COMPARISON OF SELECTED KINEMATIC STRUCTURE PARAMETERS IN MALE AND FEMALE HIGH JUMPERS

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PRIMERJAVA MOŠKIH IN ŽENSK V IZBRANIH KAZALCIH KINEMATIČNE STRUKTURE SKOKA V VIŠINO

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ABSTRACT

This work deals with selected parameters of high jump technique of top-performance competitors. Eighteen tries of men and twenty-one tries of women were evaluated by means of two-dimensional analysis. Results of males were between 205 and 229 cm, females between 175 and 205 cm. The discussed parameters are sports performance, culmination of trajectory of the centre of gravity and vertical velocity at the end of take-off.

The most suitable parameter characterising sports performance seems to be vertical velocity at the end of take-off. The moment of amortisation phase completion and corresponding vertical velocity of the body's centre of gravity are deduced from take-off knee angle changes. Analysis of results confirms that optimum values of selected parameters may be identified, depending however, on the athlete's performance. The leverage by means of which a part of horizontal velocity is transformed to vertical velocity is explained. During the amortisation phase, men reached 57.5 % and women 42 % of resulting vertical velocity by means of leverage. Hereafter, parameters such as the angle of take-off from the last step support, the angle of tread-down to take-off position, the stride length of the last stride before the take-off, and the difference in stride length between the last two strides are discussed. In contrast to men, the kinematic structure characterised by these parameters is not formed so well for women which is seen from the big scattering of values.

Key words: high jump, horizontal velocity, leverage, stride length, trajectory, vertical velocity

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IZVLEČEK

V delu so analizirani izbrani kazalci tehnike skoka v višino vrhunskih tekmovalcev. Opravljena je bila analiza osemnajstih moških in enaindvajsetih ženskih skokov v dvo-razsežnostnem prostoru. Rezultati moških so bili med 205 in 229 cm, žensk pa med 175 in 205 cm. Analizirani so bili parametri: športni dosežek, višina vrha poti težišča telesa in vertikalna hitrost pri odrivu.

Rezultat je bil najbolj opredeljen z vertikalno hitrostjo ob odrivu. Trenutek zaključka faze amortizacije in odgovarjajoča vertikalna hitrost težišča telesa sta ugotovljena iz sprememb v kotu kolena ob odrivu. Analiza rezultatov potrjuje, da je mogoče prepoznati optimalne vrednosti izbranih kazalcev, vendar v soodvisnosti od dosežka tekmovalca. Razloženo je kako se del horizontalne hitrosti preko vzvoda pretvori v vertikalno hitrost. V amortizacijski fazi so moški dosegli 57,5% in ženske 42% vertikalne hitrosti. V nadaljevanju se razpravlja o kotu odriva glede na oporno fazo zadnjega koraka, kot med položajem ob trenutku kontakta v zadnjem koraku in položajem ob odrivu in razliki v dolžini koraka med zadnjima dvema korakoma. Za razliko od moških, kinematična struktura žensk ni tako dobro opredeljena z uporabljenimi kazalci, kar je razvidno iz velike variabilnosti izmerjenih vrednosti.

Ključne besede: skok v višino, vzvod, horizontalna hitrost, vertikalna hitrost, dolžina koraka, pot težišča telesa

