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Association of anthropometric qualities with vertical jump performance in elite male volleyball players

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Aim. **The objective of this study was to examine the association between physical and anthropometric profiles and vertical jump performance in elite volleyball players.**

Methods. **Thirty-three elite male volleyball players (21±1 y, 76.9±5.2 kg, 186.5±5 cm) were studied. Several anthropometric measurements (body mass, stature, body mass index, lower limb length and sitting height) together with jumping height anaerobic power of counter movement jump with arm swing (CMJ_{arm}) were obtained from all subjects. Forward stepwise multiple linear regression analysis was performed to determine if any of the anthropometric parameters were predictive of CMJ_{arm}.**

Results. **Anaerobic power was significantly higher ($P\leq0.05$) in the tallest players relative to their shorter counterparts. A significant relationship was observed between CMJ_{arm} and lower limb length ($r^2=0.69$; $P<0.001$) and between the lower limb length and anaerobic power obtained with CMJ_{arm} ($r^2=0.57$; $P<0.01$). While significantly correlated ($P\leq0.05$) with CMJ_{arm} performance, stature, lower limb length/stature and sitting height/stature ratios were not significant ($P>0.05$) predictors of CMJ_{arm} performance.**

Conclusion. **This study demonstrates that lower limb length is correlated with CMJ_{arm} in elite male volleyball players. The players with longer lower limbs have the better vertical jump performances and their anaerobic power is higher. These results could be of importance for trained athletes in sports relying on jumping performance, such as basketball, handball or volleyball. Thus, the measurement of anthropometric characteristics, such as stature and lower limb length may assist coaches in the early phases of talent identification in volleyball.**

Key words: Volleyball - Plyometric exercise - Body height.

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Among the different team sports, volleyball is a popular sport, played in many countries worldwide. The physiological demands of the sport have gradually increased over time, with players taller, stronger and more agile in order to satisfy the greater physical demands during a game. Häkkinen [1] reported that high levels of muscular power are required to perform the majority of volleyball movements (quick start, sudden stops, jumps etc.). Vertical jumping ability is a physical parameter that is extremely important in volleyball.[2, 3] During a game players perform approximately 100 jumps during attacking and blocking.[4] Players must acquire high aerobic and anaerobic capacities to be competitive.

It is important to volleyball players to reach a maximum height above the net. Previous research has investigated the relationship between specific anthropometrical measures (body mass, body composition, and stature) and vertical jump performance.[2, 5, 6] Several investigations have demonstrated that body size and anthropometric characteristics of athletes could affect physical performance and may represent important prerequisites for successful participation in any given sport.[7-9]

A number of studies suggest a moderate positive correlation between the recorded performance and body size.[10] Body mass and stature influence strength abilities according to the scaling theories.[11] The importance of players' stature in some team sports (*e.g.*, volleyball) is accepted as it is well known that body stature positively influences all body segment lengths and, in turn, athletic performance.[12-14] It would seem that some coaches in the volleyball community may believe that short volleyball players would have to jump higher to reach this fixed height than taller players and consequently could be better jumpers. Sheppard *et al.*[15] found that despite the same training and playing experience, taller athletes tend to be faster at lateral movement and repeated lateral movement in a volleyball specific movement.

Despite the wide use of vertical jump (height jumped) in volleyball players,[2] no studies are currently available investigating the added effect of body segment lengths (as stature and sitting height, lower limb length, lower limb length/stature, etc.) on the performance of the Counter Movement Jump with arm swing (CMJ_{arm}) in volleyball players. Accordingly, the first purpose of this investigation was to determine the relationship between anthropometric parameters (as stature and sitting height, lower limb length, lower limb length/stature, etc.) and vertical jump performance (represented by the counter movement jump with arm swing [CMJ_{arm}]) in elite volleyball players. The second purpose was to determine what, if any, anthropometric parameters were predictive of CMJ_{arm} in elite volleyball players. We hypothesized that an inverse relationship would exist between stature and lower limb length and vertical jump performance. In this study the relationship between vertical jumping ability, and some body segments that could be related to body size, was examined in elite male volleyball players.

