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DIFFERENCES BETWEEN BETTER AND WORSE SKI JUMPERS REGARDING SELECTED SKI FLYING CHARACTERISTICS AT THE SKI FLYING WORLD CHAMPIONSHIPS 2010 IN PLANICA

RAZLIKE MED NAJBOLŠIMI IN SLABŠIMI SKAKALCI V IZBRANIH ZNAČILNOSTI LETENJA NA SVETOVNEM PRVENSTVU V SMUČARSKIH POLETIH V PLANICI 2010

ABSTRACT

The objective of the study was to establish the differences between the best and worst ski jumpers in terms of selected ski flying characteristics at the Ski Flying World Championships 2010 in Planica. The variables Length of flying, Time of flying, In run velocity, Outrun velocity, Take off velocity, Height of flying at 17 m, Height of flying at 110 m, Aerodynamic index at 17 m, Aerodynamic index at 120 m, as well as Speed of the wind at 20 m, 70 m, 110 m and 160 m were analysed. The ski jumpers were divided into two statistically significant different quality groups according to their jump length in all four rounds (Sig t = 0.01). The velocity of movement during the flight phase increased constantly. The average out-run velocity was about 6-10% higher than the in-run velocity. The difference between the average values of in-run velocities were statistically significant in three rounds (second, third and fourth). The worse group had a greater average in-run velocity. The same happened with the variables of take-off velocity. Only a few statistically significant differences were found in the first and in the last, fourth rounds in terms of variables of out-run velocity. The worse group of ski jumpers had higher average values of out-run velocities. At the point of 17 m and especially 110 m after the edge of the take-off platform, the better group of ski jumpers had a bigger flying height. Those differences were not statistically significant in all rounds. The biggest differences were in the first and the last competitive round. The better group of ski jumpers showed a better aerodynamic flight position at the beginning of flying and especially in the middle of flying. Statistically significant differences were found in the second, third and last, fourth rounds. The differences in wind condition between defined groups

POVZETEK

Namen raziskave je bil ugotoviti razlike v prostoru izbranih značilnosti poletov na smučeh med boljšimi in slabšimi smučarji skakalci na svetovnem prvenstvu v Planici 2010. Proučevane so bile spremenljivke Dolžina poleta, Čas poleta, Zaletna hitrost, Hitrost na odrivni mizi, Višina leta v točki 17 m, Višina leta v točki 110 m, Aerodinamični indeks v točki 17 m, Aerodinamični indeks v točki 110 m, Hitrost vetra v točki 20 m, Hitrost vetra v točki 70 m, Hitrost vetra v točki 110 m in Hitrost vetra v točki 160 m. Glede na rezultate na svetovnem prvenstvu oziroma dolžine poletov v vseh štirih serijah sta bili oblikovani dve kakovostni statistično pomembno različni skupini skakalcev (Sig t = 0,01). Hitrost gibanja smučarjev skakalcev je v fazi leta stalno naraščala. Povprečna hitrost v spodnjem prehodnem loku letalnice je bila 6 – 10 % višja kot zaletna hitrost. Razlike med povprečnimi vrednostmi zaletne hitrosti so bile statistično značilne v drugi, tretji in četrti seriji. Slabša skupina je imela v povprečju večjo zaletno hitrost. Podobno se je zgodilo tudi s spremenljivko Hitrost na odskočni mizi. Pri spremenljivkah Hitrost v spodnjem prehodnem loku so bile ugotovljene statistično značilne razlike v prvi in v zadnji, četrti seriji. Slabša skupina skakalcev je imela večjo povprečno hitrost omenjene spremenljivke. Boljša skupina skakalcev je imela višjo krivuljo leta v točki 75 m in še prav posebej v točki 110 m za robom odskočne mize. Statistično pomembne razlike v višini leta so bile v točki 17 m ugotovljene v prvi in v zadnji četrti seriji in v točki 110 m v prvi seriji. Boljša skupina skakalcev je imela bolj ugoden aerodinamični indeks letenja v točki 17 m in še posebej v srednjem delu poleta v točki 110 m. Statistično značilne razlike so bile v točki 17 m ugotovljene v drugi, tretji in četrti seriji in v točki 110 m v vseh štirih serijah. Razlike v vetrovnih were not statistically significant in general terms. In the first part of flying, only in the first round were there significant differences at the measuring point of 20 m after the take-off bridge. In the middle of flying at 110m the wind conditions were importantly different in the second and fourth jumps.

Keywords: ski jumping, biomechanics, flying characteristics, World Championships 2010

pogojih med definiranimi skupinami na splošno niso bile statistično značilne. V prvem delu leta, v točki 20 m, je bila samo v prvi seriji ugotovljena statistično značilna razlika. V osrednjem delu leta, v točki 110 m, so bile vetrovne razmere statistično značilno različne v drugi in četrti seriji poletov.

