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Research Article

THE RELATIVE IMPORTANCE OF STRENGTH AND POWER QUALITIES TO VERTICAL JUMP HEIGHT OF ELITE BEACH VOLLEYBALL PLAYERS DURING THE COUNTER-MOVEMENT AND SQUAT JUMP

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ABSTRACT

Despite the inclusion of beach volleyball as an Olympic discipline with a fully professional world tour, little research has been published that has examined the physical qualities of internationally competitive athletes. Thirty international-standard beach volleyball athletes (14 male, 16 female) performed countermovement jumps (CMJ) and squat jumps (SJ) on a force platform. Ground reaction force (GRF) was collected from three SJ separated by 30 seconds passive rest, followed by three CMJ separated by 30 seconds passive rest. Significant differences (P<0.01) between male and female groups were found for all measured GRF characteristics of the SJ and CMJ, with the exception of peak rate of force development, relative peak force, power and relative average power for the CMJ test. For centre of mass displacement (jump height) the male mean was 8.33cm greater than the female mean. The strongest positive correlations with female jump height were SJ: Relative Peak Power (*r=0.90*); CMJ: Relative Average Power (*r=0.67*) The strongest positive correlations with male jump height were SJ: Relative Peak Power (*r=0.94*); Male CMJ: Relative Peak Power (*r=0.83*). No significant difference (P<0.05) was shown between male and female stretch shortening cycle (SSC) performance as examined by a prestretch augmentation and eccentric utilisation ratios for jump height and peak power. The findings of this study suggest that relative peak and average power outputs are factors highly associated with vertical jump height in elite male and female beach volleyball players

Key words: vertical jump, performance, jumping.

Reference Data: Riggs MP, Sheppard JM. The relative importance of strength and power qualities to vertical jump height of elite beach volleyball players during the counter-movement and squat jump. *J. Hum. Sport Exerc.* 2009; 4(3):221-236

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INTRODUCTION

The increasing professionalism in the sport of beach volleyball is evident by the progression from the 1992 FIVB Beach Volleyball World series of 6 events with a total prize pool of $950,00 to the 2008 series which consisted of 39 events (19 women's / 20 men's) and a total prize pool of approximately $8,300,000 (FIVB, 2008). As such, there is a growing demand for a clearer understanding of the physical requirements to be an internationally competitive elite beach volleyball athlete. An increased understanding in this area could also contribute to improvements in training methods and provide targets for developing athletes.

A large proportion of literature that has studied the sport of volleyball has had a strong focus and emphasis on athlete vertical jump ability and in association to this their overall jump height (Gehri et al., 1998; Maffiuletti et al., 2002; Newton et al., 1999; Smith et al., 1992). Homberg and Papageorgiou (1994), showed that in one hour of game play an elite German beach volleyball player executed on average 85 jumps. This is supported by match analysis conducted on eight men's FIVB world tour matches in 2006 that showed an average team total of 145 maximal jumps during the course of play (unpublished findings). It has also been identified that the skill of blocking accounts for 27% of the total jumps within a game of beach volleyball (Giatsis, 2001). The higher an athlete can jump when performing a block jump, the greater potential for a reduction in effectiveness of the attacking opponent. In turn, the higher an athlete is capable of jumping the higher they can contact the ball above the net, allowing for improved hitting angles or attacking options. This supports the importance of maximal vertical jump height in the sport of volleyball and beach volleyball, yet little research has been done specifically looking at the vertical jump of beach volleyball athletes.

Any differences observed in jump characteristics between male and female elite beach volleyball athletes may also be of interest. Quantifying any variation between the sexes may impact training practices and potentially talent identification tools. A small number of studies have compared the difference in jump height performance between the two groups (Komi and Bosco, 1978; Mayhew and Salm, 2001), but none, to the authors knowledge, have exclusively focussed on the sport of beach volleyball. Perez-Gomez et al. (2008), examined gender difference in sprint running and cycling performance using physical education students and demonstrated that the absolute lean mass of the lower extremities were linearly related to the peak and mean Wingate test power outputs in both genders ($r = 0.66 – 0.77, P<0.01$). Males had higher lean muscle mass than females and produced higher scores accordingly. While the test used by Perez-Gomez is different to executing the skill of a vertical jump, it is a lower-body power movement and supports evidence of significant gender differences in force and power production ability (Perez-Gomez et al., 2008).

Squat Jump (SJ) and countermovement jump (CMJ) are commonly used tests to measure athlete-jumping ability. SJ is used as a measure of lower-body concentric strength/power, while CMJ as a measure of lower-body reactive strength/power (Newton et al., 2006). By using the two jump test variations it is also possible to calculate the influence of the stretch shortening cycle (SSC) (Newton et al., 2006; Walshe et al., 1996), which has been identified as a fundamental physical factor in a variety of sports (McGuigan, 2006). Different studies have used different methods to measure the effect of the SSC: Walshe et al. (1996) used an augmentation of a prior

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stretch; Young (1995a) used a measure of reactive strength; and Komi and Bosco (1978) used a force platform to calculate differences in measures of energy production during the jump phase prior to take off. The aforementioned studies suggest the two tests, SJ and CMJ, are valid and relevant measurement tools of athletic lower-body force and power ability. The fact that both these types of jumps are components in beach volleyball, and the parallel squat position is a major trait exhibited by beach volleyball athletes (Homberg and Papageorgiou, 1994), the support to use these two tests to identify any physical differences between athletes and genders is strong. Using ground reaction forces as a way to calculate variables such as peak power, maximum rate of force development, relative peak power and jump height has been validated by a variety of studies (Komi and Bosco, 1978; Garhammer et al., 1992; Young, 1995b; Baca, 1999; Aragon-Vargas et al., 2000; Dugan et al., 2004; Muramatsu et al., 2006; Sheppard et al., 2008a; Sheppard et al., 2008b).

