Bojan Jošt
Milan Čoh
Janez Pustovrh
Maja Ulaga

ANALYSIS OF SELECTED KINEMATIC VARIABLES OF THE TAKE-OFF IN SKI JUMPS IN THE FINALS OF THE WORLD CUP '99 AT PLANICA

ANALIZA IZBRANIH KINEMATIČNIH SPREMENLJIVK ODSKOKA SMUČARJEV SKAKALCEV V FINALU SVETOVNEGA POKALA '99 V PLANICI

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ABSTRACT

The objective of the study was to establish, by means of a 2-D kinematic analysis, the correlation between the selected kinematic parameters of the take-off of the jumpers and their performance from the aspect of the jump length, on a sample of the best ski jumpers (first series n = 42; second series n = 30) participating in the final competition of the World Cup in Ski Flights at Planica in 1999 (K 180 m).

By means of an analysis of correlation and single-factor analysis of variance, a smaller number of statistically significant correlations between the defined kinematic variables and the jump length was obtained. The differences in the vertical velocity of the take-off on the edge of the take-off platform confirmed a tendency towards positive correlation between this variable and the jump length (the group of the best ski jumpers attained the smallest vertical velocity in both jumps; in the first jump, the differences between the various quality groups of ski jumpers were statistically significant. The best group of ski jumpers showed tendencies towards a more pronounced transfer of the hips and the common centre of gravity in the forward direction (the take-off rotation factor) relative to the axis of the ankle (the differences between the various quality groups of ski jumpers were statistically significant in the second jump).

Key words: ski jumps, kinematics, take-off analysis, World Cup Competition, Planica K 180 m, 1999

IZVLEČEK

Namen te študije je bil s pomočjo 2D kinematične analize, na vzorcu najboljših smučarjev skakalcev (prva serija n = 42; druga serija n = 30), nastopajočih na finalni tekmi svetovnega pokala v poletih v Planici 1999 (K 180 m), ugotoviti povezanost med izbranimi kinematičnimi parametri odskoka smučarjev skakalcev in uspešnostjo z vidika dolžine skoka.

S pomočjo korelacijske analize in eno-faktorske analize variance je bilo ugotovljeno manjše število statistično pomembnih povezav definiranih kinematičnih spremenljivk z dolžino skoka. Razlike v vertikalni hitrosti odskoka v točki na robu odskočišča so potrdile tendenco pozitivne povezanosti te spremenljivke z dolžino skoka (skupina najboljših skakalcev je pri obeh skokih imela najmanjšo hitrost, pri prvem skoku so bile razlike med različnimi kakovostnimi skupinami skakalcev statistično pomembne). Najboljša skupina skakalcev je kazala tendence bolj izrazitega prenosa bokov in skupnega težišča telesa v smeri naprej (faktor rotacije odskoka) glede na os gležnja (razlike pri drugem skoku so bile med različnimi kakovostnimi skupinami skakalcev statistično značilne).

Ključne besede: smučarski skoki, kinematika, analiza odskoka, tekmovanje za svetovni pokal, Planica K 180 m, 1999

University of Ljubljana – Faculty of Sport, Gortanova 22, SI-1000 Ljubljana, Slovenia
Tel: +386 61 140-10-77
Fax: +386 61 448-148
E-mail: bojan.jost@sp.uni-lj.si

INTRODUCTION

In the bio-mechanical layout studies of the technique used in ski jumping, the problem lies in the aggravated measurement environment. To properly diagnose the characteristics of the ski-jumping technique, complete dynamic, kinetic and kinematic data is necessary. In the present research, however, the subject of the study of the take-off technique is limited only to the kinematic aspect. By means of this aspect we could determine and hypothetically confirm or reject some theoretical assumptions concerning the technique in ski jumping under real competition conditions.