Introduction

Works dealing with high jumping kinematic structure analysis are published in technical literature quite often. Tries of both men and women are dealt with. In most cases, analyses are limited to statement of selected parameters' values for small groups of competitors. A systematic approach to the topic of high jump is given by Gjumishev (1989). High jumping strategy from the aspect of impulse of force in the joint centre of gravity, separate segments contribution, separate joints' moments contribution, use of elastic energy and energy transfer between separate segments are found in Brüggemann (1994). In Dursenjev's (1989) opinion, vertical force is generated by upward stretching of leg and back. Krjazhev, Strizhak, Popov, and Borovnik (1989) deal with the height of the centre of gravity at the moment of take-off, magnitude of the take-off impulse, and the height of the centre of gravity over the bar in a group of female athletes. Killing (1996) describes the high jump as a movement in a three-dimensional space with a high level of freedom. He specifies »tunnel« and »funnel« models as two possibilities of the run-up final phase. Every competitor has his/her individual optimum structure. Brüggemann and Loch (1992) confirmed the fact that individual athletes even within a homogenous group use different techniques of overcoming the maximum height. They published results of three-dimensional high jumping analysis for ten men and eight women. Maximum trajectory culmination, 246 cm in men, was reached by Sotomayor in his try for 236 cm, and 214 cm for women, by Henkel in her try for 205 cm. Dapena (1980 a, b) analyses issues of start banking towards the centre of curvature, vertical velocity, rising angle (40° to 48°), stride length, horizontal velocity, take-off knee bending and take-off duration in six competitors. The one-before-the-last stride is longer than the last one. Horizontal velocity in Stones is as high as 8.5 $m.s^{-1}$. His take-off time fluctuates between 140 ms and 200 ms. Another work specifies the relationship between the bow start to the take-off position and angular moment required for somersault execution over the bar with the help of a three-dimensional analysis. This issue is found also in the work of Dapena and Chung (1988). The authors put radial velocity generated by body rotation around the tread-down area in connection with vertical velocity. The flight phase rotation may accelerate due to a decrease of the body momentum (Dapena, 1991). Blasco (1992) is in search for relationships between EMG activities of six muscular groups during the take-off and height of the centre of gravity in the take-off position, after the take-off and during the pass-over the bar. Veldmann (1989) verbally describes the work of body segments in different run-up phases. He deals with run-up, acceleration, lowering of the centre of gravity, take-off, flight, pass-over the bar and tread-down phases. Issues connected with the body speed during take-off, rising angle and height of the centre of gravity during take-off are found also in McWatt (1989). Čoh, Čuk, and Borstnik (1993) analyse kinematic parameters with the help of three-dimensional analysis for 13 men and 11 women. Sotomayor (236 cm), 8.5 $m.s^{-1}$, and Kostadinova (205 cm) reached the highest horizontal velocity, 7.5 $m.s^{-1}$. In total 17 parameters are analysed. Müller and Hommel (1997) found the highest horizontal velocity of 8.04 $m.s^{-1}$, vertical velocity of 4.8 ms.-1, and tread-down angle of 38° in Sotomayor's try for 237 cm. Ritzdorf (1983) characterises flop 1 by means of a high run-up speed, 7.5 $m.s^{-1}$ to 8.2 $m.s^{-1}$, and short take-off time, 0.16 sec to 0.18 sec. Flop 2 is characterised by a slower run-up speed, 7 m. s^{-1} to 8 $m.s^{-1}$, and longer take-off time, 170 ms to 210 ms. Ritzdorf, Conrad and Loch (1988) made an intraindividual analysis of ten tries of Kostadinova at the 1987 World Championships in Rome and 1988 Olympic Games in Seoul. In addition to heights of the centre of gravity during take-off and flight phases, vertical velocity (max. 4.42 $m.s^{-1}$ in tries for 206 cm) and take-off time, from 115 ms to 140 ms, are presented there.

Material

Bases of investigations were obtained from video-records taken, in particular, at the 1997, 1998 and 1999 international competition »Banskobystrická latka«. The sample of men consisted of 18 tries of the following competitors: Benko for 215 cm; Bočkay for 220 cm; Brown for 228 cm; Fedorkov for 210 cm and 225 cm; Ferenc for 205 cm; Janku J. for 224 cm; Janku T. for 228 cm; Grant for 224 cm; Kemp for 215 cm; Kotewitz for 224 cm; Kovács for 210 cm; Kressig for 228cm; Liolin for 220 cm; Searnblom for 220 cm; Sjoberg for 228 cm; Sonn for 225 cm; and Zhu for 229 cm. The sample of women consisted of 21 tries of the following competitors: Bìlocká for 185 cm; Fiodorova for 193 cm; Göllnerová for 180 cm; Gulevitsch for 193 cm; Iagar for 196 cm; Janku for 175 cm; Kováčiková for 190 cm and 193 cm; Lapina for 180 cm; Medgyesová for 175 cm and 180 cm; Melová for 184 cm, 193 cm and 194 cm; Nezdaøilová for 180 cm; Øiháková for 184 cm; Shevtschik for 193 cm; and three tries from Atlanta 1996 of Astafjeva for 201 cm; Babakova for, 201 cm; and the winning Olympic try of Kostadinova for 205 cm.

