2-way mixed ANOVAs [within factor: CMJ type (4 jumps) or muscle activation % iMVC (4 jumps); between factor: athlete status (2 groups)]. Post-hoc analysis was then performed using paired *t*-tests with Bonferroni-correction to determine differences between specific kinetic and temporal variables from different jumps, and muscle activation levels between different jumps.

Multiple linear stepwise regression models were performed between respective jump performance measures (jump height was used to measure BV and UV CMJ performance; while PR was used to measure UH and UM CMJ performance) and the kinetic and temporal variables. From these analyses, the best multiple predictor model of jump performance in each direction was derived. The forward stepwise linear regression model began with the most significant predictor and continued to add or delete variables until none significantly improved the fit.

To identify which CMJs may be used to distinguish between elite and non-elite athlete status, differences in the dependent variables that were not comparable between jump types (height, PR, H-power, M-power), were assessed using independent samples *t*-tests to assess the difference between the two groups only. Statistical analysis was completed using SPSS version 21 (SPSS Inc., Chicago, IL), and the significance level was set at $p < 0.05$.

Results

Comparisons of peak V-power among the four jumps revealed that there were significant differences between all CMJs (BV > UV > UH; BV > UM; UV > UM; $p < 0.001$; Table 1) but not between UH and UM CMJ ($p = 1.000$; Table 1). The resultant take-off velocity was significantly different ($p < 0.001$; Table 1) between all CMJs (BV > UH > UM > UV).

Peak BF EMG was greater during the downward phase of the UH in comparison to BV ($p < 0.001$; Table 1), UV ($p < 0.001$; Table 1) and UM CMJ ($p < 0.001$; Table 1). Similarly, UH CMJ produced significantly greater levels of peak BF EMG during the upward phase in comparison to the BV ($p < 0.001$; Table 1), UV ($p = 0.001$; Table 1) and UM CMJ ($p < 0.001$; Table 1). There were no differences in peak BF EMG or VL EMG between BV, UV and UM CMJ ($p \geq 0.296$; Table 1).

Predictive models for the four multidirectional jumps are shown in Table 2. Peak power in the direction of the jump was the best single predictor of jump performance accounting for 61.4%, 64.8%, 54% and 56% of BV CMJ height, UV CMJ height, UH CMJ PR and UM CMJ PR, respectively.

Projectile range was significantly greater in elite than non-elite players for UH CMJ ($p < 0.001$; Fig. 1) only. Peak V-power was significantly greater in elite than non-elite players for all CMJs ($p \leq 0.032$; Fig. 1) except for BV ($p = 0.197$; Fig. 1), which did not show any significant differences in performance variables between elite and non-elite players ($p \geq 0.109$, Fig. 1).

Discussion

The main aims of our study were to investigate differences in the kinetic, kinematic and EMG variables between BV CMJ and unilateral CMJs in different directions, establish the best predictors of all CMJ performance, and investigate differences in CMJ performance between elite and non-elite soccer players. We are the first to report that unilateral CMJs require different hamstring activation levels and muscular power capabilities, and that the best kinetic predictor of CMJ performance in soccer players is peak power in the direction of the jump. Moreover, our study shows that BV CMJ performance was similar between elite and non-elite soccer players but unilateral jump performance in different directions was greater in elite soccer players.

It is important that any series of similar tests selected for elite athlete populations assesses separate physical capabilities and are therefore, able to provide the greatest information linked to performance in the shortest amount of time. In accordance with results in non-elite team sport athletes [11], when peak V-power was compared during the four different types of jumps used in our study, there were significant differences between jumps with the exception of the UH and UM CMJ. Furthermore, UH and UM CMJs achieved a greater velocity at take-off than the UV CMJ. This may be because when the body is projected in the horizontal direction, the mechanical constraint of gravity opposing motion is lower than the load represented by body weight during a vertical jump [23, 24]. Our study is the first to show that UH, UM and UV CMJs assess direction-specific capabilities in terms of vertical power and take-off velocity in soccer players.

