3-D KINEMATICS AND KINETIC ANALYSIS OF G-SLALOM IN ELITE SKIERS AT VALBADIA WORLD CUP RACE IN 2002

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Introduction

In competitive skiing one of the most important factors influencing the performance is to keep a high level of average velocity while maintaining an optimal trajectory. In each turn around the gates, the skiers has to change his instantaneous trajectory an this produce a very high centripetal force acting on the centre of mass of the body (CG). A great amount of eccentric and concentric muscular activity is needed to counteract this kind of load (BERG 1995). Provided the limited amount of studies reporting movement kinematics during ski competition (POZZO 2001), we focused our work on collecting three-dimensional kinematics data on athletes during a world cup giant slalom race. The data reported in this work are related to the World Cup men’s slalom, which took place in December 2002 in Val Badia (Italy).

Methods

Four digital camcorders (Canon XM2- 50 Hz) were located along the slope and acquired the skier’s motion throughout three gates in the middle part of the race. A dedicated software for video analysis, allowing the operators to freely pan, tilt and zoom the TV cameras, was used in order to ensure the largest possible working volume (Baroni et al., 1998). The system calibration was performed by means of the DLT method. The 3-D localization of the control points (gate poles, nets supports, etc.) was obtained by means of a geodetic theodolite immediately before the start of the race. The biomechanical model of the skier consisted of 17 body landmarks in correspondence of joint centres, foot edges, head centre, as well as skis and poles extremities. The total body centre of mass (CG) was calculated according to Gubitz. The joints ranges of motion were calculated on average slope plane (xz horizontal plane), uphill 23°, and on the orthogonal direction to this plane, namely vertical direction (y). The instantaneous radius of the turn was calculated for the path of the CoG in the critical phase of turning the gates. This allows evaluating the centripetal acceleration which, in turn, is an indirect indicator of the centripetal force acting on the CoG of the skiers.

Fig. 1. Images sequences of the turns considered in the analysis
**Results**

The results are presented referring to four athletes who are representative for the first 10 skiers of the race. Following parameter are discussed:

- CG trajectories on the slope
- instantaneous radius of the turn and centripetal acceleration
- CG velocity on the slope
- CG vertical movement with respect to the slope plane and angles of body inclination
- Body angles

**CG trajectories on the slope**

Fig. 2 shows the trajectories of CG on the slope plane. The gates were located at a distance of 27-29 m from each other. From a macroscopic overview, trajectories seem to be very close to each other, especially during the gate clearance.

A deep analysis however, shows that some differences appear mostly during the changing of the edge. This means that the centripetal acceleration is influenced by both factors, the trajectory and the instantaneous velocity.

**Instantaneous radius of the turn and centripetal acceleration**

The characteristics of turning are summarised in tab.1. There different combination between and within the subjects. The maximum and minimum of trajectory radius were founded for Bode-Miller (24.9m) and for Simoncelli (11.3m). Some skies tend to maintain the minima or the maxima. Centripetal accelerations are calculated via instantaneous values of CG velocity and of corresponding trajectory radius. Calculated values are in the range of di16.6 m\(^2\)/s\(^2\) to 32.3 m\(^2\)/s\(^2\). If this values are multiplied by the subjects mass an estimation of the centrifugal force acting on the CG is obtained. The calculated force are well in agreement with those values collected by direct measurements via force plate mounted between boots and skies.

**CG velocity on the slope**

Fig. 3 shows the time history of the instantaneous CG velocity on the slope plane for two representative athletes. Obviously, CG deceleration and acceleration occurs during the gate
clearance (vertical dashed line on the graph). Different patterns with respect to the peak values, are easy to be recognised. This means, that different amounts of CG acceleration are influencing the mean velocity of CG. So, for same trajectories, a high mean CG velocity is the goal of the skiers’ technique.

In fig.4 mean peak values and the mean value of CG velocity are presented. Maximum mean velocity value of 20 m/s\(^{-1}\) was obtained by Bode-Miller, while peak values are similar for Bode-Miller, Mayer and Simoncelli. The most significant difference between the skiers is the minimum peak value. Simoncelli shows the greatest difference between maximum and minimum peak value, i.e. the highest acceleration and deceleration on CG. Blardone conversely, has the lowest peak values variations. According to these data, it is possible to introduce a overall criterion of mechanical effectiveness of the skiers’ technique. By constant mean CG velocity, small variations of CG acceleration represent a better distribution of loading forces on the CG.