Materials and methods

Participants

Thirty-three male volleyball players (21±1 y, 76.9±5.2 kg, 186.5±5 cm) all from the first division of the Tunisian Championship participated in this study. Subjects were recruited from a squad of highly trained, competitive volleyball players. They trained 8 to 10 times (12-16 hours) per week. The subjects and their parents were fully informed about the possible risks and discomfort associated with the study, and all signed a written informed consent form previously approved by the local ethics committee and in accordance with the ethical standards of the Helsinki Declaration of 1975.

Anthropometric measurements

The following anthropometrical measurements were collected: body mass, stature, sitting heights and lower limb length. All measures were conducted on the same day and were completed in the standardized order described below. Body mass was measured to the nearest 0.1 kg using an electronic scale (Seca, Hamburg, Germany), with subjects standing barefoot and dressed in shorts or light clothing. Stature and sitting heights were measured using a wall stadiometer and sitting height table (GPM – Swiss Made). These measurements were determined while subjects were barefoot. Lower limb length was measured, as described by Steudel-Numbers *et al.*[16] with a tape from the anterosuperior iliac spine to the center of the medial malleolus of the ipsilateral leg with the subject in the supine position.

Vertical jump testing

After an adequate warming up of 10 min, jumping height was assessed using an infrared photocell mat connected to a digital computer (Optojump System, Microgate SARL, Bolzano, Italy) by the same investigator. The optical acquisition system allowed the measurement of contact and flight times during a jump and calculates the height of jump to a precision of 1/1000 s.[17]

Counter movement jump with arm swing (CMJ_{arm}):

The subject started from an upright standing position, made a downward movement until reaching an approximate knee angle of 90° and subsequently began to push-off with the help of the arms. All subjects performed familiarization trials before doing three consecutive experimental trials for CMJ_{arm}.

The highest value for each jump was retained. Every subject was given a 15-second interval between attempts.

Maximal anaerobic power

Power output (P) was estimated from the vertical jump test [18] by the power prediction equation of the Lewis formula,[19] which is used with the vertical jump.

$$P = \sqrt{4.9} \cdot BM \cdot \sqrt{h}$$

Where BM is the body mass in kg and h is the vertical jump height in meters.

Statistical analyses

All data were analyzed using SPSS version 11.0. Analysis of data was conducted using the median score of three trials for anthropometric data and the highest value of three trials for all other data. Means and standard deviation were calculated for each variable. Differences in vertical jump performance between the tallest (N.=16) and shortest (N.=17) players were compared using an independent *t*-test. Pearson product moment correlation coefficients were determined to examine the relationship between vertical jump performance and anthropometric variables. A forward step-wise multiple linear regression analysis was performed with vertical jump as the dependent variable. Several potential predictors were chosen to develop a vertical jump prediction equation: stature, body mass, lower limb length, sitting height, the Cormic Index (sitting height/stature) and the ratio of lower limb length/stature. In developing a prediction equation, we limited the number of potential predictors. When potential predictors are highly correlated with each other a multicollinearity problem may be created in the equation and, in turn, lead to a prediction error. In statistics, Multicollinearity can also be detected with the help of tolerance and its reciprocal measure, called the variance inflation factor (VIF). The VIF quantifies the severity of multicollinearity in an ordinary least squares regression analysis. It provides an index that measures how much the variance of an estimated regression coefficient (the square of the estimate's standard deviation) is increased because of collinearity. When high multicollinearity is present, confidence intervals for coefficients tend to be very wide and t-statistics tend to be very small. Coefficients will have to be larger in order to be statistically significant, i.e. it will be harder to reject the null hypothesis when multicollinearity is present. To screen for multicollinearity among the regressor variables, several statistical tests including variance inflation factor and tolerance values were applied to the final model (Table I). The level of significance was set at P≤0.05.

