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Original research article

ACTIVE LANDING AND TAKE-OFF KINEMATICS OF THE LONG JUMP *

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Abstract. *The aim of this paper was to perform a kinematic analysis of the take-off, and especially to examine the relationships of active landing (AL) and run-up velocity (RUV) with the take-off variables and the length of jump (L), as well as to determine the influence of our model and individual influence of each independent variable on the dependent variable – (L). The authors' intention was to apply the obtained results in practice – with the possibility of helping a population of average women long jumpers to approach the model of an elite woman long jumper. An experimental method was applied in the research to the sample of 25 successful long jumps of different length and the velocity of the approach of the junior world champion Ivana Španović. The results were measured by the Qualisys ProReflex MCU 240 motion capture 3D infrared system. The Pearson correlation analysis was used to establish the correlation between the variables. The standard multiple regression was used to measure the percentage of the influence of the model and each variable at L. It was found that the variables of the take-off change with the increase of RUV. The highest correlation with RUV was determined for the variables: (L) $r = 0.696$ and $p = 0.000$ and (TA) $r = 0.603$ $p = 0.001$. The standard multiple regression was used to calculate that our model (RUV, AL, KATD, AATD, LATD, TA, TOD) explained the variance L with 69%. It was concluded that TOD, LATD and RUV statistically significantly explain the variance L. To realize the maximum length of the jump, the jumpers should achieve the highest possible RUV and minimize the loss of the resulting take-off velocity with AL, the LATD should be about 63°, the KATD and TA should be increased, while the TOD should be shortened with the increase of RUV. It was found that AL does not correlate with RUV, but there is a statistically significant correlation of AL with TOD, which has a large impact on L.*

Key words: *biomechanics of sport, run-up velocity, take-off duration, take-off angle.*

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INTRODUCTION

Rational and efficient processes of learning and performing the long jump technique at trainings and competitions should be based on a detailed biomechanical analysis. Coaches cannot perceive all of the important elements of the technique by visual perception (observation), therefore the need for kinematic, dynamic and other analyses of the long jump technique has become usual for athletic practice. The run-up velocity (RUV) and the take-off technique are the most important for the long jump length (L) (Luhtanen & Komi, 1979; Seyfarth, 2000; Bridget, Galloway & Linthorne, 2002; Chow & Hay, 2005; Bridgett & Linthorne, 2006; Muraki, Ae, Koyama & Yokozawa, 2008). The take-off technique has been studied with the aim of finding and defining the variables that would represent the main factors of the performance (optimization) of a take-off (Čoh, & Mikuž 2002; Bridgett & Linthorn, 2006). It was determined that run-up velocity (RUV) has a considerable influence on the kinematic variables of a take-off: leg angle at touchdown (LATD), total angle (TA), take-off duration (TOD), knee angle (KATD) and ankle joint angle at touchdown (AATD) (Alexander, 1990; Bridgett et al., 2002; Graham-Smith & Lees, 2005; Bridgett & Linthorne, 2006; Janković, 2009). Only a few studies have examined the connection of the take-off variables with the active landing (AL), while the need for the study of the influence of the run-up velocity on the take-off technique and the increase of the number of variables that should be taken into consideration is a logical continuation in the long jump technique study. According to Koh & Hay (1990b) and Leblanc (1997) the way in which the AL is performed is important for the success of a long jump in order to make body movement redirection more efficient and intensive. The AL movement is a consequence of a natural sequence of activities in human locomotion. It is present in many ways of motion: walking, running and jumping. In the last run-up stride, the AL movement plays a key role in the transformation of mostly horizontal velocity of the run-up into the resultant velocity of a take-off. The foot is directed downward and backward with the AL movement (Flynn, 1973; Marino & Young, 1988) through the simultaneous extension of the hip and knee joints. Koh & Hay (1990a, b) defined the AL as the difference between the velocities of the centre of mass of the take-off foot and the centre of mass of the body just before the take-off. It is a movement in which the jumper swings back the take-off foot before contact with the ground in order to optimize the position of the leg and reduce the horizontal component of ground reaction force, acting on the horizontal braking torque of the jumper (Koh & Hay, 1990a; LeBlanc, 1997). The AL is more pronounced in the last two strides before the jump and it is more intense in elite athletes compared to beginners (LeBlanc, 1997). It is assumed that the change of the AL and a RUV of the individual will affect certain variables of the take-off (LATD, TA, TOD, KATD, AATD) and the length of the long jump. It is also assumed that there is a significant influence of the model (active landing, run-up velocity, and the take-off variables) on the length of the jump. The aim of this study was to perform a kinematic analysis of the take-off, and in particular to examine the relations between the AL and RUV and the variables of the take-off and the L, and to determine the influence of our model and the individual impact of each independent variable on the dependent variable – (L). The authors' intention was to put the obtained results into practice – as an opportunity to help the average population of female jumpers resemble the model of an elite long jumper.

