3-D KINEMATICS OF THE START IN THE DOWNHILL AT THE BORMIO WORLD CUP IN 1995
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INTRODUCTION
In downhill the results obtained by elite athletes are very close to each other, so that a few hundreds of second can make the difference towards winning a race. Therefore, every little improvement of the total time can make the final difference. In past studies (Rauch 1975, Mueller 1991, Cotelli 1994) the effects of different type of the leg movement before starting and the force exerted on the ground were analysed in an experimental situation. There is no relevant research on normal competition at high level.

In this study the starting phase was analysed with the following purpose: to evaluate the individual characteristics in the kinematics of the movement sequence, to verify the relationship between these parameters and the time performance, and to classify individual and group specific technique.

METHODS
For the purpose of 3-D kinematics, two stationary camcorders (50Hz) were located 30 m from the starting line on both sides of the track at 85° to each other (fig.1). The space volume of the starting gate and the 8m in front of this was calibrated with a rigid frame (1x2x10m) in order to apply DLT algorythms (Aziz-Karara 1971). The slope of the ground was 44%.

Another camcorder was placed perpendicular to the travel line in order to film the first 25 m subsequent to the start and to obtain time and velocity of partial distance every 5m (Chow 1993). To obtain coordinates of motion the video sequences were digitised via video converter (Screen machine Mod. 5011) connected to a 486 PC. 17 body landmarks were defined (joint’s centre, foot edges and head centre), 2 points were used for the poles and 2 points for each ski. Centre of gravity of the body (CoG) was calculated with the algorythm of Gubitz (1978). Raw data were smoothed with 3th order cubic spline functions.

Numerical differentiation routine allowed the calculation of the first derivative of linear and angular parameters. Maximal error was 30 mm for linear distance, 0,70 ms⁻¹ for linear velocity. Standard statistics procedure were applied to obtain mean values and standard deviation. Furthermore, functional relationships between parameters were investigated by regression analysis. 13 athletes of the 20 best world ranked in 1995 were taken into account for the study. Duration of movement phases, distances between CoG and body markers and starting gate, velocity of CoG and body segments, 3-D body angles, 2-D angles (poles and trunk in sagittal plane, legs in the frontal plane) and angular velocity were defined. Three critical positions were identified (fig.2): the maximal backwards location of the feet (MIN-F), the moment of touching the gate (START) and the take off of the poles (T-OFF).

Subjects
The present analysis was performed on the following 13 athletes participating to the race. In the brackets is reported the starting number.

<table>
<thead>
<tr>
<th>(7) Alphand, Luc</th>
<th>(18) Runngaldier, Peter</th>
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<tr>
<td>(8) Ortlieb, Patrick</td>
<td>(22) Krauss, Stefan</td>
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<tr>
<td>(9) Mader, Guenther</td>
<td>(23) Assinger, Roland</td>
</tr>
<tr>
<td>(11) Vitalini, Pietro</td>
<td>(29) Mahrer, Daniel</td>
</tr>
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<td>(12) Kjus, Lasse</td>
<td>(31) Knaus, Hans</td>
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<td>(14) Skaardal, Atle</td>
<td>(2) Trinkl, Hannes</td>
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<td>(16) Giradelli, Marc</td>
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RESULTS
Trajectory
Fig 3 shows the average trajectories of CoG, the ankles, the hips and the shoulders for all the athletes. The highest position of the CoG is reached before the contact with the gate and in this phase this curve is different from that of the hip. The ankles show a quite linear trajectory in the positive part of the X axis. Shoulders reach their highest position at the contact with the gate, followed by an inverse curvature with respect to the hips.

