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Original Article

Qualification differences in interrelationships of takeoff variables of male long jumpers

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Abstract:
The objective of this study was to explore the interrelationships between key variables of takeoff technique among long jumpers of various performance levels. Attempts of thirty-seven male athletes were filmed with a video camera, operating at 240 Hz, during their competitive performances in long jumps and analysed using 2D video analysis (SkillSpector software was used). The characteristics of takeoff movements of athletes who had effective distance from the first (7.54 m) to eighteenth (6.76 m) and from the nineteenth (6.74 m) to thirty-seventh (4.93 m) were compared. Correlation and multiple regression analysis were used to evaluate the interdependence between the characteristics of takeoff technique in long jump. It was found that jumpers of higher performance level had significantly larger takeoff velocity of the center of gravity (8.73 ± 0.43 and 8.24 ± 0.47 $m \cdot s^{-1}$, respectively), its horizontal (8.00 ± 0.41 and 7.68 ± 0.45 $m \cdot s^{-1}$) and vertical (3.48 ± 0.38 and 2.95 ± 0.43 $m \cdot s^{-1}$) components, and takeoff angle (23.5 ± 2.3 and 20.6 ± 2.5°). Also, they performed takeoff significantly faster (ground contact time 0.129 ± 0.009 and 0.140 ± 0.014 s, respectively). Only one strong or medium correlation was exhibited between the effective distance and kinematic takeoff characteristics in both groups of athletes (r = 0.71 between effective distance and knee angle at touchdown in the less qualified group). Multiple regression analysis identified knee angle at touchdown and takeoff velocity as key variables of long jump for less qualified jumpers.
Key Words: takeoff velocity, takeoff angle, ground contact time, long jump distance.

Introduction

Many authors have investigated long jump takeoff technique (as a key phase of complete long jump technique) for various performance levels of male and female jumpers (Lees, Fowler, & Derby, 1993; Lees, Graham-Smith, & Fowler, 1994; Panoutsakopoulos, Papaiakovou, Katsikas, & Kollias, 2010). It would be logical to assess the takeoff technique of a given sex-age groups based on the results of takeoff phase simulation (Hay, Miller, & Canterna, 1986; Alexander, 1990; Seyfarth, Blickhan, & Van Leeuwen, 2000). However, direct dependences between effective distances (*ED*) and key variables of the long jump technique are not always observed in various groups of jumpers. Thus, Graham-Smith and Lees (2005) observed only a non-significant correlation between approach velocity (r = 0.496, P > 0.05), horizontal (r = 0.215, P > 0.05) and vertical (r = 0.279, P > 0.05) velocities at takeoff, on the one hand, and effective distance jumped, on the other hand, in the group of finalists of AAA Championships in the UK (effective distance from 7.14 to 7.84 m), which is not in general agreement with Hay et al. (1986) and Alexander's (1990) models. This may be due to differences in the studied athletes and models (e.g., different muscular strength of knee extensors for different athletes), differences in their technical training, and the effectiveness of movements during flight and landing. Also Koh and Hay (1990) observed only non-significant correlations of measures of landing leg motion with measures of performance. At the same time, another study has found a strong correlation (r = 0.94) between effective distance and horizontal takeoff velocity in a group of female long jumpers (effective distance from 5.88 to 6.79 m) (Panoutsakopoulos & Kollias, 2007). One more research (Nemtsev, Nemtseva, Sukhanov, Lytkin, & Parfenova, 2015) showed that the interrelationships between the key variables of long jump technique in groups of female jumpers of different performance levels may be not only of different value, but of different direction: the correlation between horizontal and vertical velocities in the more qualified group of female jumpers (effective distance from 5.62 to 6.31 m) was medium and positive (r = 0.65), whereas in the less qualified group

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(from 4.70 to 5.58 m) it was weak and inverse (r = – 0.27). In this regard, the study of the interrelationships between effective distance and key technique variables in different qualification groups of jumpers makes it possible to better understand the features of their performance and to identify the ways to improve it. So, the aim of this study was to explore the interrelationships between the key variables of long jump technique in groups of Russian jumpers of different performance levels.

