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KINEMATIC DETERMINATION OF THE BEGINNING OF A SKI TURN

KINEMATIČNA DEFINICIJA ZAČETKA SMUČARSKEGA ZAVOJA

Abstract

This paper proposes a new kinematic determination of the beginning and the end of a ski turn that is consistent with expert opinion and has been based on the point of intersection between the projection of the trajectory of gravity centre and the projection of the trajectory of the arithmetic mean of the skis. The 3D kinematic measurements were made during slalom (SL) training sessions of the Slovene national team and the giant slalom (GS) world championship in Kranjska Gora. The determination has been successful, yielding the desired results in all cases measured both in SL and GS. It is important that the determination is universally applicable across difference instances if different techniques and circumstances are to be compared or described. Given the rapid improvements and varieties of the ski racing technique in the past ten years, there is a clear need for a universally applicable determination.

Key words: alpine skiing, slalom, giant slalom, technique, kinematics, measurement

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Izvleček

V delu smo predstavili novo kinematično definicijo začetka in konca smučarskega zavoja. Definicija sovpada z mnenjem smučarskih strokovnjakov in temelji na določanju presečišč med projekcijo trajektorije težišča telesa in projekcijo trajektorije aritmetične sredine smuči. Tri dimenzionalne kinematične meritve smo opravili na slalomu (Slovenska smučarska reprezentanca) in na veleslalomu za Svetovni pokal v Kranjski Gori. V vseh primerih lahko preko definicije dobro določimo začetek zavoja. Pomembno pri definiciji je, da je univerzalna za vse tehnike. Saj bi sicer naleteli na težave takoj, ko bi želeli dobro opisati katero od tehnik in sploh, ko bi želeli primerjati razlicne tehnike med seboj, kajti vse te primerjave in opise je težko izvesti, v kolikor ni mogoče natančno določiti začetka zavoja. Določitev takšne definicije je še toliko bolj pomembna v zadnjih letih, ko so izboljšave tehnik zelo hitre, poleg tega pa smučarji uporabljajo več različnih tekmovalnih tehnik.

Ključne besede: alpsko smučanje, slalom, veleslalom, tehnika, kinematika, meritve

INTRODUCTION

The history of alpine skiing reaches back to the end of the 19th century (Guček, 1998). It has been a history of non-stop development, which has distinctly accelerated in the past ten years as the new 'carving' skis were created (Supej, Kugovnik, Nemec, & Šmitek, 2001; Supej, Kugovnik, & Nemec, 2002). To be able to determine the beginning and the end of a ski turn is one of the most important aspects of describing the technique that applies either to a slalom or a giant slalom turn. To date, many different 'heuristic' determinations have been made, such as those that apply to planting the pole, off weighting, weight change, etc. (Pišot, Murovec, Gašperšic, Sitar, & Janko, 2000; Žvan, 1997). They have all been effective enough, but as techniques have changed, the heuristic determinations have rendered inaccurate.
Today, top-level racing skiers (those taking part in World Cup races) use three different racing techniques: 'classical' up/down motion, 'double' motion and most recently 'counter' motion (Supej et al., 2001; Supej, Kugovnik, & Nemec, 2002). It is difficult to determine the true beginning of the turn for an entire run, unless different determinations are used to describe different techniques. For this reason it has been necessary to establish a reliable biomechanical parameter that can be measured. The main goal of this study was to establish just such a reliable parameter that is universally applicable to different techniques.

METHODS

Participants

The study applies to both slalom and giant slalom and measures competitive skiers who use different techniques, in both training (SL) and racing (GS) conditions. In the case of slalom, a sample of five top-level skiers was chosen, all from the Slovenian national ski team. Each performed three runs on the same course set-up. Altogether, we recorded only fourteen runs because one of the skiers fell during his second run. In the areas measured, the gates were positioned at absolute distances of ds_1= 12.35 m and ds_2=1.8 m and shifted by d_r=4 m (see Figure 1). The inclination of the slope was 18.5°±1°.

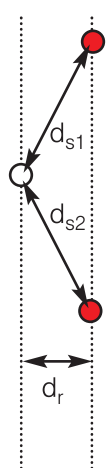

Figure 1: Absolute distance between neighbouring gates ds_1, ds_2 and the shift d_r between the gates

The giant slalom measurements were taken during the World Cup championship in Kranjska Gora 2001 (Pokal Vitranc), on two different terrains, whose inclinations were 22.5°±2° and 20°±2°, respectively. Performance of twenty different individuals was measured on the first slope and of fourteen on the second. In the areas measured on the first slope, the gates were positioned at an absolute distance of d_{s1}= d_{s2}=24.4 m and shifted by d_r=8.8 m (Figure 2). On the second slope the absolute distances were d_{s1}=22.8 m and d_{s2}=18.6 m and the shift d_r=8.45 m (Figure 2).