With the so-called V-technique that gained ground in the 1991/92 season, the technique used in ski-jumping changed significantly. These changes are certainly most obvious under the most difficult inertial conditions and in the competitions that place the highest demands on the competitors. For this reason, the competition in the finals of the World Cup in Ski Flights in 1999 was selected to investigate the characteristics of the technique used by ski jumpers. Precisely in ski flights there shows the largest variability of the ski-jumping technique that was the subject of many researches during its history. Some of these researches (Janura, Vaverka and Elfmark, 1995; Arndt, Brugemann, Virmavirta and Komi, 1995; Komi and Virmavirta, 1997) were more focused on the study of the push-off and ascending phase of early flight in ski jumpers, while others again focused more on the study of the flight technique (Hiroshi, Shunsuke, Tadaharu, Hirotoshi and Kazutoshi, 1995). A dividing line between the take-off and flight is difficult to draw. However, between the two there certainly exists the relationship of cause (take-off) and effect (flight). The present research concentrates on the study of the take-off in the support phase of the push-off and the transition into flight, which we could call the phase of ascent. According to the theoretical model of take-off (Vaverka, 1987; Vaverka, Janura, Elfmark and Salinger, 1997), the ski jumper must solve five independent motor tasks (factors of a successfully performed take-off): vertical take-off velocity, rotation of the ski jumper, aerodynamic aspect, activity of the arms and accuracy of the take-off.

Performance of a ski jumper from the aspect of the aerodynamic factor depends on the optimisation of the push-off factors in the support phase of the take-off. Maximisation of the positive effect of an individual factor shows only in the optimisation of the common determinant of the take-off technique, which contributes consequentially to the maximisation of positive aerodynamic effects in the flight phase. This means that the factors (vertical push-off acceleration, rotation, accuracy of the push-off and the activity of the arms) are causal factors exerting influence on the aerodynamic factor of the take-off whose true import does not reveal itself before the ascent phase.

The objective of the present research was to analyse the selected kinematic variables of the ski-jumping technique defined in the take-off phase, and to determine their correlation with performance of ski jumpers at the final competition of the World Cup at Planica in 1999. The take-off phase represents a constituent part of a ski jump which in the absolute physical sense determines significantly the length, or in other words, the successfulness of the jump. Of course, the later phase of flight also decisively affects the length of the jump in many respects. Some experts even attribute dominant importance to the flight phase. Thus, we could formulate a hypothesis that motor activity of the ski jumper in the take-off and ascent phase is extremely important; however, in general, the differences between the kinematic motor variables do not differentiate statistically significantly the quality groups of ski jumpers from the aspect of the jump length.

METHODS

In the research there were analysed the jumps of ski jumpers (42 in the first series and 30 in the final series) who participated in the final competition of the World Cup in Ski Flights at Planica (K 185 m) on 19th March 1999. The ski jumpers were divided into 4 quality groups according to the jump length (table 1).

The data on the length of the jumps were taken from the official results of the competition for the world cup.

The kinematic parameters of movement were measured by means of a 2-D video analysis (ARIEL PERFORMANCE). The recording was carried out with two pairs of video cameras PANASONIC AG455, with a frequency 25 frames per second. The first pair of cameras recorded the last 10 m of the take-off

Table 1: Number of the Ski jumpers divided into 4 quality groups according to the jump length

Name of the group	Jump length (m)	First jump (n)	Second jump (n)
First (the best) group	200 and more	3	4
Second group	180-199.5	20	8
Third group	160-179.5	11	14
Fourth (the worst) group	less than 160	8	4

