

**Research article**

**DIFFERENCES IN THE MECHANICAL CHARACTERISTICS OF  
THE VERTICAL JUMP BETWEEN ATHLETES IN SPORTS  
GAMES**

*UDC 796:531.31*

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**Abstract.** *The vertical jump is one of the most common ways to evaluate the explosive power of the lower extremities in athletes. For the development of explosive power, plyometric exercises are mostly used as a form of training. The participants were handball players (N=13), volleyball players (N=13) and basketball players (N=13) from city of Nis. They all competed in the highest state competitions. After analyzing all the data, the conclusions are that the mechanical characteristics estimated by the accelerometer are statistically not significantly different in the examined groups of athletes, except in the jump height, and the kinematic characteristics of the vertical jump obtained by the video analysis statistically do not differ significantly, except in the variations of the angular velocity in the hip joint and the ankle.*

**Key words:** *mechanical characteristics, vertical jump, kinematic, accelerometer*

INTRODUCTION

The use of vertical jumps for the purpose of assessing explosive muscle strength of the legs has been present in professional literature, but also in practice for more than 80 years (Sargent, 1921). Many textbooks, manuals and other publications suggest the use of vertical jumping tests to assess explosive muscle strength (Astrand & Rodahl, 1986).

Explosive power is defined as the individual ability of the nervous-muscular system to apply strain in the shortest possible time. The notion of explosive power is related to the reactive ability of the neuromuscular apparatus (Verhošanski, 1979). In the definition of explosive force, Zatsiorsky introduced the term reversible force in the theory and practice of athletes, consisting of two successive phases: the eccentric (stretch) and concentric

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Received April 11, 2017 / Accepted May 11, 2018

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(shortening). In addition to the regularity of the movement in the rebound, it is important that the body is optimally prepared before reactive training, not only for the prevention of injuries, but also because only an optically innervated muscle can be adapted to the effect of “reactive” training. Preparation before reactive training can be general and special (Weineck, 2000).

In the non-experimental application of plyometric exercises in the pre-competition season, volleyball players Borowsky used six plyometric exercises four weeks before the competitive season and received the expected results in a psychological and physiological way. In the theory and practice of volleyball training, there are several models for the development of explosive leg muscle strength, e.g. Model Chu, (1991). The application of the plyometric method (reversible method - Zatsiorsky) emphasized the need to consider the possibility of its application with youth volleyball players, on the one hand, and the efficiency of a certain set of plyometric exercises on the development of the jump, if it is used after the technical tactical training, on the other.

However, most studies that examined the height of the jump and the measured muscle strength (in Watt, W) have shown that the above-mentioned connection is at best moderate  $r \approx 0.50$ ; for example (Aragon-Vargas & Gross, 1997), and often not lower (Kukolj, Ropret, Ugarkovic & Jaric, 1999), thus questioning the validity of the vertical jump height as an index of the explosive muscular strength of man. One of the possible factors responsible for these results is the size of the body (Jaric, Mirkov & Markovic, 2005; Markovic & Jaric, 2004). Namely, both the theoretical predictions and the experimental findings clearly show that the muscular strength is in a positive correlation with body size (body mass), while the height of the jump is independent of the size of the body. A large number of studies evaluated the performance of the vertical jump of basketball players at different playing positions (Smith, & Thomas, 1991). The difference in the skill level of the vertical jump is in a direct relation with the height of the jump, which was confirmed by the study, which included the eight best players in all positions and the rest of the team (Hoare, 2000; Latin, Berg, & Baechle, 1994). In recent research (Delextrat, & Cohen, 2008), vertical jump values showed an 8.8% higher value among elite and average players. The research of Berg & Latin (1995) compares the median values of the vertical jump between basketball players and soccer players. It was concluded that there is similarity in these abilities, but that strength values were greater among soccer players.

Handball is a powerful sport, a sport with a focus on running, jumping, sprinting, throwing, pushing and blocking (Gorostiaga, Granados, Ibañez, González-Badillo, & Izquierdo, 2004). Since elite handball demands are increasing every day, it is necessary to maintain an adequate level of force and strength during the season (Buchheit, et al., 2008; Marques, & González-Badillo, 2006). A combination of speed training and explosive power is necessary to improve the maximum speed of jumping and jumping height (Chelly, et al., 2009; Christou, et al., 2006), as well as the development of maximum anaerobic abilities and explosive capacities (Buchheit, et al., 2009; Buchheit, et al 2008; McMillan, Helgerud, Macdonald, & Hoff, 2005). Reduced maximum power and explosive strength were observed in 5.5 seconds of strength training, suggesting that hand-to-hand training requires weight training and strength training (Jensen, Jacobsen, Hetland, & Tveit, 1997).

