# ANALYSIS OF CORRELATION BETWEEN SELECTED KINEMATIC VARIABLES OF THE TAKE-OFF AND THE LENGHT OF THE SKI-JUMP

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The objective of the study was to establish, by means of 2-D kinematic analysis, the correlation between 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). Analysis of correlation and single-factor analysis of variance were used. A smaller number of statistically significant correlations between the defined kinematic variables and the jump length was determined. The differences in the vertical velocity of the take-off on the edge of the take-off platform confirmed a tendency towards positive correlations 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

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

**METHODS:** In the present research, the performance of ski jumpers on 19th March 1999 was analysed (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). The ski jumpers were divided into 4 quality groups according to the jump length.
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 of 25 frames per second. The first pair of cameras recorded the last 10 m 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) was used. It was defined by 9 points denoting the joints, the extreme limit points of the limbs and the skis. 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, the first point (position - a) was 4m before the edge of the take-off platform, the second point (position - b) was on the edge of the take-off platform, and the third point (position - c) was 4m after leaving the edge of the take-off platform. It could be defined as the following set of kinematic parameters (Figure 1).

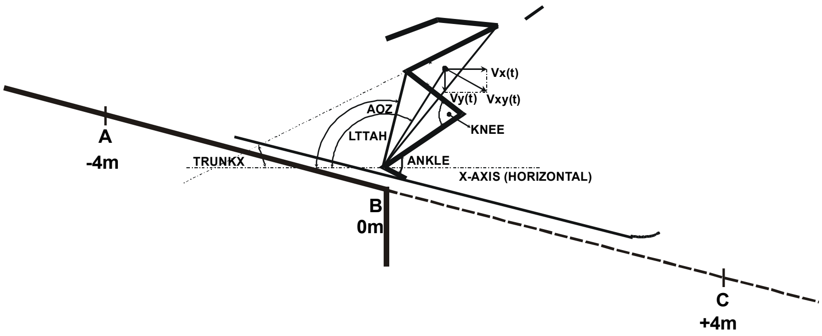


**Figure 1 - Graphical representation of the selected kinematic variables in the transition phase from the takeoff to the flight phase in ski jumping (the names of the variables are given in Table 1).**

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, a 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 AND DISCUSSION:** The results are presented in Table 1. On the basis of the results showed in Table 1, the following theoretical conclusions can be drawn:

- The differences in the vertical velocity (Vy) 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 most qualified ski jumpers had the smallest velocity in both jumps in the first jump, and 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 most qualified ski jumpers had a smaller average angle between the shin and the foot (ANKLE). 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 specific tendencies mentioned previously are a reflection of the dynamics of the specific take-off technique used by the ski jumpers: these dynamics were greater in the best group of ski jumpers. The studies by Virmavirta and Komi (1993 and 1994) showed a tendency towards a high level of the push-off force developed in a 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.
- The best group of ski jumpers showed tendencies towards a more pronounced transfer of the hips (AOZ) and the common body centre of gravity (LTTAH) 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 (KNEE) 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, an inverse conclusion could be made that a greater push-off dynamics in the take-off of the best ski jumpers.

**Table 1** **Statistical Analysis between the Length of the First (1) and Second (2) Ski-Jump (LJ) and the Selected Kinematic Parameters, Take Off and Transition Phase, WC Planica 1999, K180m. Legend: 1. First Jump, 2. Second Jump, (a) Position 4m before the Edge of the Take Off Table, (b) Position on the Edge of the Take Off Table, (c) Position 4m after Leaving the Edge of the Take-Off Table**

| | | First group | | Second group | | Third group | | Fourth group | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | R | Mean | SD | Mean | SD | Mean | SD | Mean | SD | F prob |
| LJ1 (m) | | 208.5 | 9.1 | 186.9 | 3.9 | 171.3 | 6.8 | 133.0 | 25.7 | |
| LJ2 (m) | | 207.1 | 5.4 | 188.0 | 7.2 | 174.2 | 4.9 | 150.7 | 6.5 | |
| 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 |
| 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* |
| 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* |
| 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 |
| 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 |

| | r | First group | | Second group | | Third group | | Fourth group | | F prob |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | |
| 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 |
| 8. 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 |

*means statistically significant differences between the quality groups of ski jumpers or statistically significant correlation, $p < 0.05$.

**CONCLUSION:** The research thus points, hypothetically at least, out the importance of the aerodynamic factor in the early phase of flight (transition phase). At each point of the ski-jumper's flight, there was a specific dynamic and moment structure that depends on the unique traits of the takeoff technique of each individual ski jumper. The goal of the take-off technique applied by the jumper in the support phase is therefore to attain optimal conditions to maximize the effect of aerodynamic forces and its moments (from the aspect of a successful jump) at the point of transition phase and in later flight.

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