Material & methods

Thirty-seven male long jumpers and combine events athletes were filmed during their competitive performances in long jumps at 2014 Winter Championship of the Southern Federal District of Russia. Distances of all clear trials in long jumps were corrected by measuring the distance from the toes of the supporting foot to the takeoff line (effective distance). The kinematic characteristics of the best attempts were taken into consideration. The best effective distances of all the participants were ranged and all jumpers were divided into two groups: Group A (age 22.0 ± 4.1, effective distances from the first (7.54 m) to eighteenth (6.76 m), 7.14 ± 0.23 m) and Group B (age 17.5 ± 2.8, effective distances from the nineteenth (6.74 m) to thirty-seventh (4.93 m), 6.16 ± 0.47 m). No measurements of body height and mass were available. Videotaping was done with a high-speed digital camera Casio EX-ZR700, operating at a frequency of 240 Hz. The camera was placed at about 5 m from the middle of the long jump runway, with the optical axis of the camera perpendicular to the long jump runway and in line with the front edge of the takeoff board. A 4.24 m horizontal field of view was selected. SkillSpector (Version 1.3.2) software was used for 2D video analysis. Twenty-point Full Body model was employed to assess the kinematic characteristics of athletes' body segments and centre of gravity movements. 2D direct linear transformation method with six calibration points was used for calibration. The following measurements were taken: takeoff velocity (value of the center of gravity *(CG)* velocity vector at takeoff); horizontal and vertical *CG* takeoff velocities; *CG* height at touchdown and at takeoff; *CG* takeoff angle (angle between *CG* velocity vector and the horizontal); ground contact time (*GCT*); knee angle at touchdown and minimal knee angle during support time; leg angle at touchdown (to be consistent with the mathematical models of the takeoff (Alexander, 1990; Seyfarth et al., 2000), it was defined as the angle between the half-line from the ankle of takeoff leg through the hip joint and the horizontal half-line from the ankle to the opposite of run-up direction); *CG* to heel distance at touchdown in the horizontal plane. Coordinate data were smoothed using a quintic spline filter. Measurement accuracy was 0.02 m for displacement and 0.17 $m \cdot s^{-1}$ for velocity.

The Kolmogorov-Smirnov test showed that the data set is well-modeled by a normal distribution in both Group A (*p* from 0.324 in the *CG* height at takeoff to 0.994 in the effective distance) and Group B (*p* from 0.485 in the *GCT* to 0.964 in the takeoff angle). Therefore, parametric statistical methods were applied for the analysis. The mean and standard deviation were calculated for each characteristic. One-way analysis of variance (ANOVA) was used to assess the significance of kinematic data of long jump differences between the athletes of Groups A and B. Pearson's correlation coefficient was used to evaluate the relationship between the characteristics of takeoff technique in long jump. The evaluation of Pearson's correlation coefficient was done in accordance with Suslakov's (1982) categorisation: ± 1.00 – functional relationship; ± 0.99-0.70 – strong statistical relationship; ± 0.69-0.50 – medium statistical relationship; ± 0.49-0.20 – weak statistical relationship; ± 0.19-0.09 – very weak statistical relationship; modulus of the correlation coefficient less than 0.09 – no correlation. To define the 95% confidence interval for Pearson's correlation, Fisher *r*-to-*z* transformation was used, and standard error of *z* was calculated**.** Fisher *r*-to-*z* transformation was applied to assess the significance of the difference between two correlation coefficients. A multiple regression was used to measure the quantitative relationship between the effective distance in long jump and the characteristics of takeoff techniques ('backward' stepwise regression procedure was employed, probability of F-to-remove ≥ 0.100). The coefficient of determination was used to assess the association between variables. Only three independent variables were selected for the multiple regression analyses of data in both A and B groups to observe of a 5:1 ratio of jumpers to independent variables, in accordance with Vincent (2005).

Results

As shown in Table 1, long jumpers of higher performance level demonstrated significantly higher takeoff velocity ($p < 0.01$), horizontal ($p < 0.05$) and vertical ($p < 0.001$) takeoff velocities, and takeoff angle ($p < 0.01$). Long jumpers of lower performance level had significantly larger value of *GCT* ($p < 0.01$). Values of *CG* height at takeoff and touchdown, leg angle at touchdown, *CG* to heel distance, knee angle at touchdown, and minimum knee angle during support time had only non-significant differences between long jumpers of Groups A and B ($p > 0.05$).