Instruments

Standard 17-point 3D kinematic measurements were taken with 4 camcorders covering 2 kinematic subspaces at the SL event at 50 frames per second and 6 camcorders covering 3 kinematic subspaces at 25 frames per second at the GS event (Kugovnik, Nemec, Pogacar, & Coh, 2000; Pozzo, Canclini, Cotelli, Martinelli, & Roeckmann, 2001). Sony DV-CAM and Sony mini-DV camcorders were used. All the subspaces were calibrated using cubes with the base of 1 m. APAS Ariel 3D kinematic software was used to translate the 2D data into 3D data.

Data analysis

To analyse raw data as it emerged from the APAS software, we used a specially designed KinSki software, which enabled us to analyse videos and simultaneously employ over 30 of the calculated parameters essential for ski turn analysis (Figure 2).

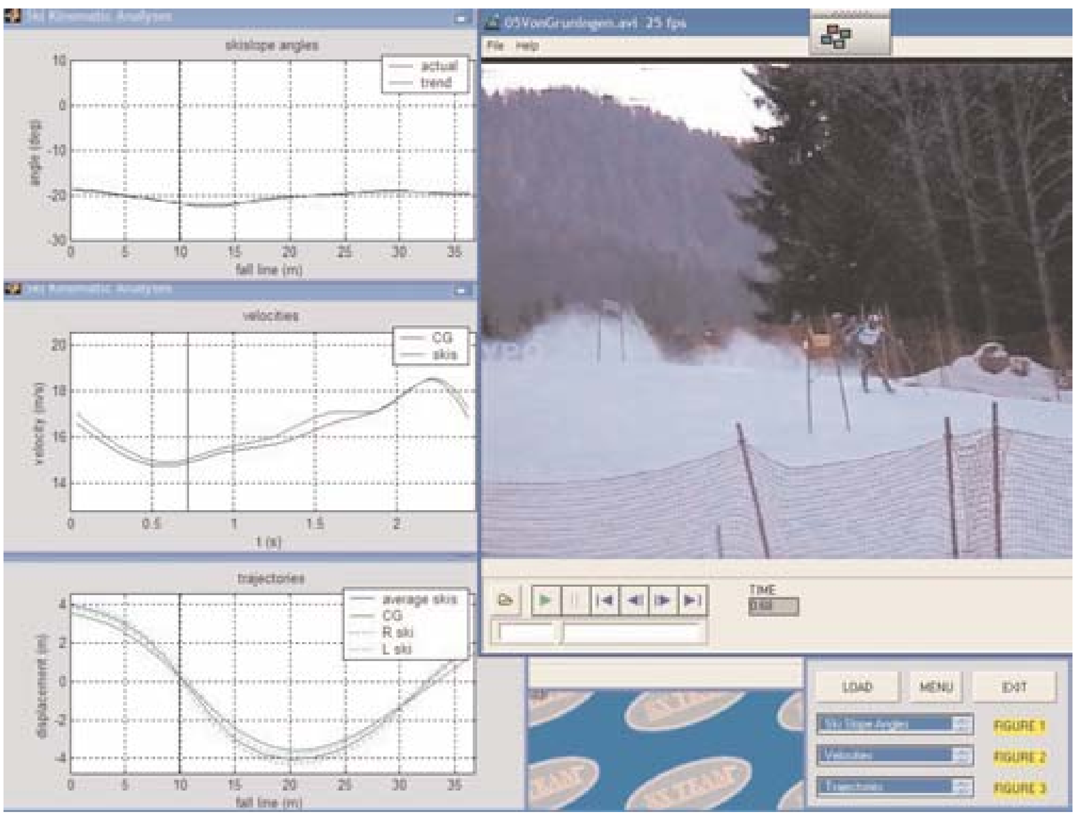

Figure 2: Principal biomechanical parameters presented with video recordings using KinSki program

A number of the principal biomechanical parameters are presented graphically and simultaneously with video recordings using KinSki computer program, as measured in the case of the skier Michael Von Grueningen during a giant slalom turn (see Figure 2). The skier is approximately at the end-point of the previous turn, beginning the next one. The point at which the turn begins or ends cannot be shown precisely in a single video frame, given a frame rate of 25 Hz. It can, however, be determined mathematically with utmost precision.