THE METHOD

The sample of participants

The participant was the world Junior category long jump champion and current champion of Serbia (Ivana Španović – body height 175 cm, weight 66 kg, age 21, with a personal record of 6.78 m). The research data were collected during 4 training sessions, during two of which she jumped with the competition run-up of 20 strides, and during the other two with a changing run-up length of 8 to 18 strides. In this kind of research on an elite individual sample compared to non-professional jumpers, it can be assumed that all the jumps were performed with an optimal take-off technique with a modulation of run-up velocity (Čoh & Mikuž, 2002; Bridgett & Linthorne, 2006).

The sample of variables

Linthorn & Bridgett (2006) defined a RUV as the horizontal velocity of the body center at touchdown. An alternative method was used to determine the mean velocity of the body centre during the phase of the flight of the last run-up stride (Yu, 1999). Lees, Fowler & Derby (1993) got higher velocity of a run-up at touchdown during the alternative way of measuring velocity. Smaller values of RUV obtained with the first method of measuring are likely the consequence of an impact that occurs at touchdown (Lees et al., 1993). The obtained differences are relatively small (0.25 m/s) so that the measurement of the RUV at touchdown is considered adequate. Run-up velocity was presented as the horizontal velocity of the hip marker at touchdown which is consistent with the research carried out by Alexander (1990). The start of the take-off was defined as the first frame in which the foot of the take-off leg is in contact with the ground, and the end as the first frame in which the foot is not in contact with the ground (Hay, Miller & Cantera, 1986; Lees, Grahan-Smith & Fowler, 1994). The vector variable of the take-off leg angle in relation to the vertical (Fig. 1) was carried out in relation to the position markers on the hip and ankle. This variable is often called the leg angle at touchdown (LATD). The variable KATD is the angle made by the hip, knee and ankle markers (Fig. 2). The variable AATD is the angle made by the knee, ankle and toes markers (the ball of the foot) (Fig. 2). The variable TA is the total angular movement of the take-off leg in the sagittal plane during take-off (Fig. 3). All of the angle values are in degrees and rounded to one decimal place. The AL is calculated as the difference of marker velocities on the ankle and hip joint one frame before the take-off (Fig. 4). The variable length of time for a take-off represents the time during which the take-off leg is in contact with the ground. It was determined by analyzing the spatial coordinates of the markers of the longitudinal axis of the foot. For the detection of touchdown, a marker was placed on the heel. To determine the moment when the contact with the ground ceased, the movement of the markers on the toes was analyzed horizontally and vertically. It is considered that there is a possible error at the level presented in previous studies (Bezodis, Thomson, Gittoes & Kerwin, 2007). The length of the jump was measured according to track and field rules (the International Association of Athletics Federations - IAAF, 2009) using a tape measure with an accuracy of 1 cm, but measured from the point of the take-off – the effective length of the jump, i.e., it was measured from the zero reference point of the coordinate system in which the QTM calibration was performed. In the subsequent data processing the effective length of each jump was calculated on the basis of the position of markers on the toes. The variable is expressed in cm.

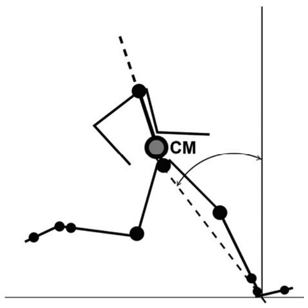

Fig. 1. Leg angle at touchdown.

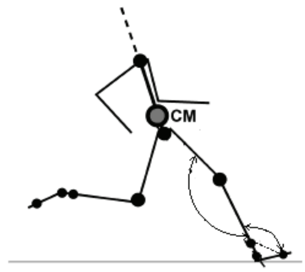

Fig. 2. Knee angle and ankle joint angle at touchdown.