Considering all the above, as well as the fact that in the performance of the vertical jump the athlete starts his own body mass, our assumption is that the height of the jump is a valid index of muscular strength normalized to the size of the body.

## METHODS

### The sample of participants

The participants in this study were athletes from the best clubs in city of Niš: handball players from the handball club "Železničar", a member of the Super Handball League of Serbia (SRLS), basketball players from the basketball club "Konstantin", who competed in the first basketball league of Serbia (KLS), and volleyball players from the volleyball club "Niš", which is a member of the first league of Serbia. The total number of participants was 39 (13 + 13 + 13). Participants had to satisfy the requirements that they had participated in their selected sport longer than 5 years, that they were seniors, healthy, and involved in the training process.

### Measuring instruments

The sample of measuring instruments for the assessment of body characteristics of the sample:

- Body height (BH in cm),
- Body mass (BM in kg).

The sample of measuring instruments for the assessment of mechanical characteristics by the accelerometer:

- Force (F in N),
- Power (P in W),
- Speed (V in cm /s),
- Jumping height (H in cm).

The sample of measuring instruments for the assessment of mechanical characteristics by kinematic analysis:

- Maximum angular velocity in the ankle joint (MAVAJ in deg/s),
- Maximum angular velocity in the knee joint (MAVKJ in deg/s),
- Maximum angular velocity in the hip joint (MAVHJ in deg/s).

### Statistical analyses

All the kinematic parameters were obtained using the Casio FX fast motion camera, with a recording speed of 300 frames per second. Video processing and digitization was done using the kinematic analysis program HUMAN HMA Technology Inc. In addition to the accelerometer, the participants also had reflective markers at representative points using automatic digitization. With graphs of the change in the angular velocity values, maximum values were obtained in the phase of the eccentricity and the concentration. Each video consisted of over 550 video frames and for each attempt angular values and corner angles in the lower limb joints were calculated.

In this research, basic, descriptive data processing was used to determine the measures of central tendency (arithmetic mean) and measurements of variability (standard deviation, range, maximal and minimal result). To verify the normal distribution of results, skewness, kurtosis and the Kolmogorov Smirnov test were used. A univariate analysis of variance (ANOVA) and multivariate variance analysis (MANOVA), as well as a post hoc analysis - the least significant difference test (LSD) were used to determine differences in arithmetic means among the groups of athletes.

## RESULTS

**Table 1** Multivariate analysis of mechanical characteristics of athletes in sports games estimated by the accelerometer

	Value	F	Hypothesis df	Error df	Sig.
Wilks' Lambda	0.72	1.492a	8.00	66.00	0.18

In Table 1 we see the results of a multivariate variance analysis for a set of variables used to evaluate the mechanical characteristics using an accelerometer. The value of Wilks' Lambda of 0.72, with the F approximation of 1.492 and 8 degrees of freedom, which gives a statistically significant difference at the level of 0.18 among the tested groups of athletes.

**Table 2** Univariate analysis of mechanical characteristics of athletes in sports games estimated by the accelerometer

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Sport	F	42.40	2.00	21.20	1.17	0.32
	P	243.36	2.00	121.68	0.56	0.58
	V	1434.51	2.00	717.26	0.38	0.69
	H	161.91	2.00	80.96	3.01	0.06

In order to determine which variables contributed to the significance of the differences, a non-univariate analysis of variance was calculated, which is shown in the following table 2. It is noted that only variable H of jumping height has a high level of significance of 0.06, which has given the greatest contribution to the difference of all mechanical characteristics among the tested groups of athletes.

**Table 3** Post hoc analysis - the least significant difference test (LSD)

Variable	(I) Sport	(J) Sport	Difference arithmetic mean (I-J)	Sig.
H	Basketball players	Volleyball players	-1.30	0.53
		Handball players	3.52	0.09
	Volleyball players	Basketball players	1.30	0.53
		Handball players	4.823*	0.02
	Handball players	Basketball players	-3.52	0.09
		Volleyball players	-4.823*	0.02

In the subsequent analysis of variance, a post hoc analysis (table 1.2) of the smallest significant differences for the variation of jump height H was calculated. Comparing pairs of examined athletes, it was noted that the difference in jumping height between volleyball players and handball players is statistically significantly different (0.02) and that it contributed to the statistically significant difference at the univariate level. In other pairs of athletes, there was no statistically significant difference in the arithmetic mean of the height of the jump, although there is a large difference between the basketball players and the handball players.

