3D AND 2D KINEMATIC ANALYSIS OF CLASSICAL TECHNIQUE IN ELITE CROSS COUNTRY SKIERS DURING A WORLD CUP RACE (S.CATERINA 1995) AND WORLD CHAMPIONSHIPS (RAMSAU 1999)
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INTRODUCTION
In the last 25 years new equipment and new skating technique has determined great changes in cross country skiing. (G.M. Street 1992)
Furthermore, due to the changes in the races’ tracks, in the equipment and in the skiers’ physiological improvement, the Classical Technique should receive much more attention in biomechanical investigations.
In previous studies (Komi 1987, Bilodeau 1995) concerning the Diagonal Stride technique and Double Pole (Smith 1996) and Duoble Pole with Kick, it has been shown that faster skiers had longer cycle lengths than slower ones, whereas cycle rate didn’t differ significantly.
The analysis of other kinematic and dynamic parameters for the world best athletes is a further issue to be addressed to better understand the factors influencing performance. Also, there is a need to analyze the motion of elite skiers during their maximal performance like a World Cup Race.
The first purpose of this study was to set up a motion recording and analysis system for 3D and 2D kinematics in elite cross country skiers during a high level race.

METHODS
The skiers analyzed in this study were engaged in a 10 km World Cup Race in S.Caterina Valfurva (1995) and, the first time, they were videotaped by two fixed cameras, Canon EX2Hi, operating at 50 Hz and located at 90° to each other to allow optimal conditions for 3-D coordinates reconstruction, in a section of 8 m, a 9° uphill, where they used the Diagonal Stride Technique.
Later on they were videotaped in a 10 km race of the World Championships in Ramsau (1999), in a flat section of 20 m, by a panning camera, SONY DCR-TRV900E, located 30 m perpendicular to the track, where the preferred technique was the Double Pole with Kick. All skiers were not limited by artificial markers and no preparation was required of the athletes. All measurements were collected in a manner that did not interfere with the competition.
In each race, 11 male skiers, Table 1, from different countries, were considered for this study. Nine of these were participants in both competitions. All the subjects concluded the first race with a distance 6,3 % (first race) or 6,9 % (second race) longer than the time of the better skier included in the group (the winner in the first race, that in second place in the other race).
Table 1 – Skiers analyzed and races results (10 km TC)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Skier</th>
<th>Race Time (s)</th>
<th>DT %</th>
<th>Rank</th>
<th>Skier</th>
<th>Race Time (s)</th>
<th>DT %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dahlie B.</td>
<td>1536.6</td>
<td></td>
<td>2</td>
<td>Stadobler A.</td>
<td>1474.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Smirnov V.</td>
<td>1558.0</td>
<td>1.44%</td>
<td>3</td>
<td>Hjelmeset O.B.</td>
<td>1477.1</td>
<td>0.16%</td>
</tr>
<tr>
<td>4</td>
<td>Isometsa J.</td>
<td>1575.5</td>
<td>2.53%</td>
<td>4</td>
<td>Prokurorov A.</td>
<td>1478.8</td>
<td>0.28%</td>
</tr>
<tr>
<td>5</td>
<td>Alsgaard T.</td>
<td>1581.1</td>
<td>2.88%</td>
<td>5</td>
<td>Dahlie B.</td>
<td>1485.6</td>
<td>0.74%</td>
</tr>
<tr>
<td>6</td>
<td>Siversten S.</td>
<td>1585.9</td>
<td>3.17%</td>
<td>10</td>
<td>Valbusa F.</td>
<td>1505.6</td>
<td>2.10%</td>
</tr>
<tr>
<td>10</td>
<td>Fauner S.</td>
<td>1602.5</td>
<td>4.15%</td>
<td>11</td>
<td>Isometsa J.</td>
<td>1509.2</td>
<td>2.34%</td>
</tr>
<tr>
<td>11</td>
<td>Kirvesniemi H.</td>
<td>1602.5</td>
<td>4.17%</td>
<td>13</td>
<td>Kirvesniemi H.</td>
<td>1516.2</td>
<td>2.81%</td>
</tr>
<tr>
<td>12</td>
<td>Jonsson N.</td>
<td>1603.6</td>
<td>4.24%</td>
<td>14</td>
<td>Alsgaard T.</td>
<td>1516.7</td>
<td>2.85%</td>
</tr>
<tr>
<td>18</td>
<td>Prokurorov A.</td>
<td>1615.9</td>
<td>4.97%</td>
<td>19</td>
<td>Mai F.</td>
<td>1527.9</td>
<td>3.61%</td>
</tr>
<tr>
<td>29</td>
<td>Stadobler A.</td>
<td>1635.8</td>
<td>6.13%</td>
<td>25</td>
<td>Fauner S.</td>
<td>1550.2</td>
<td>5.12%</td>
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<tr>
<td>32</td>
<td>Valbusa F.</td>
<td>1638.6</td>
<td>6.29%</td>
<td>31</td>
<td>Jonsson N.</td>
<td>1576.0</td>
<td>6.87%</td>
</tr>
</tbody>
</table>