The primary focus of this project was to collect data from international elite male and female beach volleyball athletes to quantify and assess the ground reaction force and power characteristics exhibited during a SJ and CMJ. It was hypothesised that male beach volleyball athletes would be able to demonstrate higher ground reaction force and power characteristics and achieve greater jump heights than their female counterparts and that force, velocity, and power characteristics observed in the jumps would have a strong association with jump height.

METHODS

Experimental Approach to the Problem

Descriptive data involving age, height, and mass, and force-time Squat Jump (SJ) and CMJ data were collected 14 days prior to the 2008 Swatch FIVB World Tour Adelaide Australia Open Beach Volleyball event to assess ground reaction forces in elite male and female beach volleyball players.

Subjects

Thirty athletes, comprising 16 female and 14 male elite beach volleyball athletes consented to participate in the SJ and CMJ testing, and the procedures involved in the study were in accordance with and approved by institutional ethics. The mean age, height, and body mass were: female 26.8±4.7 years, 178.2±7.1 cm, 70±4.4 kg and male 25.2±5.5 years, 192.6±3.3 cm, 91.5±4.7 kg.

Procedures

The vertical jump test required each athlete to perform three SJ with a 30s passive rest period between each effort, followed by three CMJ with a 30s passive rest period between each effort. Both the SJ and CMJ were performed in accordance with the Australian Institute of Sport's National Sport Science Quality Assurance protocols for the Assessment of Strength and Power (version 1.7). It should be noted that during analysis any SJ that demonstrated a counter movement at the start of the jump phase was not included in the final data analysis, as recommended by Sheppard and Doyle (2008b), and as such, not all SJ performed were included in the final results.

Ground reaction force data was collected using the AccuPower power assessment system (AMTI, Frappier Acceleration, USA), which uses a triaxial force plate and specifically designed data acquisition software. Sampling was set at 200 Hz. Using the

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force-time data, kinetic and kinematic data were obtained using Microsoft Excel (Microsoft Corporations, Redmond, Washington, USA), to calculate ground reaction force and power variables, with the variables of interest from the propulsive phase for this investigation being; peak and mean force, peak and mean power, peak velocity, impulse, and maximum displacement of the centre of mass (COM). Jump height in this study refers to the displacement of the centre of mass (COM) and does not take into account athlete reach height. CMJ impulse was calculated from the force-time curve, using the below equation:

$I = m.a.\Delta t$
I= Impulse
m = mass (kg)
a = acceleration (ms^{-2})
Δt = *change in time*

The change in time (Δt) was deemed as the point at which the force in the propulsive phase of the CMJ was equal to or as close to equal to the athletes body weight in newtons to the point of toe-off (figure 1).