In our analysis, we tried to cover the best tries of the competitors. Repeated tries of the same competitor were made always in following years.

Method

Selected parameters of the high jump kinematic structure were obtained by means of two-dimensional analysis of kinograms. The use of three-dimensional analysis asks for installation of two cameras, which would be connected with big problems at international competitions. The camera was installed in the middle of a circle by which the trace of the last three run-up strides can be approximated (fig. 1). In such an arrangement, the selected section of recorded movement can be replaced well by a plane vertical to the camera. In such an arrangement, distance changes between the investigated subject and camera are negligible. During the take-off, the body rotates around all three spatial axes. Therefore, only movements performed in the plane vertical to camera can be evaluated. For calibration of records, the known distance between the bar height and the point in which the trajectory of the centre of gravity passed it was used.

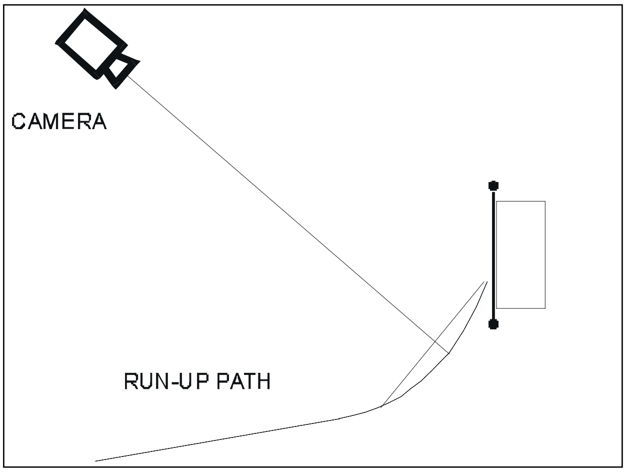

Fig. 1. Arrangement of Recording

	men n = 19					women n = 21					
	s. p.	vv1	vv2	x̄	s. d.	s. p.	vv1	vv2	x̄	s. d.	dimension
s. p.	1,00			221,00	7,24	1,00			188,57	8,70	cm
vv_1	0,71	1,00		4,00	0,21	0,62	1,00		3,57	0,25	$m.s^{-1}$
vv_2	0,37	0,40	1,00	2,30	0,27	0,48	0,65	1,00	1,95	0,27	$m.s^{-1}$
vh_3	0,38	0,26	0,77	7,47	0,48	0,25	0,41	0,43	6,68	0,31	$m.s^{-1}$
h_6	0,77	0,77	0,26	[illegible]	[illegible]	0,70	0,14	0,56	184,30	8,47	cm
α_1	0,15	0,31	0,52	56,17	5,49	0,08	0,22	0,27	60,76	5,79	grade
α_2	-0,26	-0,01	-0,55	54,46	4,10	-0,41	-0,34	-0,26	56,10	2,56	grade
l_1	0,13	0,47	0,57	197,70	11,80	0,00	0,04	-0,04	180,24	11,97	cm
l_2-l_1	0,04	0,52	0,25	15,17	17,08	0,15	0,18	0,26	13,38	15,69	cm

sports performance	s. p.
vertical velocity at the end of take-off	vv_1
vertical velocity at the end of amortisation	vv_2
horizontal velocity at the beginning of take off	vh_3
culmination height of centre of gravity	h_6
angle of take-off from the one-before-the last stride support	α_1
angle of treads-down to the support position	α_2
the last stride length	l_1
difference in lengths of the last and one before the last stride	l_2-l_1

Tab. 1. Correlation Coefficients, Average Values and Standard Deviations of Selected Parameters

Results

All positions were taken from video-records made with a frequency of 50 pictures per second. Beginnings and ends of support and flight phases of the last three strides and the take-off are shown in fig. 2. In total 42 parameters were obtained by means of kinograms processing and analysis. Eight of them were selected for interpretation purposes (tab. 1).