Effective distance had neither strong nor medium correlations with the studied characteristics of takeoff technique in the group of higher performance level (Table 2). In Group B only one strong correlation was found between effective distance and knee angle at touchdown (Table 2). In addition, Table 2 shows that in both groups of jumpers there is a strong relationship between takeoff velocity and horizontal takeoff velocity ($r = 0.94$) along with only a weak correlation between takeoff velocity and vertical takeoff velocity. In both groups of athletes, there is a strong correlation between takeoff angle and vertical takeoff velocity (r = 0.87 in Group A and 0.86 in Group B).

Group A of long jumpers exhibited a strong correlation between *CG* height at touchdown and at takeoff (r = 0.90), whereas in Group B there is only a weak correlation between these indicators (r = 0.49). Group B revealed strong dependences of ground contact time from leg angle (r = – 0.79) and *CG* to heel distance at touchdown (r = 0.79). There is only medium correlation between these characteristics in Group A (r = 0.66 and – 0.59, respectively).

Table 1.Characteristics (Mean ± Standard Deviation) of takeoff technique of long jumpers from Group A (ED from 6.76 to 7.54 m) and Group B (ED from 4.93 to 6.74 m).

Characteristics	6.76 – 7.54 m	4.93 – 6.74 m	F (p value)
Takeoff velocity ($m \cdot s^{-1}$)	8.73 ± 0.43	8.24 ± 0.47	11.16 (0.002)
Horizontal takeoff velocity ($m \cdot s^{-1}$)	8.00 ± 0.41	7.68 ± 0.45	5.00 (0.032)
Vertical takeoff velocity ($m \cdot s^{-1}$)	3.48 ± 0.38	2.95 ± 0.43	15.99 (0.000)
Takeoff angle (°)	23.5 ± 2.4	21.0 ± 2.8	8.62 (0.006)
Takeoff *CG* height (m)	1.18 ± 0.06	1.15 ± 0.05	1.76 (0.193)
Ground contact time (s)	0.129 ± 0.009	0.140 ± 0.014	9.30 (0.004)
Touchdown *CG* height (m)	0.91 ± 0.05	0.91 ± 0.03	0.01 (0.934)
Leg angle at touchdown (°)	57.3 ± 2.6	57.9 ± 2.8	0.48 (0.494)
CG to heel distance (m)	0.44 ± 0.05	0.44 ± 0.06	0.10 (0.752)
Knee angle at touchdown (°)	166.7 ± 4.8	165.1 ± 5.1	0.92 (0.343)
Minimum knee angle (°)	137.1 ± 4.8	134.5 ± 5.1	2.47 (0.125)

Table 2. Dependences (coefficients of Pearson's correlation without zeros and points) between characteristics of takeoff technique in Group A (bottom and left) and Group B (top and right, bold) of long jumpers.

Data	ED	V_{TO}	HV_{TO}	VV_{TO}	A_{TO}	CGH_{TO}	GCT	CGH_{TD}	A_L	D_{CGH}	A_K	$MinA_K$
ED	1	**49**	**44**	**27**	**10**	**47**	**-41**	**15**	**22**	**01**	**71**	**37**
V_{TO}	32	1	**94**	**44**	**06**	**39**	**07**	**14**	**-27**	**28**	**30**	**43**
HV_{TO}	21	94	1	**12**	**-28**	**33**	**03**	**19**	**-15**	**11**	**18**	**31**
VV_{TO}	38	47	15	1	**92**	**29**	**13**	**-11**	**-40**	**54**	**40**	**45**
A_{TO}	28	03	-30	89	1	**16**	**11**	**-18**	**-32**	**48**	**33**	**31**
CGH_{TO}	06	-27	-30	00	11	1	**24**	**49**	**-10**	**46**	**54**	**13**
GCT	-30	-63	-70	00	31	58	1	**-32**	**-79**	**79**	**-26**	**-40**
CGH_{TD}	-09	-25	-18	-26	-19	90	40	1	41	**-20**	**20**	**05**
A_L	-28	33	48	-29	-51	-04	-43	21	1	**-86**	**18**	**16**
D_{CGH}	27	-42	-56	25	49	58	66	37	-72	1	**10**	**-15**
A_K	17	31	47	-31	-50	17	-31	36	30	-09	1	**28**
$MinA_K$	12	28	41	-23	-40	-22	-46	-06	09	-31	41	1

Notes: ED – effective distance, V_{TO} – takeoff velocity, HV_{TO} – horizontal takeoff velocity, VV_{TO} – vertical takeoff velocity, A_{TO} – takeoff angle, CGH_{TO} – CG height at takeoff, GCT – ground contact time, CGH_{TD} – *CG* height at touchdown, A_L – leg angle at touchdown, D_{CGH} – *CG* to heel distance, A_K – knee angle at touchdown, $MinA_K$ – minimum knee angle during support time.

