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Alexander Neale Eagles
Faculty of Science, Health, Education, and Engineering, University of the Sunshine Coast, Maroochydore, Queensland, Australia

Mark Gregory Leigh Sayers
Faculty of Science, Health, Education, and Engineering, University of the Sunshine Coast, Maroochydore, Queensland, Australia

Dale Ingham Lovell
Faculty of Science, Health, Education, and Engineering, University of the Sunshine Coast, Maroochydore, Queensland, Australia

Correspondence
Alexander Neale Eagles
Faculty of Science, Health, Education, and Engineering, University of the Sunshine Coast, Maroochydore, Queensland, Australia

Ground reaction force and joint kinematic comparison between the standing vertical jump and the standing broad jump

Alexander Neale Eagles, Mark Gregory Leigh Sayers and Dale Ingham Lovell

Abstract
Background: The standing vertical jump (SVJ) and standing broad jump (SBJ) are athletic assessment and talent identification tools. Limited biomechanical comparison of the styles exists. The aim of this project was to assess the differences in kinetics and kinematics between SVJ and SBJ.
Materials and Methods: Ten semi-professional soccer players (22.4±3.1 years) volunteered to participate in the study. Participants completed six SVJ and six SBJ on a force platform with reflective markers attached for motion capture analysis. Ground reaction forces (GRF) and kinematic hip, knee and ankle data was then analysed.
Results: SVJ height displayed a significant moderate relationship with SBJ length ($r = 0.80$, $P = .006$). There was a moderate relationship found between SBJ distance and SBJ resultant GRF ($r = 0.71$) and a weak relationship found between SVJ height and SVJ resultant GRF ($r = -0.1186$). There was a non-significant relationship between knee and hip extension velocities between jumping styles ($r = 0.04$, $P = .920$), ($r = 0.56$, $P = .091$). A strong relationship was found between jumps for ankle plantar flexion velocities ($r = 0.90$, $P < .001$).
Conclusions: The SVJ and SBJ do not measure comparable attributes of participants and should be considered separate testing and training options.

Keywords: Biomechanics, jumping, sport.

1. Introduction
The standing vertical jump (SVJ), a jump for height, and standing broad jump, a jump for distance, (SBJ) are used frequently throughout the athletic community as part of talent identification and athletic performance testing [1]. Traditionally the SVJ is used more often than the SBJ [2], however recent research has suggested that the latter may be more applicable to the athletic performance [1]. For example, although McGee *et al.* (2003) found a strong relationship between SVJ and SBJ performance; their research indicated that the SBJ was a better predictor of sprinting ability [1]. The latter is particularly pertinent as sprinting ability is considered an essential component to performance in many field-based sports [1, 3, 4]. Similarly these activities are often used as training options [5], however the predominant use of the SVJ may not be the most appropriate as developing explosive strength in the vertical plane is unlikely to optimize requirements in the horizontal plane required in many sports [6].
Fundamentally performance in the SVJ and SBJ are used to provide an indication of lower limb power and explosive strength [1, 7, 8]. Consequently the jumping style that offers the best insight into these lower limb attributes represents the most appropriate testing option. While previous research has identified a strong relationship between SVJ and SBJ performance in terms of height and distance respectively [1], there is a lack of research that has reported on the similarities, and/or differences in lower limb mechanics between these jump types. From a biomechanical testing perspective, the manner in which each lower limb segment is involved in contributing to the jumping movement is of interest to allow an understanding of whether lower limb kinematics contributes comparably between the jumping styles.
Athletic based testing and monitoring is founded on the premise that a given test will allow meaningful insight into a participant's ability to perform in a given sport.

Therefore it is important to be aware if the commonly employed SVJ and SBJ measure different attributes. Thus, the aim of this project was to assess the differences in kinetics and kinematics between SVJ and SBJ. Specifically we examined the interrelationships between lower limb kinematics and the ground reaction force and how the nature of this interaction influences jump performance. The hypotheses for this study were: hip, knee and ankle angular velocities would contribute differently between the SVJ and SBJ; and ground reaction force would be closely related to performance (height/distance).