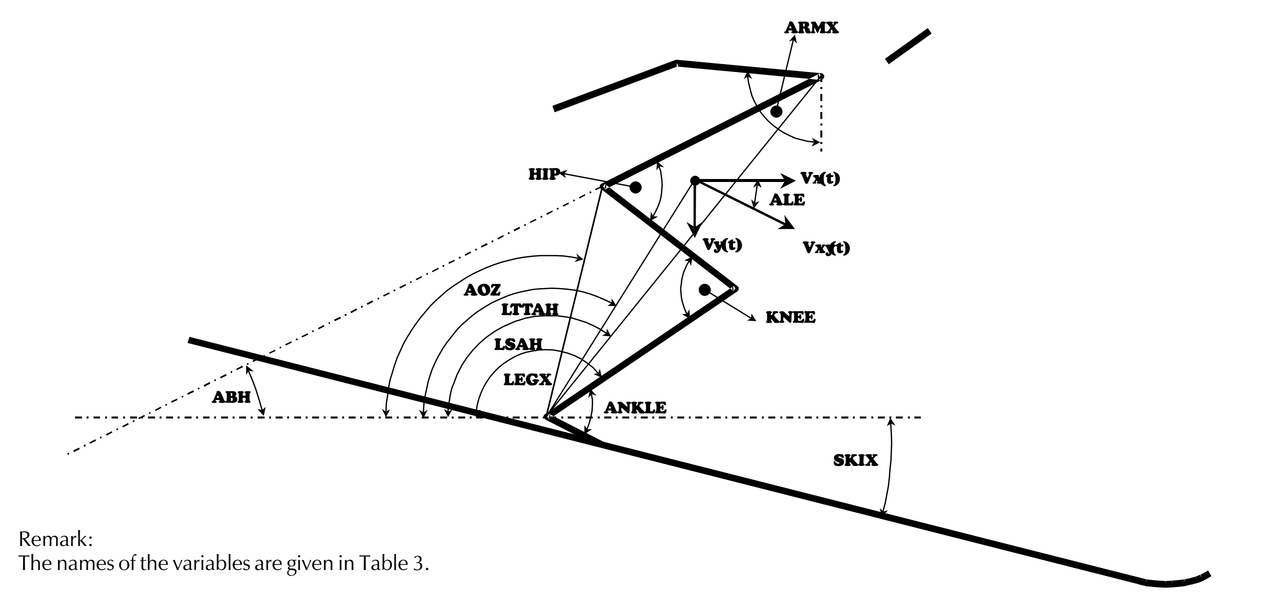

Figure 1. Graphical representation of the selected kinematic variables in the support phase of the take-off.

platform, and the second pair of cameras, the first 10 m of the flight.

Digitalisation of the frames was carried out manually. For kinematic analysis, a 7-segment 2-D model (upper arm, lower arm, trunk, hips, thigh, shin, skis), defined by 9 points denoting the joints, the extreme limit points of the limbs and the skis was used.

The calibration of the space on the push-off platform was carried out by means of two cubes with a side 1 m long that were placed at the beginning and end of the space measured. For the calibration of the space during the phase of ascent, a specially-made cross was used. This cross enabled the calibration of the space at the level of the curve of the ski jumpers' ascent.

In the support phase of the take-off, i.e. at the first point (position - a) 4 m before the edge of the take-off platform, at the second point (position - b) on the edge of the take-off platform, and at the third point (position - c) 4 m after leaving the edge of the take-off platform, the following set of kinematic parameters was defined (Figure 1). All angles given in Figure 1 were measured in the sagittal plane on the right side of the body.

To establish statistical significance of the differences between the groups, single-factor analysis of variance (ONEWAY) was used. The significance of the correlation between the kinematic variables and the length of the jump was established by Pearson's coefficient of correlation. The criterion of statistical significance was in both statistical procedures accepted with a 5 % two-sided alpha error.

RESULTS

The results of the single-factor analysis of variance conducted on the variables of the jump length are shown in Table 2.

The differences between the defined quality groups of ski jumpers in the variables of the jump length were statistically significant. The difference in the average length of the jumps between the two extreme groups was 75.5 m in the first jump and 55 m in the second jump.

Table 3 (first, second and third part) gives the results of the single-factor analysis of variance and the correlation between the criterion variable and defined kinematic parameters defined in the support phase of the take-off 4 m before the edge, on the edge of the take-off platform, and in the phase without support 4 m after leaving the edge of the take-off platform in the first and second jump.

The variable which indicates the angle between the right foot and the shin (ANKLE) attained generally the minimal value at the point 4 m before the edge of the take-off platform in all groups of ski jumpers. The group of the best ski jumpers had on the average the smallest value in both ski jumps. In the second ski jump, the difference between the best group (Mean = 81.1°) and the worst group (Mean = 85.5°) was statistically significant (F prob. = 0.00). After that, the value of the mentioned angle increased in all three groups of ski jumpers. The largest average value (Mean = 109.8°) was established in the first jump and in the second quality group of ski jumpers. The

Table 2: Results of the analysis of variance of the length of the jump, WC Planica, 1999, K180m

	First group		Second group		Third group		Fourth group		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F prob.
DSK 1(m)	208.50	9.12	186.90	3.97	171.31	6.89	133.00	25.71	0.00*
DSK 2(m)	207.12	5.40	188.00	7.26	174.21	4.91	150.75	6.50	0.00*

Legend:
DSK1 - length of the 1st jump; DSK2 - length of the 2nd jump; ž Mean - arithmetic mean of the group; SD - standard deviation within the group; F prob. - significance of the F-test, where the asterisk (*) denotes statistically significant differences between the quality groups of the ski jumpers.