The length of the last (l_2) and the one-before-the last stride (l_1) from which the difference of the stride length can be calculated (l_1 - l_2) are read in kinograms. In addition, a kinogram can show both the angle of take-off from the one-before-the last support (α_1) and the angle of tread-down to the take-off position (α_2). The trajectory of the joint centre of gravity is also illustrated there. From its course, the height of culmination of the centre of gravity (h_6) may be identified. Horizontal and vertical components of velocity of the joint centre of gravity are deduced from derivation of horizontal and vertical components of trajectory. Vertical velocity at the end of take-off (vv_1) and horizontal velocity at the beginning of take-off (vh_3) are taken directly from those courses.

An important part of vertical velocity is generated by means of the take-off leg leverage. The knee bend during amortisation does not lower the centre of gravity. It is compensated by stretching the body when the take-off leg works as a lever in the forward motion. The leverage works during the whole take-off phase. It is joined by the mechanism of the take-off knee stretching and planary flexion, as well as by the work of swinging parts at the end of amortisation

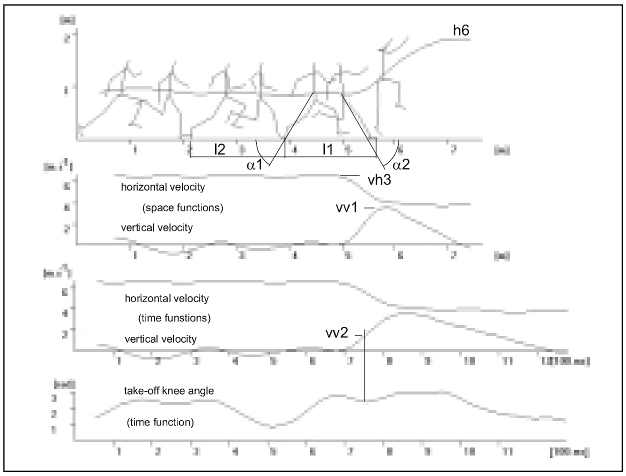

Fig. 2. Evaluated Parameters

(Slamka and Moravec, 1990). The end of the amortisation phase and the beginning of active take-off may be identified from the course of the take-off knee angle changes. At the end of amortisation, the knee begins to stretch out and the knee angle increases. That moment determines the post-amortisation vertical velocity value (vv_2). Therefore, the courses of velocity and angle change are illustrated as time functions in the lower part of fig. 2.

Results of selected parameters are recorded in a diagram. Trend lines go through the points as polynoms of the 2-nd degree (MS Excel). Their closeness is represented by the coefficient R^2 which is higher than the linear regression correlation coefficient.

Discussion

Interpretation of results will issue from sports performance and other eight selected parameters. Sports performance means the height of the bar for which the try was made. It is evident that the competitor may have a considerable margin over the bar. Therefore, sports performance does not fairly represent the result in connection with other parameters.

The height of trajectory culmination is another relative parameter. A competitor bending his/her body backward over the bar has an advantage. Problems with anthropometrical points orientation for calculation of the joint centre of gravity rise, as the bending becomes intense. In such a position, calculation is less precise. In this case, an important role in judgement of exerted effort is played by the body height of competitor. From the aspect of exerted efforts, taller athletes have an evident advantage in this parameter.