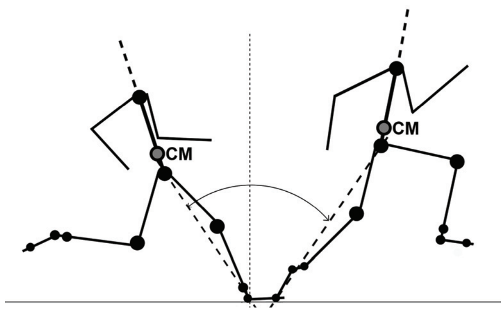

Fig. 3. Complete angular movement of the take-off leg in the sagittal plane during the take-off – total angle.

Fig. 4. Kinogram of the active landing.

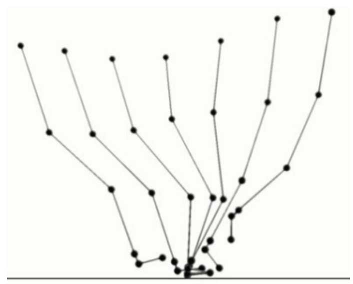

Fig. 5. Kinogram of the take-off.

Protocol of the experiment

Relationships between the variables: RUV, AL and the take-off were obtained by a kinematic analysis of a take-off of the respondent – an interventional study (Greig & Yeadon, 2000; Bridgett et al., 2002). The sample consisted of 25 successfully executed long jumps from different run-up lengths or velocities. The largest number of jumps was executed from the run-up length of 14 and 18 running strides, which was the result of the state of fitness of the respondent, i.e., training-competition period in which the measurements were made. The jumps were recorded in the athletic hall so that the outside influences, especially atmospheric effects (wind, solar radiation, temperature fluctuations) were avoided. Runway and landing places were in accordance with the rules of track and field (IAAF, 2009). The take-off zone was half a meter in front of and behind the board for the long jump. The athlete was familiar with the position of the take-off zone and she was given instructions to perform take-offs without the adjustment in relation to the board. She was required to pay maximum attention to the execution of the jumps, and less on run-up accuracy and the take-off leg positioning in relation to the board. Each jump was performed with maximum intensity in relation to the given conditions, i.e., the length of the run-up. After the usual warm-up procedure, the long jump was performed with different lengths of the run-up.

Kinematic variables of landing were measured by a 3D infrared (IR) Qualisys ProReflex motion capture (MCU 240) system with a signal sampling frequency of 240 Hz. The system comprised three (IR) cameras and a personal computer with the original Qualisys track manager (QTM) software, to later store the data that were analyzed. Retroflective markers (diameter 19 mm) were positioned at the points that represented centers of the joints of the take-off leg: a hip – trochanter major, a knee – caput fibulae, an ankle joint – maleolus lateralis, toes – V, metatarsal bone and a heel– calcaneus.

Fig. 6. Position markers on the body.

Fig. 7. Position markers on the leg.

The respondent was informed in detail about the nature, objectives and possible risks of the study and signed an informed consent in accordance with that. The experimental protocol was approved by the Ethics Committee for Research of the Faculty of Sport and Physical Education, University of Belgrade.

Statistical data processing

There was a normal distribution of the results according to Vincent (1995). The obtained data were analyzed by descriptive and comparative statistics. From the area of descriptive statistics, the representative dispersion parameters were calculated for each variable: arithmetic mean (mean), maximum value (maximum), minimum value (minimum) and standard deviation (std. deviation). The Pearson correlation analysis was used to determine the correlation between the variables. A standard multiple regression was used to measure the percentage of influence of our model and each individual variable on the length of the long jump.

RESULTS AND DISCUSSION

The descriptive statistics of the variables are displayed in Table 1. The values of the variables and their mutual correlations are similar to the ones in the papers published so far (Alexander, 1990; Arampatzis, Brüggemann & Walsch, 1999; LeBlanc, 2000; Seyfarth, 2000; Bridgett & Linthorne, 2006).

Table 1. Descriptive statistics of the variables.