The X and Y distances of the CoG with respect to the origin of the coordinates system were considered according to the critical positions mentioned above. At MIN-F and at START the X coordinate mean values are $-0.07 \pm 0.07$ m and $0.26 \pm 0.09$ m respectively. Mahrer shows the minimum value with $0.13$ m while Assinger the maximum one with $0.41$ m. The maximal Y coordinate mean values is $0.98 \pm 0.08$ m Fig. 4 shows the two extreme trajectories of CoG, where the critical values were found in Assinger (1.14 m) and in Alphand (0.81 m). This parameter is also dependent by the body height The variation of the Y CoG coordinate corresponds to the elevation and represent the work done in the upwards direction. The mean values was $0.28 \pm 0.08$ m; Assinger showed the third value (0.35 m) and Alphand the lowest one (0.12 m).
**Velocity**

Typical time history of CM travel velocity (Vxcg) and resultant velocity (Vrcg) is shown in fig. 5. Time to reach Vxcg-max from start (ΔT1) and from poles take-off (ΔT2) is also defined. In the first part of the curve there are some discontinuities due to the movements with high acceleration content of the feet.

![Fig. 5. Time history of CoG velocity at the start](image)

The horizontal velocity of CM (Vxcg) revealed following mean values 1.54±0.25 ms⁻¹ in MIN-F, 2.27±0.37 ms⁻¹ in START and 5.52±0.16 ms⁻¹ as peak value after T-OFF.

For the vertical movement three typical values of CM velocity (Vycg) were found according to the sequence: bending-upwards jump-falling: -0.62±0.20 ms⁻¹, 1.00±0.31 ms⁻¹ and −0.88±0.26 ms⁻¹. In contrast to the horizontal velocity there is more variability for the vertical velocity during the upwards phase. Vitalini reaches a maximum of 1.69 ms⁻¹ while Alfand the minimum of 0.41 ms⁻¹

**Time structure**

Time to reach Vxcg peak value lasted 0.65±0.04s after START (ΔT1) and 0.34±0.15s after poles T-OFF (ΔT2). The difference between these two variables gives the duration of poles push-off phase (ΔT3) which was 0.31s±0.05s. In this case the maximum was found in Assinger (0.42 s) and the minimum in Mader (0.20 s). Another interesting time variable is represented by the duration elapsed from START to the maximal velocity of the feet, which must “run ahead” of CoG to support the falling into the ground. The mean value was 0.31s±0.10s which corresponds to the value of the pole push-off phase and is shorter then the time needed to reach peak Vxcg value after START.

**Body Position**

The horizontal distance (projection) of the shoulders and feet were considered at the critical positions and are reported in Tab. 1. The maximum difference between right and left ankle was 0.24m (Runggaldier) while the greatest leaning backwards was -0.96m (Ortlieb)

Tab.1: Mean values standard deviation of X coordinate of ankle and shoulders at critical positions. Negative values indicate the rear position to the gate.

<table>
<thead>
<tr>
<th></th>
<th>XminAnk-ri [m]</th>
<th>XminAnk-le [m]</th>
<th>XShou-ri(Start) [m]</th>
<th>Xshou-le(Start) [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>-0.73</td>
<td>-0.77</td>
<td>0.65</td>
<td>0.64</td>
</tr>
<tr>
<td>SD</td>
<td>0.13</td>
<td>0.14</td>
<td>0.11</td>
<td>0.10</td>
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**Angles and angular velocity**

The three dimensional angle of knee, hip and elbow joints and the two dimensional angle of trunk and poles with respect to the horizontal line in the sagittal plane will be discussed.
Knee angle shows a minimum during the leg flexion just before the backwards leaning of the feet and the mean value is 132°±7°, with a maximum of 143° (Mader) and a minimum of 113° (Trinkel).

Hip angle shows a typical three phase structure :87°±9° before START, 157°±12° after START and 62°±10° during the legs recovering.

For elbow joint it was found a minimum of 66°±3° before START while at START the value was 80°±5°. Of course, the most significant variation occurred in the following push-off phase.

The inclination angle of the trunk was progressively decreasing from 32°±5° at MIN-F to 19°±8° at T-OFF and finally to 10°±5° as minimum. The poles showed following values: 62°±5° at MIN-F, 58°±6° at START and 41°±4° at T-OFF.

On the frontal plane, an angle was defined between the line connecting the ankle joint with the hip joint and the Z-axis, i.e. describing the abduction-adduction movements of the leg. One leg behaves as support and the other is mostly used as propulsion. The mean values are 53°±5° for the pushing leg and 87°±4° for the supporting leg.