Table 3: Correlation analysis between the length of the jump and the kinematic parameters and results of the analysis of variance

		First group		Second group		Third group		Fourth group		
	r	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F prob
1. Angle between right foot and right shin in XY-plane - ANKLE (angular degrees)										
1a	-.29	82.47	2.59	84.72	4.04	86.08	3.30	86.77	4.16	0.30
1b	-.02	95.61	4.51	95.50	6.52	97.75	6.25	96.11	4.15	0.79
1c	.06	105.46	5.54	109.84	4.20	107.49	4.92	107.60	5.23	0.31
2a	-.38*	81.11	4.54	82.37	2.09	86.94	3.63	85.57	2.94	0.00*
2b	.08	95.89	1.93	92.45	4.28	94.27	4.41	93.42	4.13	0.56
2c	-.26	104.42	4.32	104.47	3.56	108.89	5.79	107.79	4.22	0.17
2. Angle between velocity vector TT (body's centre of gravity) and X-axis in XY-plane - ALE (angular degrees)										
1a	-.22	8.18	0.40	7.96	0.51	7.80	0.51	8.20	0.66	0.40
1b	-.28	5.19	0.21	5.88	0.49	5.94	0.38	6.06	0.34	0.03*
1c	.19	7.35	0.86	7.08	0.96	7.04	0.79	6.69	0.21	0.61
2a	.09	8.25	0.28	7.94	0.57	8.12	0.69	8.04	0.67	0.86
2b	-.06	5.51	0.20	5.96	0.73	5.96	0.52	5.86	0.44	0.54
2c	.11	6.37	0.56	6.84	0.78	6.68	0.43	6.16	0.72	0.25
3. Angle between right shin and X-axis in XY-plane - LEGX (angular degrees)										
1a	.16	133.94	2.88	132.79	5.00	130.98	4.99	131.01	1.70	0.55
1b	-.06	119.12	2.82	120.03	7.64	117.59	6.25	120.36	6.92	0.78
1c	.00	108.56	3.52	105.72	4.55	106.72	4.20	106.35	4.29	0.74
2a	.05	133.83	3.96	136.11	3.60	132.77	3.79	133.59	5.63	0.33
2b	-.01	117.42	4.06	122.81	6.01	120.37	4.94	118.89	4.91	0.35
2c	.16	105.80	2.33	108.59	3.06	105.47	3.78	104.86	2.94	0.17
4. Angle between ankle-shoulder and X-axis in XY-plane - LSAH (angular degrees)										
1a	.06	123.37	0.98	123.77	3.33	121.37	3.72	123.42	3.44	0.31
1b	.18	121.53	1.22	121.31	3.83	119.12	4.01	119.72	4.94	0.46
1c	.18	120.55	2.54	118.69	3.70	118.55	3.75	117.94	4.74	0.80
1a	.14	122.48	2.61	123.89	1.52	122.35	2.98	122.13	2.98	0.41
1b	.31	121.14	2.56	122.82	2.67	119.61	2.78	119.16	2.86	0.06
2c	.32	120.49	3.46	121.53	2.22	118.04	3.07	117.80	2.58	0.04*
5. Angle between ankle-TT and X-axis in XY-plane - LTTAH (angular degrees)										
1a	.13	110.81	1.45	109.38	3.65	107.74	3.69	108.93	2.75	0.47
1b	.17	111.36	2.11	109.97	4.41	108.44	4.15	108.71	4.67	0.63
1c	.20	111.10	3.26	107.98	3.68	108.24	4.16	107.31	4.60	0.56
2a	.18	110. 55	2.85	111.86	2.15	108.76	2.94	109.49	4.61	0.15
2b	.27	110.92	2.87	112.42	3.07	109.28	3.23	107.97	3.74	0.09
2c	.33	110.15	3.16	111.06	2.30	107.61	3.37	106.72	2.40	0.04*