	N	Minimum	Maximum	Mean	Std. Deviation
RUV (m/s)	25	7,12	8,38	7,90	0,33
L (cm)	25	548	630	583,52	19,98
TOD (ms)	25	112	146	129,48	8,11
LATD (deg°)	25	22,9	31,7	26,80	2,36
TA (deg°)	25	40,4	49,9	45,49	2,80
AATD (deg°)	25	107,0	127,5	117,25	5,65
AL (m/s)	25	-4,99	-2,36	-3,65	0,58
KATD (deg°)	25	146,8	166,2	157,49	6,43
Valid N (listwise)	25				

Legend: RUV – run-up velocity; AL – active landing; LATD - leg angle at touchdown; KATD - knee angle at touchdown; AATD - ankle joint angle at touchdown; TA - total angle; TOD - take-off duration; L – the length of the jump.

Table 2. Pearson correlation coefficients.

		RUV	L	TOD	LATD	TA	AATD	KATD	AL
RUV	Pearson Correlation	1	.696**	-.260	.238	.603**	.125	.306	.001
	Sig. (2-tailed)		.000	.209	.252	.001	.551	.137	.995
	N	25	25	25	25	25	25	25	25
L	Pearson Correlation	.696**	1	-.391	.503*	.509**	.027	.034	-.131
	Sig. (2-tailed)	.000		.053	.010	.009	.897	.872	.534
	N	25	25	25	25	25	25	25	25
TOD	Pearson Correlation	-.260	-.391	1	.130	-.099	.612**	.507**	.729**
	Sig. (2-tailed)	.209	.053		.534	.637	.001	.010	.000
	N	25	25	25	25	25	25	25	25
LATD	Pearson Correlation	.238	.503*	.130	1	.672**	-.056	-.097	.087
	Sig. (2-tailed)	.252	.010	.534		.000	.791	.646	.679
	N	25	25	25	25	25	25	25	25
TA	Pearson Correlation	.603**	.509**	-.099	.672**	1	-.195	-.166	-.157
	Sig. (2-tailed)	.001	.009	.637	.000		.350	.427	.453
	N	25	25	25	25	25	25	25	25
AATD	Pearson Correlation	.125	.027	.612**	-.056	-.195	1	.778**	.580**
	Sig. (2-tailed)	.551	.897	.001	.791	.350		.000	.002
	N	25	25	25	25	25	25	25	25
KATD	Pearson Correlation	.306	.034	.507**	-.097	-.166	.778**	1	.699**
	Sig. (2-tailed)	.137	.872	.010	.646	.427	.000		.000
	N	25	25	25	25	25	25	25	25
AL	Pearson Correlation	.001	-.131	.729**	.087	-.157	.580**	.699**	1
	Sig. (2-tailed)	.995	.534	.000	.679	.453	.002	.000	
	N	25	25	25	25	25	25	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Legend: RUV – run-up velocity; AL – active landing; LATD - leg angle at touchdown; KATD - knee angle at touchdown; AATD - ankle joint angle at touchdown; TA - total angle; TOD - take-off duration; L – the length of the jump.

The influence of run-up velocity on the take-off variables

The long jump could basically be considered a projectile event with a difference in degrees, i.e., the RUV is the most significant for the length of jump (Bridget et al., 2002). Bridgett & Linthrone (2006) determined a nonlinear relationship between the RUV and the L at higher velocities. This phenomenon may be explained by the change in performing the take-off which is caused by a higher RUV i.e., by the change in the take-off technique. Siluyanov & Maximov (1977), and Bridgett & Linthorne (2006) determined, on an individual sample, that the increase in the RUV of 0,1 m/s increases the L by 6 to 9 cm. The results – Bridgett et al. (2002) showed an increase in the jump length of 8 cm with an increase in the run-up velocity of 0,1 m/s, whereas the results shown by Hay (1993b) on a large mixed sample of jumpers (a total of 306 jumps) showed that the increase in RUV of 0,1 m/s increases the L by 12 cm. In the case of I.Š. a linear relationship between Vzh and (L) (r= 0,696, p = 0,00) has been found which may be explained by the high level of the take-off technique at higher run-up velocities as well. In her case the rise in the RUV of 0,1 m/s increased the L by 4,2 cm on average. A lower average increase in the L in I.Š. may be interpreted as the consequence of a relatively smaller range of the run-up velocities in comparison to the research of Bridgett & Linthorn (2006) and Hay (1993b), and it is probably a consequence of the sample as well, which in Hay's research (1993b) included a large number of respondents with different performances ranging from beginners to professional long jumpers.

