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The psychology of Relationship between Squat's Kinematics' Variables, Anthropometric Measurements and Jump Serve Kinematics' Variables amongst Volleyball Players

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Abstract: The aim of the current study was to investigate the impact of the kinematic variables of squatting and anthropometric measurements on jump height, ball throwing angle and ball speed in jump serve amongst Jordanian volleyball players. The researcher used the descriptive method. Eight male volleyball players took part in this study. The researcher used an iPhone camera (30\sec) to record the players' performance. Marks were placed on the joints of the players in order to observe the kinematics of their jump serve. Kinovea © software was then used to analyze the jump serve and bodyweight squat. After data analysis (by means of multiple linear regression, one-way ANOVA, and standard deviation), it was concluded that body-mass, height, and BMI affect the jump height, and that squat depth does affect the throwing angle in the jump serve. It was also found that flexion time of the legs and arms do not affect ball speed during the serve. Therefore, it is recommended that volleyball training should focus more on strengthening the lower limbs.

Keywords: Squat, Kinematics' Variables, Anthropometric Measurements, Volleyball Jump Serve.

Introduction

Volleyball has become one of the most popular sports world-wide. This sport places great demand on the athlete in terms of psychological, physiological and biomechanical capabilities, all of which are essential to ensure good performance. Volleyball is considered to be a sport that is dominated by power, as can be seen when the players jump high or strongly strike the ball. This is why volleyball training focuses more on strength training and muscle development rather than endurance training [1]. Obviously, leg strength is very important in volleyball, seeing how many skills require the player to jump very high [2]. One of these skills is the most important skill; the jump serve. The serve is the most important skill in the game because it establishes the tempo and the momentum of the game. As previously mentioned, leg strength is important in volleyball, and one of the most common leg strengthening exercises is the squat. The purpose of the current study is to investigate the impact of squat's kinematics' variables and anthropometric measurements on jump height, ball throwing angle and ball speed in the jump serve. Coaches and physical education teachers have important jobs with great responsibility. They are responsible for helping athletes and students learn, have fun, achieve goals, get on with each other, mentor and understand the various skills of a sport.

This study will help coaches and physical education teachers to know more about the jump serve, and the selected kinematics variables' and anthropometric measurements' impact on the serve regarding jump height, ball throwing angle, and ball speed. Do the anthropometric measurements being taken into consideration affect the jump height in the jump serve? Do squat kinematic variables affect the ball throwing angle in the jump serve? Does the squat depth and flexion time of the legs and arms affect ball speed in the jump serve?

Squatting is widely used in physical therapy and sports training as a closed-kinetic chain exercise because it is a great compound exercise, meaning that it activates multiple major muscle groups. Based on depth, squats can be classified into deep-squats (full-squats) or semi-squats (half-squats, quarter-squats, etc.) [3]. All are common exercises but demand different amounts of power and put more emphasis on different muscle groups [4].

Squatting requires a certain degree of mobility in the lower limbs and trunk area. Despite being a three-dimensional movement, the majority of the movement in a squat occurs along the sagittal plane. This is why squat depth is commonly determined using the angle of knee flexion [3], or the descent expressed as a percentage of leg length [5].

Biomechanically, the squat is a closed–chain movement, requiring simultaneous extension patterns of the ankle, knee and hip joints. The squat can be performed in many different ways, including variations in foot width (sumo squats), foot position (single leg squats, Bulgarian squats), load position (front squats, sissy squats) and depth (full range squats, shallow squats) [6].

As mentioned earlier, squats are a great compound exercise because they activate many major muscle groups such as; the glutes, hamstrings, quadriceps, and calves. Glute activity increases with depth and also with increases in stance [7]. The quadriceps reach maximum activity at approximately 90 degrees of knee flexion [8], indicating that half-squats are optimal for enhancing quadriceps development [9]. The hamstrings act eccentrically during the descent and concentrically during the ascent [10]. Calf muscle activity increases during the descent phase and decreases during the ascent phase, peaking at 60-90 degrees of knee flexion to eccentrically control ankle dorsiflexion during the descent [8].

The anthropometric measures being taken into consideration in this study are; mass, body height, and BMI. The mass can be measured using a standard scale, and the body height can be measured using a measuring tape (or 'meter'). Reference [11] refers to the body mass index (BMI) as a simple indicator relating the weight of an individual to his or her height. Body mass index is defined as the weight in Kilograms, divided by the square of height in meters (Kg/m^2) [12].