		First group		Second group		Third group		Fourth group		
	r	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F prob
6. Angle between ankle-hip axis and X-axis in XY-plane - AOZ (angular degrees)										
1a	.15	93.45	2.15	89.31	3.67	89.55	3.43	89.93	3.90	0.33
1b	.24	101.10	3.40	98.09	4.65	97.87	3.92	96.77	5.22	0.57
1c	.24	104.64	4.03	100.29	3.92	100.89	4.38	99.49	5.13	0.35
2a	.17	92.52	3.44	94.33	3.25	90.17	3.43	91.73	5.70	0.11
2b	.27	100.68	3.31	101.94	3.75	98.34	4.09	96.34	4.37	0.09
2c	.30	102.75	2.66	103.89	2.91	100.12	4.00	98.89	2.21	0.04*
7. Angle between right shin and right thigh in XY-plane - KNEE (angular degrees)										
1a	.06	95.04	4.91	90.03	5.71	92.31	6.14	92.34	5.40	0.43
1b	.31*	143.50	4.38	136.72	9.28	141.18	7.62	133.28	10.96	0.18
1c	.46*	172.00	3.89	169.11	4.40	168.16	3.09	166.09	6.30	0.22
2a	.21	92.32	4.58	92.32	2.41	91.16	5.56	90.10	2.75	0.83
2b	.33	146.65	8.79	138.93	6.72	136.52	6.83	135.22	5.53	0.07
2c	.28	173.61	3.14	170.58	4.42	169.04	3.93	168.08	1.77	0.15
8. Angle between right thigh and right trunk side in XY-plane - HIP (angular degrees)										
1a	.04	50.59	3.11	47.99	7.15	47.82	4.59	49.63	8.94	0.87
1b	.19	98.37	7.37	92.75	12.46	95.32	5.76	91.29	12.94	0.72
1c	.25	126.11	8.83	119.03	9.45	118.37	4.96	117.60	11.22	0.54
2a	.03	51.32	6.16	54.08	8.40	49.68	9.35	50.40	10.46	0.73
2b	.11	101.34	5.74	98.69	11.49	96.08	13.80	91.77	10.07	0.68
2c	.07	122.25	4.75	122.23	9.55	120.80	11.97	117.00	4.84	0.84
9. Angle between right trunk side and X-axis in XY-plane - TRUNKX (angular degrees)										
1a	.15	178.40	0.65	174.83	4.87	175.47	5.19	173.72	6.46	0.60
1b	.06	164.24	2.21	163.99	7.90	163.45	5.46	162.35	7.83	0.95
1c	-.01	154.46	4.09	155.81	7.49	156.50	3.11	154.84	6.81	0.93
2a	.16	174.83	4.98	174.36	5.48	174.25	4.93	173.28	5.46	0.97
2b	.13	162.72	2.93	163.05	8.25	160.80	9.97	162.35	4.39	0.93
2c	.13	157.16	4.36	156.94	6.91	153.71	8.99	155.95	3.58	0.73
10. Angle between right upper arm and Y-axis in XY-plane - ARMX (angular degrees)										
1a	-.09	95.91	7.91	96.30	8.05	96.77	8.82	98.43	7.88	0.93
1b	-.18	93.22	7.54	96.67	8.92	100.65	15.05	100.93	6.23	0.53
1c	.05	93.46	5.57	104.78	39.77	99.85	15.10	99.43	5.27	0.90
2a	-.05	84.74	6.02	92.31	9.74	93.16	8.72	90.42	7.85	0.39
2b	-.32	82.54	6.93	95.95	9.17	98.43	10.37	98.80	6.50	0.04*
2c	-.35*	87.99	12.58	94.42	6.36	97.25	8.59	103.84	10.75	0.10
11. Angle between frontal part of skis and X-axis in XY-plane - SKIX (angular degrees)										
1a	.06	11.43	0.41	11.35	0.57	10.96	0.91	10.93	0.94	0.38
1b	-.09	11.37	0.77	12.33	0.81	12.59	0.66	12.13	1.05	0.16
1c	-.04	12.71	2.55	13.05	1.94	13.13	1.25	12.58	2.52	0.92
2a	-.33	10.51	0.81	11.05	0.47	11.01	0.47	11.35	0.48	0.18
2b	.27	12.34	0.66	11.80	0.65	11.80	0.95	10.89	1.11	0.15
2c	-.02	12.96	3.29	14.57	1.65	13.58	1.73	13.24	1.60	0.49
12. Velocity TT (body's centre of gravity) in x-direction by time - Vx(t) (m/s)										
1a	.08	27.78	0.30	27.92	0.36	27.67	0.48	27.66	0.58	0.37
1b	.25	27.61	0.27	27.70	0.45	27.50	0.39	27.41	0.21	0.29
1c	.17	26.01	0.23	26.05	0.46	25.98	0.26	25.90	0.34	0.83