The TOD decreases with the increase in RUV and it is proportional to the distance traveled and the velocity of the centre of gravity of the body during take-off (Bridgett & Linthorne, 2006). Alexander's model (2000) predicts the TOD of 110 m/s at RUV of 9 m/s, in an elite jumper, the measured value of RUV was 9,46 m/s, and TOD was 127 m/s (Čoh & Mikuž, 2002). In Bridgett & Linthorne's study (2006) the decrease in TOD along with the increase in RUV was not linear, since there is an optimal time period in order to achieve an optimal force impulse. During take-off, there is an eccentric-concentric muscle contraction whose efficacy depends on two physiological factors: 1) switching time (use of elastic energy stored in the muscles and tendons during the take-off), 2) muscle stiffness (depends on the pre-activation of muscles, golgi and myiotic reflex). The time period where the elastic strain energy can be used is called a life-time, it lasts about 100 ms (Čoh, & Mikuž, 2002). In I.Š. there is a trend of a decrease in the TOD with the increase in RUV, but it is not statistically significant (r = -0,26 p = 0,209) which is probably a consequence of the sample of jumps. The participant's average values of RUV and TOD were 7,90 m/s and 129 ms respectively, and the ratio between the amortization and extension phase during take-off was 48% to 52% on average. Čoh & Mikuž (2002) found TOD with a duration of 127 ms and a relation between the amortization and extension phase of 66% to 34%, which may be defined as a good indicator of the take-off efficacy (Lees et al., 1994). Regarding the fact that during a sprint, the ratio of these phases is 40% to 60%, in I.Š. the duration of these phases should be time optimized, since the vertical component of the take-off velocity is mostly generated during the amortization phase (Lees et al., 1994).

The decrease in the LATD in relation to the horizontal one, along with the increase in RUV, is necessary because of the optimal TOD achievement. For this reason, at higher velocities, the foot at touchdown is placed further in front of the projection of the center of body mass in comparison to a lower RUV, which reduces LATD (Alexander, 1990; Hay, 1993a). Contrary to such statements, Bridgett & Linthorne (2006) stated that the optimal LATD is 61° in relation to the horizontal and that it does not change significantly with the increase in RUV in an elite jumper. This is most probably achieved by the modulation of leg stiffness, since it is possible to perform the take-offs at different take-off angles and achieve the lengths of jumps at the level of 95% of the maximum (Seyfarth, Blickhan & Van Leeuwen, 2000). The best individual take-off strategy depends on the ability to generate the necessary leg stiffness, and the differences in stiffness may be compensated by the change in the take-off angle (Seyfarth et al., 2000). According to Linthorne and Bridgett (2006) the dispersion of results obtained for LATD was higher with the increase in RUV than in the other studied variables, which they explained by the absence of a more significant influence of the LATD on the L. In I.Š. the average LATD in relation to the vertical was 27°, i.e. 63° in relation to the horizontal and it did not change significantly with the increase in RUV (r = 0,238 p = 0,252).

The increase in RUV increases TA as well, at 5 m/s it is 40°, and at a RUV of 11 m/s it is 60° (Bridgett & Linthorne, 2006). The increase in the TA is necessary to perform a complete stretching of the take-off leg, to show the SSC effect and to achieve sufficient force impulse during take-off. In I.Š. a statistically significant correlation between RUV and TA was found (r = 0,603 p = 0,001), as her average value was 45,5°. Ivana Španović's velocities ranged from 7,12 m/s to 8,38 m/s, so that we cannot directly compare the obtained results to the study of Bridgett & Linthorne (2006). With the trend of the results obtained by a regression analysis, the values of I.Š. may be predicted. The equivalent of RUV of 11 m/s in men is 9,5 m/s in women. With I.Š. the TA extrapolated for RUV of 9,5 m/s by a regression analysis was 58,02°. With an increase in RUV, the TA rises as well, which means that the conditions for mechanical work increase, i.e., the need for them to be performed in a longer-optimal period of time were created, which is similar to the results of Bridgett & Linthorne (2006).

