Video-Based Estimation of Head Impact Velocities in Ski Competitions accidents: A Comparison with Helmet Standard impact speed requirements

Martina Ferrara, Nicolò Dall'Acqua, Alberto Foltran, Giuseppe Zullo, Nicola Petrone

I. INTRODUCTION

Ski disciplines such as alpine skiing (e.g., downhill and super-G) and freestyle skiing are high-risk activities for traumatic brain injury. Improving the understanding of injury mechanisms and advancing the design of effective protective equipment are therefore critical priorities.

External forces acting on athletes, such as ground reaction forces, inertial forces and aerodynamic drag, define the sport-specific physical demands. Accurate characterization of these forces is essential for developing targeted conditioning programs that prepare athletes for sport-specific loads and contribute to injury risk reduction [1].

Based on data from the International Ski and Snowboard Federation (FIS) Injury Surveillance System (ISS) at the alpine World Cup (WC) level, head injuries represent 8%–10% of all injuries that require medical attention [2].

This is the reason why this project focuses on the analysis of speed impacts of the head of professional athletes during ski competitions (in particular World Cup) through video footages.

II. METHODS

Accurate video analysis in sports is essential, particularly for injury prevention. Although many software solutions exist, minimizing estimation errors often requires tailored methodological approaches.

Most videos from FIS World Cup (WC) and World Ski Championships (WSC) are provided by Infront Media Platform at 25 fps. However, this approach is inherently limited, as it depends on the clear visibility of reference objects and the athlete's head segment. In addition, such footage typically includes camera motion (panning) and zooming, since the athlete is kept centered in the frame, making motion compensation a necessary preprocessing step. To address this, we implemented a MATLAB-based motion compensation method using a feature-based image registration pipeline, where each frame is aligned to a fixed reference frame (master). A manually defined Region of Interest (ROI) restricts the analysis to a stable area, improving robustness. Keypoints are detected using SURF (Speeded-Up Robust Features) and feature descriptors are computed and matched to establish correspondences between frames. The transformation is then estimated using a 2D similarity model, accounting for translation (camera panning), rotation and uniform scaling (zoom), enabling effective compensation of camera-induced motion and improving analysis accuracy. Robustness is ensured through RANSAC-based outlier rejection, so that only inlier correspondences are retained for the final transformation estimation. This process is repeated across multiple frames, with each frame independently aligned to the same reference (master) frame, resulting in a sequence of motion-compensated images. A limitation of this approach is the use of a similarity transformation, which assumes negligible perspective distortion and that the scene is approximately planar or that camera motion is limited.

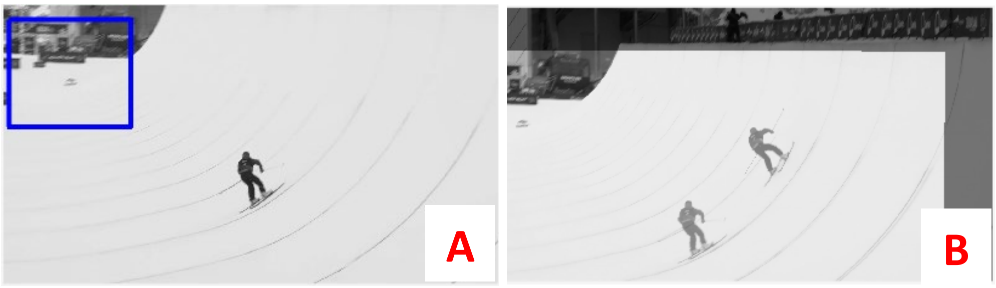


Figure 1A: Original frame with the selected ROI as reference (blue rectangle). Figure 1B: On the left the original frame, on the upper right the final frame with camera panning and zooming correction.

M. Ferrara is a PhD student in Mechanical Engineering in the Department of Industrial Engineering at Padova University in Italy (martina.ferrara.1@phd.unipd.it). N. Dall'Acqua is a Product Manager Protection and Packs at POC in Stockholm, Sweden. A. Foltran is Research fellow in Mechanical Engineering in the Department of Industrial Engineering at Padova University. G. Zullo is a Post Doc in Mechanical Engineering in the Department of Industrial Engineering at Padova University. N. Petrone is a Professor in Machine Design in the Department of Industrial Engineering at Padova University.

The following step builds upon a method formerly developed [3] which was based on the usage of Kinovea software. In fact, after camera correction, a pixel-to-millimetre scale needs to be defined using a fully visible object of known size (e.g., ski length, with ~±5% error).

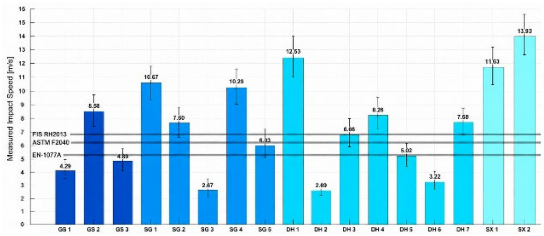
The subsequent step is head tracking, which relies on identifying the impact frame and tracking the motion of selected features: the impact area (e.g., the head) and a nearby fixed reference object (e.g., a pole, billboard, or track line). The displacement of these features is tracked over the 5–7 frames preceding the impact.

Figure 2A: Imposition of the reference scale (length of the ski). Figure2B: Tracking of the head and of a fixed object (pole).

The verification methodology currently adopted relies on GPS data acquired from protective devices (primarily airbags) worn by athletes and supplied by various manufacturers. These data enable a comparison between the athlete's steady-state skiing speed (measured by the airbag system) and the corresponding value estimated through our proposed method. Ad-hoc full-scale tests will also give further validation to the proposed method by the comparison with MoCap systems in some indoor simulated falls.

III. INITIAL FINDINGS

Focusing on the snow, camera and motion planes and on the component of impact velocity orthogonal to the ground, the previous analyses [3] showed that in 10 out of 17 cases (58.82%) the head impacts exceeded all three helmet standards (EN 1077A, ASTM F2040, and FIS RH2013). The average impact speed was 7.49 ± 2.38 m/s, while 11 out of 17 crashes exceeded the standards. The mean orthogonal impact velocity was 8.39 ± 2.06 m/s.



standard	speed impact required
FIS RH2013	6.8 m/s
ASTM F2040	6.2 m/s (flat) / 4.8 m/s (hemispherical/edge)
EN 1077A (Class A)	5.42 m/s

Figure 3: Values measured from the videos: from left to right, GS, SG, DH and SX are presented, following the color change. The horizontal lines instead represent the thresholds reported in the table on the right. The error bar is set at 12%.

IV. DISCUSSION

This study focuses highlights a possible gap between helmet certification tests and the real protective needs of athletes. This discrepancy may stem from the historical limitations of testing technology when current standards were developed. Helmet certifications are primarily based on linear drop tests using rigid steel anvils, whereas impacts in ski racing are typically oblique in nature. Furthermore, testing conditions such as steel or sandpaper surfaces do not realistically represent real-world scenarios, which are more likely to involve snow of different compactness or ice. Therefore, updating certification standards to better replicate realistic impact conditions would provide a more accurate assessment of helmet performance and better reflect actual injury mechanisms.

An interesting development for this study could be focusing also on head kinematics, energy absorption and injury outcomes, to better understand these high-risk situations.

V. REFERENCES

[1] Gilgien M et al., Frontiers in Physiology, 2018.
[2] Florenes TW et al., Br J Sports Med, 2009.
[3] Dall'Acqua N et al., International Sports Engineering Association – Engineering of Sport. 3., 2022.