Introduction
In competitive cross-country skiing (CCS) the athletes’ performances are frequently close to each other and are influenced by the complexity of the environmental conditions (air and surface temperatures, track techniques, gradients, etc.). This implies that the experimental quantitive description of the CCS technique as a way to improvise athletes’ performances is a notable challenge. Nevertheless, during the past 15 years the now skiing technique has reached a great popularity and has received attention by biomechanical research. This has lead to several studies describing the CCS skiing technique, but the kinematic analysis of world best athletes during high-level competitions deserves further attention in order to better understand factors influencing the performance. Reliable kinematics analyses of different CCS techniques aiming, for example, to the quantification of the related mechanical work, requires repeated 3D motion capture sessions in challenging environmental conditions, counting on a long working volume, because of the extended stride length (Müller, 2000). This implies not negligible methodological issues especially when aiming to the evaluation of the kinematics associated to the two main ski skating techniques, V1 and V2, on live CC skiers during high-level race.

Results 1
For each subject, that performed V2 skiing on the both recording sections, kinematics parameters were selected: cycle time (CT) and cycle length (CL), CG displacement (both horizontal and vertical), average velocity (Vaave), CG horizontal and vertical minimal velocity (Veamin), CG velocity vector angle (VAA) with respect to the skiing direction on the horizontal plane (Fig. 6).

The mean values of these parameters were calculated for flat sections (2) (uphill) cycle.

Fig. 6 shows a typical stick diagram on the horizontal plane as well as the contact and flight phases of poles and leg, the CG velocity vectors and velocity angle related to the V2 skiing on flat terrain.

Figs 7 and 8 shows a typical stick diagram, the CG vertical displacement and the contact and flight phases of poles and skis in V1 skating technique in correspondence of the uphills section. In fact only one subject (Pozzi) adopted the V1 technique.

Results 2: Time Structures and displacement
The mean values of V2 skiing cycle time (CT) was 0.71 ± 0.01 s on flat terrain (7 subjects) and 0.73 ± 0.01 s on uphills (6 subjects). However, in the first case the poles pushing time was about 30% of full cycle, in the second case about 15% of full cycle.

Fig. 6 and 7 show the individual values of cycle length (CL) on flat terrain and on uphills. Bar graphs shows the parts of cycle length covered during poles pushing (PL) and the poles flight (FL) phases. In flat terrain the CL average value was 3.96 ± 0.27 m, 26% of which corresponds to the poles pushing phases. In the uphills CL was 3.80 ± 0.27 m and in the case of 50% was covered during poles pushing.

The vertical displacement of CG shows a characteristic oscillating pattern in both case, flat and uphill. However the mean values of total displacement, involving negative and positive displacement) were 0.19 ± 0.02 m on flat terrain and 0.23 ± 0.03 m on uphills.

Results 3: CG velocity vector and push-off angle
Fig. 8 shows the characteristic patterns of the push-off angle (Fig. 9) which was introduced by Lindgren in 1999. In the first pushing phases this parameter was 90° on flat, and less than 90° on uphill. Fig. 11 and 12 show CG horizontal average velocity (Vave), and the velocity vector angle (VAA). The mean values of this parameters was 3.96 ± 0.27 m on flat and 3.80 ± 0.27 m on uphills. Further, the vector velocity angle VAA were calculated as the absolute angles between different anatomical landmarks; the displacements of the body's center of gravity (CG), and horizontal and vertical track (horizontal plane) and on the orthogonal direction to this plane (vertical displacement).

Materials and methods
The collection of data presented in this work were performed in 12.02.2000 during the World Cup freelstyle CC competition at World Cup in S.Caterina (I). Two couples of digital camcorders (SONY 50 Hz) were focused on two sections of the 7.5 km track (2 laps): an uphills (6°), 20 metres long section at the 2.3 km mark and a flat 40 metres long section at the 6.5 km mark (Fig. 1). Due to the technical requirement of a wide working space volume, dedicated software for video analysis, with free panning, tilting and zooming TV cameras was used (Baroni et al., 1999). This method was performed by means DLT method. The 3D-positions of the control points for centre calibration were measured by means of a geodesic theodolite and were marked out with 50 rigid poles.

The biomechanical model of the skier consisted of 17 body landmarks, 4 additional points were used for the poles and for the skin identification. Joint angles were calculated as the absolute angles between different anatomical landmarks; the displacements of the body’s centre of gravity (CG) and horizontal and vertical track (horizontal plane) and on the orthogonal direction to this plane (vertical displacement).

Seven skiers (Table 1), from different countries, including the 3 best in the ranking, were considered in this work. In the Fig. 2 and 3 are presented the motion sequences based on the images recorded by camera and elaborated via PC.

Summary and conclusions
Seven elite skiers engaged in World Cup race, including the 3 best in the ranking list, were considered in this work. 3D Video analysis was performed on flat section and on uphills section (Fig. 2).

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