A kinematic determination of the beginning of a ski turn

The trajectory of the skier's motion is described point by point in a three-dimensional Cartesian coordinate system, whose y-axis is the downward thrust of gravity and whose x- and z-axes are perpendicular to the y-axis in the horizontal plane. The x-axis points in the direction of the fall line. Since the skier's trajectory is a pseudo planar motion, we rotate x- and y-axes around the z-axis to find the angle that corresponds to the inclination of the trend slope. The result is a rotated coordinate system (x_n, y_n, z), where index n refigures the new coordinate system.
We are interested in four different trajectories: the left ski t_1, the right ski t_2, the arithmetic mean of the skis t_3 and the CG (center of gravity) t_4. Each trajectory of motion is described by one of these four equations $t_{1-4}'=(x_n,1\text{-}4, y_{n,\ 1-4}, z_{1-4})$. The perpendicular projection of all the points to $y_n=0$ resolves the problem into two dimensions: $t_{1-4}'=(x_{n,1-4}, z_{1-4})$, where z can be described in terms of x: $z_{1-4}=z_1\text{-}4(x_{n,1-4})$.
Both the beginning and the end of the ski turn can in this case be calculated as being the point of intersection between the trajectory of the CG and the arithmetic mean of skies (see also Figure 2). Because discrete kinematic data can be spoiled by random error, we first 'smooth' the data using a Butterworh digital filter and apply the sixth order polynomial function to each trajectory in the region of the point of intersection, and then calculate analytically the point of intersection itself, which is ipse facto the beginning of the ski turn.

RESULTS

The nature of motion ensures that the trajectory of the CG always crosses the trajectory of the AMS (the arithmetic mean of the skis) in our new coordinate system at one point, as the skier's motion changes from one turn into another. Figure 3 shows an example of trajectories in the new two-dimensional coordinate system. It can be clearly seen from the diagram that the beginning of the new turn and the end of the previous turn coincide.

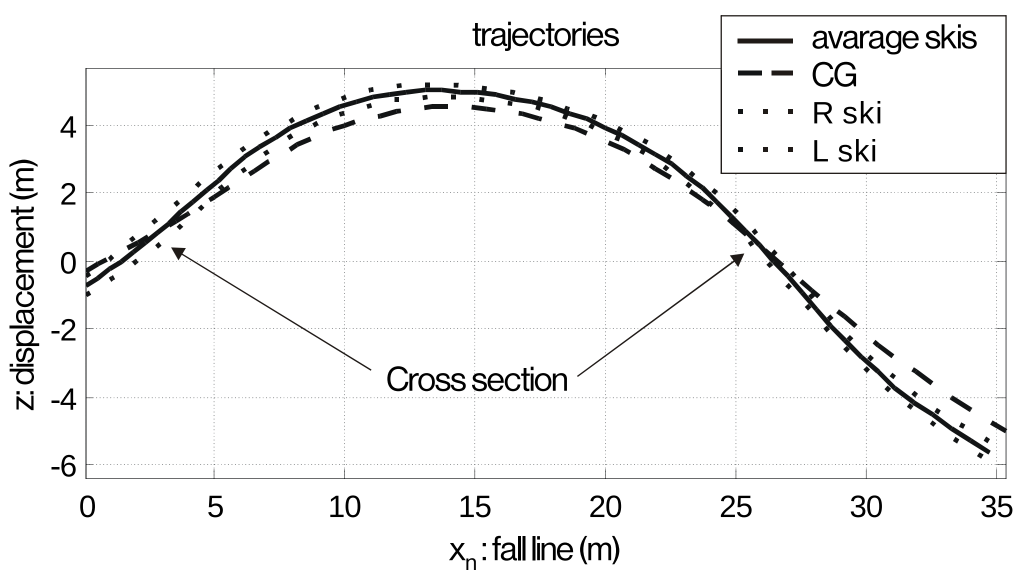

Figure 3: Trajectories of motion in the new coordinate system

Figure 3 shows trajectories of motion in the new coordinate system. The skier measured with KinSKi computer program was M. Von Grueningen during GS World Cup race in Kranjska Gora 2001. The points of intersection of the CG and AMS are shown.

The cross marks on Figures 4 to 6 show the points of intersection or the beginnings of turns in SL measurements (Kronplatz) and in GS measurements during the first and the second run (WC Kranjska Gora 2001) respectively. The points of intersection were calculated by the KinSki computer program.