The influence of the active landing and the run-up velocity on the duration of a take-off and the angles at touchdown

At a lower RUV the jumpers have a lower angle of the KATD in order to enhance the pivot mechanism in those conditions. With the rise in RUV, the KATD also increases because of two main reasons: 1. in order to reduce the force impulse in the knee joint and thus prevent a fall during the amortization phase of the take-off and 2. in order to control the pivoting of the take-off leg and to enable the achievement of the optimal vertical component (Alexander, 1990; Graham–Smith & Lees, 2005; Bridgett & Linthorne, 2006) of the movement of the body centre of mass. A lower KATD increases energy consumption during the eccentric contraction and disables a more complete stretching of the take-off leg at the end of the take-off (Lees et al., 1993). Seyfart et al. (2000) stated that the straighter leg at touchdown is always a benefit for a jumper. On a sample of 12 finalists at the Athletics World Championship in 1997, the KATD was 161° at the velocities of about 9,5 m/s, and in the jumpers it was 166° at the velocities of about 10 m/s (Arampatzis et al., 1999). In the finalists at the Championship of England (Graham-Smith & Lees, 2005), the values were 166.7 ± 4.7˚ at the RUV of 9.94 ± 0.37m/s. With I.Š. there was a trend of an increase in the KATD with the increase in RUV, but a statistically significant correlation was probably not obtained (r = 0,306 p = 0,137) due to a smaller range of the velocities. Bridgett & Linthorne (2006) also obtained a higher dispersion of the results with this variable which they explained by the non-sensitivity of the length of the jump to KATD. The mean value of RUV in the competition length of the run-up of 20 running strides in I.Š. was 8,32 m/s and the average KATD was 165°. Although a higher KATD is considered a benefit, in I.Š. it has been determined that it caused a lower value of AL (r = 0,699 p = 0,000), which influences the increase in braking impulses and the loss of horizontal velocity during take-off (Koh & Hay, 1990a). This indicates the need for creating the conditions for the performance of high intensity AL at high KATD, which requires optimal flexibility in the hip joint and the increase in the strength of the extensors of the hip and the thigh hamstring.

The AL has been defined as the difference between the velocities of the centre of mass of the foot of the take-off leg and the body's centre of mass just before the take-off (Koh & Hay, 1990a, b). Tidow & Weimann (1994) stated that the AL is performed by the ischiocavernosus muscles. In order to perform the AL movement, apart from the muscles of the thigh hamstring and the gluteus muscles which perform the backward swing of the leg, the contraction of the tibialis anterior muscle which will perform the dorsal foot flexion and thus reduce the moment of the leg's inertia and prepare the foot for the contact with the ground, i.e., it will be active and the ankle angle, will be reduced with the increase in active landing values, which is also important. In I.Š. it has been determined that the increase in the AL values also leads to a statistically significant decrease in the ankle angle at touchdown (r = 0,580, p = 0,002).

The higher AL values provide lower losses of the horizontal velocities during take-off which causes higher resultant velocities at the end of the take-off. The velocity of the body center of mass at the end of the take-off represents one of the most significant predictors of the achieved length of the long jump (Čoh & Mikuž, 2002). A high correlation between the resultant velocity at the end of the take-off and the length of the jump (from r = 0,74 to r = 0,83) was found at (Hay et al., 1986; Nixdorf & Bruggemann, 1990). The reduced loss of the velocity at the end of the take-off also influences the lower loss of the horizontal momentum of the jumper during take-off which was confirmed in the studies of LeBlanc (2000), Čoh & Mikuž (2002). During the take-off, both the negative horizontal (braking) impulses which reduce the velocity of the jumper and the positive horizontal impulses which accelerate the jumper during the take-off occur (Marino & Young, 1988). The loss of the resultant velocity during take-off mostly depends on the intensity and the duration of the braking impulses, and the highest values of these impulses are achieved in the amortization phase. The AL movement enables the positioning of the take-off foot closer to the projection of the body center of mass during take-off optimizing, and thus the ratio between the amortization and extension phases, the take-off duration and the values of the braking impulses (Marino & Young, 1988). It has been determined that more intense AL influences the reduction of take-off duration (LeBlanc, 1997). With I.Š., a significant correlation between the AL and the TOD has been found (r = 0,729, p = 0,000). It may be assumed that the AL also influenced the reduction of the braking impulses during take-off, so that we may conclude that she probably managed the AL well in most jumps since a high correlation with the TOD was found, i.e., there were no significant changes in the angle of the knee joint at touchdown.