		First group		Second group		Third group		Fourth group		
	r	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F prob
2a	.20	27.68	0.71	27.74	0.38	27.53	0.62	27.56	0.47	0.85
2b	.10	27.55	0.35	27.28	0.36	27.60	0.33	27.36	0.22	0.17
2c	.23	25.90	0.21	25.87	0.44	25.97	0.27	25.63	0.39	0.40
13. Velocity TT (body's centre of gravity) in y-direction by time - Vy(t) (m/s)										
1a	.22	-4.03	0.14	-3.94	0.30	-3.83	0.26	-4.05	0.40	0.46
1b	.23	-2.51	0.11	-2.86	0.24	-2.89	0.18	-2.93	0.19	0.04*
1c	-.20	-3.20	0.34	-3.17	0.39	-3.12	0.36	-2.97	0.13	0.58
2a	-.16	-4.08	0.27	-3.92	0.25	-3.94	0.33	-3.95	0.35	0.84
2b	.02	-2.70	0.10	-2.85	0.35	-2.90	0.23	-2.81	0.21	0.56
2c	-.10	-2.81	0.23	-3.05	0.32	-2.97	0.19	-2.76	0.26	0.20
14. Velocity TT (body's centre of gravity) in xy-plane by time - Vxy(t) (m/s)										
1a	.06	28.07	0.28	28.20	0.38	27.94	0.48	27.96	0.61	0.41
1b	.24	27.73	0.28	27.85	0.46	27.65	0.40	27.57	0.23	0.33
1c	.19	26.21	0.25	26.24	0.46	26.17	0.27	26.07	0.35	0.76
2a	.22	27.98	0.73	28.02	0.37	27.81	0.60	27.84	0.44	0.84
2b	.09	27.68	0.35	27.43	0.36	27.76	0.33	27.50	0.23	0.16
2c	.24	26.05	0.21	26.05	0.43	26.14	0.27	25.78	0.40	0.34

Legend:
1 - first jump
2 - second jump
- position 4 m before the edge of the take off table,
- position on the edge of the take-off table,
- position 4 m after leaving the edge of the take-off table
* - means statistically significant differences between the quality groups of ski jumpers or statistically significant correlation, $p < 0.05$

minimisation of the value of this angle at all three points confirms the basic assumption on the optimisation of successfulness of the ski- jumping technique from the aspect of rotation of the ski jumper at simultaneous optimisation of the aerodynamic aspect of the course of the take-off and ascent.

The angle of the vector of the velocity of the common centre of gravity of the body and the skis to the x-axis (ALE) changed in general in all groups of ski jumpers at all three defined space points. The minimal value of this angle was attained on the edge of the take-off platform. The difference between the average value of the best group (Mean = 5.19°) and the worst group (Mean = 6.06°) was statistically significant (F prob. = 0.03). The mentioned realisation confirms the tendency towards the development of a high vertical take-off velocity on the edge of the take-off platform as a result of a high level of the generation of the push-off force impulse.