The angular velocity of knee, hip and elbow joints were investigated. For the knee and hip joints three values were considered: \( \text{max1} \) during the first extension (backwards leaning of the feet), \( \text{min} \), during the following recovering phase under the CoG and, finally, \( \text{max2} \) during the push-off after START. For the elbow joint two values occurred at the flexion (\( \text{fle} \)) and extension (\( \text{ext} \)). Tab 2 gives an overview of the values.

<table>
<thead>
<tr>
<th>Knee</th>
<th>Hip</th>
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<tr>
<td>( \omega_{\text{rigth \ max1}} )</td>
<td>( \omega_{\text{left \ max1}} )</td>
</tr>
<tr>
<td>M</td>
<td>236</td>
</tr>
<tr>
<td>SD</td>
<td>59</td>
</tr>
<tr>
<td>Min</td>
<td>166</td>
</tr>
<tr>
<td>Max</td>
<td>402</td>
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<table>
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<th>Elbow</th>
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<tr>
<td>( \omega_{\text{rigth \ fle}} )</td>
<td>( \omega_{\text{left \ fle}} )</td>
</tr>
<tr>
<td>M</td>
<td>-236</td>
</tr>
<tr>
<td>SD</td>
<td>88</td>
</tr>
<tr>
<td>Min</td>
<td>-143</td>
</tr>
<tr>
<td>Max</td>
<td>-441</td>
</tr>
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</table>

**Partial velocity in the run up**

According to the methods, velocity values were calculated referring to the partial distances(5 m) in the 25 m subsequent the start. Fig. 6 gives an overview of the singular values taken at the corresponding markers (T2, T3, T4, T5). It is easy to note that those athletes who achieve the best score at the 30m have not necessarily equivalent best values in the early part of the 30m run up. Differences in the gliding properties of the materials, in the body mass and the possibility to perform efficient pushing movements seem to be the reason to account for.
Correlation analysis

The first issue to be respond is whether relations exist between the velocity achieved by the start on the gate and the velocity gained during the 30m run-up after the start. The $V_{xcg\ max}$ shows correlation with the: velocity of 1st partial distance $VT_2$ at 15m beyond the gate ($r=0.70$) but not with that of the subsequent partial distances. The correlation coefficients indeed decrease with the progressive values of the partial velocity.

It is also interesting to know which kind of relation exist between the $V_{xcg}$ and the other parameters of the whole movement analysed. The $V_{xcg}$ correlates with the vertical movement of CoG. Fig. 7 shows the relationship between the $V_{xcg}$ and the vertical coordinate of CoG ($r=-0.61$) as well the lowering velocity ($r=-0.52$), so those athletes who jumped less vertically and moved their CoG slowly down to
the ground obtained as well the highest values of Vxcg. There is also a significant correlation with the distance of the feet in the backwards leaning during the preparation phase (r=0.68). Another relationship exist between Vxcg and some angular parameters (fig.8): with the leaning angle of the trunk with respect to the ground (r=-0.55) and with the angular velocity of elbow flexion (r=-0.77).

Thus, keeping the trunk flat to the ground and slowly flexion of the elbow joints induce an increase in the maximal Vxcg.

On the other hand, time to reach Vxcg maximum (ΔT1) contributes to a total performance time. There is a significant correlation (r=0.64) between ΔT1 and the poles push-off time (ΔT2). This last parameter is correlated with inclination of the trunk (r=0.68) and of the poles (r=0.60) at the MIN-F.

Discussion

Although the number of subjects is not optimal to ensure statistical significance, the results identify parameters and mean values which describe objectively this movement pattern. The negative correlation of Vxcg with time to push-off may relate to the capacity to create great force impulse in short time. The other correlations of Vxcg suggest that the CoG should move slowly downwards (to the ground) and reduces the maximal height; that the trunk should keep as parallel as possible to the ground and that the elbow joint should be flexed slowly.

On the other hand, to reach peak Vxcg early the push-off time should be short and to achieve this, at MIN-F, the body and the poles should have a small inclination angle with respect to the ground. Elite athletes seem to be able to create great force impulse with the upper limbs supporting on the poles and to execute this action in a short time, whereas body and poles inclination play an important role. The question arise if this finding is also true for other slopes of the ground

Acknowledgement

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