When determining the specificity of different jump assessments, it is also useful to compare muscle activation profiles. Knowledge of muscle activation during unilateral CMJs in different directions can give an insight into the contribution of specific muscles to CMJ performance in each direction. Although our muscle activation data were assessed using two different EMG systems, the EMG signals during jumping actions were normalised to EMG of the same muscle during a maximum isometric voluntary contraction, where that muscle was acting as the agonist (using the same EMG system). Therefore, we maintain that this methodological issue did not compromise our findings. Our EMG data showed that UH CMJ required greater BF activation during the upward and downward phases in comparison to all other CMJs. These results are in line with findings from a previous study investigating horizontal-forward and vertical bilateral jumps [15], and also support previous reports of a greater magnitude of hip joint flexion and more vigorous use of the hip joint during horizontal-forward compared to vertical jumps [13, 15]. Furthermore, a similar upward phase peak VL activation during UV and UH CMJ is also in accordance with previous research comparing bilateral vertical and horizontal-forward jumps [15]. Therefore, our study is the first to show that the VL has a similar contribution to jump performance in all directions, but the BF plays a greater role in determining UH CMJ performance.

It is useful to establish which muscle groups contribute to jump performance in each direction, but knowledge of which kinetic and kinematic variables best predict unilateral CMJ performance in each direction would give an insight into the specific performance variables to monitor and train for improved unilateral CMJ performance [11]. Our results showed that peak V-power explained 61% and 65% of the variability in BV and UV CMJ height, respectively, which is in agreement with previous research [11, 16, 25]. Peak H-power and peak M-power were the best predictors for UH and UM CMJ PR, accounting for 54% and 56% of the shared variance, respectively. Subsequently, the practitioner should aim to assess and improve peak power in the direction of the jump when monitoring and developing direction-specific jump performance.

Prior to assessing and prescribing training interventions for elite soccer players, it is imperative to determine whether the capabilities assessed are characteristics of elite performance. There was no difference in BV CMJ height and BV CMJ peak V-power between elite and non-elite players, thus possibly suggesting that this assessment cannot differentiate between soccer performance levels and should not be included in elite soccer fitness testing protocols as an assessment of muscular power [5]. This is in agreement with some [17, 26] but not all previous research [27]. Peak V-power during the UV CMJ was significantly greater in elite than non-elite players, thus suggesting that this variable is a determinant of elite soccer performance. Elite players also performed significantly greater UH CMJ PR, UH CMJ peak V-power and UM CMJ peak V-power than non-elite soccer players. Considering most of the maximal actions performed during elite youth soccer match play were maximal accelerations directed in the horizontal-forward or mediolateral directions [6, 28], our findings could suggest that UH and UM CMJ are specific indicators of elite soccer player status. However, it cannot be discounted that the elite soccer players outperformed non-elite players at UV, UH and UM jumping tasks due to their habitual soccer training.

Conclusion

Unilateral CMJs assess direction-specific kinetic, kinematic and electromyographic components. The UH CMJ required greater resultant take-off velocity and hamstring activation than UV and UM CMJ, while peak power in the jump direction is the best predictor of unilateral CMJ performance in soccer players. In comparison to non-elite players, elite soccer players performed better in UV, UH and UM but not in BV CMJ assessments. Thus, UV, UH and UM CMJs, which assess independent direction specific leg power qualities, could potentially differentiate elite from non-elite soccer playing status and could therefore be included in elite soccer power profiling assessment protocols.

Practical Implications

- Unilateral CMJs in different directions, but not bilateral vertical countermovement jump, should be included in soccer-specific maximal power assessment protocols, as well as talent ID and development programmes.
- When monitoring and developing direction-specific jump performance, the practitioner should aim to assess and improve peak power in the direction of the jump.
- Training interventions for improving unilateral horizontal-forward jump performance should focus specifically on the hamstring muscle group.