On the other hand, if the peculiarities of the neuromuscular mechanisms of leg actions (e.g. stretch-shortening cycle) are taken in to account, a certain amount of deceleration-acceleration onto the CG is necessary to obtain the optimal response from the muscular system (power, force).
CG vertical movement with respect to the slope plane and angles of body inclination

The vertical CG motion with respect to the slope plane can be divided into two parts: the lowering-lifting of the legs by flexion-extension of the ankle-knee- and hip joints, and the body tilting on the frontal plane, i.e. the inverse pendulum-like inclination of the body with respect to centre of the curve during the turns.

In the fig. 5 the time history of the vertical CG motion (red line) and his corresponding vertical velocity (blue line) are demonstrated for two representative athletes. Same amount of vertical displacement are associated to a different pattern of vertical velocity, and vice versa. In the first turn, for example, the peak velocity value is 1.2 ms\(^{-1}\) for both skiers, while the amount of the vertical displacement is quite different.

![Fig. 5 time history of vertical CG motion (red line) and velocità (blue line) for two representative skiers](image)

The mean values and standard deviations of vertical CG lowering, lifting and total displacement are illustrated in fig. 6. For all the skiers, the mean value of total displacement is 50±30 cm and 1,3±0,5 ms\(^{-1}\) for the corresponding velocity. Simoncelli has the same values of total displacement as Mayer and Bode-Miller, whereas the values of the CG velocity are significant higher. .

![Fig. 6 Mean values and standard deviation of CG vertical displacement (white bar) and of the corresponding lowering (blue bar) and lifting velocity (yellow bar).](image)
Thus, it is relevant to obtain a separate evaluation of the two components of the vertical CG motion. As shown in Fig. 7, two parameters can define these two elements. One is the inclination angle of the legs with respect to vertical axes on to the frontal plane and the other is the virtual segment linking the ankle joint with the hip joint (ΔL-leg). The inclination angle was calculated separately, for the virtual leg segment and for the tibia anatomical segment.

Fig. 8 describes the time history of the vertical CG movement (black line) and of the legs-segment variations (left panel) for two skiers. Mayer shows a tendency to lower the CG with a great amount of flexion-extension of the legs, whereas this is not the case for Bode-Miller. This means, that for similar vertical CG displacement, the tilting mechanism is more pronounced in Bode Miller. In Fig. 8 (right panel) the mean values and standard deviations of the tilting angle for all athletes are shown. Simoncelli tends to assume a more pronounced inclination for all the considered angles.

**Body joint angles**

The variation of the virtual leg segment is due primarily by the knee joint variation. In Tab. 2 the peak values of maximal knee flexion and extension and the corresponding angular velocity are documented. Mean values are $150 \pm 16$ deg and $60 \pm 6$ deg for extension and flexion respectively, and $165 \pm 35$ deg $s^{-1}$ and $-140 \pm 30$ deg $s^{-1}$ for the corresponding angular velocities.

Simoncelli is the skier with the extreme joint minimum values, whereas Blardone shows the highest maximum values. The highest values of angular velocity for both the flexion and extension are presented in Simoncelli.
Based on this data a partial analysis of correlation between relevant parameters was carried out. Significant linear correlation were found between CG velocity on the plane and the knee joint angular maximum as well as the flexion and extension angular velocity of the same joint. Due to the very small number of subjects of the sample, this statistical results are to be taken very carefull.

**Summary and conclusions**

The main findings of this work support the possibility to obtain relevant data (radius of turns, centripetal acceleration, peak values of CG velocity) to be used for determine the actual loading conditions in competitive situation and for evaluate specific constrains which are to be matched by the biomechanical system. Nonetheless, it is possible to make some distinctions in the individual patterns of joint motion, which could be of great relevance for training purposes.

**REFERENCES**


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**Tab. 2** Peak values of knee flexion and extension(degrees) and of corresponding angular velocity(degrees/s) for all the skiers.