**Table 4** Multivariate analysis of mechanical characteristics of athletes in sports games estimated by the kinematic method

	Value	F	Hypothesis df	Error df	Sig.
Wilks' lambda	0.54	1.854a	12.00	62.00	0.06

Table 4 shows the results of the multivariate variance analysis for a set of variables which were used to evaluate the mechanical characteristics using the kinematic method. The value of Wilks' Lambda of 0.54, with F approximation of 1.854 and 12 degrees of freedom, gives a statistically significant difference at the level of 0.06 among the tested athletes' groups.

**Table 5** Univariate analysis of the mechanical characteristics of athletes in sports games estimated by the kinematic method

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Sport	MAVHJEG	14626.31	2.00	7313.15	3.03	0.06
	MAVHJCG	1596.05	2.00	798.03	0.45	0.64
	MAVKJEG	4850.00	2.00	2425.00	1.52	0.23
	MAVKJCG	6053.90	2.00	3026.95	0.96	0.39
	MAVAJEG	188.77	2.00	94.39	0.21	0.81
	MAVAJCG	34699.13	2.00	17349.56	6.22	0.01

\*EG – Experimental Group; CG – Control Group

In order to determine the variables that contributed to the significance of the differences, a univariate analysis of the variance was calculated, as shown in Table 5. It can be noted that the variables MAVHJEG and MAVAJCG have a high level of significance of 0.06 and 0.01, respectively. They made the greatest contribution to the difference between all the mechanical characteristics among the groups of athletes examined at the multivariate level.

**Table 6** Post hoc analysis - the least significant difference test (LSD)

Dependent variable	(I) Sport	(J) Sport	Difference arithmetic mean (I-J)	Sig.
MAVHJEG	Basketball players	Volleyball players	-42.77*	0.03
		Handball players	-3.62	0.85
	Volleyball players	Basketball players	42.77*	0.03
		Handball players	39.15*	0.05
	Handball players	Basketball players	3.62	0.85
		Volleyball players	-39.15*	0.05
MAVAJCG	Basketball players	Volleyball players	-29.31	0.17
		Handball players	43.31*	0.04
	Volleyball players	Basketball players	29.31	0.17
		Handball players	72.62*	0.00
	Handball players	Basketball players	-43.31*	0.04
		Volleyball players	-72.62*	0.00

In the subsequent analysis of variance, a post hoc analysis of the smallest significant differences for the variables MAVHJEG and MAVAJCG was calculated, shown in Table 6. Comparing the pairs of the studied athletes, a statistically significant difference in angular velocities in the hip joint in the eccentric MAVHJEG phase between volleyball and handball players, and between the volleyball players and basketball players (0.05, 0.03, respectively) was noted, and that it contributed to a statistically significant difference at the univariate level. No statistically significant difference in arithmetic means for this variable was obtained for the basketball players and handball players.

Regarding the corner velocity in the hips in the concentric phase of the vertical jump MAVAJCG, based on the post hoc analysis of the smallest significant differences, from Table 6 it can be seen that all pairs of investigated athletes differ statistically significantly, except basketball players and volleyball players.

## DISCUSSION

The aim of this study was to determine the differences in the mechanical characteristics of the vertical jump in basketball, handball and volleyball seniors. On a sample of athletes in sports, basketball, handball and volleyball, competing in the highest national ranking of the competition, an examination was performed to evaluate the values of the mechanical characteristics of the vertical jump using the accelerometer method and the kinematic method. The obtained values were statistically processed in order to determine the differences in the tested variables.

Based on the results of a multivariate variance analysis of mechanical characteristics estimated by accelerometer (table 1), statistically significant difference where fined at the level of 0.18 among the tested groups of athletes. Base on that, univariant analysis of the same mechanical characteristics estimated by accelerometer (table 2) was done, and the results indicate that there is significant difference only in one variable and that is jumping height (H) with Sig.  $\geq 0.06$  which was confirmed in the previous study (Peña López,

Moreno-Doutres, Coma Bau, & Cook, 2018). Since these athletes, which are compared among themselves, are from three different sports (basketball, volleyball and handball) in which the vertical jump is not represented equally and the height does not have the same importance, these kind of results are expected. With that sad, the emphasis on the increasing height of vertical jump during practices is not the same in these sports. Variable jumping height (H) was further analyzed by post hoc analyze – LSD (table 3) after which it was concluded that the only significant difference exists between volleyball and handball players  $\text{Sig.} \geq 0.02$ . The fact that handball is a sport with continuous body contact handball players usually have big body weight and that usually have a negative influence on vertical jump performance (Hermassi, Chelly, Tabka, Shephard, & Chamari, 2011). On the other hand, volleyball is non-contact sport and because of lack of body contact players do not need to develop high body mass. Vertical jump and explosive strength are important in volleyball game because there are the basis of attack (spike) and defense (block). Also, the reason for these results can be the similarities of the test and jumps movements of volleyball players and largest number of vertical jumps per player in one game (Sheppard, Nolan, & Newton, 2012; Sheppard et. all, 2008; Fontani, Ciccarone, & Giulianini, 2000) when comparing with basketball (McInnes, Carlson, Jones, & McKenna, 1995) and handball (Póvoas et. all, 2012). Jumping performance differences are attributable to different training backgrounds (Kollias, Panoutsakopoulos, & Papaiaikovou, 2004) and the height of the vertical jump is strongly correlated with the strength of the lower limbs – explosive strength (de Ruiter, de Korte, Schreven, & De Haan, 2010). With that sad plyometric is the most usable training for developing explosive strength of lower limbs. The execution of plyometric jumps aiming for maximum jump height in the shortest possible contact time led to an improvement of power output.