World health organization regards a BMI of less than 18.5 as underweight and may indicate malnutrition, an eating disorder, or other health problems, while a BMI equal to or greater than 25 is considered overweight and above 30 is considered obese. These ranges of BMI values are valid only as statistical categories [11]. Table (1) shows BMI categories.

Table (1): BMI categories

Category	BMI (Kg/m^2)	
	from	**to**
Underweight	<	18.5
Normal range	18.6	23
Overweight – at risk	23.1	25
Overweight – moderately obese	25.1	30
Overweight – severely obese	30.1	<

Even though not many studies have been carried out regarding this specific topic, some studies have covered similar topics. A study carried out by reference [13] investigated the biomechanical factors associated with successful overhand floater serves. Specifically, the study investigated the kinematics of the server at ball-hand contact. Six subjects performed floater serves for this investigation. Subjects served three trials under each of the following conditions: (a) short and long serves and (b) three ball-valve positions at ball-hand contact. Three-dimensional cinematographic methods were used to obtain the data. Descriptive statistics were utilized to compare floater and non-floater serves with respect to distance and ball-valve position. The results showed that (a) more long serves were classified as floater compared to short serves; (b) long serves were associated with greater linear displacement, linear speed, and angular speed at ball-hand contact compared to short serves; and (c) few posture differences were evident in the serving arm of subjects serving floater and non-floater serves, or long and short serves.

Another study carried out by reference [14] aimed to examine the effect of squat depth on maximum vertical jump performance. Researchers hypothesized that jump height would increase with increasing depth of squat due to the greater time available for the generation of muscular force. Ten participants performed jumps from preferred and deep squat positions. A computer model simulated jumps from the different starting positions. The participants showed no difference in jump height in jumps from deep and preferred positions. Simulated jumps produced similar kinematics to the participants' jumps. The optimal squat depth for the simulated jumps was the lowest position the model was able to jump from. Because jumping from a deep squat is rarely practiced, it is unlikely that these jumps were optimally coordinated by the participants. Differences in experimental vertical ground reaction force patterns also suggest that jumps from a deep squat are not optimally coordinated. These results suggest there is the potential for athletes to increase jump performance by exploiting a greater range of motion.
A study carried out by reference [15], aimed to analyze the relationship of range of motion (ROM) in the sagittal plane and timing parameters during a bodyweight squat to the depth of the squat. 60 participants (20 females and 40 males) took part in this study. They were instructed to perform a bodyweight squat to the maximal depth position. Kinematic data were obtained using the optical motion capture system. The time for the descent phase of squatting was normalized from 0% (initial position, start of movement) to 100% (squat position-stop of movement). The ROM of ankle, knee, hip, pelvis and spine in the sagittal plane and the normalized time when the maximum joint angles occurred during the descent were analyzed to investigate the relationship between them and the squat depth in males and females. The knee ROM contributed most significantly, from all joints to

squatting depth in both females and males (r = 0.92, p < 0.001). The squat depth was related to lumbar, hip and knee motion in females and to all kinematics parameters in males. Maximal ankle dorsiflexion and pelvis anterior tilt were reached earlier than the maximal angles of knee, hip and spine during squatting. Pelvis and ankle timing was negatively correlated with the squat depth (rs = -0.64, p <0.001 and rs = -0.29, p = 0.02, respectively). This suggests that pelvis and ankle timing can be important to keeping balance during squatting and can lead to achieving the desired depth.
The findings of a study carried out by reference [16] suggest that relative peak and average power outputs are factors highly associated with vertical jump height in elite male and female beach volleyball players. This study specifically aims to determine the relationship between the kinematic variables associated with squatting, and the anthropometric measures of the body, on the jump serve in volleyball.

Method

The researcher used the descriptive method to answer the research questions. Eight male volleyball players who are members of Jordanian youth volleyball team and have more than (4) years of experience took part in this study. Subjects were excluded if they reported lower extremity or back pain, or a history of lower extremity or back injury or surgery. Table (2) shows characteristics of the study sample. The aim of the study was explained to the participants, and they were shown the required squat technique. The participants were given a proper warm-up.

Then the researcher and the assistant put bright marks on players' bodies. The marks were put on the shoulder joint, elbow joint, wrist joint, body center of gravity, hip joint, knee joint, and ankle joint. The participants were numbered from (1) to (8). Their weight was measured by a scale, their height by a measuring-tape, and their age and years of experience were determined by asking them directly.