Ključne besede: smučarski skoki, biomehanika, značilnosti leta, Svetovno prvenstvo 2010

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INTRODUCTION

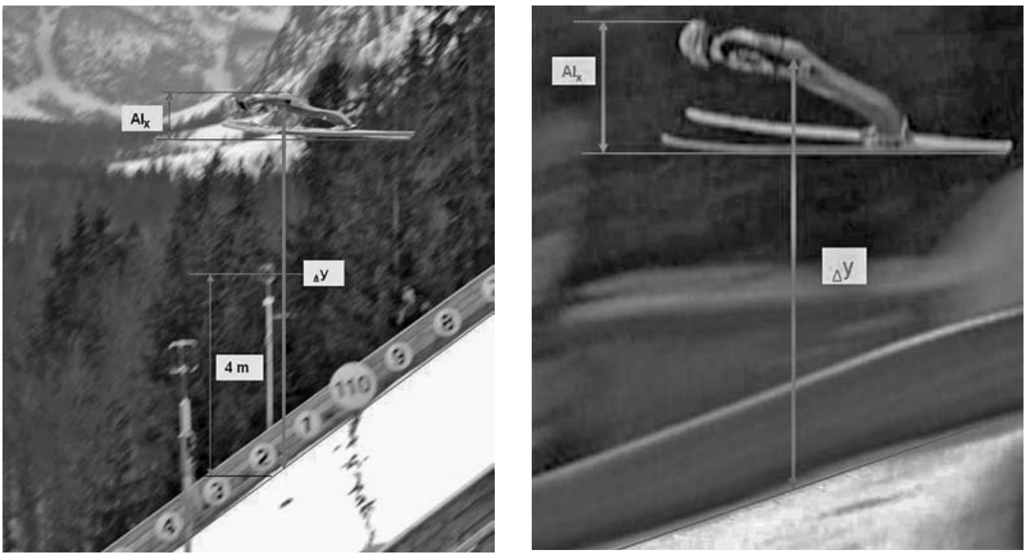
The Ski Flying World Championships 2010 were selected to investigate chosen characteristics of the technique used by ski jumpers on the biggest jumping hill in the world. For experts and researchers in ski jumping a performance analysis of the ski jumping technique is most frequently undertaken. They wish to find the optimal technique that allows ski jumpers to reach the best competitive performance. In ski flying there is great variability in the ski jumping technique and this has been the subject of many studies during its history. Some studies have focused more on the push-off and early flying (Arndt, Brügemann, Virmavirta, & Komi, 1995; Janura, Vaverka, & Elfmark, 1995; Jošt, Čoh, Pustovrh, & Ulaga, 1999; Komi & Virmavirta, 1997; Müller & Schwameder, 2003; Virmavirta & Komi, 1993a; Virmavirta & Komi, 1993b; Virmavirta & Komi, 1994; Virmavirta, Kiveskas, & Komi, 2001), while others have concentrated more on the study of the central flying technique (Hiroshi, Shunsuke, Tadaharu, Hirotoshi, & Kazutoshi, 1995; Jin, Shmizu, Watanuki, Kubota, & Kobayashi, 1995; Mahnke & Hochmuth, 1990; Tavernir & Cosserat, 1993). The flying phase is, as a matter of common sense, a consequence of the previous in-run and take-off phase. The performance of the in-run phase first depends on the in-run velocity (Vaverka, 1987; Ettema, Braten, & Bobbert, 2005). The in-run velocity before the take-off table has a direct influence on the horizontal velocity in the take-off phase and the first part of flying. Early flight is considered a crucial phase in the length of a jump (Schmölzer & Müller, 2005; Virmavirta, Isolehto, Komi, Brüggemann, Müller, & Schwameder, 2005). The ski jumper's transition from the approach position into the optimal flight position is a complex and difficult motor task which, using the terminology of psychomotor behavior, requires a high level of strength, co-ordination, accuracy, balance, orientation in space, visualisation, boldness, courage etc. Thus, in the first part of the flying phase differences between the best and worse ski jumpers are consequences of the quality of the take-off phase (Jošt, Kugovnik, Strojnik, & Colja, 1997; Mahnke & Hochmuth, 1990; Tavernier & Cosserat, 1993; Watanabe K., & Watanabe I., 1993; Hiroshi, Shunsuke, Tadaharu, Hirotoshi, & Kazutoshi, 1995; Virmavirta, Kiveskas, &

Komi, 2001). The performance of ski jumpers in terms of the aerodynamic factor first depends on optimisation of the push-off factors in the support phase of the take-off (Virmavirta & Komi, 1989; Komi & Virmavirta, 1997; Kaps, Schwameder, & Engstler, 1997; Sasaki, Tsunnoda, Uchida, Hoshino, & Ono, 1997). The factors vertical push-off acceleration, rotation, accuracy of the push-off and the activity of the arms are causal factors for a good technique in the take-off phase. These factors influence the aerodynamic efficiency in the first part of flying (Vaverka, Janura, Elfmark, & Salinger, 1997). The take-off phase on the biggest jumping hill in Planica finishes after approximately 0.7 second of the flying phase, which means about 17 m after the take-off bridge. Ski jumpers must optimally achieve two relatively independent movement actions at that point. The first one is to reach the optimal aerodynamic position of flying and the second one is the minimisation of the vertical velocity of flying. From this point of view, it can be expected that the better group of ski jumpers has a smaller angle of flying after the take-off bridge than the worse group and a better aerodynamic position. The central part of the flying phase is a constituent part of a ski jump which in an absolute physical sense significantly determines the successfulness of ski jumpers.