2. Materials and Methods

Ten semi-professional soccer players volunteered to participate in the studies (22.4 ±3.1 years, 1.79 ±0.064 m height, 73.2 ±9.1 kg weight). This population group was chosen to ensure they were familiar with SVJ and SBJ performance testing. The players had participated in soccer for 11.1±4.2 years and regularly performed 3-5 training sessions per week and 1 game per week during the playing season. Following the screening procedure and the completion of a medical history questionnaire all participants were deemed healthy and free from any cardiovascular or neuromuscular irregularities. Prior to participation, the experimental procedures and potential risks were explained to the participants and all provided written informed consent. Data was collected following preseason training but before match-play to minimize the effect of injuries and maximize training status. The study was approved by the Institutional Research Ethics Committee in accordance with the Declaration of Helsinki.

Participants attended a motion analysis laboratory on two separate occasions to participate in a familiarization session and a testing session. The test session consisted of a warm-up that included a series of cycle ergometry and dynamic range of movement activities before participants randomly completed six SVJs and six SBJs. Both jumps incorporated a countermovement and followed standard test protocols [7], [9]. Ground reaction force (GRF) data were sampled using two multicomponent force platforms (Bertec, Columbus, Ohio, USA) at 1000 Hz, with the duration of the data collection period set at 3 seconds. Force platform data were then processed using Visual 3D computer software (Visual3D, C-Motion, Inc. Maryland, USA), with all GRF data presented as the vector resolution (RGRF) of the vertical (Fz) and horizontal (Fy) forces. The force-time data were filtered using a fourth-order Butterworth low-pass filter with the cutoff frequency of 25 Hz.

In order to collect kinematic data retro-reflective markers were placed bilaterally on each participant's navicular, medial and lateral malleoli, the superior distal ends of the 1st and 5th metatarsals, medial and lateral femoral epicondyles, greater trochanters, anterior and posterior superior iliac spines and a single marker placed on the spinous process of S2 for center of mass (COM) approximation (Figure 1) [10, 11]. Additionally, four marker clusters were positioned laterally mid segment on both upper and lower legs. The position of all markers was tracked at 500 Hz using a 9-camera motion capture system (Qualisys AB, Gothenburg, Sweden). These data were then modeled using standard procedures [12] in 3D using standard biomechanical software (Visual3D, C-Motion, Inc. Maryland, USA) to construct a seven-segment rigid body model of the lower limbs and pelvis (Figure 1). A global reference system was established with the positive y-axis directed anteriorly, the x-axis perpendicular and to the right of the y-axis and the positive z-axis pointing vertically. Ankle, knee and hip kinematics were calculated relative to the global reference system with movements defined using Euler angle calculations as angular rotation about each segments x, y, z axes. All rotations were defined using the right hand orthogonal rule such that flexion, adduction and internal rotation are positive rotations of the distal segment about the joint's respective the x, y and z-axes. The movement angles were normalized using mean angles from a static capture. Standard inverse dynamics procedures were used to calculate the net joint moments and net muscle powers at the hip, knee and ankle joints, with negative net muscle torques representing extensor torques. Jump height was calculated from the kinematic data as the difference between the height of the S2 marker during normal stance (taken from the static trial) and the maximum height of this marker during the jump. Hip/knee and Knee/ankle angle-angle graphs were used to determine inter joint coordination patterns.

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 11.0; SPSS, Inc., Chicago, IL, USA). A one-way ANOVA was used to compare differences in peak RGRF and hip, knee and ankle peak angular velocities, torques and powers between jump types. Cohen's effect sizes were also calculated between each of the joint angular velocities, torques and powers as a measure of the relative magnitude of any differences in these variables between jump types. The levels of effect size were deemed *small* (d = 0.2), *medium/moderate* (d = 0.5), or *large* (d = 0.8) [13]. Pearson's Product Moment Correlation analyses were used to determine the relationships between variables and SVJ height and SBJ distance and to also determined the relationships between performances in the two jump types. All data from our laboratory involving identified a minimum sample size of 10 was established to achieve a statistical power of 80%.

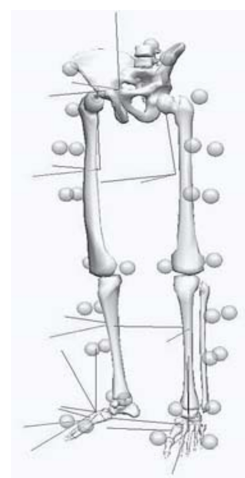

Fig 1: Motion Capture system lower body construct and marker placement

3. Results

A significant strong relationship was found between SVJ height and SBJ length (r = 0.80, P = .006) (Table 1), although a weak non-significant relationship was found between SVJ RGRF and SBJ RGRF (r = - 0.31, P= 0.362). There was a moderate significant relationship found between SBJ distance and SBJ RGRF (r = 0.71, P= 0.021) and a weak non-significant relationship found between SVJ height and SVJ RGRF (r = -0.12, P= 0.737). Peak hip extension velocity, peak hip extension torque, peak knee extension torque and peak planter flexion torque variables differed significantly between jumping styles (Table 2 and 3).