The most suitable parameter for reached performance evaluation seems to be vertical velocity at the end of take-off (vv_1). Fig. 3 shows the dependence of sports performance on vertical velocity at the end of take-off. In the same vertical velocity, men attain results about 20-cm higher than women, which is more than the difference in their average body heights. This fact may be explained by better work of men over the bar. Men work more effectively and their body bends more intensely over the bar. Fig. 4 shows the dependence of culmination of the trajectory of the centre of gravity on vertical velocity at the end of take-off. Vertical shift of curves approximately corresponds to the difference in body heights. In both cases shown in fig. 3 and 4, high correlation values were reached and therefore, the parameter of vertical velocity at the end of take-off may be used as the sports performance index.

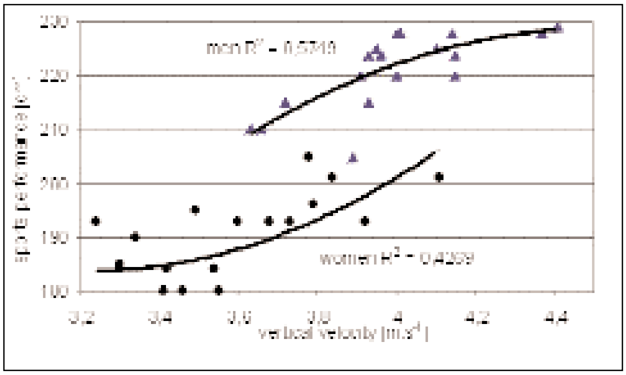

Fig. 3. Sports performance Dependence on Vertical Velocity at the End of Take-Off

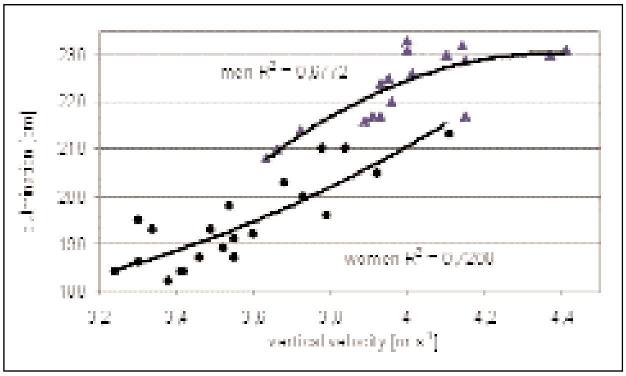

Fig. 4. Dependence of Culmination of Centre of Gravity on Vertical Velocity at the End of Take-Off

The dependence of vertical velocity at the end of take-off on horizontal velocity before the take-off is presented in fig. 5. An optimum horizontal velocity in women is just below 7 $m.s^{-1}$. In men, we notice an extreme value of the run-up speed, 8.75 $m.s^{-1}$, attained by Zhu in his try for 229 cm. This athlete is known for a quick run-up. This parameter singles him out from the sample of men. If we take account of this fact, we can state that optimum horizontal velocity in men is from 7.5 to 8 $m.s^{-1}$.

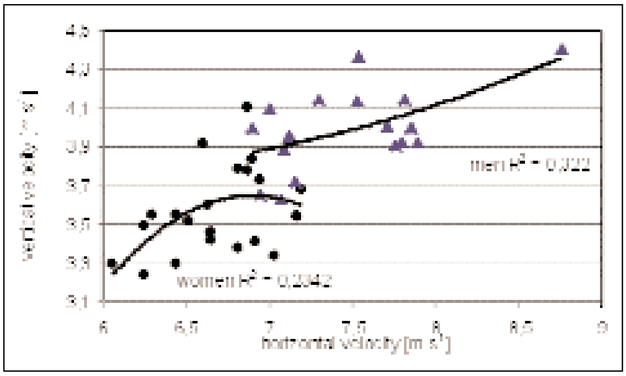

Fig. 5. Dependence of Culmination of Centre of Gravity at the End of Take-Off on Horizontal Velocity at the beginning of Take-Off