Experts have conducted many studies of the ski jumping flying technique (Watanabe & Watanabe, 1993; Müller, Platzer, & Schmolzer, 1996; Sasaki, Tsunoda, & Hoshino, 2000; Schmölzer, & Müller, 2002; Joo, Young, & Young, 2004; Seo, Watanabe, & Murakami, 2004; Seo, Murakami, & Yoshida, 2004; Schmölzer & Müller, 2005; Denoth & Gerber, 2008). Thus, a hypothesis could be formulated that the technique activity of a ski jumper in the flight phase is extremely important. Jumpers must achieve optimisation of the technique movement. This optimisation involves two different factors. The first factor is the angle of the flying curve. The worse group of ski jumpers has a bigger angle of the flying curve than better one (Jošt, 1994; Virmavirta et al., 2005). The second factor is an optimal aerodynamic position in the flying phase. The best ski jumpers have a better aerodynamic position than the worst ski jumpers (Jošt, Kugovnik, Strojnik, & Colja, 1997; Jošt, Vaverka, Kugovnik, & Čoh, 1998). In that research, a specific aerodynamic index was investigated. This index is based on the distance determined by two extreme points on the system body and skis of the ski jumper in a horizontal direction. It can be expected that the better group of ski jumpers has a statistically significant better aerodynamics index than the worse group in the two mentioned reference points on the jumping hill (17 m and 110 m). One goal of this study was to find out the difference between two groups of ski jumpers in the average values of their out-run velocity, measured at a distance from 245 m to 255 m. It can be expected that the worse group of ski jumpers had a bigger out-run velocity than the better group. This information about the out-run velocity is important for the development of flying hills in the future. Some experts wish to know this velocity when contemplating the construction of a bigger jumping hill that would allow flights of over 300 m. Wind conditions on jumping hills are not only a matter of fairness but, even more importantly, a matter of safety. Since 2001 the tangential wind speed has been measured, which is the influence of the wind on the flight trajectory and the length of the jump. Tangential wind speed is a three-dimensional measurement of the velocity of the wind reduced to the flight trajectory level. Based on experience gathered from tangential wind measuring, a so-called wind corridor has been defined to provide some more fairness to the athletes. As a result, "wind" must also be added to the calculation of the success of ski jumpers. The last goal of this study was to test the differences between two extremely different quality subgroups of ski jumpers as regards average values of wind speed variables.

METHOD

The research analysed the jumps of ski jumpers participating on two competitive days of the Ski Flying World Championships 2010 in Planica (HS215m). On the first day, Friday 19 March, 40 jumpers jumped in the first competitive round and the best 31 then jumped in the second round. On the second final competitive day, Saturday 20 March, 30 jumpers competed in the third and fourth, final round. The ski jumpers were divided into two extremely different quality groups according to their final competition success. In the first group, the best four jumpers were included. Jumpers lower than 12th place were included in the second (worse) group. The data for the variables Length of jump (m), Time of flying (s), In-run velocity (km/h), Take-off velocity (km/h), and Out-run velocity (km/h) were taken from the official results of the competition office. The kinematic variables of ski jumping technique movement, Aerodynamic index of flying (m) and Height of the flying curve (m) were measured by means of a 2-D video analysis. The recording was carried out with video cameras with a frequency of 50 frames per second. The first camera recorded the flying between 10 m and 25 m, the second camera recorded the flying between 100 m and 120 m (see Picture 1). Digitalisation of the frames was carried out manually.



Legend: AIx – Aerodynamic index of flying (m); Δy – vertical height of flying (m)

Picture 1: Measurement procedure for taking data for the variables Height of flying and Aerodynamic index (left - position at 110 m, right - position at 17 m)

The wind conditions were measured at five different areas along the landing area of the jumping hill. Measuring instruments were positioned at 20 m, 70 m, 110 m, 160 m and 195 m. Data from each of the wind measuring points were registered four times per second for the whole flight phase of the jump and all measurement data from this period were then calculated together to produce a "Tangential Wind Speed" value for a specific point of flying. To establish the statistical significance of the differences between the groups, an independent t-test was used which determines whether two sample means differ reliably from each other. The criterion of statistical significance was accepted with a 5% two-sided alpha error (Sig t < 0.05).

RESULTS

The morphological variables Body height, Body weight and the variable Length of Ski did not statistically significant differentiate the better and worse groups of ski jumpers (see Table 1).