The results of the present study demonstrate that the hip and knee segments contribute in different capacities to the SVJ compared to the SBJ, while the ankle contributes comparably with respect to angular velocity and power to it produces significantly more torque in the SBJ (Table 3). A significant strong relationship was found between peak ankle (r = 0.90, *P*< .001) plantar flexion velocities for the two jump types (Figures 2c). Conversely non-significant moderate and weak relationships were found between peak hip (r = 0.56, *P* = .091) and knee (r = 0.04, *P* = .920) extension velocities across the two jumps (Figures 2a and 2b).

Analysis of the sagittal hip/knee and knee/ankle angle-angle graphs (Figure 3) indicates that the SBJ involved greater hip extension than during SBJ, while the SVJ achieves greater knee flexion with the patterns of movement between these segments remaining similar (Figure 3).

Table 1: Comparison between SVJ and SBJ: Resultant GRF, height and distance. Data presented as mean and standard deviations

Participant	SVJ RGRF	Height (metres)	SBJ RGRF	Distance (metres)
1	1.06 (± 0.07)	0.480 (± 0.04)	0.96 (± 0.05)	2.293 (± 0.10)
2	1.27 (± 0.05)	0.572 (± 0.07)	1.23 (± 0.10)	2.417 (± 0.13)
3	1.09 (± 0.05)	0.468 (± 0.04)	1.10 (± 0.12)	2.324 (± 0.07)
4	1.09 (± 0.08)	0.465 (± 0.05)	1.04 (± 0.04)	2.298 (± 0.04)
5	0.92 (± 0.02)	0.672 (± 0.09)	1.27 (± 0.08)	2.722 (± 0.09)
6	1.07 (± 0.06)	0.521 (± 0.03)	1.21 (± 0.09)	2.339 (± 0.15)
7	2.04 (± 0.07)	0.464 (± 0.09)	1.05 (± 0.09)	2.154 (± 0.17)
8	2.21 (± 0.08)	0.573 (± 0.04)	1.08 (± 0.06)	2.386 (± 0.08)
9	1.36 (± 0.11)	0.589 (± 0.05)	1.24 (± 0.05)	2.429 (± 0.07)
10	1.22 (± 0.09)	0.674 (± 0.06)	1.17 (± 0.06)	2.400 (± 0.10)

Table 2: Mean (±1SD) ground reaction force and peak lower limb extension velocity SVJ and SBJ. Results include level of statistical significance and effect size (Cohen d).

Variable	Variable	Mean (±SD)	*P*	*d*
Resultant GRF (N)	SVJ	865.4 (±142.5)	0.246	0.51
	SBJ	969.4 (±251.1)		
Relative GRF (BW)	SVJ	1.14 (±0.10)	0.224	0.56
	SBJ	1.31 (±0.42)		
Hip Angular Velocities (deg/s)	SVJ	-528.4 (±66.9)	0.003*	1.53
	SBJ	-428.4 (±63.9)		
Knee Angular Velocities (deg/s)	SVJ	-623.5 (±85.2)	0.113	0.75
	SBJ	-672.2 (±35.3)		
Ankle Angular Velocities (deg/s)	SVJ	-578.4 (±62.5)	0.180	0.62
	SBJ	-531.7 (±85.6)		

* Indicates a significant difference at (*P*<0.05)

Table 3: Mean (±1SD) peak lower limb extension torque and power data for SVJ and SBJ. Results include level of statistical significance, effect size (Cohen d) and Pearson's product moment correlations. Values are relative to Body weight