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References

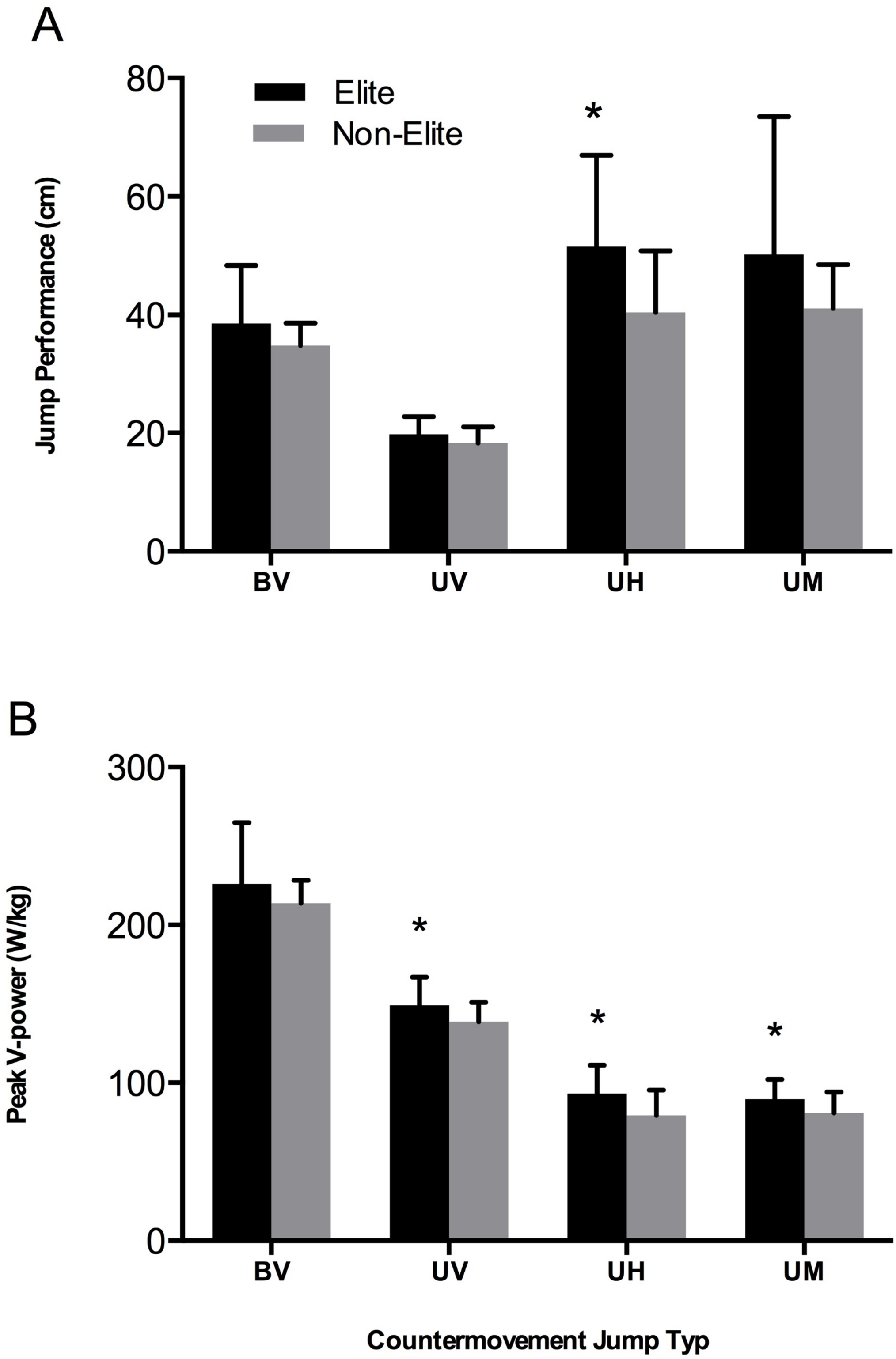
1. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. *Sports Med.* 2011; 41(1):17-38. DOI: 10.2165/11537690-000000000-00000.
2. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. *J Sports Sci.* 2012; 30(7):625-631. DOI: 10.1080/02640414.2012.665940.
3. Chelly MS, Ghenem MA, Abid K, et al. Effects of in-season short-term plyometric training program on leg power, jump-and sprint performance of soccer players. *The Journal of Strength & Conditioning Research.* 2010; 24(10):2670-2676.
4. Rønnestad BR, Nymark BS, Raastad T. Effects of in-season strength maintenance training frequency in professional soccer players. *The Journal of Strength & Conditioning Research.* 2011; 25(10):2653-2660.
5. Premier-League. *Elite Player Performance Plan*, London, PL; 2011.
6. Bradley PS, Di Mascio M, Peart D, et al. High-intensity activity profiles of elite soccer players at different performance levels. *J Strength Cond Res.* 2010; 24(9):2343-2351. DOI: 10.1519/JSC.0b013e3181aeb1b3.