The influence of the active landing, the run-up velocity and the take-off on the length of jump

The model and each individual variable influenced the length of the long jump regression. Preliminary analyses have shown that the assumption of normality, linearity, multi co-linearity and homogeneity of the variance were not violated. The adjusted R square (0,688 and p = 0.000) which Tabachnik & Fidell (2007) proposed for a smaller sample (tables 3 and 4) was calculated. The results of this study have shown that the model (RUV, AL, LATD, TA, TOD, KATD, AATD) explained the variance (L) in 69% and that it is statistically significant, F(7,17) = 8,55, p = 0,000. In order to determine how much each variable in the model (RUV, AL, LATD, TA, TOD, KATD, AATD) contributed to the prediction L, the Beta column in the section Standardized Coefficients (Pallant, 2009) from table 5 was used. The values were as follows: RUV = 0,565 p = 0,033; TOD = -0,566 p = 0,034; LATD = 0,571 p = 0,004; TA = 0,212 p = 0,417; AATD = -0,407 p = 0,075; KATD = -0,247 p = 0,349; AL = -0,140 p = 0,53. From the aforementioned, it may be concluded that the variables (TOD, LATD and RUV) separately contribute most to the length of the jump, when the variance explained by the remaining variables in the model is excluded. By squaring the semi partial correlation coefficients, it can be seen how much of the total variance L is uniquely explained by each individual variable (RUV, AL, LATD, TA, TOD, KATD, AATD) and how much the r^2 (R square) would be reduced if they were excluded from the model (Tabachnik & Fidell, 2007), i.e., the values of the influence of the individual variables on the total variance L were determined and they are as follows: RUV = 7%, TOD = 6.92%, LATD = 14.5%, TA = 0.9%, AATD = 4.71%, KATD = 1.21%, AL = 0.53%.

Table 3. Impact of the model (RUV, AL, KATD, AATD, LATD, TA, TOD) on the variable (L).

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.882[a]	.779	.688	11.165

a. Predictors: (Constant), RUV, AL, KATD, AATD, LATD, TA, TOD
b. Dependent Variable: L

Table 4. Statistical significance of the model.

ANOVA[b]						
	Model	Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	7456.940	7	1065.277	8.545	.000[a]
	Residual	2119.300	17	124.665		
	Total	9576.240	24			

a. Predictors: (Constant), RUV, AL, KATD, AATD, LATD, TA, TOD
b. Dependent Variable: L

Table 5. Results of the standard multiple regression (impact of the independent variables on the dependent variable).

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1 (Constant)	406.559	132.151		3.076	.007	127.744	685.374					
Vzh	33.743	14.542	.565	2.320	.033	3.062	64.424	.696	.490	.265	.220	4.549
CT	-1.394	.605	-.566	-2.304	.034	-2.670	-.117	-.391	-.488	-.263	.216	4.639
Uatd	4.831	1.446	.571	3.340	.004	1.779	7.882	.503	.629	.381	.445	2.247
Uk	-1.511	1.818	-.212	-.831	.417	-5.346	2.324	.509	-.198	-.095	.201	4.975
Ustd	1.438	.758	.407	1.898	.075	-.160	3.036	.027	.418	.217	.283	3.530
Uktd	-.768	.797	-.247	-.963	.349	-2.450	.915	.034	-.227	-.110	.198	5.054
Zag	-4.810	7.501	-.140	-.641	.530	-20.636	11.017	.131	-.154	-.073	.272	3.683

Legend: RUV – run-up velocity; AL – active landing; LATD - leg angle at touchdown; KATD - knee angle at touchdown; AATD - ankle joint angle at touchdown; TA - total angle; TOD - take-off duration; L – the length of the jump.

CONCLUSIONS

A great number of elite coaches and athletes understand the importance of improving all the elements influencing the efficacy of technique performance. It is not completely clear how to identify the optimal technique at the individual level, how to control it under various conditions (training and competition stress) and how to correct it quickly (Hanin & Hanina, 2009). For these reasons, there is a need for the application of contemporary scientific achievements in order to influence the improvement of the results in athletics by complex educational-training methods.