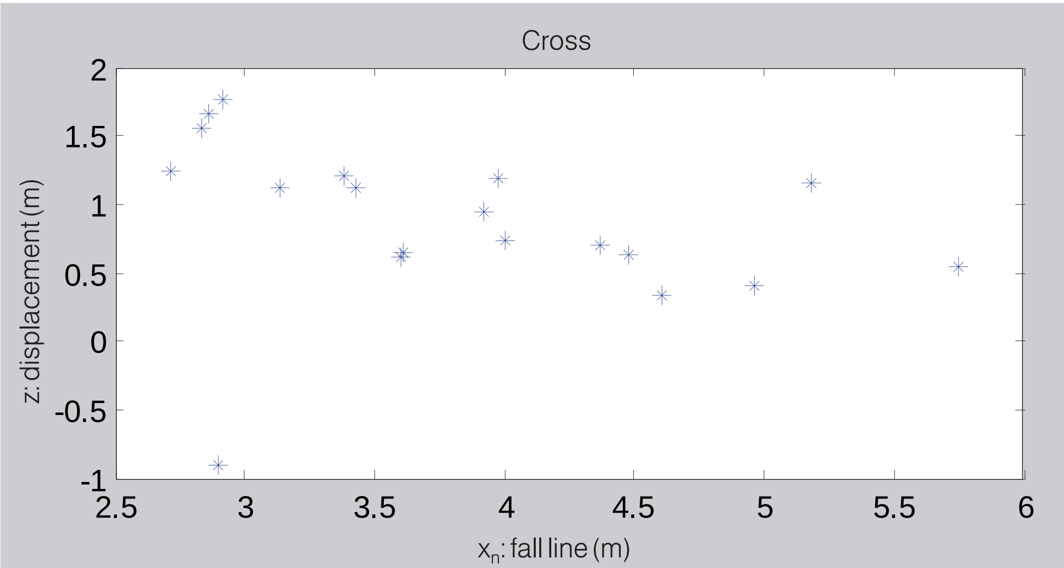

Figure 4: The beginnings of the turns in SL measurements in Kronplatz

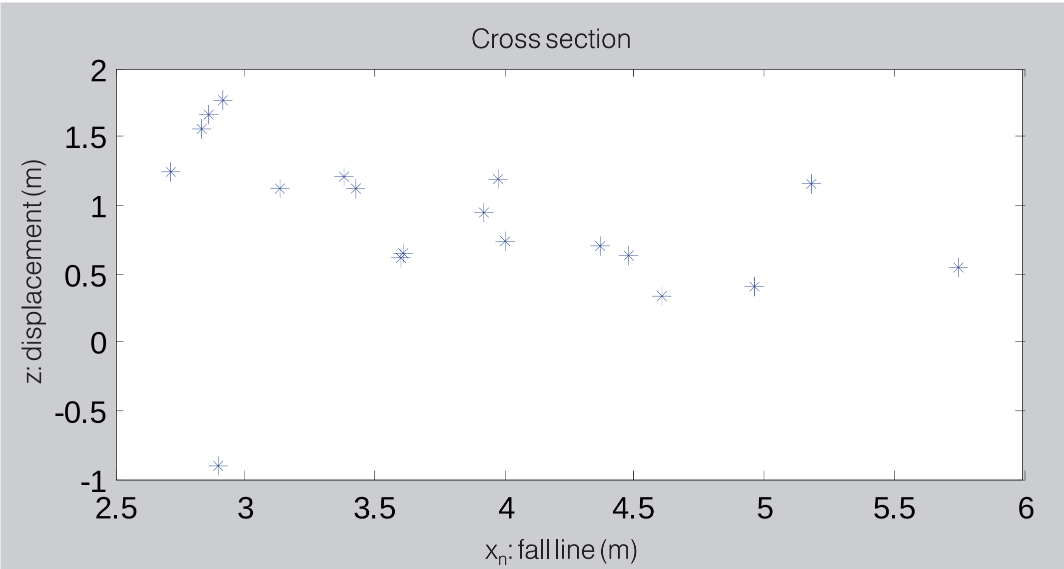

Figure 5: The beginnings of the turns in GS measurements on the first, steeper slope (Kranjska Gora 2001)