Table 1: Results of t test, morphological variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Body height (cm)	177.4	4.6	165.0	186.0	B	4	174.2	5.3	.20
					W	25	177.5	4.5	.31
Body weight (kg)	61.0	3.7	52.0	68.0	B	4	59.2	3.7	.42
					W	25	60.8	3.7	.46
Length of Ski (cm)	255.1	7.6	235.0	271.0	B	4	252.0	7.8	.54
					W	25	254.4	7.2	.59

Legend: n – number of jumpers in the selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of the groups (p<0.05)

The jumping distances were on average much greater in the Saturday competition than on the Friday when the jumpers completed the first and second competitive afternoon rounds in relatively bad wind conditions (see Table 2). The jumpers needed some practice to reach the optimal flying technique which then bolstered their competitive performances in terms of bigger distances. The differences between the defined quality groups of ski jumpers in the variables Length of jump and Time of flying were statistically significant (sig t <= 0.05). The maximal difference in the average length of the jumps between the two groups was 34.1 m during the first competition round on Friday.

Table 2: Results of t test, Length of jump variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Length of jump 1 (m)	190.7	19.3	160.0	223.5	B	4	214.8	3.6	**.00**
					W	26	180.7	15.0	**.00**
Length of jump 2 (m)	200.3	10.7	178.5	223.0	B	4	207.7	10.2	**.01**
					W	18	194.8	8.9	.07
Length of jump 3 (m)	205.7	14.2	170.0	227.0	B	4	222.7	8.4	**.00**
					W	17	197.7	11.5	**.00**
Length of jump 4 (m)	207.1	15.0	178.5	236.5	B	4	226.5	10.6	**.00**
					W	17	199.0	10.3	**.00**

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups (p<0.05)

Similar results as for the Length of jump variables were found for the Time of flying variables (see Table 3).

Table 3: Results of t test, Time of flying variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Time of flying 1 (sec.)	6.15	0.51	5.24	7.09	B	4	6.8	.14	**.00**
					W	26	5.8	.40	**.00**
Time of flying 2 (sec.)	6.38	0.35	5.76	7.29	B	4	6.7	.20	**.00**
					W	18	6.2	.25	**.00**
Time of flying 3 (sec.)	6.72	0.47	5.76	7.71	B	4	7.3	.33	**.00**
					W	17	6.4	.32	**.00**
Time of flying 4 (sec.)	6.83	0.52	5.90	7.91	B	4	7.5	.41	**.00**
					W	15	6.5	,33	**.01**

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

The in-run velocity was on average a little less than the velocity on the take-off table. The differences between the groups were statistically significant in three rounds as regards both velocities (see Table 4).

Table 4: Results of t test, In-run and Take-off velocity variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
In-run velocity 1 (km/h)	105.5	0.86	104.1	106.6	B	4	105.3	.19	.82
					W	26	105.4	.72	.62
In-run velocity 2 (km/h)	106.1	0.49	105.3	107.1	B	4	105.5	.13	**.00**
					W	18	106.2	.39	**.00**
In-run velocity 3 (km/h)	104.0	0.78	102.4	105.3	B	4	103.0	.28	**.00**
					W	17	104.4	.46	**.00**
In-run velocity 4 (km/h)	104.1	1.01	102.6	105.6	B	4	102.7	.09	**.00**
					W	17	104.8	.38	**.00**
Take-off velocity 1 (km/h)	105.7	0.80	104.1	107.0	B	4	105.2	.15	.45
					W	26	105.5	.83	.08
Take-off velocity 2 (km/h)	106.2	0.55	104.6	107.2	B	4	105.5	.61	**.00**
					W	18	106.3	.47	**.06**
Take-off velocity 3 (km/h)	104.0	0.91	102.2	105.6	B	4	103.0	.21	**.00**
					W	17	104.6	.69	**.00**
Take-off velocity 4 (km/h)	104.0	1.21	101.9	105.7	B	4	102.5	.21	**.00**
					W	17	104.9	.65	**.00**

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

The outrun velocity was approximately 6 to 10% greater than the in-run velocity mentioned before (see Table 5). In the Friday competition the out-run velocity was much higher than in the

Sunday competition. On Friday afternoon the wind conditions were not as good as during the Sunday competition in the morning.

Table 5: Results of t test, Out-run velocity variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Out-run velocity 1 (km/h)	119.6	2.95	114.0	126.0	B	4	117.2	1.79	**.07**
					W	26	119.9	2.74	**.04**
Out-run velocity 2 (km/h)	119.5	3.05	113.9	126.2	B	4	119.1	2.21	.65
					W	18	119.9	3.17	.58
Out-run velocity 3 (km/h)	109.8	2.08	101.0	119.1	B	4	110.3	3.59	,86
					W	17	107,9	2,76	.73
Out-run velocity 4 (km/h)	112.9	3.84	102.7	120.0	B	4	110.5	4.13	**.02**
					W	17	114.7	2.80	.12

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

The variable which indicates the flying height attained was generally the minimal value at the 17 m point after the take-off bridge for all groups of ski jumpers (see Table 3). The better group of ski jumpers had on average the highest values in all rounds. The differences between the better group and the worse group were statistically significant in the first and fourth rounds. One surprise was the flying height at 110 m after the take-off bridge. Only in the first round was there a statistically significant difference between the better and worse groups (sig t = 0.05).