7. Withers R, Maricic Z, Wasilewski S, et al. Match analysis of Australian professional soccer players. *J Hum Mov Stud.* 1982; 8:159-176.
8. Reilly T, Thomas V. A motion analysis of work-rate in different positional roles in professional football match-play. *Journal of human movement studies.* 1976; 2(2):87-97.
9. Anderson L, Orme P, Michele RD, et al. Quantification of Seasonal-Long Physical Load in Soccer Players With Different Starting Status From the English Premier League: Implications for Maintaining Squad Physical Fitness. *International journal of sports physiology and performance.* 2016; 11(8):1038-1046.
10. Nedelec M, McCall A, Carling C, et al. Recovery in soccer: part I - post-match fatigue and time course of recovery. *Sports Med.* 2012; 42(12):997-1015. DOI: 10.2165/11635270-000000000-00000.
11. Meylan CM, Nosaka K, Green J, et al. Temporal and kinetic analysis of unilateral jumping in the vertical, horizontal, and lateral directions. *J Sports Sci.* 2010; 28(5):545-554. DOI: 10.1080/02640411003628048.
12. Hewit JK, Cronin JB, Hume PA. Asymmetry in multi-directional jumping tasks. *Phys Ther Sport.* 2012; 13(4):238-242. DOI: 10.1016/j.ptsp.2011.12.003.
13. Nagano A, Komura T, Fukashiro S. Optimal coordination of maximal-effort horizontal and vertical jump motions–a computer simulation study. *Biomedical engineering online.* 2007; 6(1):1-9.
14. Jones SL, Caldwell GE. Mono-and biarticular muscle activity during jumping in different directions. *Journal of Applied Biomechanics.* 2003; 19(3):205-222.
15. Fukashiro S, Besier TF, Barrett R, et al. Direction control in standing horizontal and vertical jumps. *International Journal of Sport and Health Science.* 2005; 3(Special_Issue_2005):272-279.
16. Markovic G, Jaric S. Is vertical jump height a body size-independent measure of muscle power? *Journal of sports sciences.* 2007; 25(12):1355-1363.
17. Cometti G, Maffiuletti NA, Pousson M, et al. Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. *Int J Sports Med.* 2001; 22(1):45-51. DOI: 10.1055/s-2001-11331.
18. Vanrenterghem J, De Clercq D, Cleven PV. Necessary precautions in measuring correct vertical jumping height by means of force plate measurements. *Ergonomics.* 2001; 44(8):814-818.
19. Grimshaw P, Fowler N, Lees A, et al. *BIOS Instant Notes in Sport and Exercise Biomechanics*, Garland Science; 2004.
20. Meylan CM, Cronin JB, Oliver JL, et al. The reliability of jump kinematics and kinetics in children of different maturity status. *The Journal of Strength & Conditioning Research.* 2012; 26(4):1015-1026.
21. Walsh M, Boling MC, McGrath M, et al. Lower extremity muscle activation and knee flexion during a jump-landing task. *Journal of athletic training.* 2012; 47(4):406.
22. Freriks B, Hermens H, Disselhorst-Klug C, et al. The recommendations for sensors and sensor placement procedures for surface electromyography. *Seniam.* 1999; 8:13-54.

23. Samozino P, Edouard P, Sangnier S, et al. Force-velocity profile: imbalance determination and effect on lower limb ballistic performance. *Int J Sports Med.* 2014; 35(6):505-510. DOI: 10.1055/s-0033-1354382.
24. Samozino P, Rejc E, Di Prampero PE, et al. Optimal force-velocity profile in ballistic movements--altius: citius or fortius? *Med Sci Sports Exerc.* 2012; 44(2):313-322. DOI: 10.1249/MSS.0b013e31822d757a.
25. Dowling JJ, Vamos L. Identification of kinetic and temporal factors related to vertical jump performance. *Journal of Applied Biomechanics.* 1993; 9:95-95.
26. Wisloff U, Helgerud J, Hoff J. Strength and endurance of elite soccer players. *Medicine and science in sports and exercise.* 1998; 30(3):462-467.
27. Arnason A, Sigurdsson SB, Gudmundsson A, et al. Physical fitness, injuries, and team performance in soccer. *Med Sci Sports Exerc.* 2004; 36(2):278-285. DOI: 10.1249/01.MSS.0000113478.92945.CA.
28. Varley MC, Aughey RJ. Acceleration profiles in elite Australian soccer. *International journal of sports medicine.* 2013; 34(1):34-39. DOI: 10.1055/s-0032-1316315.

Figure Captions

Figure 1 Jump performance (BV and UV: vertical height; UH and UM: projectile range) (A) and peak V-power (B) of elite (*black bars*; n = 23) and non-elite (*grey bars*; n = 20) soccer players during unilateral countermovement jumps in different directions. Data are mean ± SD. $^{*}p < 0.05$, $^{**}p < 0.01$.