Table I.—*Examination for multicollinearity of the regression variables in elite male volleyball players (N.=33).*

	Tolerance	Variance inflation factor
Body mass	0.956	1.046
Stature	0.797	1.255
Sitting height	0.845	1.183
lower limb length/stature	0.364	2.751
Sitting height/stature (Cormic Index)	0.989	1.011
Body mass/stature	0.998	1.002

Table II.—*Mean values of anthropometric data in elite male volleyball players (N.=33).*

	Mean ± SD
Body mass (kg)	76.9±5.2
Stature (cm)	186.5±4.6
Sitting height (cm)	93.5±4.6
Lower limb length (cm)	98.5±4.0
Lower limb length / stature	0.5±0.3
Sitting height/ stature (Cormic Index)	0.5±0.3
Body mass / stature (kg/cm)	0.4±0.3

Results

The intra-class correlation coefficient (ICC) for the dependent variables, used to establish test-retest reliability,[20, 21] for CMJ_{arm} test ranged from 0.85 to 0.96. Table II illustrates the descriptive statistics for body mass, stature, sitting height, lower limb length, lower limb length/stature, Cormic Index, and body mass/stature ratios.

Table III shows the summary of multiple regression models for predicting CMJ_{arm} in volleyball players. A linear and significant positive relationship between lower limb length and CMJ_{arm} (r=0.83; P<0.001; Figure 1) as well as between lower limb length and anaerobic power was observed (and r=0.75; P<0.01; Figure 2).

TABLE III.—*Summary of multiple regression models obtained with lower limb length for predicting vertical jump performance (CMJ_{arm}) in elite male volleyball players (N.=33).*

	Constant	B	Beta	r^2	Adjusted r^2	Signification
CMJ_{arm}	-27.13	0.77	0.83	0.69	0.68	0.001

CMJ_{arm}: counter movement jump with arm swing.

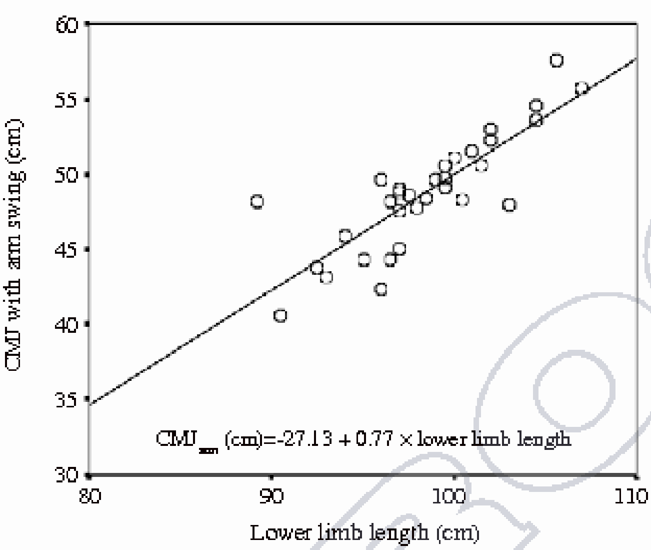

Figure 1.—Relationship between the lower limb length and the counter movement jump with arm swing (CMJ_{arm}) (r^2=0.69; P<0.001).

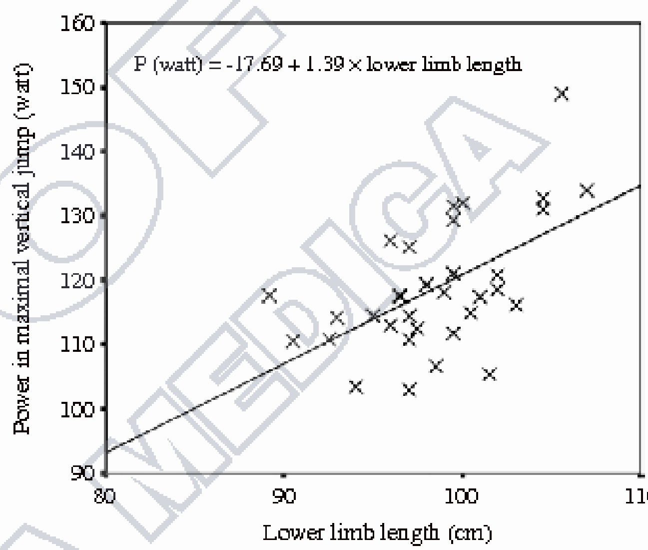

Figure 2.—Relationship between the lower limb length and the power obtained in maximal vertical jump test with represented by the counter movement jump with arm swing (CMJ_{arm}) (r=0.75; P<0.01).