Table 6: Results of t test, Height of flying at 17 m variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Height of flying at 17m 1 (m)	4.30	0.22	3.90	4.70	B	4	4.60	.13	**.00**
					W	9	4.30	.14	**.01**
Height of flying at 17m 2 (m)	4.00	0.19	3.60	4.60	B	3	4.06	.14	.49
					W	18	3.99	.14	.53
Height of flying at 17m 3 (m)	4.10	0.18	3.90	4.50	B	1	4.27	.	.90
					W	9	4.24	.18	.
Height of flying at 17m 4 (m)	4.00	0.24	3.50	4.60	B	4	4.24	.07	**.03**
					W	7	4.00	.17	**.01**

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

The successfulness of ski jumpers depended especially on the Aerodynamic flight position of the system body and ski. Bigger differences were expected in the variable Aerodynamic index of flying. After the take-off at the 17 m point there were significant differences between the groups in the second, third and fourth rounds (see Table 7). Statistically significant differences between the groups existed in all rounds in the middle of the flying at the 110 m the point (sig t = 0.01).

Table 7: Results of t test, Height of flying at 110 m variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Height of flying at 110 m 1(m)	5.20	1.41	2.70	7.90	B	4	6.78	.65	**.00**
					W	24	4.67	1.19	**.00**
Height of flying at 110m 2 (m)	6.30	1.20	3.90	9.00	B	4	6.75	.65	.37
					W	17	6.14	1.17	.22
Height of flying at 110m 3 (m)	5.00	1.22	2.3	7.00	B	3	5.62	1.33	.34
					W	16	5.00	.96	.50
Height of flying at 110m 4 (m)	5.20	1.35	2.40	7.90	B	4	5.87	1.38	.24
					W	14	5.06	1.14	.33

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. - Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

During large sections of the competition, the wind speed did not statistically significant differentiate the better and worse groups. An important difference was detected in the first and second rounds at the 20 m point (sig t = 0.00). In the first round, the better group had worse wind conditions, while in the second round the worse group had better wind conditions (see Table 8).

Table 8: Results of t test, Aerodynamics index at 17 m and Aerodynamics index at 110 m variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Aerodynamics index at 17 m 1 (m)	1.77	0.16	1.43	2.07	B	4	1.65	.14	.33
					W	9	1.75	.18	.29
Aerodynamics index at 17 m 2 (m)	1.77	0.18	1.41	2.00	B	3	1.46	.04	**.00**
					W	18	1.79	.17	**.00**
Aerodynamics index at 17 m 3 (m)	1.72	0.16	1.46	2.08	B	1	1.46		
					W	10	1.76	.16	**.05**
Aerodynamics index at 17 m 4 (m)	1.57	0.26	0.94	1.92	B	4	1.37	.28	**.04**
					W	6	1.67	.09	.13
Aerodynamics index at 110 m 1 (m)	0.70	0.09	0.52	0.90	B	4	.59	.04	**.00**
					W	25	.73	.08	**.00**
Aerodynamics index at 110 m 2 (m)	0.70	0.09	0.52	0.92	B	4	.62	.09	**.01**
					W	17	.73	.07	.08
Aerodynamics index at 110 m 3 (m)	0.67	0.08	0.49	0.83	B	4	.55	.05	**.00**
					W	16	.72	.06	**.00**
Aerodynamics index at 110 m 4 (m)	0.65	0.07	0.52	0.81	B	4	.57	.05	**.00**
					W	14	.69	.06	**.01**

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

The wind conditions did not dramatically affect the performance of ski jumpers in the middle of flying (see Table 9). There were significant differences between both groups at the 110 m point in the second round (the better group had worse wind conditions) and the fourth round (the better group had better wind conditions).

Table 9: Results of t-test, Wind velocity at 20 m, Wind velocity at 70 m, Wind velocity at 110 m, Wind velocity at 160 m variables