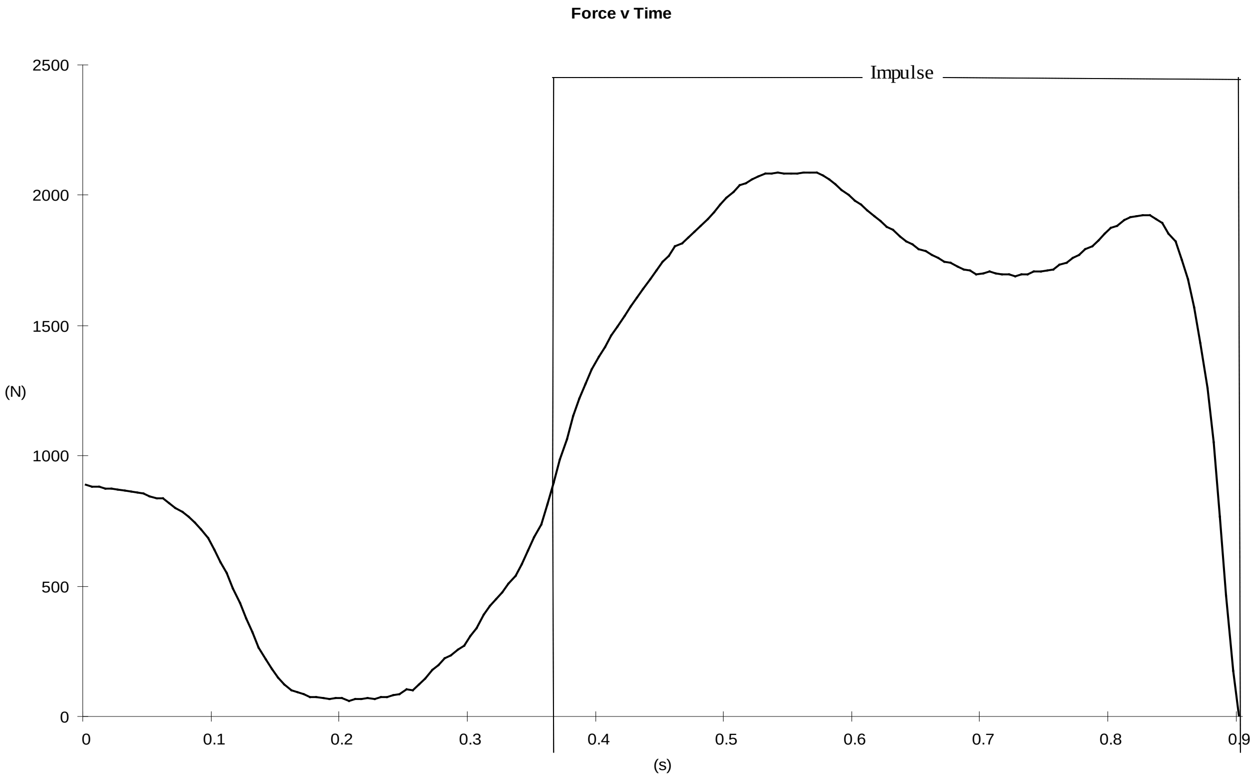

Figure 1. *Illustration of the procedure for determining the start and end point for impulse calculations in a CMJ.*

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Eccentric utilisation ratio was calculated by dividing the athlete's mean CMJ results by SJ results. Both jump height and peak power were used to determine this ratio. The stretch shortening cycle performance as a percentage was calculated using the below equation:

$$\text{SSC performance (\%)} = (\text{CMJ-SJ}) \times \frac{1}{\text{SJ}} \times 100$$

Statistical Analysis

Statistica 6.0 (Statsoft, Tulsa, Oklahoma, USA) was used to calculate group (male and female) descriptive statistics (means and standard deviations) and develop correlation matrices for each sex and jump type. To identify any statistical difference between the grouped sex means for each of the calculated characteristics independent T-tests were conducted and cohen's effect size (cohen's d) were calculated to assess the magnitude of any differences observed with the following criteria: >0.70, large; 0.30-0.70, moderate; <0.30, small (Cohen, 1988). Statistical significance was set at $p< 0.05$.

RESULTS

Tables 1 and 2 display the mean scores for both male and females during the SJ and CMJ respectively. Table 3 (a-d) display the correlations between the kinetic and kinematic variables in the SJ and CMJ. Figures 2-5 illustrate the strongest relationships amongst the variables; CMJ height and relative peak (figure 2) and average (figure 3) power in females, and SJ height (figure 4) and CMJ height (figure 5) with relative peak power in males.

Table 1. *SJ Male and Female Mean Descriptive Statistics, P-Value and Effect Size (ES)*

	MALE (n = 14)		FEMALE (n = 16)		P-Value	ES
Force$_{(peak)}$ *(N)*	1961.12 ± 103.9	(1786.90 - 2146.57)	1422.37 ± 100.54	(1281.93 - 1636.97)	<0.01	0.93
RFD$_{(max)}$ *(kN/s)*	7.76 ± 1.92	(5.68 - 13.28)	5.10 ± 1.47	(2.90 - 7.71)	<0.01	0.61
Impulse	269.13 ± 17.06	(244.04 - 290.53)	185.41 ±20.27	(152.87 - 226.63)	<0.01	0.91
Jump Height $_{(CoM)}$ *(cm)*	44.45 ± 4.73	(35.93 - 53.00)	36.13 ± 6.26	(25.03 - 44.08)	<0.01	0.60
Power$_{(Peak)}$ *(W)*	2639.20 ± 247.57	(2221.83 - 3058.50)	1665.28 ± 298.91	(1157.61 -2185.01)	<0.01	0.87
Mean Force *(N)*	1515.88 ± 85.4	(1338.28 - 1642.32)	1104.47 ± 84.33	(943.91 - 1306.42)	<0.01	0.92
Mean Power *(W)*	933.44 ± 135.79	(685.60 - 1155.79)	560.93 ± 131.40	(363.24 - 828.75)	<0.01	0.81
Relative Force$_{(peak)}$ *(N/kg)*	21.48 ± 0.59	(20.46 - 22.37)	20.37 ± 1.25	(17.90 - 23.01)	<0.01	0.49
Relative Power $_{(peak)}$ *(W/kg)*	28.96 ± 3.01	(23.99 - 34.33)	23.87 ± 4.35	(16.17 - 31.28)	<0.01	0.56
Relative Mean Power *(W/kg)*	10.25 ± 1.64	(7.40 - 12.97)	8.06 ± 2.07	(5.26 - 13.26)	<0.01	0.51
Relative Jump Height *(cm/kg)*	0.49 ± 0.06	(0.39 - 0.59)	0.52 ± 0.10	(0.36 - 0.67)	<0.01	0.18

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Table 2. *CMJ Male and Female Mean Descriptive Statistics, P-Value and Effect Size (ES)*