The prediction model was found to have an r^2 equal to 0.69 for CMJ_{arm} (P<0.001). Our data indicate that the possible predictors produced a significant positive effect in the CMJ_{arm} (Table III). Only the lower limb length was found as predictor of CMJ_{arm}. Although significantly correlated (P≤0.05) with CMJ_{arm}, stature, LLL/stature and sitting height/stature ratios were not significant (P>0.05) predictors of CMJ_{arm} (Table IV). The step-wise multiple regression analysis excluded stature and body mass as well as some other calculated ratios from the equation because of their multicollinearity.

Anaerobic power and sitting height were significantly higher (P≤0.05) in the tallest players relative to their shorter counterparts. However, no significant differences (P>0.05) were detected between the two groups notably for CMJ_{arm}, lower limb length, lower limb length/stature, and Cormic Index (Table V).

TABLE IV.—*The correlation coefficient values (r) obtained between anthropometric parameters and vertical jump performance (CMJ_{arm}) in elite male volleyball players (N.=33).*

	r	P value
Body mass (kg)	0.17	0.34
Stature (cm)	0.39	≤ 0.05
Sitting height (cm)	- 0.33	0.06
Lower limb length (cm)	0.83	< 0.001
Lower limb length /stature	0.65	< 0.001
Cormic Index	- 0.66	< 0.001
Body mass/stature (kg/cm)	0.02	0.89

CMJ_{arm}: counter movement jump with arm swing; r: Pearson product moment correlation coefficient.

Discussion

Our first objective in the study was to investigate the relationship between vertical jump performance

TABLE V.—*Differences in vertical jump performances (CMJ_{arm}), anaerobic power and anthropometric parameters obtained between tallest and shortest players.*

	Tallest players (N.=16) Mean ± SD	Shortest players (N.=17) Mean ± SD
Body mass (kg)	77.7±6	75.5±4.1
Stature (cm)	189.3±3.6	182.9±2.1**
Sitting height (cm)	96.1±4.0	90.8±3.7**
Lower limb length (cm)	98.9±4.0	97.5±3.7
Lower limb length / stature	0.5±0.16	0.5±0.17
Cormic Index	0.5±0.16	0.5±0.17
Body mass/stature (kg/cm)	0.4±0.16	0.4±0.17
Anaerobic power	1202.4±106	1130.0±79.6*
CMJ_{arm} (cm)	50.07±3.9	47.63±3.5

*: P≤0.05; **: P<0.001; significant difference between shortest and tallest players.

and anthropometric measurements. Stature, lower limb length, ratios of lower limb length/stature and sitting height/stature showed significant relationships with CMJ_{arm}. Our results are in agreement with other studies on the kinanthropometric qualities of track and field athletes. In fact, Carter *et al.* have described the kinanthropometric characteristics of Olympic athletes. It is not surprising that tall athletes have a clear advantage in most athletic events. Equally, very strong correlations were observed between relative depth jump performance and relative spike jump and relative CMJ [2]. In addition, our data is similar to the study of Pelin *et al.*[22] indicating that volleyball and basketball players were characterized by their longer lower limb length. However, these findings were in opposition to those of Scott *et al.*[5] who showed that stature and body mass were not significantly correlated with vertical jump performance.

We found a significant relationship ($r=0.83$; $P<0.001$) between lower limb length variable and CMJ_{arm}. In other words as lower limb length increased, vertical jump performance improved. The contribution of the lower limb length in the CMJ_{arm} was 69%. The results could be explained by a mechanical possible theory is that taller subjects have longer time and distance to produce force (acceleration) due to their longer legs, resulting in a higher jump. In general, smaller subjects have shorter limbs and, therefore, a shorter distance over which to accelerate.

Skeletal muscle mechanics can restrict jumping performance due to the limits of maximal shortening velocity and maximal power output affecting jump acceleration and distance. Skeletal muscle performance could cause greater limitations on jumping performance when body size is small.[23, 24] Therefore, to achieve the same jumping performance the smaller subjects will require higher force, greater peak power output and higher maximum shortening velocity to enable them to accelerate faster to achieve the same take-off velocity.[25]

Other factors that may influence the results are that the increase in lower limb length produces a gain of the height of the center of mass, which was not measured in this study but it represents the height of the second sacred vertebra, S2.[26] The position of center of mass is higher in the body as the lower limbs are longer [26] and then could be a factor for increasing the jumping height since it has been shown that the maximum reach height is a product of the height of the center of mass and the position of the body around the center of mass at the apex of flight.[27] Marsh [28] suggested that several potential adaptations could increase jumping performance as: 1) the total average power required for the jump has to be provided by skeletal muscle but may be enhanced by elastic potential energy stored prior to or during the jump; and 2) the distance from the centre of mass to the most distal part of the limb could be increased by having relatively long legs.