To calibrate the space volume a rigid frame (8x2x1 m) was used. The video images were digitized by means of a 12 bit A/D converter (Screen Machine mod. 5011 D) and then elaborated in a PC by appropriate software. For each camera view, 25 data points were digitized. The 25 points included 23 points for the athlete and 2 additional control points.

Coordinates of centre of gravity (CoG) were calculated with the algorithm of Gubitz (1978).

3-D coordinates were obtained by DLT algorithm (Aziz, Karara 1971). The maximal error was lower than 2% for coordinates and about 5% for derivated parameters.

The picture, Fig. 2, show an example of 4 frames recorded by each camera during the World Cup Race in S.Caterina in 1995. The Camera Frequency was 50 Hz and the frames was synchronized with maximal error of 0.01 s. (one hundred of sec). The skier

Fig. 2 - Diagonal Stride: Recorded Images

VideoCamera frequency = 50 Hz

WC S.Caterina Valfurva 1995 - 10 km TC
was the winner of the competition. The uphill section, where he was videotaped, was located at the 6.3 km mark.
The snow temperature was -1.0 °C and air temperature was +2.5 °C, under cloudy conditions.
All skiers, like the one consider in the picture, used the Diagonal Stride Technique.
In the PC-elaborated picture, Fig. 3, you can see four subsequent motion positions recorded for this study in the 10 km Classical Tecnique race in Ramsau 1999.
The flat section, where he was videotaped, was located at the 3 km mark, after the longer uphill of the track and all skiers analyzed, like these, used the Doble Pole Technique. The snow temperature was -1.0 °C and the air temperature was 0°C, under cloudy and windy conditions.

RESULTS
For each subjetc, and for each techniques, kinematic parameters were selected: distance, horizontal velocity, vertical displacement and time phase of CoG and of hands, feet and poles during contact and flight phase respectively, elbow joint angle.

Diagonal Stride technique

Fig. 4 shows a typical graph of stick diagram and the time history of
Horizontal Velocity of Centre of Gravity (VxCoG) that was found for all subjects during Diagonal Stride. The graph shows the Average Value of CoG's Velocity of 11 subjects with Standard Deviation.

The greater (green) dashed line refers to the subjects analyzed by the upper stick diagram. The latest four positions of the stick diagram are synchronized with the minimun and maximal values of the characteristic oscillating pattern of VxCoG.

In the lower section the graph shows the contact and flight phases of poles and feet. The contact time is represented by a continuos line. The flight time is represented by absence of line.

The inner lines (orange) represents the time phases of left foot and right foot. The outer lines (blue) represents the time phases of the left and right poles.

In a typical step, during the second half part of contact time of the left foot and the right pole, for example, when they are pushing, the VxCoG is increasing. After the pushing, the VxCoG is decreasing almost the same value and same time, like it will be shown later.

The graph in Fig. 5 shows the Vertical Displacement of CoG for the same previous subject during Diagonal Stride. Even for this parameter it was found a characteristic oscillating pattern, where minimun and maximal values are slightly retarded with minimun and maximal values of Velocity of CoG.