Variable	Variable	Mean (±SD)	*P*	*d*	*r*
Peak Hip Extension Torque (N·m/kg)	SVJ	-3.06 (±1.42)	0.031*	0.89	-0.229
	SBJ	-2.12 (±0.48)			
Peak Hip Extension Power (W/kg)	SVJ	8.68 (±9.16)	0.12	4.68	0.488
	SBJ	6.87 (±1.39)			
Peak Knee Extension Torque (N·m/kg)	SVJ	-1.75 (±1.09)	0.014*	1.069	0.268
	SBJ	-0.92 (±0.13)			
Peak Knee Extension Power (W/kg)	SVJ	9.84 (±10.36)	0.097	0.604	0.582
	SBJ	5.36 (±1.67)			
Peak Ankle Planter Flexion Torque (N·m/kg)	SVJ	-2.08 (±0.55)	0.000*	2.18	0.168
	SBJ	-3.90 (±1.09)			
Peak Ankle Planter Flexion Power (W/kg)	SVJ	9.06 (±3.91)	0.459	0.047	-0.194
	SBJ	8.91 (±1.69)			

* Indicates a significant difference at (*P*<0.05)

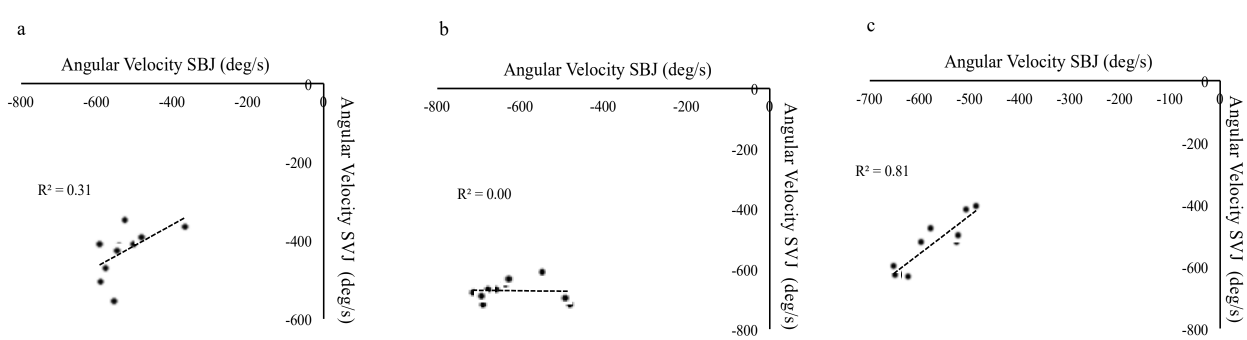

Fig 2: SVJ vs. SBJ joint maximum extension velocities (degrees per second) during the concentric phase a) Hip extension velocity SVJ vs. SMJ (*P* = .091) b) Knee extension velocity SVJ vs. SBJ (*P* = .920) c) Ankle extension velocity SVJ vs. SMJ (*P*< .001).

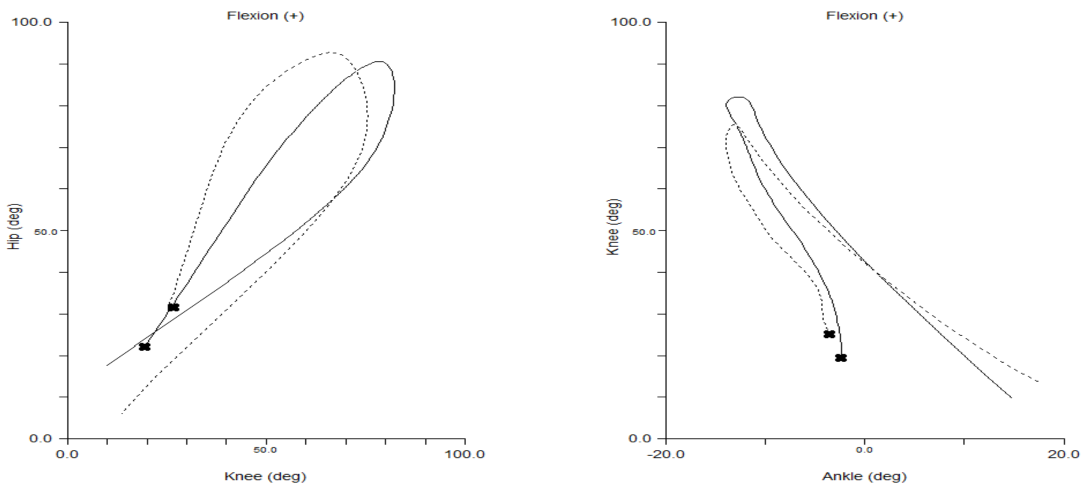

Fig 3: a) Mean hip and knee angle/angle graph for SVJ vs. SBJ, b) Mean knee and ankle angle/angle graph for SVJ vs. SBJ. * *X = jump initiation, Dotted line = SBJ, Solid line = SVJ*