Height and body mass were recorded with subjects dressed in light clothing, without shoes, using a standard scale. Height was recorded in centimeters. Body mass was recorded in kilograms. BMI was calculated as body mass in kilograms divided by height in meters squared. The BMI is expressed in units of kg/m^2 [11]. The age was taken directly from the participant.

After that, participants started to perform squats respectively by their numbers, and this was how the first video recorded, then the second video recorded their jump serve performance. Then, the researcher analyzed participants' performance using Kinovea © software.

Table (2): characteristics of the study sample

Player number	Mass (kg)	Height (cm)	BMI (kg/m^2)	Age (years)	Years of experience
1	81	193	21.7	19	4
2	77	190	21.3	19	4
3	69	185	20.2	17	4
4	75	187	21.4	17	4
5	68	178	21.5	18	5
6	75	188	21.2	18	4
7	73	190	20.2	17	4
8	80	194	21.3	19	5
Mean	73.89	187.44	21.01	17.67	4.2
sd	4.68	4.77	0.62	0.87	0.43

From an up-right position with eyes forward, feet shoulder-width apart and arms extended forward, the participants performed a body-weight squat to the maximum depth that they could hold for three seconds. ROM of the hip, knee, and ankle in the sagittal plane, as well as when maximum angles of each joint were achieved, were recorded. Squat depth was defined as leg length using the height of a mark placed on the second sacral spinous process. The depth had to be equal to or greater than 90% of leg length without causing any pain. Squat depth was calculated using the following equation:

$$\Delta h = \ (h\_max - h\_min)/h\_max \quad \times 100\%$$

$$\Delta h - descent$$

$$h\_max - the\ highest\ position\ of\ S2\ mark$$

$$h_{min} - the\ lowest\ position\ of\ S2\ mark$$ [15]

Figure (2): S2 mark placement and it height measured for descent calculation

Table (3): h_{max} and h_{min} measurements for the participants

Player number	h_{max} (cm)	h_{min} (cm)	Δh (%)
1	103.38	31.68	69.53
2	99.62	76.62	23.36
3	94.74	36.16	61.83
4	106.11	47.23	55.48
5	98.10	32.48	66.89
6	99.75	37.15	62.75
7	106.78	39.50	63
8	101.45	37.60	62.93

Player number (2) was excluded from the study as his squat depth percentage was lesser than (30%) as shown in table (3).

Each participant performed three jump serves with correct technique. The following kinematic variables were analyzed: ball speed, throwing angle, jump height, and time of arm contraction while serving.

The researcher coded and entered the data of each participant into the Statistical Package for Social Sciences (SPSS) version 16. Data were analyzed using multiple linear regression, means, one-way ANOVA, and standard deviation. The validity and reliability of Kinovea software was improved in many previous studies, the study by reference [17] was one of them. Under the title "Validity, reliability and usefulness of smartphone and Kinovea motion analysis software for direct measurement of vertical jump height", the researchers concluded that the Smartphone and Kinovea software method is a valid and reliable, low-cost instrument to monitor changes in jump performance in a healthy, active population diverse in gender and physical condition.

Study Tools

- iPhone camera (30 frame/ second)
- Meter
- Bright marks
- Tri-holder for the camera

Results and Discussion

Multiple linear regression was conducted in order to answer all three of the main questions that this study aimed to address. Firstly, do the anthropometric measurements being taken into consideration affect the jump height in the jump serve? The results are shown in tables (4), (5), and (6).

Table (4): The anthropometric characteristics of the study sample

Anthropometric measurements	mean	sd
Mass	73.89	4.68
Height	187.44	4.77
BMI	21.01	0.62
Age	17.67	0.87

Table (5): regression fitting indices for the anthropometric measurements affecting the jump height model

predictors	R	R^2	ANOVA results					
			Source	SM	df	MS	f	sig
Height	0.825	0.681	Regression	206.923	4	51731	2.669	.15
Mass			Residual	96.893	5			
BMI			total	303.816	9	19.379		
Age								

Table (5) reflects the results of multiple linear regression to investigate the impact of anthropometric measurements affecting the jump height. The coefficient of determination expressed by R^2 was (68.1 %), this value expresses that the portion of explained variance of the variable jump height is assigned to the mentioned anthropometric measurements (height, mass, BMI, and age).

Table (6) provides the results of one-way ANOVA. If the sig value <0.05, the impact model is accepted, and if sig>0.05, it is rejected meaning that the variable that the sig value represents has no effect on vertical jump height.