Fig. 6 shows the patterns of Elbow Joint angles, left and right. Even for each of these lines it was found a typical oscillation, where phase differecence is one cycle.

The minimun elbow joint angle's value is reached after the pole contact; the maximun at the end of the pole contact.

**Double Pole with Kick technique**

Fig. 7 shows a typical graph of stick diagram and the time history of Horizontal Velocity of Centre of Gravity (VxCoG). The characteristic pattern of VxcoG was found for all subjects; the graph shows the Average Value of CoG's Velocity of 11 subjects with Standard Deviation.

The greater (violet) dashed line refers to the subjects analyzed by the upper stick diagram. You can note a greater...
variability of the VxCoG patterns compared with those of the Diagonal Stride technique. The lower section shows the contact (continuous line) and flight (absence of line) phases of poles and feet. The analyzed Double Pole with Kick cycle begins at pole take off, continues at pole plant, when begins the most important pushing phase which causes the Velocity to increase. The next phase is a glide phase in which the arms and poles swing forward in recovery and preparation for the new pushing.

In a typical cycle the most important VxCoG increase is due to the poles pushing, whereas the feet pushing were shorter, due to the velocity, and not significant.

The Fig. 8 shows the Vertical Displacement of CoG for the same previous subject. Even for this parameter it was found a characteristic pattern, where minimum value was reached at the end of poles pushing.

The graph of Fig. 9 shows a typical pattern of Elbow Joint angles, left and right. At the poles contact the Elbow angle reached a local maximal value and afterwards the elbow are flexed less than 20°. This was immediately followed by 70° to 80° of extension of Elbow joint.

**SUMMARY AND CONCLUSION**

Video analysis based on 3D and 2D camera algorithm was used to characterize the motion patterns of top level skiers engaged in a 10 km Classical Technique of World Cup Race in S.Caterina Valfurva (1995) and World Championships in Ramsau (1999). Eleven skiers from different countries, included the 5 best in the ranking, in each races were analyzed. Nine of these were participants in both competitions. In this study kinematics parameters were obtained for the Diagonale Stride, in a section of 8 m with 9° uphill slope, and for Double Pole with Kick in a 20 m flat section.

In the motion analysis we considered the Horizontal Velocity of CoG like a guide parameter. In the first technique we found a regular oscillation, in the second a pulse oscillation. Although the increasing and decreasing percentage of VxCoG had different mean values (5% in the first, 10% in the second), we found the same absolute value in each technique.

The cycles time, however, were very different from each other: 0.5 ± s and 1.3 ± s respectively.

In the Diagonal Stride the VxCoG increasing time was equal to decreasing time.
In the Diagonal Pole Technique the VxCoG increasing time was half of the decreasing time.
The mean values of cycles length of CoG, due to the poles and feet pushing, were 3.2 ± 0.2 m meters in Diagonal Stride and 7.9 ± 1.1 m in Double Pole with Kick.
In the first technique the length covered during feet flight phase was less than 60% (58%) of the full cycle length. In the second, the length covered during poles flight phase was about 70% (68%) of the full cycle length.
The vertical motion of CoG showed very different patterns in the two techniques.
The mean values of total displacement (involving negative and positive displacement) were about 8 cm in the Diagonal Stride and 19 cm in the other technique.

The graphs of the Fig. 10 show a wide variability between the analyzed subjects.
The Elbow Joint angles were measured at the poles contact (touch-down). We found respectively a mean value of 88° ± in Diagonal Stride and 111° ± in Double Pole with Kick. Afterwards, the Elbow flexed to minimum mean values respectively of 83° and 91°.
In conclusion, top level skiers during their maximal performance in Classical Technique were analyzed.

In according with previous study (Marino 1977, Komi 1987, Bilodeau 1995, Smith 1996), we found that the faster skiers have longer cycle lengths. Indeed the correlation coefficients are r=0.45 (Canclini 1998) for Diagonal Stride and r=0.53 for Double Pole with Kick.
The elbow joint angle shows no correlation. However, the measurement of other parameters could help to better understanding the general pattern of technique and to discriminate individual style of elite skiers.

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