	M	SD	MIN	MAX	GROUP	n	M	SD	Sig t
Wind velocity at 20 m 1 (m/s)	- 0.02	0.78	- 1.30	1.77	B	4	-1.02	.03	**.00**
					W	21	.24	.78	**.00**
Wind velocity at 20 m 2 (m/s)	- 0.19	0.57	- 1.38	0.80	B	4	-.02	.12	.10
					W	18	-.47	.51	**.00**
Wind velocity at 20 m 3 (m/s)	0.74	0.55	- 0.17	2.02	B	4	.57	.27	.35
					W	17	.88	.63	.15
Wind velocity at 20 m 4 (m/s)	1.09	0.63	- 0.02	2.45	B	4	1.00	.30	.46
					W	17	.84	.40	.40
Wind velocity at 70 m 1 (m/s)	- 0.38	0.67	- 1.75	0.94	B	4	-.54	.30	.56
					W	21	-.34	.65	.36
Wind velocity at 70 m 2 (m/s)	- 0.54	0.43	- 1.26	0.65	B	4	-.54	.83	.71
					W	18	-.64	.35	.83
Wind velocity at 70 m 3 (m/s)	0.95	0.60	- 0.31	2.06	B	4	.48	.37	.13
					W	17	1.02	.67	.06
Wind velocity at 70 m 4 (m/s)	0.85	0.81	- 0.78	3.05	B	4	.96	.61	.21
					W	17	.50	.65	.24
Wind velocity at 110 m 1 (m/s)	- 0.75	0.80	- 2.87	0.76	B	4	-.61	.26	.50
					W	21	-.92	.89	.20
Wind velocity at 110 m 2 (m/s)	- 0.61	0.38	- 1.31	0.53	B	4	-1.11	.16	**.00**
					W	18	-.48	.36	**.00**
Wind velocity at 110 m 3 (m/s)	1.05	0.42	0.05	1.79	B	4	1.31	.26	.20
					W	17	.98	.48	.09
Wind velocity at 110 m 4 (m/s)	1,44	0.82	- 0.68	3.37	B	4	1.74	.15	.13
					W	17	1.09	.80	**.01**
Wind velocity at 160 m 1 (m/s)	- 0.20	0.69	- 1.70	0.83	B	4	-.42	.31	.32
					W	21	-.06	.69	.13
Wind velocity at 160 m 2 (m/s)	- 0.51	0.53	- 1.94	0.45	B	4	-.71	.19	.87
					W	18	-.66	.52	.78
Wind velocity at 160 m 3 (m/s)	0.83	0.57	- 0.49	1.72	B	4	1.05	.53	.36
					W	17	.76	.57	.37
Wind velocity at 160 m 4 (m/s)	0.75	0.75	- 0.97	2.81	B	4	.51	.44	.72
					W	17	.67	.86	.60

Legend: n – number of jumpers in a selected group, M – arithmetic mean of the group; SD – standard deviation within the group; Sig t. – Significance of the t test, where bold text denotes statistically significant differences between the quality of groups ($p<0.05$)

DISCUSSION

The research results revealed some statistically significant differences in some variables which are crucial factors of a ski jumping performance. The worse group of ski jumpers had in all rounds a bigger in-run and take-off speed than the better group. This is incomparable with the results of previous research. Many research results in the past found a positive correlation between in-run speed and performance in ski jumping. But this study was produced in the different conditions of a ski jumping competition. The better group of ski jumpers had a smaller in-run track in the competition. Based on previous kinematic studies, the magnitude of the approach and release velocities observed during competition for reaching greater jump distances are of subordinate importance (Müller & Schwameder, 2003). For investigating performances the take-off and flight quality are more important than the in-run and take-off release velocity. The average height of flying at the 17 m point was different between the two groups of ski jumpers. In the first and the last rounds statistically significant differences were found. A jumper must, during the contact take-off phase, develop an adequate level of force impulse which will enable him to develop a suitable (optimal) vertical velocity of movement after the take-off bridge (Jošt, Kugovnik, Strojnik, & Colja, 1997). In the first part of flying the best ski jumpers were more successful in achieving the optimal flying height and reaching the optimal aerodynamic position. A combination of both factors is important for determining performances in ski jumping (Arndt, Brügemann, Virmavirta, & Komi, 1995; Jošt, Vaverka, Kugovnik, & Čoh, 1998; Jošt, Čoh, Pustovrh, & Ulaga, 1999). It is evident that the best ski jumpers during the contact take-off phase produced an optimal level of energy to reach the optimal vertical take-off release velocity and to reach the optimal aerodynamic flight position (Virmavirta & Komi, 1993a; Virmavirta & Komi, 1993b; Virmavirta & Komi, 1994). Jumpers need part of this energy to achieve the optimal aerodynamic position in the first part of the flying phase and another part to ensure a higher flying curve.

In central part of the flying phase the extent of flying differences between the average values of the better group and the worse group were not statistically significant at the 110 m point. The best ski jumpers with a smaller angle of flying had in all rounds a bigger flying curve height. The height amplitude of flying is a consequence of many different kinematic factors. In accordance with the theory of the technique of a ski jumper's movement in the flight phase, the jumper must, at each point in the flight, assume such a position that maximises their horizontal velocity along with as simultaneous minimisation of the vertical velocity of the movement of the common centre of gravity (Jošt, Vaverka, Kugovnik, & Čoh, 1998; Schmölzer & Müller, 2005; Virmavirta et al., 2005; Vaverka, 1987). The aerodynamic index in the central part of flying at 110 m was a statistically significant factor of differentiation between the ski jumper groups (sig t = 0.01). The better group of ski jumpers had a better aerodynamic position at the beginning and especially in the middle of the flying phase.