4. Discussion

The purpose of this study was to assess the differences in kinetics and kinematics between SVJ and SBJ with the aim of determining whether performance in one jump is transferable to the other. Specifically we examined the interrelationships between lower limb kinematics and the ground reaction force and how the nature of this interaction influences jump performance. The results of the study indicate the SVJ and SBJ represent different movements and assess different abilities of participants.

A key finding in our study was that peak lower limb mechanics differ between the jumping styles. During the SVJ the knee achieves greater flexion range and extension torque compared to the SBJ signifying a greater contribution of knee extensors to generate force in the vertical plane (Table 3, Figure 3). Additionally, during the SBJ the hip moves through a larger range of movement and achieves a significantly greater extension torque and a more extended position at take-off compared to the SVJ (Table 3, Figure 3), suggesting a greater reliance on hip extensors to generate force. These findings are consistent with previous research, which demonstrated increased reliance of muscle that acts in hip extension during horizontal jumping and greater extension moments at the knee in the SVJ compared to the SBJ [14]. Collectively these findings show that the amount, torque and velocity of hip extension is greater in the SBJ compared to the SVJ (Figure 2 & 3). Ankle planter flexion contribution was predominantly comparable between the jumping styles, however the SBJ produced significantly greater torque compared to the SVJ. The results indicate the torque produced in planter flexion may be of greater significant to performance in the SBJ due to the horizontal nature of the movement. While previous research has suggested that muscle strength is the main determinate of SVJ performance [15], our results indicate producing larger values of force does not necessarily correlate to greater performance (Table 1). This has been demonstrated elsewhere with prior research indicating the vertical momentum developed by a system depends on the magnitude of the vertical impulse applied, and producing larger force does not ensure a greater impulse or a better result [16].

The movement of hip extension is predominately controlled by gluteus maximus, which primarily acts to extend the flexed femur at the hip joint [17]. Collectively a deep group of small muscles, which include piriformis, obturator internus, gemellus superior, gemellus inferior and quadratus femoris act to externally rotate the femur at the hip joint [17]. The more superficial larger gluteus minimus and medius abduct the femur at the hip joint and prevent excessive pelvis drop [17]. Correct activation patterns with the ability of the hip musculature to achieve positions of external rotation and abduction have been found to be more efficient for force production in dynamic movements [18, 19]. Given the gluteal muscles have been found to play such an important functional role in running, jumping and agility based movements [18, 20, 21], tests that can give an indication of functional performance are important to athletic based testing and monitoring. The SVJ and SBJ both offer meaningful insight into lower limb kinematics and kinetics that underpin performance. However given the SBJ produces greater maximum hip extension values it may be more appropriate to test this movement over the more commonly adopted SVJ. The ability to produce explosive strength in the lower limbs has been shown to have a strong relationship with performance [22, 23]. Consequently depending on the context of the athletic demands one or both of the tests may be appropriate given results demonstrate the jumping styles differ in GRF production and contribution particularly at the hip and knee respectively. Athletic and sporting performance staff need to again consider the demands of the sport and the principle of specificity [6].

5. Conclusions

Our results determined that the SVJ and SBJ while similar are not the same from a kinematic and kinetic perspective at the hip, knee and ankle. Further, GRF values demonstrated a weak correlation to performance in the SVJ suggesting it may be more difficult to control force produced in the vertical plane compared to horizontal plane. Therefore due consideration of the specificity principle [19] needs to be taken when selecting which jump to analyze. In agreeance with previous research [1] our results also indicate significant moderate correlations between SVJ and SBJ (r = 0.80, P = .006) with an 80% statistical power. Due attention of the above findings needs to be taken into consideration when applying the jumping styles as training modalities as training and performance in one jump may not be reflective of the other. Taking into consideration many field based sports require development of explosive strength in the sagittal plane, it may be more appropriate to test SBJ ability over the traditional SVJ. Conditioning and performance staff should consider the specific requirements of the sport and appreciate the two tests measure different capacities predominantly at the hip and knee joints.

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