	MALE (n = 14)		FEMALE (n = 16)		P-Value	ES
$Force_{(peak)}$ (N)	2157.29 ± 161.73	(1881.23 - 2487.98)	1629.65 ± 175.90	(1323.65 - 2050.93)	<0.01	0.84
$RFD_{(max)}$ (kN/s)	12.93 ± 4.37	(8.65 - 22.96)	10.70 ± 4.28	(5.88 - 20.24)	0.16	0.25
Impulse	417.06 ± 21.27	(377.94 - 454.06)	294.04 ± 31.10	(252.98 - 354.86)	<0.01	0.92
Jump Height (cm)	46.86 ±3.81	(40.30 - 55.49)	38.58 ± 5.77	(28.63 - 48.57)	<0.01	0.65
$Power_{(Peak)}$ (W)	2588.15 ± 284.13	(2099.36 - 3052.47)	1824.40 ± 621.57	(1166.88 - 3891.48)	<0.01	0.62
Mean Force (N)	1760.57 ± 101.38	(1603.42 - 2038.56)	1310.74 ± 126.10	(1083.90 - 1557.66)	<0.01	0.99
Mean Power (W)	660.18 ± 101.93	(509.92 - 948.83)	442.11 ± 188.29	(264.91 - 1061.16)	<0.01	0.58
Relative $Force_{(peak)}$ (N/kg)	23.66 ± 1.88	(20.32 - 27.49)	23.35 ± 2.56	(20.46 - 29.47)	0.71	0.07
Relative $Power_{(peak)}$ (W/kg)	28.41 ± 3.50	(23.49 - 33.99)	26.13 ± 8.89	(16.30 - 55.91)	0.38	0.17
Relative Mean Power (W/kg)	7.23 ± 1.03	(5.81 - 9.70)	6.34 ± 2.71	(3.71 - 15.25)	0.26	0.21
Relative Jump Height (cm/kg)	0.52 ± 0.06	(0.44 - 0.62)	0.55 ± 0.10	(0.40 - 0.78)	0.20	0.18

Table 3A. *Female SJ Correlation Matrix*

	Body Mass	$Force_{(peak)}$	$RFD_{(max)}$	Impulse	Jump Height $_{(CoM)}$	$Power_{(Peak)}$	Mean Force	Mean Power	Relative $Force_{(peak)}$	Relative $Power_{(peak)}$	Relative Mean Power	Relative Jump Height
Body Mass	1.00											
$Force_{(peak)}$	0.61*	1.00										
$RFD_{(max)}$	-0.25	0.23	1.00									
Impulse	0.58*	0.80*	0.29	1.00								
Jump Height $_{(CoM)}$	-0.03	0.54*	0.54*	0.80*	1.00							
$Power_{(Peak)}$	0.17	0.82*	0.50*	0.84*	0.90*	1.00						
Mean Force	0.53*	0.82*	0.53*	0.77*	0.56*	0.73*	1.00					
Mean Power	-0.03	0.58*	0.74*	0.60*	0.77*	0.80*	0.81*	1.00				
Relative $Force_{(peak)}$	-0.37	0.51*	0.54*	0.31	0.66*	0.77*	0.40	0.73*	1.00			
Relative $Power_{(peak)}$	-0.22	0.57*	0.59*	0.60*	0.90*	0.92*	0.53*	0.82*	0.91*	1.00		
Relative Mean Power	-0.33	0.37	0.76*	0.39	0.73*	0.70*	0.61*	0.95*	0.80*	0.83*	1.00	
Relative Jump Height	-0.39	0.28	0.59*	0.51*	0.93*	0.77*	0.34	0.74*	0.76*	0.92*	0.81*	1.00

** correlations are significant at p < .05*

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***Table 3B**. Female CMJ Correlation Matrix*

	Body Mass	Force (peak)	RFD(max)	Impulse	Jump Height (CoM)	Power(Peak)	Mean Force	Mean Power	Relative Force (peak)	Relative Power (peak)	Relative Mean Power	Relative Jump Height
Body Mass	1.00											
Force(peak)	0.30	1.00										
RFD(max)	-0.14	0.65*	1.00									
Impulse	0.49	0.73*	0.34	1.00								
Jump Height (CoM)	-0.14	0.56*	0.34	0.67*	1.00							
Power(Peak)	0.11	0.75*	0.57*	0.72*	0.63*	1.00						
Mean Force	0.55*	0.82*	0.59*	0.65*	0.37	0.54*	1.00					
Mean Power	0.06	0.85*	0.63*	0.68*	0.64*	0.97*	0.61*	1.00				
Relative Force(peak)	-0.31	0.82*	0.75*	0.43	0.65*	0.67*	0.49	0.80*	1.00			
Relative Power (peak)	-0.08	0.70	0.61*	0.63*	0.66*	0.98*	0.44	0.96*	0.74*	1.00		
Relative Mean Power	-0.09	0.80*	0.66*	0.61*	0.67*	0.95*	0.53*	0.99*	0.85*	0.97*	1.00	
Relative Jump Height	-0.51	0.36	0.34	0.38	0.92*	0.49	0.10	0.52*	0.68*	0.59*	0.60*	1.00