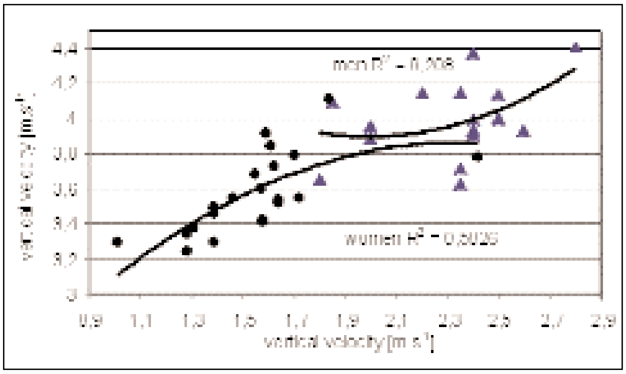

Fig. 6. Dependence of Vertical Velocity at the End of Take-Off on Vertical Velocity at the End of Amortisation

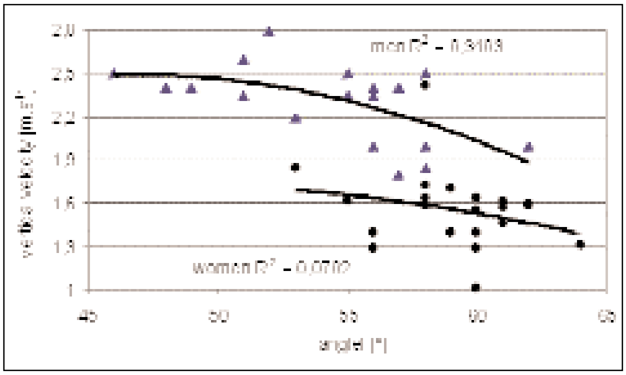

Fig. 8. Dependence of Vertical Velocity at the End of Amortisation on the Angle of Tread-Down to the Support Position

Fig. 6 shows the dependence of vertical velocity at the end of take-off on post-amortisation vertical velocity. Both curves fluently follow each other. We suggest that the higher the vertical velocity at the end of take-off, the bigger is the share of post-amortisation vertical velocity in its generation. Vertical velocity before the end of amortisation is generated only by the work of leverage through the take-off leg (Moravec and Slamka 1998). This fact confirms the significance of horizontal velocity at the beginning of take-off and work of leverage in the resulting vertical velocity generation. In the phase of amortisation, the leverage transforms horizontal velocity decrease to vertical velocity. Leverage and active take-off are mutually replaceable in the resulting vertical velocity generation. This means that the same vertical velocity may be reached from various post-amortisation vertical velocities, as well as different resulting vertical velocities may be reached from the same post-amortisation vertical velocity. The kinematic structure depends on the competitor's type (speed, strength).

Fig. 7 shows the dependence of post-amortisation vertical velocity on the angle of take-off from the one-before-the last support. For men, it is more advisable to take a more acute angle as a prerequisite for generation of a more acute angle of tread-down to the take-off position. Fig. 8 shows the dependence of post-amortisation vertical velocity on tread-down angle. Similarly as in the previous case, here it is also more advisable for men to take a more acute angle. The leverage works better in such situations. In more acute angle, a competitor starts to the take-off position with his/her centre of gravity lowered in the last phase of the run-up, which will shorten his/her flight phase before the take-off. This conception is helped also by shortening of the last stride before the take-off.

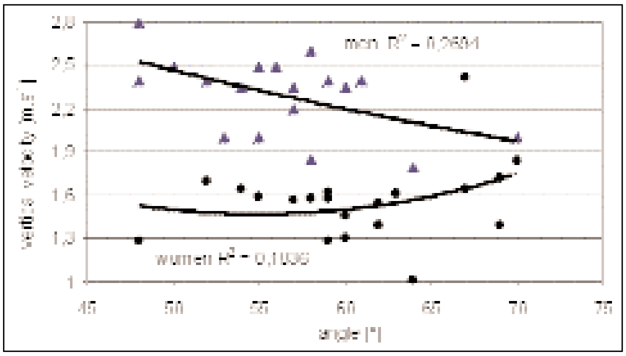

Fig. 7. Dependence of Vertical Velocity at the End of Amortisation on Angle of Take-Off from One-Before-the Last Support