When it comes to results of the mechanical characteristics estimated by kinematic method they are also processed with multivariate analysis (table 4) and the statistically significant difference can be seen at the level of 0.06 among the athletes' groups. After univariate analysis (table 5) statistically significant difference was observed in two variables (MAVHJEG  $\text{Sig.} \geq 0.06$  and MAVAJCG  $\text{Sig.} \geq 0.01$ ), which have been further processed by LSD analyze (table 6). Statistically significant difference in angular velocities in the hip joint in the eccentric phase (MAVHJEG) was found between volleyball and handball players  $\text{Sig.} \geq 0.05$ , and between volleyball players and basketball players  $\text{Sig.} \geq 0.03$ . The release time of the stored elastic energy can be optimized by increasing the amount of activity of the eccentric muscle (McBride, McCaulley, & Cormie, 2008; Finni, Komi, & Lepola, 2000). These results are based on the fact that maximal vertical jumps need a greater engagement of the hip extensor muscles (Giatsis, Panoutsakopoulos, & Kollias, 2018; Bobbert & Casius, 2005; Lees, Vanrenterghem, & De Clercq, 2004) and we saw that volleyball players have the best result in jump height (H).

When it comes to second variable, the angle velocity in the ankle joint in the concentric phase of the vertical jump (MAVAJCG), statistically significant difference was found between handball players and other athletes (Basketball players  $\text{Sig.} \geq 0.04$  and Volleyball players  $\text{Sig.} \geq 0.00$ ). The results are also showing that handball players have lower values than other athletes. This can be the reason of vertical jump height itself. Because vertical jump is classic plyometric move it should be done explosively as possible. Fast concentric contraction also results in rapid eccentric contraction which causes high velocity in the joints of the lower extremities. In a previous study (Toumi,

Best, Martin, & Poumarat, 2004) has been suggested that improvements in vertical jump may be because of increased activation in the eccentric phase in leg joints

#### CONCLUSION

The aim of this research was to determine the differences in the mechanical characteristics of the vertical jump in basketball, handball and volleyball seniors.

On a sample of athletes in sports, basketball, handball and volleyball, competing in the highest national ranking of the competition, an examination was performed to evaluate the values of the mechanical characteristics of the vertical jump using the accelerometer method and the kinematic method. The obtained values were statistically processed in order to determine the differences in the tested variables. Based on the results and its discussion, the following conclusions can be drawn:

- The mechanical characteristics estimated by the accelerometer are statistically not significantly different in the studied groups of athletes, except in the jump height.
- The kinematic characteristics of the vertical jump obtained by the video analysis statistically do not differ significantly, except in the variations of the angular velocity in the hip joint and in the ankle.

**Acknowledgement:** *The research was conducted within the project Biomechanical efficiency of top Serbian athletes (ON179019) funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

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## RAZLIKE U MEHANIČKIM KARAKTERISTIKAMA VERTIKALNOG SKOKA IZMEĐU SPORTISTA

*Vertikalni skok je jedan od najčešćih načina za procenu eksplozivne snage donjih ekstremiteta kod sportista. Za razvoj eksplozivne snage, piliometrijske vežbe se uglavnom koriste kao vid treninga. Ispitanici su bili rukometaši (N = 13), odbojkaši (N = 13) i košarkaši (N = 13) iz grada Niša. Svi su se takmičili u najvišem rangu državnog takmičenja. Posle analize svih prikupljenih podataka zaključeno je da mehaničke karakteristike procenjenim akcelerometrom nisu statistički značajne u ispitivanim sportskim grupama, osim u visini skokova, a kinematičke karakteristike vertikalnog skokova dobijene video analizom, statistički ne pokazuju značajnu razlikzu, izuzev u varijacijama ugaone brzine u zglobu kuka u skočnom zglobu.*

Ključne reči: *mehaničke karakteristike, vertikalni skok, kinematika, akcelerometar*