** correlations are significant at $p < .05$*

***Table 3C.** Male SJ Correlation Matrix*

	Body Mass	Force (peak)	RFD(max)	Impulse	Jump Height (CoM)	Power(Peak)	Mean Force	Mean Power	Relative Force (peak)	Relative Power (peak)	Relative Mean Power	Relative Jump Height
Body Mass	1.00											
Force(peak)	0.25	1.00										
RFD(max)	-0.43	0.41	1.00									
Impulse	0.42	0.07	-0.22	1.00								
Jump Height (CoM)	-0.32	-0.07	0.11	0.59*	1.00							
Power(Peak)	0.01	0.00	0.17	0.47	0.77*	1.00						
Mean Force	0.49	0.78*	0.45	0.19	-0.07	0.26	1.00					
Mean Power	0.31	0.63*	0.34	0.07	0.19	0.55*	0.84*	1.00				
Relative Force(peak)	-0.44	0.76*	0.67	-0.23	0.14	-0.01	0.39	0.36	1.00			
Relative Power (peak)	-0.43	-0.12	0.35	0.23	0.83*	0.9*	0.02	0.35	0.18	1.00		
Relative Mean Power	-0.04	0.56*	0.53	-0.07	0.33	0.59*	0.70*	0.93*	0.54*	0.55*	1.00	
Relative Jump Height	-0.72*	-0.18	0.30	0.23	0.89*	0.57*	-0.28	0.00	0.31	0.83*	0.27	1.00

** correlations are significant at $p < .0500$*

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Table 3D. *Male CMJ Correlation Matrix*

	Body Mass	**Force $_{(peak)}$**	**RFD$_{(max)}$**	**Impulse**	**Jump Height $_{(CoM)}$**	**Power$_{(Peak)}$**	**Mean Force**	**Mean Power**	**Relative Force $_{(peak)}$**	**Relative Power $_{(peak)}$**	**Relative Mean Power**	**Relative Jump Height**
Body Mass	1.00											
Force$_{(peak)}$	0.87*	1.00										
RFD$_{(max)}$	-0.10	0.01	1.00									
Impulse	0.60*	0.73*	-0.08	1.00								
Jump Height $_{(CoM)}$	-0.28	0.01	0.01	0.59*	1.00							
Power$_{(Peak)}$	0.09	0.45	0.00	0.81	0.88*	1.00						
Mean Force	0.56*	0.72*	0.55*	0.67	0.24	0.50	1.00					
Mean Power	-0.11	0.22	0.56*	0.53	0.75*	0.75*	0.72	1.00				
Relative Force$_{(peak)}$	-0.29	0.22	0.21	0.23	0.58*	0.69*	0.29	0.63*	1.00			
Relative Power $_{(peak)}$	-0.43	-0.03	0.04	0.42	0.94*	0.86*	0.17	0.73*	0.78*	1.00		
Relative Mean Power	-0.42	-0.07	0.54*	0.29	0.77*	0.66*	0.47	0.95*	0.68*	0.81*	1.00	
Relative Jump Height	-0.63*	-0.34	0.04	0.24	0.92*	0.67*	-0.04	0.64*	0.59*	0.93*	0.79*	1.00

** correlations are significant at p < .0500*

Comparison of the squat jump scores resulted in the observation that there were significant differences in the group means for all measured variables ($P < 0.01$) except relative jump height. The countermovement jump comparison demonstrated a significant difference ($P < 0.001$) between impulse, jump height, peak power, average force and average power, while no significant difference ($P > 0.05$) was shown between peak RFD, relative peak force, power and relative average power.

A correlation coefficient (*r* value) for jump height was calculated for both the male and female groups, SJ and CMJ. The strongest positive correlations were:

Female SJ: Relative Peak Power ($r = 0.90$), *see figure 2*

Female CMJ: Relative Average Power ($r = 0.67$), *see figure 3*

Male SJ: Relative Peak Power ($r = 0.94$), *see figure 4*

Male CMJ: Relative Peak Power ($r = 0.83$), *see figure 5*

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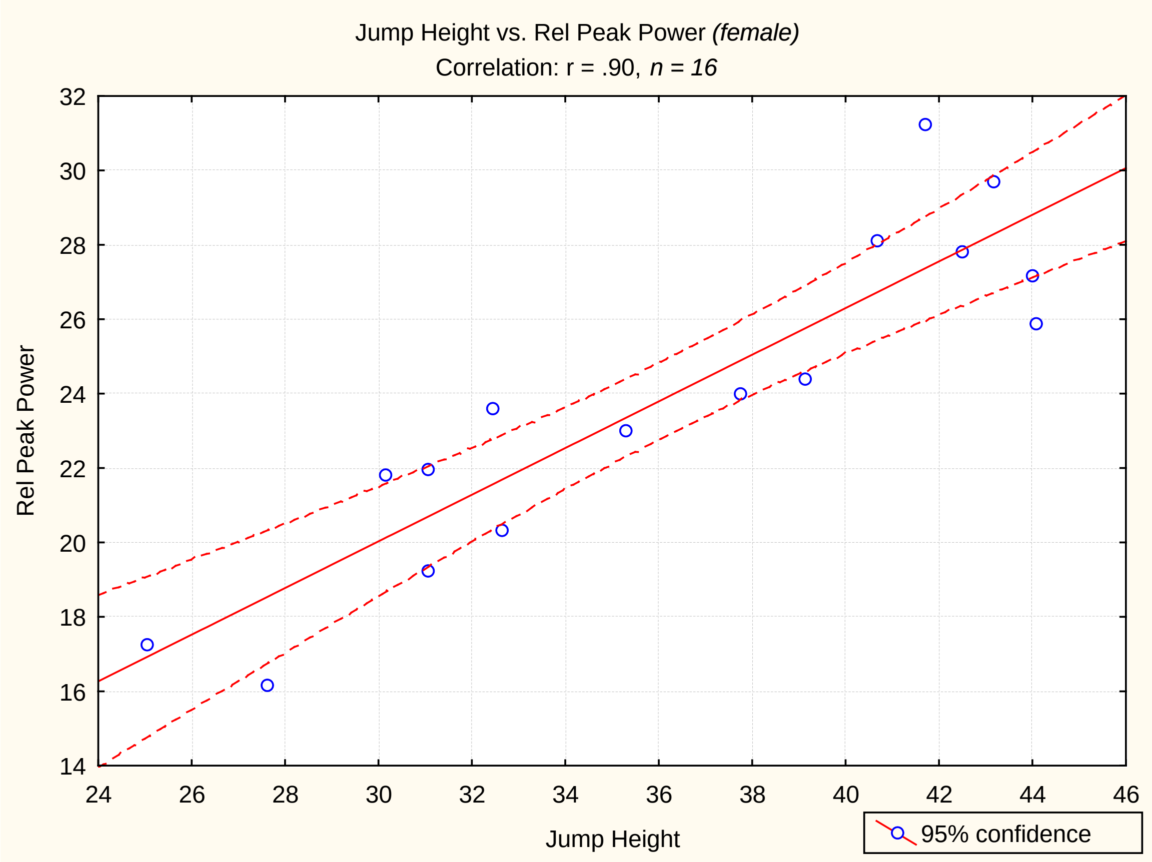