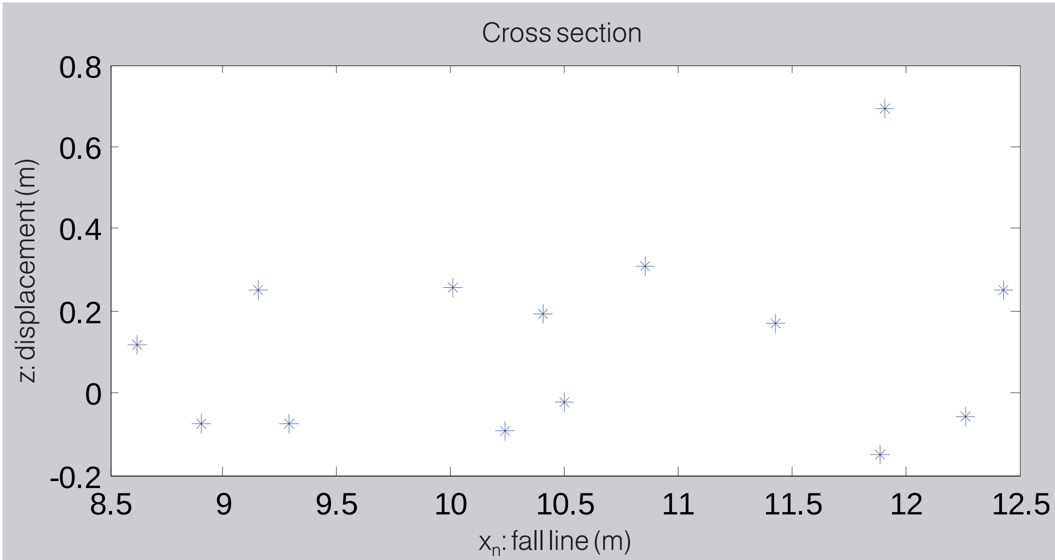

Figure 6: The beginnings of the turns in GS measurements on the second, flatter slope (Kranjska Gora 2001)

DISCUSSION

The results indicate that the same analytical procedure has been applied successfully to different ski techniques demonstrated in SL and GS. It appears to be a satisfactory definition of the point at which a ski turn begins and ends. The biomechanical determination defines the skier as being perpendicular transversally to the plane of the slope. In such position, however, the skier is unable to turn, as he is unable to restrain radial forces and the skis are flat on the ground, and not on their edges. In other words, by this definition, the skier has either ended the previous turn or begun a new one (Supej, & Kugovnik, 2000). This is consistent with the mathematical formulation that defines the beginning of the turn as being the point at which the second derivate of $z_{1-4}(x_{n,1-4})$ is zero.

So why not just apply the mathematical definition directly? The reason is that three trajectories have been recorded and one calculated (AMS). It is difficult to decide which is the most appropriate to use. The AMS is the obvious candidate, but this is problematic, because we are dealing with discrete data which is prone to error. For this reason it would not be appropriate to rely on subsequent calculation to calculate the beginning of the turn, since any error would have magnified itself. And even if it were possible to calculate the mathematical point precisely, there are further problems, because skiers often use the 'X stance' to turn, meaning that one ski is still finishing the end of the previous turn at the same time as the other is already beginning a new one (Supej et al., 2001). Nevertheless, the new determination seems to be only superficial, the ski experts have confirmed that the calculation is consistent with video image as synchronized to the measurements processed by the KinSki software.

It must be also taken into consideration that the obvious way to define a ski turn is through ground reaction forces, but as indicated by the measurements of two different slalom techniques (the new and the current one), this explanation is not accurate. In the case of the new technique the point of the beginning of the turn cannot be shown clearly; in the case of the current technique this expresses itself as a short interval lasting up to 15% of a slalom turn (see Supej, Kugovnik, & Nemec, 2002). It is clear from Figures 4 to 6 that we have managed to determine the point of intersection, the moment of the turn in all the cases measured (SL and GS). This also allows for the differences between the best world cup racers to become noticeable. Obviously, the spread of points of intersection in slalom is much smaller than it is in GS, because the absolute distances between the gates are shorter. Also, we can see that the spread of points of intersection is also smaller on flatter slope in GS and, not surprisingly, the spread toward the fall line is higher than it is in the perpendicular direction, which is a consequence of longer distances between the gates toward the fall line and much higher velocities along the x-axis vector than along the z-axis vector.

The most important reason why we wanted to determine measurably and universally the beginning and the end of a ski turn is that this determination is crucial to all scientific and heuristic descriptions of ski technique. Or, to put it simply, if the beginning of a ski turn cannot be specified, the technique cannot be described. Otherwise we are left with the possibility of relying upon heuristic determinations that are not universal and do not enable comparison between different techniques.

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