It has been determined that in the case of Ivana Španović some of the values of the take-off variables change with the change in the RUV and the AL, which partially confirmed the first hypothesis. A standard multiple regression has determined that the model is statistically significant (Adjusted R square is 0, 69 and p = 0,000) and that it explains the variance L which confirms the second hypothesis. The length of the long jump is mostly explained in percentages by the LATD which is in accordance with Alexander's mathematical model (1990) and it is not in accordance with the surveys of Seyfarth et al. (2000) and Bridgett & Linthorne (2006) who stated that L is non-sensitive to LATD and that it depends on RUV, KATD and the strength of the muscles. A great influence of RUV and TA on L has been determined, which is in accordance with the survey of Bridgett & Linthorne (2006). In order to achieve the maximum L, the jumpers should achieve the highest run-up velocity possible, minimize the loss of the take-off resultant velocity by the AL movement, increase the take-off angle (LATD, KATD and TA) and TOD should have a descending trend. It may be concluded that I.Š. directed her movement toward the end of the kinetic chain, i.e., she was not focused on LATD when increasing RUV. I.Š. achieved a high redundancy at the touchdown which is shown by the dispersion of the results (LATD) with the increase in RUV. It has been determined that the run-up velocity did not correlate with the active landing, but there was a statistically significant correlation between the AL and TOD variable which significantly influenced L.

Although this study examined the influence of the various run-up velocities on the take-off technique in an elite respondent, the results obtained cannot be generalized due to a small sample of jumps and a unique kinematical model for the jumpers cannot be found due to the athletes' different morphological characteristics and their different physical fitness levels.

A generalized (formulary) design-planning of the macro cycle cannot lead to reaching the expected level of the achievement of the results. Only through monitoring biomechanical and other parameters, by which the long jump training is controlled, it makes sense to expect the improvement of the movement activity technique in the long jump and the achievement of results (Janković, 2009).

It is necessary to carry out more surveys dealing with this issue in order to determine more precisely which variables represent the major factors for the optimal performance of the take-off in the long jump, the achieved length and to examine the changes in kinematical variables at maximum run-up velocities, because it is important to know what is essentially happening in real (competitive) conditions.

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KINEMATIKA ZAGREBANJA I ODSKOKA KOD SKOKA UDALJ

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Cilj ove studije je bio da se izvrši kinematička analiza odskoka, a posebno da se ispitaju odnosi zagrebanja (AL) i brzine zaleta (RUV) sa varijablama odskoka i dužinom skoka (L), i da se utvrdi uticaj našeg modela i pojedinačan uticaj svake nezavisne na zavisnu varijablu - (L). Namera autora je da se dobijeni rezultati primene u praksi - kao mogućnost da se pomogne prosečnoj populaciji skakačica u približavanju modelu vrhunske daljašice. U istraživanju je primenjena eksperimentalna metoda na uzorku od 25 uspešno izvedenih skokova udalj iz različitih dužina i brzina zaleta, juniorske prvakinje sveta Ivane Španović. Podaci su izmereni 3D infracrvenim sistemom marke Qualisys ProReflex MCU 240 motion capture. Za utvrđivanje povezanosti između varijabli korišćena je Pearson korelaciona analiza. Standardnom višestrukom regresijom je određivan procentualni uticaj modela i pojedinačno svake varijable na L. Utvrđeno je da se varijable odskoka menjaju sa povećanjem (RUV). Najveću korelaciju sa (RUV) imaju varijable: (L) r = 0,696 p = 0,000 i (TA) r = 0,603 p = 0,001. Standardnom višestrukom regresijom je izračunato da naš model (RUV, AL, KATD, AATD, LATD, TA, TOD) sa 69% objašnjava varijansu L. Zaključeno je da TOD, LATD i RUV statistički značajno objašnjavaju varijansu L. Za realizovanje maksimalne dužine skoka skakači/ce treba da postignu što veću RUV i minimizuju gubitak rezultantne brzine odskoka pomoću AL, LATD treba da je oko 63°, KATD i TA povećavati a TOD skraćivati sa povećanjem RUV. Utvrđeno je da AL ne korelira sa RUV ali postoji statistički značajna korelacija AL sa TOD, koje ima veliki uticaj na L.

Ključne reči: *biomehanika sporta, brzina zaleta, trajanje odskoka, napadni ugao.*