The multiple regression analysis showed great differences between equations of relationships between effective distance and the variables of takeoff technique in Groups A and B: they include different dependent variables. The regression equations determined for effective distance were following (1 – for higher effective distance athletes, 2 – for lower effective distance athletes):

1) $ED = 0.234 \cdot VV_{TO} - 7.603 \cdot GCT + 7.309;$

2) $ED = 0.057 \cdot A_K + 0.303 \cdot V_{TO} - 5.797;$

where ED – effective distance, VV_{TO} – vertical takeoff velocity, GCT – ground contact time, A_K – knee angle at touchdown, V_{TO} – takeoff velocity.

The summary of the multiple regression analyses is shown in Table 3. The significance value gives reason to assume that regression model for more qualified jumpers is non-significant.

Table 3. Summary of multiple regression analysis (coefficient of variation, R^2; standard error, SEe; ANOVA statistic, F; the significance value, P).

Group (*ED*)	R^2	*SEe*	*F*	*P*
A (6.76 – 7.54 m)	0.233	0.217	2.28	0.136
B (4.93 – 6.74 m)	0.593	0.317	11.65	0.001

Discussion

The results of this study showed that the relationship between the characteristics of takeoff technique in the long jump obtained by simulation (Alexander, 1990; Seyfarth et al., 2000) and confirmed by the studies on one athlete (Bridgett & Linthorne, 2006) may differ from the relationships observed in a group of athletes. One of the main conclusions derived from the long jump modeling was that a long jumper has to run up as fast as possible and set the leg down at a steeper angle (Alexander, 1990). Indeed, in the present study the athletes of Group A showed significantly higher takeoff velocity, which allowed them to show longer *ED*. However, only a weak correlation was found between takeoff velocity and *ED* in both groups of long jumpers. Also, only a weak correlation was revealed between horizontal takeoff velocity and *ED* in the groups of long jumpers of different performance levels. At the same time, the regression analysis has shown that it is important to increase takeoff velocity in order to improve *ED* in B group. A non-significant relationship between approach velocity and effective distance ($r = 0.496$, $P > 0.05$) was observed, for example, by Graham-Smith and Lees (2005) among the participants of AAA Championships in the UK (*ED* from 7.17 to 7.84 m). Graham-Smith and Lees (2005) (as well as Campos et al. (2013)) also found only a weak correlation between *ED* and horizontal ($r = 0.215$, $P > 0.05$ (Graham-Smith & Lees, 2005) and $r = – 0.231$, $p < 0.189$ (Campos, et al., 2013) and vertical ($r = 0.279$, $P > 0.05$ (Graham-Smith & Lees, 2005) and r = 0.454, p < 0.01 (Campos, et al., 2013)) takeoff velocities, and no correlation between *ED* and center of mass height at takeoff (which are important in the long jump according to the model of Hay et al. (1986)). Graham-Smith and Lees (2005) explained this by the variability in relation to the range for each variable. It is also possible that different athletes might use, more or less effectively, a variety of mechanisms of long jump models (Alexander, 1990; Seyfarth et al., 2000). In the present study *CG* height at touchdown does not differ significantly in Groups A and B (Table 1). Only a weak correlation between this measurement and *ED* was exhibited in Group B, along with a very weak correlation in Group A (Table 2) (the differences between correlation coefficients in Groups B and A were non-significant, p = 0.211). At the same time, Campos et al. (2013) found medium significant relationships between *ED* and relative center of mass height at takeoff (r = 0.577; p < 0.001) in the group of eight male finalists of the IAAF World Indoor Championships Valencia 2008.