It is well documented that it is easier to raise the center of mass against gravity in a subject with a longer lower limb length than in a subject with a shorter lower limb length.[29] In fact, it is widely supposed that short lower limb (shorter athlete) would require greater ability to generate the power needed to raise the center of mass against gravity.[30]

In addition, our results showed that the lower limb length was positively and significantly correlated with anaerobic power. Muscular power has been considered an important physical ability, particularly responsible for success of rapid movements (*e.g.*, jumping).[31] The muscular power was higher among the players having longer lower limbs (Table V). The significant positive correlation of anaerobic power with lower limb length implies that a higher level of maximal strength and power in the "high strength" player results in more powerful jumps.[32] Our data are in agreement with the results obtained by Marques *et al.*[33] in volleyball players that indicated that the middle blockers (who were the tallest and heaviest players), are significantly stronger ($P<0.05$) than the setters. Dowling and Vamos [34] suggested peak power may have been a necessity for vertical jump performance, but it was not the only determining parameter. Thus, experimental results indicate that a taller person could be better in activities with a significant strength component.[35]

This study suggests that the players with longer lower limb length have both an advantage of the positive association between lower limb length and the anaerobic power and the raised position of a center of mass at takeoff. Data from this work support the study of Sheppard *et al.*[15] who found that taller athletes have a greater capacity to perform the fast lateral movement and jumping tasks involved in elite volleyball. Although there are relatively short athletes who have achieved the highest levels of success in volleyball, these findings would likely be due to their skills and other physical abilities compensating for their lack of stature, and their achievements should not be viewed as attributable to their short stature.[15] These results appear to be relevant for trained athletes in sports relying on jumping performance, such as basketball, handball or volleyball.

In accordance with the findings of Rob *et al.*,[24] these results suggest that differences in jumping performance among individuals may be related to morphological variables such as greater relative leg length, which would lead to greater available muscular power output and longer distance over which to accelerate during take-off, respectively. Our findings are in disagreement with those of Davis *et al.*[36] who investigated the relationship of body segment length and vertical jump displacement in 78 recreational athletes (55 men and 23 women, aged of 21.9±2.9 years). They examined the contribution of segmental skeletal length to vertical jump performance by measuring skeletal length of the trunk, femur, tibia, and foot. Using regression analysis these authors identified that foot length was the only significant skeletal length predictor of vertical jump performance in men.

The present study demonstrates that the lower extremity plays an important role in enhancing vertical jump performance. Tall subjects with longer lower limbs tend to be better jumpers than shorter subjects. As such, in accord with Sheppard *et al.*,[15] tall players have a distinct advantage in that they can more rapidly defend space above the net due to their larger reach height in comparison to shorter athletes. The lower limb length was found to be highly correlated with CMJ_{arm} and anaerobic power in elite male volleyball players. The players with longer lower limbs had the better CMJ_{arm} and their anaerobic power was higher. However, comparisons of CMJ_{arm} performances between the tallest and the shorter players revealed that tallest players had a greater but non significant ($P>0.05$) vertical jump than shorter players (Table V). The non significant result could probably due to the fact that there were no differences in lower limb length between the two groups. Thus, the tallest players do not have necessarily the longest lower limbs.

Conclusions

These findings provide evidence that the players with longer lower limbs have better vertical jump performance and higher anaerobic power. In fact, lower limb length is of major importance for the jumping performance in volleyball and that this has to be tested in training. The coaches could use the measurement of anthropometric characteristics, such as stature and lower limb length for talent identification in volleyball. Equally it is not sufficient to have a great stature to perform better vertical jump performance but it is also necessary to have long lower limb in the same time. These results appear to be relevant for volleyball players. Further research is required to validate these findings in larger samples, among specific athletic populations that require vertical jumping.

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