A
Jump Performance (cm)
80
60
40
20
0
Elite
Non-Elite
*
BV
UV
UH
UM
B
Peak V-power (W/kg)
300
200
100
0
*
*
*
BV
UV
UH
UM
Countermovement Jump Typ

Tables

Table 1 Between jump differences in kinetic, kinematic and peak electromyographic (EMG) variables in soccer players (n=43); mean ± SD.

	BV CMJ	UV CMJ	UH CMJ	UM CMJ
Peak V-Power ($W \cdot Kg^{-1}$)	220.21 ± 30.1[bcd]	144.15 ± 16.18[acd]	86.73 ± 18.28[ab]	85.48 ± 13.45[ab]
Resultant Take-off Velocity ($m \cdot s^{-1}$)	2.666 ± 0.247[bcd]	1.926 ± 0.152[acd]	2.376 ± 0.447[abd]	2.229 ± 0.431[abc]
Downward Phase Duration (s)	0.588 ± 0.171	0.561 ± 0.156	0.585 ± 0.198	0.697 ± 0.306
Upward Phase Duration (s)	0.264 ± 0.031[c]	0.321 ± 0.233	0.228 ± 0.042[ad]	0.248 ± 0.048[c]
Downward Phase VL_{act} (% iMVC EMG)	114.27 ± 82.63	105.87 ± 56.78	121.85 ± 56.75	106.07 ± 53.08
Downward Phase BF_{act} (% iMVC EMG)	44.91 ± 37.87[c]	53.56 ± 28.64[c]	120.96 ± 54.20[abd]	48.94 ± 30.55[c]
Upward Phase VL_{act} (% iMVC EMG)	183.66 ± 97.23	192.95 ± 114.99	167.47 ± 79.15	163.26 ± 79.02
Upward Phase BF_{act} (% iMVC EMG)	83.14 ± 40.66[c]	89.37 ± 45.12[c]	127.05 ± 60.02[abd]	81.26 ± 56.00[c]

BF_{act}, biceps femoris muscle activation; BV CMJ, bilateral vertical countermovement jump; iMVC, isometric maximal voluntary contraction; UV CMJ, unilateral vertical countermovement jump; UH CMJ, unilateral horizontal countermovement jump; UM CMJ, unilateral medial countermovement jump; VL_{act}, peak vastus lateralis muscle activation.

Post hoc bonferroni test: [a] Significantly different to BV CMJ, [b] Significantly different to UV CMJ, [c] Significantly different to UH CMJ, [d] Significantly different to UM CMJ ($p < 0.05$)

Table 2 Significant kinetic and kinematic predictors of jump performance in elite (n=23) and non-elite (n=20) players; mean ± SD.

Resultant GRF (N)	BV CMJ	UV CMJ	UH CMJ	UM CMJ
Predictor 1	Peak V-Power	Peak V-Power	Peak H-Power	Peak M-Power
Model significance	< 0.001	< 0.001	< 0.001	< 0.001
R^2	0.641	0.648	0.540	0.560
Predictor 2	Duration upward phase	Peak VGRF	Peak V-Power	Peak V-Power
Model significance	< 0.001	< 0.001	< 0.001	< 0.001
R^2	0.783	0.896	0.767	0.740
Change in R^2	0.143	0.248	0.227	0.180
F Change significance	< 0.001	< 0.001	< 0.001	< 0.001
Predictor 3			Peak VGRF	Peak VGRF
Model significance			< 0.001	< 0.001
R^2			0.901	0.859
Change in R^2			0.134	0.119
F Change significance			< 0.001	< 0.001
Predictor 4				Duration upward phase
Model significance				0.001
R^2				0.894
Change in R^2				0.035
F Change significance				0.001
Predictor 5				Peak Rel. MGRF
Model significance				< 0.001
R^2				0.907
Change in R^2				0.013
F Change significance				0.029
Predictor 6				Duration upward phase
Model significance				< 0.001
R^2				0.920
Change in R^2				0.013
F Change significance				0.022

BV CMJ, bilateral vertical countermovement jump; UV CMJ, unilateral vertical countermovement jump; UH CMJ, unilateral horizontal countermovement jump; UM CMJ, unilateral medial countermovement jump; V-power, relative vertical power; HGRF, horizontal ground reaction force; H-power, relative horizontal power; MGRF, medial ground reaction force; M-power, relative medial power; VGRF, vertical ground reaction force.