The angle between the thigh and shin (KNEE) shows that 4 m before the edge of the take-off platform, the ski jumpers were still closer to the so-called approach squat position. Then followed a fast extension of the legs at the knee joint. In the first jump it reached an average value of 143.5 angular degrees on the edge of the take-off platform in the best group, and 133.2 angular degrees in the worst group. Similar tendencies were also observed in the second jump. The mentioned variable showed a statistically significant correlation with the length of the jump on the edge of the take-off platform (r = 0.31) and 4 m after leaving the edge of the take-off platform (r = 0.46).

The angle between the chord connecting the ankle with the hip axis and X-axis (AOZ) increased from the point defined 4 m before the edge of the take-off platform up to the point defined 4 m after leaving the edge of the take-off platform in all groups. At the last point, the difference between the average value of the best group (Mean = 102.7°) and the worst group (Mean = 98.8°) was statistically significant (F prob. = 0.04).

A statistically significant difference (F prob. = 0.04) was established in the second jump in the angle between the right upper arm and Y-axis in the XY-plane (ARMX). The average of the best group on the edge of the take-off platform (Mean = 82.5°) was significantly lower than the average of the qualitatively worst ski jumpers group (Mean = 98.8°).

DISCUSSION

Any motor activity of a ski jumper reflects significantly in the velocity of movement of the common centre of gravity, which shows in the direction of the trajectory of the flight curve of the common centre of gravity of the jumper-skis system and also in its horizontal and vertical component. The velocity in the direction of the trajectory of the curve of the movement of the common centre of gravity (Vxy) did not show statistically significant differences between the individual qualitatively different groups of ski jumpers. In both jumps, a slight tendency towards the reduction of this velocity was noticed in the course of the push-off and ascent, considering the total development of the take-off and ascent. A more noticeable and in the first jump even statistically significant difference (F prob. = 0.04) was established in the vertical velocity of the movement of the common centre of gravity (Vy) at the point on the edge of the take-off platform. In the best ski jumpers, the average value of the vertical velocity was the lowest in both jumps. The horizontal velocity of the lifting of the centre of gravity of the jumper-skis system did not show statistically significant differences between the groups of ski jumpers classified with respect to the jump length. The horizontal velocity (Vx) decreased also in both jumps, at the defined distance of 8 m, during the course of the take-off and ascent.

The results showing the velocity of the movement of the common centre of gravity thus in some way confirm the hypothesis that during the time of the ski-jumper's take-off and in the first ascending phase of his flight there occur no statistically significant differences associated with the jump length. The difference shows only in the vertical velocity of the movement of the common centre of gravity reached immediately before the edge of the take-off platform. This hypothetically means that during the take-off, the jumper must develop an adequate level of force impulse which will enable him to develop suitable (optimal) vertical velocity of the take-off. However, due to the fact that the ski jumpers have just begun the flight phase, the parameters of the movement of the common centre of gravity show consequentially in the continuation of the flight as a reflection of the geometry of the position of the jumper-skis system in the air. In accordance with the theory of the technique of the movement of a ski jumper in the flight phase, the jumper must, at each point of the flight, assume such a position which will maximise the horizontal velocity at simultaneous minimisation of the vertical velocity of the movement of the common centre of gravity.

The jumper-skis system represents several apparently mutually separated body segments and the skies, which, however, in a real situation act in a close interdependence and interrelation. At each point of the push-off and ascent, the ski jumper should place his body segments and the skis so as to maximise the positive tendencies of the aerodynamic effects during the whole time of the take-off and flight, and at the same time minimise the angle of elevation of the movement of the common centre of gravity. It is exactly at this angle (ALE) that in the first jump, a statistically significant difference was established between the groups of the best and worst ski jumpers (F prob. = 0.03). The angle of elevation while ascending depends above all on the magnitude of the time and space of the production of the push-off force. The studies by Virmavirta and Komi (1993a, 1993b and 1994) showed a tendency towards a high level of the push-off force developed in short time at the point as close as possible to the edge of the take-off platform. As a consequence, this contributes to the raising of the angle of ascent of the common centre of gravity of the jumper-ski system towards the edge of the take-off platform. The raising of the trajectory of the flight curve of the common centre of gravity of the jumper-skis system is possible only if a favourable shin position is assumed in the support phase of the push-off of the ski jumpers. This angle (ANKLE) was statistically significant and the most important factor for distinguishing between the best and the worst group of ski jumpers (F prob. = 0.00), especially in the second jump.