Table (6): the impact values of the anthropometric measurements affecting the jump height and the related statistical significance

predictors	B	Std. Error	Beta	t	sig
Height	42.492	14.666	32.933	2.897	.034
Mass	-51.976	18.115	-39.560	-2.869	.035
BMI	195.027	67.022	19.830	2.910	.033
Age	-4.990	2.980	-.707	-1.675	.155

Table 6 also shows the unstandardized (B) and the standardized (beta) individual impact values. It can be observed when referring to the beta impact values that mass had the greatest influence on vertical jump height. Due to the value being negative, it can be concluded that there is an inverse relationship, meaning that a decrease in mass will lead to an increase in vertical jump height, and vice versa. The value was positive for ‘height’ on the other hand, indicating that an increase in height leads to an increase in vertical jump height and vice versa. Mass, height, and BMI were proven to be statistically significant with regard to their influence on vertical jump height, whereas age was proven to be irrelevant.

Tables (4), (5), and (6) showed that the participant. recorded a normal BMI range according to world health organization. There were no significant differences in the selected anthropometric measurements together and the variable jump height, this result corresponds to a result founded by reference [18] which was that mass and

BMI do not have significant effects upon the jump, and concluded that body size, and body height do not significantly contribute to the jump height athletes.

Secondly, do squat kinematic variables affect the ball throwing angle in the jump serve? The results are shown in tables (7), (8), and (9). Table (8) reflects the results of multiple linear regression to investigate the impact of squat related kinematic variables on the ball throwing angle. The coefficient of determination expressed by R^2 for this model was (93.5 %). This value expresses that the portion of explained variance of the variable ball throwing angle is assigned to the mentioned anthropometric measurements being used and the remainder (6.5 %) refers to unknown reasons.

The table provides the results of one-way ANOVA. The sig value of this model rounded to two decimal points was = 0.05 suggesting that all the mentioned variables affect the ball throwing angle.

Table (7): means and standard deviation for the squat related kinematic variables

squat related kinematic	mean	sd
Hip angle (º)	36.56	8.50
Knee angle (º)	44.56	10.01
Ankle angle (º)	72.67	10.70
h(max) cm	101.24	4.73
h(min) cm	38.35	5.59

Table (8): regression fitting indicators for the squat related kinematic variables affect the ball throwing angle model

predictors	R	R^2	ANOVA results					
			Source	**SM**	**df**	**MS**	**f**	**sig**
Hip angle (º)	0.967	0.935	Regression	162.945	5	32.589	8.669	.05[b]
Knee angle (º)			Residual	11.277	3			
Ankle angle (º)			total	174.222	8	3.759		
h(max) cm								
h(min) cm								

Table (9): the impact values of the squat related kinematic variables on the ball throwing angle and the related statistical significance

predictors	B	Std. Error	Beta	t	sig
Hip angle (º)	.330	.225	.602	1.470	.238
Knee angle (º)	1.573	.402	3.374	3.913	.030
Ankle angle (º)	-.916	.185	-2.100	-4.945	.016
h(max) cm	.952	.556	.966	1.712	.185
h(min) cm	-3.160	.783	-3.782	-4.034	.027

Table (9) shows both the unstandardized (B) and the standardized (beta) individual impact values by looking at the ‘sig’ column, it can be determined that three out of the five mentioned variables have sig values less than 0.05. These three variables were knee angle, ankle angle, and minimum height. The knee angle variable showed the greatest impact value (t) out of the three. The impact value was positive, meaning that there is a direct relationship between knee angle and ball throwing angle. The other two variables, on the other hand, had a negative impact value indicating an inverse relationship between them and the ball throwing angle, h(min) had a negative (t) value indicating an inverse relationship between it and ball throwing angle.

Both the hip angle and the max hip position (height) had shown no significant impact values on ball throwing angle as the related sig values were> 0.05

As seen in the tables (7), (8) and (9), the squat related kinematic variables affect the ball throwing angle in the jump serve, specifically the knee angle and ankle angle. Surprisingly, this means that the squat depth affects the ball throwing angle.