Figure 2. *Scatterplot of female SJ Jump Height vs. Relative Peak Power.*

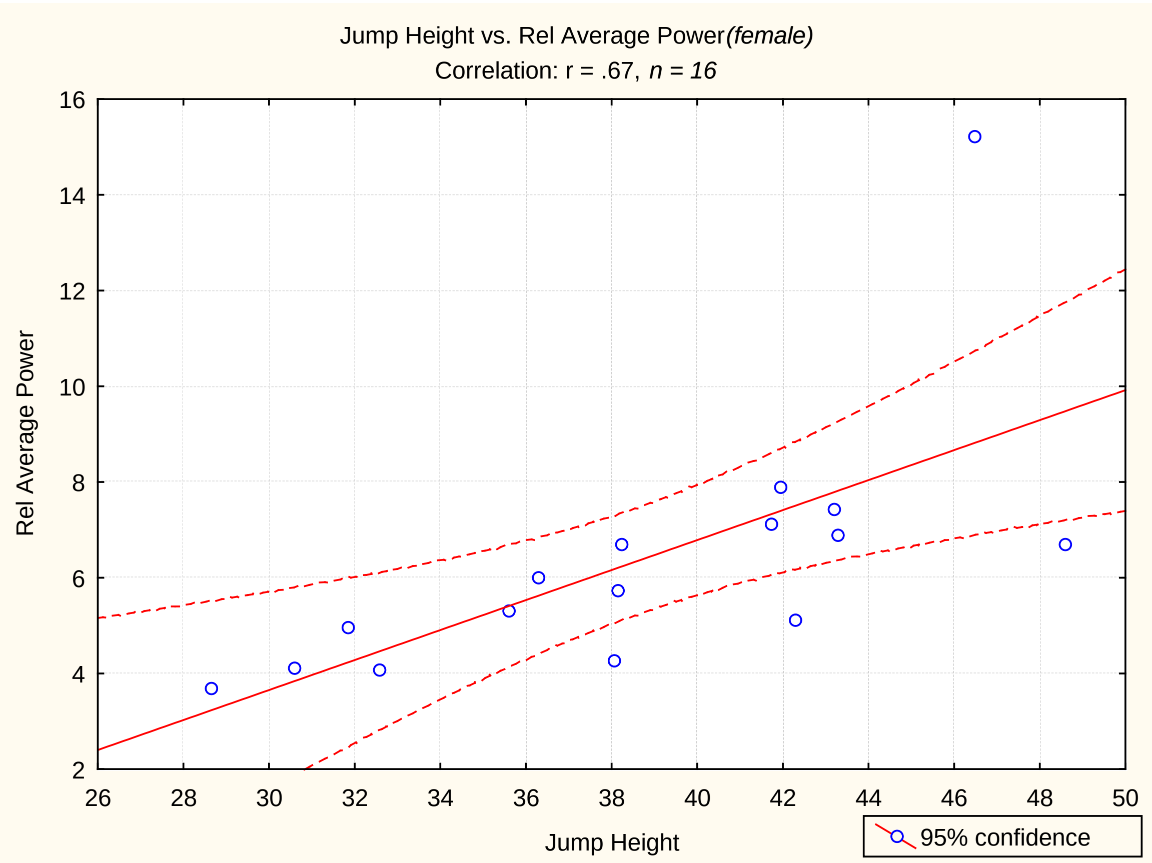

Figure 3. *Scatterplot of female CMJ Jump Height vs. Relative Average Power.*

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Figure 4. *Scatterplot of male SJ Jump Height vs. Relative Peak Power.*