Fig. 9 shows the dependence of vertical velocity at the end of take-off on the last stride length. An optimum stride length for men is about 210 cm. In fig. 10, notice that an optimum length of the last stride

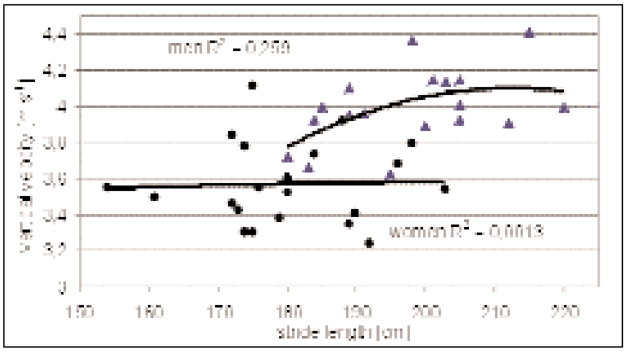

Fig. 9. Dependence of Vertical Velocity at the End of Take-Off on the Last Stride Length

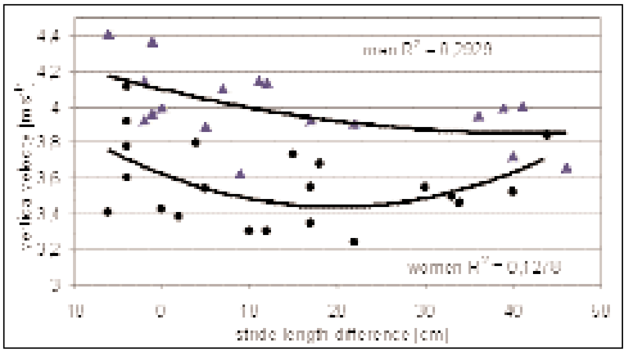

Fig. 10. Dependence of Vertical Velocity at the End of Take-Off on Length Difference between the Last Two Strides

for men is about 10 cm shorter than the one-before-the last stride length. A competitor can generate a shorter flight phase before taking the take-off position by means of the last stride shortening. During the flight phase, the competitor's body is exposed to gravitation generating a free fall. Vertical velocity before taking the take-off position reaches small negative values. A shorter flight phase generates a slight decrease of vertical velocity and the flight phase effect is negligible. This way, a competitor will generate better conditions for the use of the jumping take-off potential (Slamka and Moravec 1986).

In fig. 7 to 10, the courses of women are also shown. However, their interpretation is hardly possible due to the large dispersion of values. It seems that the kinematic structure characterised by these parameters is not formed yet so well for women.

Conclusion

Tries analysis in samples of men (n = 18) and women (n = 21) confirmed that an important part of vertical velocity is generated by means of horizontal velocity transformation with the help of leverage through the take-off leg. The leverage works also during the active phase of take-off. We suppose that competitors, able to put their run-up speed in optimum line with the angle of the take-off position, can generate as much as 60% to 70% of vertical velocity by means of leverage through the take-off leg. Resulting vertical velocity significantly correlates with horizontal velocity at the beginning of the take-off phase. A shorter take-off time is reached by higher horizontal velocity generating higher values of maximum force. Therefore, a competitor must put in line his/her run-up speed and the angle of tread-down to the take-off position with his/her strength abilities. The leverage makes a significant contribution to resulting vertical velocity generation also in the sample of women. In comparison with the male sample, a rather big dispersion of values of the selected parameters characterising the final phase of the run-up was found in women. Therefore, we came to a conclusion that kinematic structure of the run-up final phase characterised by those parameters is not formed for women yet. With regard to extreme requirements on competitor's strength during the take-off, an optimal modification of kinematic structure identified in both women and men will be useful.

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