The following significant differences between long jumpers of higher and lower performance levels were found by the present study in the values of vertical takeoff velocity and takeoff angle (Table 1). In accordance with the models of long jump, a fast run-up makes for the large horizontal component of velocity at takeoff, but shortens the duration of ground contact and hence restricts the vertical impulse (Alexander, 1990). In the present study, horizontal takeoff velocity was, indeed, significantly higher in Group A and ground contact time in this group was significantly shorter, whereas vertical takeoff velocity in Group A was significantly higher (Table 1). Furthermore, vertical takeoff velocity in Group A increased more than did horizontal velocity, if compared with Group B (18.1 and 4.1%, respectively), which led to significant increase in takeoff angle (Table 1). The present study did not identify the mechanism of the increase of vertical takeoff velocity in the group of athletes of higher performance level. In particular, the present study showed that leg angle, knee angle at touchdown and minimum knee angle differed non-significantly between Groups A and B (Table 1). Obviously, in this case the most important factor is the higher level of power abilities in Group A. Thus, in the study on one athlete, the increase in run-up speed resulted in the decrease of takeoff angle (Bridgett & Linthorne, 2006). The relationships between ground contact time and horizontal takeoff velocities are very different in Group A ($r = – 0.70$) (this strongly agrees with Alexander's (1990) model) and Group B ($r = 0.03$) (these findings are not in agreement with the relationships reported by Alexander (1990)) (differences of correlation coefficients were significant, $p = 0.012$). Obviously, this relationship is leveled by a large variation in other characteristics of the technique of the lower performance level athletes. So, *GCT* strongly depends on leg angle at touchdown (– 0.79) and *CG* projection to heel distance (0.79) in Group B, whereas in Group A these relationships were weak (– 0.43) and medium (0.66), respectively.

Takeoff angle in the present study was strongly related to vertical takeoff velocity both in Group A (confidence interval of coefficient correlation from 0.852 to 0.979) and Group B (from 0.856 to 0.978) (Table 2), as well as in Graham-Smith and Lees (2005) study ($r = 0.975$), and confidence intervals of coefficient correlation suggest that this trend is not random. However, unlike Graham-Smith and Lees (2005) study ($r = – 0.869$), the present investigation revealed only weak inverse correlations between horizontal takeoff velocity and takeoff angle in Groups A ($r = – 0.30$) and B ($r = – 0.28$). This suggests that takeoff angle is largely determined by vertical takeoff velocity. Leg angle at touchdown and *CG* to heel distance, strongly related to it ($r = – 0.72$ in Group A and – 0.86 in Group B), did not differ for the athletes of different performance levels in the present study (Table 1). This does not agree with the result of Alexander's (1990) simulation (which recommended to set down the leg at a steeper angle to improve *ED*) and the data obtained in the study with one athlete as a participant (Bridgett & Linthorne, 2006). Also, only weak correlations were found between leg angle at touchdown and *ED* in both qualifying groups of long jumpers in the present study. Despite the fact that these measurements were inversely related in Group A and positively related in Group B (Table 2), the differences in correlation coefficients were non-significant ($p = 0.156$). Besides, only a weak negative correlation was found between leg angle and vertical takeoff velocity in Groups A and B, although the decrease of leg angle led to the increase of *GCT* in group B ($r = -0.79$, Table 2) and theoretically should result in the increase of vertical impulse. Another variable identified in Alexander's model is knee angle at touchdown (Alexander, 1990). This is the only measurement in this study strongly related to *ED*. The regression analysis showed the importance of this measurement for improving *ED* in Group B. At the same time, if low performance athletes demonstrated a strong correlation between knee angle at touchdown and *ED* ($r = 0.71$), the athletes of higher performance level showed this dependence to be only weak ($r = 0.17$). The difference in correlation coefficients for different qualification groups was significant ($p = 0.047$). However, this fact needs additional verification, especially because the confidence interval of this correlation coefficient in Group B is from 0.38 to 0.88. Obviously, in the more qualified group, the power abilities of jumpers varied more than in Group B, which did not correspond to the initial positions of Alexander's model.

Conclusions

Thuswise, the long jumpers of considered qualification groups have differences in the parameters of their takeoff techniques and interrelationships between them, which partially agree with the simulations of long jump (Hay et al., 1986; Alexander, 1990; Seyfarth et al., 2000) and are partially determined by other causes. Those that agree include significantly higher takeoff velocity and its horizontal component, and significantly shorter ground contact time exhibited by the athletes of the higher performance level, as well as a strong correlation between effective distance and knee angle at touchdown in the group of jumpers of lower performance level. Those that badly agree with the simulation results include significantly higher vertical velocity at takeoff and lager takeoff angle in the more qualified group of jumpers, as well as the lack of strong correlations between effective distance and takeoff velocity, horizontal takeoff velocity, takeoff angle, leg angle, and *CG* height at touchdown. Obviously, this is due to differences in power ability of the athletes between and into two qualification groups, which does not correspond to the initial positions defined for the simulation.

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