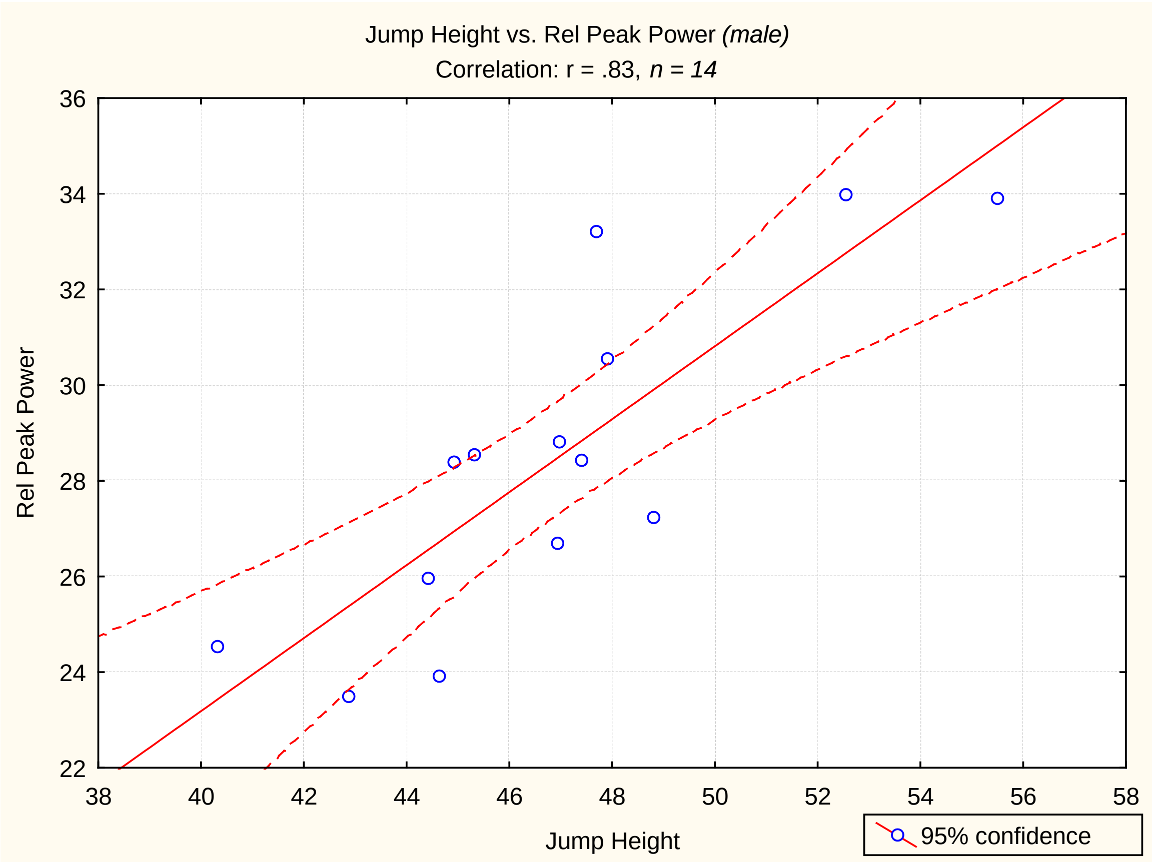

Figure 5. *Scatterplot of male CMJ Jump Height vs. Relative Peak Power.*

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Eccentric utilization ratio (CMJ/SJ) and SSC performance was calculated for jump height and peak power (as shown in table 4). There was no significant difference shown between either of the means ($p > 0.05$)

Table 4. *Eccentric Utilization Mean Scores*

	MALE (*n = 14*)		FEMALE (*n = 16*)	
Eccentric Utilization Ratio (jump height)	1.05 ± 0.05	(0.94 - 1.13)	1.06 ± 0.08	(0.95 - 1.21)
Eccentric Utilization Ratio (Peak Power)	0.98 ± 0.07	(0.87 - 1.14)	1.09 ± 0.27	(0.92 - 2.06)
SSC Performance (%)	4.89 ± 5.44	(-5.59 - 12.80)	5.67 ± 7.93	(-4.53 - 20.76)

DISCUSSION

The aim of this study was to compare ground reaction force and power characteristics exhibited by both male and female international beach volleyball athletes when performing a squat and countermovement jump on a force platform. The data collected clearly indicates a significant difference between particular ground reaction force characteristics exhibited by male and female international beach volleyball athletes. The significant differences in means demonstrated that males in this population are capable, on average, of achieving greater jump heights than females in both the SJ and CMJ tests.

Vertical jump height has been identified as a critical component in the sport of beach volleyball and volleyball (Giatsis, 2001; Giatsis et al., 2004; Sheppard et al., 2007a; Sheppard et al., In press), so the identification of possible ways to improve this characteristic and or the ability to identify individual differences negatively impacting on performance are extremely important. Due to the small number of published investigations directly investigating the physical (anthropometrical) and physiological abilities of internationally competitive beach volleyball athletes, the opportunity to compare and contrast the data collected in this project with that of other studies is limited.