The differences in wind conditions were not statistically significant between the defined groups in general terms. In the first part of flying there were significant differences at the measuring point of 20 m after the take-off bridge, but only in the first (the better group had worse wind) and the second round (the better group had better wind). In the middle of flying at 110 m, the wind conditions were significantly different in the second (the better group had worst wind) and fourth rounds (the better group had better wind).

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

- The variability of the defined quality groups of ski jumpers in terms of jump length and time of flying was large and statistically significant (sig t = 0.00).

- The velocity of flying during the flight increased constantly. The average out-run velocity was about 6-10% bigger than the in-run velocity.
- The differences between the average values of in-run velocities were statistically significant in three rounds (second, third and fourth). The worse group had a bigger average in-run velocity. The same happened with the variables of take-off velocity.
- In the variables of out-run velocity only a few statistically differences were found in the first and the last, fourth rounds. The worse group of ski jumpers had bigger average values of their out-run velocities.
- At the 17 m and especially 110 m points after the edge of the take-off platform, the better group of ski jumpers had a bigger flying height, which means a smaller average angle of flying. But these differences were not statistically significant in all rounds. The biggest differences emerged in the first and the last competitive rounds.
- The better group of ski jumpers showed tendencies towards the best aerodynamic flight position at the beginning of flying and especially in the middle of flying. Statistically significant differences were found in the second, third and fourth rounds.
- The differences in wind conditions were not statistically significant between the defined groups in general terms. In the first part of flying, only in the first round was a significant difference in the measuring point of 20 m after the take-off bridge found. In the middle of flying at 110 m the wind conditions were an important difference in the second and fourth jumps.
- The differences in wind conditions were not statistically significant between the two groups in general terms. In the first part of flying, only in the first round was a significant difference in the measuring point of 20 m after the take-off bridge found. In the middle of flying at 110 m the wind conditions were an important difference in the second and fourth jumps.

REFERENCES

Arndt, A., Brügemann, G.P., Virmavirta, M., & Komi P. (1995). Techniques used by Olympic ski jumpers in the transition from take-off to early flight. *Journal of Applied Biomechanics, 11,* 224-237.

Denoth, J., & Gerber, H. (2008). *Auswertung der Videoaufnahmen vom Weltcupspringen in Engelberg.* Honggerberg: Institut fur Biomechanik. (http://www.fis-ski.com/)

Ettema, J.C., Braten, S., & Bobbert, F.M. (2005). Dynamics of the in-run in ski jumping: a simulation study. *Journal of Applied Biomechanics, 21,* 247-259.

Hiroshi, J., Shunsuke, S., Tadaharu, W., Hirotoshi, K., & Kazutoshi, K. (1995). Desirable gliding styles and techniques in ski jumping. *Journal of Applied Biomechanics, 11,* 460-474.

Janura, M., Vaverka, F., & Elfmark, M. (1995). A comparison between the kinematic characteristics of the transition phase of ski jumping on jumping hills with different critical points. In: *Proceedings of the 13th International Symposium on Biomechanics in Sports* (pp. 219-222). Thunder Bay: Lake head University.

Jin, H., Shmizu, S., Watanuki, T., Kubota, H., & Kobayashi, K. (1995). Desirable gliding styles and techniques in ski jumping. *Journal of Applied Biomechanics, 11,* 460–474.

Joo - Ho S., Young-Jin, M. & Young - Hoo, K. (2004). A comparative study of the take off and early flight phases in ski jumping. *International Journal of Applied Sport Sciences, 16*(2), 60–71.

Jošt, B. (1994). Differences in some kinematic flight parameters between the classical and the new so called “V” technique in ski jumping. *Kinesiology, 26*(1-2), 18-21.

Jošt, B., Vaverka, F., Kugovnik, O., & Čoh, M. (1998). Differences in selected kinematics flight parameters of the most and the least successful ski jumpers of the 1996 World cup competition in Innsbruck. *Biology of Sport, 15*(4), 245-251.

Jošt, B., Kugovnik, O., Strojnik, V., & Colja, I. (1997). Analysis of kinematic variables and their relation to the performance of ski jumpers at the World championship in ski flight at Planica in 1994. *Kinesiology, 29*(1), 35-44.

Jošt, B., Čoh, M., Pustovrh, J., & Ulaga, M. (1999). Analysis of the selected kinematic variables of the take-off in ski jumps in the finals of the World cup at Planica in 1999. *Kinesiologia Slovenica, 5*(1-2), 17-25.

Kaps, P., Schwameder, H., & Engstler, C. (1997). Inverse Dynamic Analysis of Take-Off in Ski-Jumping. In: Muller, E., Schwameder, H., Kornaxl, E., Raschner, C. (eds.). *Proceedings of the First International Congress on Skiing and Science,* St. Christoph a. Arlberg, Austria. January 7-13, 1996. (pp. 72-87). Cambridge: Cambridge University Press.