Last, but not least, do the squat depth, and the flexion time of the legs and arms affect ball speed in the jump serve? The results are provided in the tables (10), (11) and (12)

Table (10): means and standard deviation for the squat depth and the flexion time of (legs and arms)

squat related kinematic	mean	sd
Squat depth ∆h (cm)	62.19	4.58
h(max) (cm)	101.24	4.73
h(min) (cm)	38.35	5.59
Flexion time of legs (s)	1.78	0.29
Flexion time of arm (s)	0.14	0.02

Table (11): regression fitting indicators for squat depth and the contraction time affect the ball speed in the jump serve amongst the volleyball players in Jordan

<table>
<tr><th rowspan="2">predictors</th><th rowspan="2">R</th><th rowspan="2">R^2</th><th colspan="6">ANOVA results</th></tr>
<tr><th>Source</th><th>SM</th><th>df</th><th>MS</th><th>f</th><th>sig</th></tr>
<tr><td>Squat depth ∆h cm</td><td rowspan="5">0.939</td><td rowspan="5">0.883</td><td>Regression</td><td>10.198</td><td>5</td><td rowspan="2">2.040</td><td rowspan="5">4.510</td><td rowspan="5">.122[b]</td></tr>
<tr><td>h(max) cm</td><td>Residual</td><td>1.357</td><td>3</td></tr>
<tr><td>h(min) cm</td><td rowspan="3">total</td><td rowspan="3">11.555</td><td rowspan="3">8</td><td rowspan="3">.452</td></tr>
<tr><td>Flexion time of legs (s)</td></tr>
<tr><td>Flexion time of arm (s)</td></tr>
</table>

Table (11) reflects the results of multiple linear regression to investigate the impact of squat depth and the contraction time affecting the ball speed in the jump service. The coefficient of determination expressed by R^2 for this model was (88.3 %), this value expresses that the portion of explained variance of the dependent variable (ball speed) is assigned to the mentioned anthropometric measurements being used and the rest amount (11.7 %) relates to unknown reasons.

The table provides the results of one-way ANOVA. The sig value of this model (0.12) rounded to two decimal points was > 0.05 suggesting that all the mentioned did not affect the ball speed.

Table (12): the impact values of the squat depth and the contraction time affect the ball speed in the jump serve amongst the volleyball players in Jordan and the related statistical significance

predictors	B	Std. Error	Beta	t	sig
Squat depth ∆h cm	10.687	2.808	40.724	3.806	.032
h(max) cm	-4.099	1.046	-16.150	-3.919	.030
h(min) cm	10.647	2.768	49.483	3.846	.031
Flexion time of legs (s)	-5.070	1.900	-1.235	-2.668	.076
Flexion time of arm (s)	-1.525	12.372	-.028	-.123	.910

Table (12) addresses both the unstandardized (B) and the standardized (beta) individual impact values. By looking at the ‘sig’ column, it can be determined that three out of the five variables have sig values <0.05. These variables were squat depth, maximum height, and minimum height. The variables of squat depth and minimum height both had positive impact values (t), meaning that there is a direct relationship between them and ball speed during the jump serve. Maximum height, on the other hand, had a negative impact value meaning that the relationship between it and ball speed is an inverse relationship. Both the leg and arms contraction times had shown no significant impact values on ball speed as the related sig values (0.076) and (0.910) respectively were > 0.05.

As seen in tables (10), (11) and (12), squat depth affects ball speed, while leg and arm contraction time don't affect ball speed. A study carried out by Lehman, et al., (2013) concluded that lower body consistently correlated with high throwing speed, in both left-handed and right-handed throwers. It was the first study to correlate throwing speed with lower body kinematic variables. This correlation is congruent with the information provided by reference [19] which stated that increased ground reaction forces created by the trail leg in the direction toward the target were highly correlated with ball speed. Theoretically, the increase in momentum would allow players to transfer more energy from the trunk, to the throwing arm, and finally to the ball.

Conclusion

Based on the results of the study, many facts can be concluded. It has been determined that there is an inverse relationship between mass and jump height, whereas there is a direct relationship between body height and jump height. BMI Regarding the throwing angle, it has been determined that there is a direct relationship between the knee angle and the throwing angle, whereas there is an inverse relationship between the ankle angle and minimum height, and ball throwing angle. It has also been concluded that squat depth and minimum height both have a direct relationship with ball speed, whereas maximum height has an inverse relationship with ball speed.

Research Limitations:

The study was limited by the following:

- The data were not collected in a game situation.
- Only one judge was used to categorize the performance.

Recommendations

Volleyball training should put more focus on strengthening the lower extremities and more research should be conducted regarding the effect of various kinematic variables on the different skills in volleyball.

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