Giatsis et al. (2004) reported on the ground reaction force results of 15 elite male beach volleyball athletes who performed 3 maximal squat jumps on a rigid surface (force platform) and also on a sand surface. The athletes were of similar age (25.6±6.2yrs) and height (188±3.5cm) but of a lower body mass (83.2±6.0 kg) in comparison to the male subjects in the present study. Giatsis's et al. (2004) findings reported that on a rigid surface the subjects produced a similar mean peak power (2678.8±340 W) to the male group in the present study, but a lower mean peak vertical force (1227.3±201.2N), higher mean maximal rate of force development and centre of mass displacement (9.98±3.41kN/s and 56.8±6.8cm respectively (table 1). The values obtained in the present study reflect the typical ground reaction force characteristics exhibited by elite

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male beach volleyball athletes. In relation to this the results from the present study showed that relative peak power demonstrated the strongest positive correlation to male SJ COM displacement. When compared, the relative mean peak power from the present study to Giatsis et al. (2004), whose subjects recorded a greater COM displacement, they also demonstrated a greater mean relative peak power. Statistical modelling done in an attempt to distinguish good jumpers from poor jumpers identified mechanical power as having a strong link to performance (Aragon-Vargas et al., 1994). Models that included peak and average mechanical power, accounted for 88% of vertical jump variation.

There appears to be no published research that has focussed exclusively on the ground reaction force characteristics demonstrated by elite female beach volleyball athletes. Other studies (Komi et al., 1977; Komi and Bosco, 1978; Perez-Gomez et al., 2008) have looked at gender differences in varied athletic performance and reported a variety of outcomes and comparisons. Komi and Bosco (1978) reported general differences in female jump height of 54 to 67 percent below males when performing a squat jump, countermovement and drop jump. They also reported differences in utilization of stored elastic energy. Perez-Gomez et al. (2008) used an all-out 30s sprint test on a mechanically braked cycle ergometer to compare male and female lower body peak and mean power capability and demonstrated males were able to produce significantly higher power output for both peak and mean power (981.2W vs. 652.8W and 701.0W vs. 465.0W respectively). The difference in power outputs was attributed to females having reduced lower extremity muscle mass, which was shown to have a clear linear relationship to peak power. The strong positive correlations shown in the present study between relative peak power and jump height in both the male and female groups reinforces the importance of beach volleyball athletes requiring a high power to weight ratio.

Anthropometric factors have been shown to impact and influence power production in 82 and 99 untrained men and women respectively when performing anaerobic power tests such as the Margaria-Kalman test, vertical jump and standing long jump test (Mayhew and Salm, 2001). Perez-Gomez et al. (2008) sites studies by Weyand et al. (2000) and Korhonen et al. (2003) and suggests that difference in sprint running performance between genders can be associated with the ability of males to produce greater GRF, which, if this is the case, supports why in this current study the male beach volleyball athletes were able to jump significantly higher than the females. As such, a major factor influencing the difference between male and female beach volleyball athlete jump heights could be based on their somatotypes, body composition, and differences in GRF capabilities.

Stretch Shortening Cycle & Eccentric utilization ratio

Being able to efficiently use the SSC during athletic performance is a critical factor in a number of sports (McGuigan et al., 2003). Several recent studies have examined the importance of strength, power and anthropometric measure to jump performance of elite volleyball players demonstrating that well developed SSC ability is critical to the execution and success of the types of maximal jumps associated with indoor volleyball (Sheppard et al., 2007b; Sheppard et al., 2007c; Sheppard et al., 2008c; Sheppard et al., 2008d; Sheppard et al., 2008e). With this in mind, by analysing the individual athlete's maximal CMJ and SJ using the pre-stretch augmentation described by Walshe et al.

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(1996), it was possible to calculate a percentage for the performance amplification gained from the SSC. This pre-stretch augmentation demonstrated no significant difference between the mean of the two genders and their use of the SSC. This is in contrast to the study by Komi and Bosco (1978), where the female subjects demonstrated a greater use, efficiency and ability to use the energy generated by the SSC than the male subjects. A possible reason for this difference may be the fact that Komi and Bosco (1978) used female physical education students, not highly trained female "jumping" athletes. Therefore the lack of difference between the genders in the present study may simply be due to the sexes having similar training histories.

In an attempt to further investigate the effect of the SSC, using the eccentric utilisation ratio (EUR) as described by McGuigan et al. (2006), a mean EUR for the two groups was calculated. The group means were calculated using each individual athlete's best CMJ and SJ jump height (COM displacement) and peak power scores. The difference between males and female was not significantly different in either case. EUR values exhibited by male and female soccer players: Jump height 1.14±0.15, 1.17±0.16 and peak power 1.03±0.2, 1.11±0.2 respectively (McGuigan et al., 2006), were higher than the scores of the male and female beach volleyball athletes. However, there was no significant difference between genders. This finding reinforces that the effect and role of SSC and the use of stored elastic energy appears to be very sport specific and based on training history, while the difference between genders competing in the same sport appears to be minimal.

CONCLUSIONS

There is a significant difference between a number of the SJ and CMJ variables produced by male and female elite beach volleyball athletes, which appear to result in male athletes being able to obtain greater jump heights. The role of the SSC in jump performance appears to be lower for beach volleyball than other "team based" sports, however it is still an important component of performance. The importance of athletes having a high power to weight ratio is evident and should be carefully considered when designing and monitoring elite beach volleyball athlete training programs. As such, peak power, body composition and relative peak power should be of particular focus and interest.

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