Komi, P.V., & Virmavirta, M. (1997). Ski-jumping take off performance: Determining factors and methodological advances. In: Müller, E., Schwameder, H., Kornexl, E., & Raschner, C. (eds.), *Science and Skiing (Proceedings of the First International Congress on Skiing and Science*, St. Christoph a. Arlberg, Austria, January 7-13, 1996). (pp. 3-26). Cambridge: Cambridge University Press.

Mahnke, R., & Hochmuth, G. (1990). Recent findings concerning aerodynamic effects in ski jumping. In: *Proceedings of the 8th International Symposium of the Society of Biomechanics in Sport* (pp. 99-105). Prague: Faculty of Physical Education and Sport.

Müller, E., & Schwameder, H. (2003). Biomechanical aspects of new techniques in alpine skiing and ski-jumping. *Journal of Sports Sciences, 21,* 679 – 692.

Müller, W., Platzer, D., & Schmölzer, B. (1996). Dynamics of human flight on skis: improvements in safety and fairness in ski jumping. *Journal of Biomechanics, 28*(8), 1061 – 1068.

Sasaki, T., Tsunoda, K., Uchida, E., Hoshino, H., & Ono, M. (1997). Joint Power Production in Take-Off Action during Ski-Jumping. In: Muller, E., Schwameder, H., Kornaxl, E., Raschner, C., (eds.). *Proceedings of the First International Congress on Skiing and Science,* St. Christoph a. Arlberg, Austria. January 7-13, 1996 (pp. 49-60). Cambridge: Cambridge University Press.

Sasaki, T., Tsunoda, K., & Hoshino, H. (2000). Analysis of aerodynamic force on ski jumpers during the initial flight phase using mathematical model. In: Science and Skiing II. Muller, E., et al. (eds.). *Proceedings of the First International Congress on Skiing and Science,* St. Christoph a. Arlberg, Austria. January 9-15, 2000. (pp. 115-128). Cambridge: Cambridge University Press.

Schmölzer, B., & Müller, W. (2002). The importance of being light: aerodynamic forces and weight in ski jumping. *Journal of Biomechanics 35,* 1059–1069.

Schmölzer, B., & Müller, W. (2005). Individual flight styles in ski jumping: results obtained during Olympic Games competitions. *Journal of Biomechanics, 38,* 1055–1065.

Seo, K., Murakami, M., & Yoshida, K. (2004). Optimal flight technique for V-style ski jumping. *Sports Engineering, 7,* 97–104.

Seo, K., Watanabe, I., & Murakami, M. (2004). Aerodynamic force data for a V-style ski jumping flight. *Sports Engineering, 7,* 31-39.

Tavernier, M., & Cosserat, P. (1993). Flight simulation in ski-jumping – Comparison of two styles of flight. In: *Proceedings of the 14th Congress of International Society of Biomechanics* (pp. 1328-1329). Paris: International Society of Biomechanics.

Vaverka, F. (1987). *Biomechanics in Ski-jumping.* AP Olomouc.

Vaverka, F., Janura, M., Elfmark, M., & Salinger, J. (1997). Inter-and intra-individual variability of the Ski jumpers take-off. In: Müller, E., Schwameder, H., Kornexl, E., & Raschner, C. (eds.), *Science and Skiing*

(Proceedings of the First International Congress on Skiing and Science, St. Christoph a. Arlberg, Austria, January 7-13, 1996). (pp. 61-71). Cambridge: Cambridge University Press.

Virmavirta, M., & Komi, P. V. (1989). The takeoff forces in ski jumping. *International Journal of Sport Biomechanics, 5,* 248-257.

Virmavirta, M., & Komi, P. V. (1993a). Measurement of take-off forces in ski jumping – part II. *Scandinavian Journal of Medicine & Science in Sports, 3,* 237-243.

Virmavirta, M., & Komi, P. V. (1993b). Measurement of take-off forces in ski jumping – part I. *Scandinavian Journal of Medicine & Science in Sports, 3,* 229-236.

Virmavirta, M., & Komi, P. V. (1994). Take-off analysis of a champion ski jumper. *Coaching and Sport Science Journal, 1,* 23-27.

Virmavirta, M., Kiveskas, J., & Komi, P.V. (2001). Take-off aerodynamics in ski jumping. *Journal of Biomechanics, 34*(4), 465–470.

Virmavirta, M., Isolehto, J., Komi, P.V., Bruggemann, G.P., Muller, E., & Schwameder, H. (2005). Characteristics of the early flight phase in the Olympic ski jumping competition. *Journal of Biomechanics, 38,* 2157–2163.

Watanabe, K., & Watanabe, I. (1993). Aerodynamics of ski jumping – Effect of “V-style” to distance. In: *Proceedings of the International Society of Biomechanics XIVth Congress* (pp. 1452-1453). Paris: International Society of Biomechanics.