An important element of the ski-jumper's push-off technique represent the angles that indicate the ability of transferring the common centre of gravity, above all the hips, in the forward direction (LSAH, LTTAH, AOZ). This tendency, as a statistically significant factor for differentiating between the group of the best and the group of the worst ski jumpers, showed at the point 4 m after leaving the edge of the take-off platform. The transfer of the common centre of gravity and the hips of the body in the forward direction is of course possible only by fast extension of the legs at the knee joint (HIP), which fact was also confirmed within the scope of this study: in the first jump, the mentioned angle was statistically significantly correlated with the length of the jump ($r = .46$; $p < .05$).

The transition of the ski jumper from the approach position into an optimal position for flight is a complex and difficult motor task, which, from the aspect of the terminology of motor behaviour, requires a high level of strength, co-ordination, accuracy, balance, orientation in space, visualisation, boldness, courage etc. Thus, in the flight phase, the differences between the best and worst ski jumpers show as a consequence (Jošt, Kugovnik, Strojnik and Colja, 1997) in the kinematics of flight, which fact was established on the dynamic level (Mahnke and Hochmuth, 1990; Tavernier and Cosserat, 1993; Watanabe K. and Watanabe I., 1993; Hiroshi, Shunsuke, Tadaharu, Hirotoshi and Kazutoshi, 1995) in the experimental study in the wind tunnel.

On the basis of the results obtained by research, the following conclusions can be drawn:

- The variability of the defined quality groups of ski jumpers from the aspect of the jump length was large and statistically significant (F prob. = 0.00);
- The velocity of movement of the common centre of gravity of the jumper-ski system in the horizontal direction and in the direction of the trajectory of the curve of the movement of the common centre of gravity during the course of the take off and in the first part of the flight (ascent) decreased constantly;
- The velocity of movement of the common centre of gravity of the jumper-skis system in the vertical direction reduced towards the point at the edge of the take-off platform, while at a distance 4 m after leaving the platform, it began to increase again. This tendency reflected in the angle formed between the vector of the trajectory of the movement of the common centre of gravity of the jumper-skis system and the horizontal (in the first jump the difference between the various quality groups of ski jumpers was statistically significant, F prob. = 0.03);
- The differences in the vertical velocity of the take-off at the point located on the edge of the take-off platform confirmed the tendency of a positive significance of this variable (the group of the best ski jumpers had the smallest velocity in both jumps; in the first jump, the differences between the various quality groups of ski jumpers were statistically significant, F prob. = 0.04);
- At the point 4 m before the edge of the take-off platform, the best group of ski jumpers had a smaller average angle between the shin and the foot (in the second jump, the difference between the groups of ski jumpers was statistically significant, F prob. = 0.00); on the edge of the take-off platform, the differences were smaller and began to increase again up to the point 4 m after leaving the edge of the take-off platform. The mentioned tendencies are a reflection of the dynamics of the specific take-off technique used by the ski jumpers: this dynamics was larger in the best group of ski jumpers;
- The best group of ski jumpers showed tendencies towards a more pronounced transfer of the hips and the common body's centre of gravity in the forward direction (the factor of the take-off rotation) with respect to the ankle axis (in the second jump, the differences between the various quality groups of ski jumpers were statistically significant (F prob. = 0.04);
- The best ski jumpers were more extended at the knee joint on the edge and four metres after leaving the take-off platform. The correlation between the HIP variable and the jump length was statistically significant (r = 46; P .05) in the first jump. Therefore, we could make an inverse conclusion about a larger push-off dynamics in the take-off of the best ski jumpers;
- The active work of the arms was less pronounced in the best ski jumpers than in the groups of poorer ski jumpers (in the second jump, the differences between individual quality groups of ski jumpers at the point on the edge of the take-off platform were statistically significant (F prob. = 0.04);
- Every change in an individual variable has a multi-factor effect on all other variables. These effects are hypothetically independent when inter-variable observation (various subjects and a comparison between them) is concerned, and they are hypothetically interdependent and inter-influential when intra-variable observation (the same subjects) is concerned. This means that despite the acting of the general tendencies there occur completely individual tendencies and the effects associated with them.

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