ANALYSIS OF SKIER KINETICS DURING THE START AND KINEMATICS OVER THE FIRST FEATURES DURING A SKI CROSS RUN

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The aim of this study was to analyse the start and the skiing technique in Ski Cross, and relate them to the performance. The project consisted of two parts: an indoor test was conducted to relate the momentum generated on the start handles to their velocity at handle release. Further, in an outdoor test, the skiers' kinematics over the first features of was related to completion time of the first section (~30 m). Five athletes from the Swedish National Team were tested using an instrumented start gate, an inertial motion unit (IMU) based suit and a differential global navigation satellite system (GNSS). Results showed marked differences in starting technique leading to distinct momentums after handle release. These differences did not immediately relate to time used to cover the first feature (Wu-Tang) in the run. Results indicate that the generation of velocity in the gate is not the main criterion for a successful performance in the initial section of a ski cross run.

KEYWORDS: Ski Cross, start gate, momentum, full body kinematics, performance.

INTRODUCTION: Ski Cross is a unique ski sport where four skiers race down the same track in direct competition. The race goes down a course with varying features (big jumps, rollers, banks etc.) making the sport unpredictable, because skiers may sometimes take over or even touch each other, occasionally leading to crashes on the course. The special race setup and the fact that it is only the first two skiers to cross the finish line that advance to the next round makes the sport very intense and appealing to spectators.

It has been shown that a good start increases the chances for success. An observational study, based on vidoes from 56 heats from the 2010 Winter Olympics in Vancouver and the 2010 World Cup final in Sierra Nevada, showed that 84.8% of the male skiers and 87.5% of the female skiers in front at the first turn of the course qualified for the next round (Argüelles et al., 2011). This highlights the importance of a good start in ski cross, as the skier in front at the first turn can choose the ideal line down the course and control the race. A study by Raschner et al. (2009), where starts were simulated in a special start training apparatus and a paper by Nedergaard et al. (2015) are, to the authors' knowledge, the only studies describing the biomechanical characteristics of the start movement.

Recent experiences from innovative course settings indicate that the ability of the athlete to negotiate the various features, especially the very first after the start become increasingly important.

It is currently unknown if and how elite ski cross skiers should adjust their starting technique within the gate in relation to the course setting immediately following the start. Therefore, the purpose of this study was to investigate starting technique and performance of elite skiers from the start gate and the first features in the course.

METHODS: Five elite Ski Cross athletes - four males and one female - from the Swedish Ski Cross Team participated in the tests (Age: 23.8 ± 3.1 years; Height: 179.6 ± 7.8 cm, Mass: 78.2 ± 8.6 kg). All the participants participated in this study after providing verbal and written informed consent.

Kinetics during the start gate phase were collected with the same instrumented start gate as described by Nedergaard et al. (2015). Start kinetics and kinematics were assessed in a separate indoor session for each athlete. Force data were sampled at 500 Hz with data collection triggered by a switch connected to the start gate. Full body kinematics were obtained using an inertial motion capture suit (XSens MVN Biomech Link, XSens, NL) sampling at 240 Hz.

For the outdoor tests, the Ski Cross slope start section (Figure 1) was built with the help of the Idre Fjäll ski resort technicians. A snow groomer was used to move the snow and create the desired profile of the course. The slope surface was then compacted by using skis and a snow shovel.
The design of the experimental slope was chosen by the Swedish Ski Cross Team coaches based on the technical skills they were interested in studying. A double Ski Cross start gate from Settele Start Systems (Settele GmbH, Lindenberg, Germany) was mounted on top of a Wu-Tang, which is a feature characterised by a steep downhill part, immediately followed by a steep uphill part; these two parts are linked together in a round shape. During the tests, all the skiers used the right start gate. After the Wu-Tang, there was a second descending part followed by a single bump. The total effective distance covered by the athletes was 27 m. The end of the course was marked by the finish line photocell.

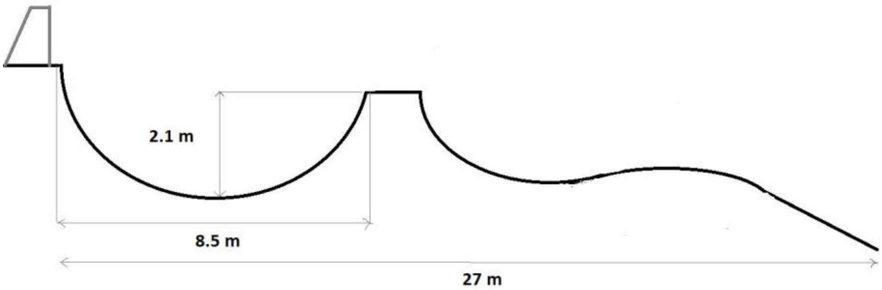

Figure 1: Dimensions of the start area. (Drawing is not to scale; the start platform was about 0.4 m higher than the highest point of the Wu-Tang).

During outdoor tests, the athlete wore the XSens suit and carried at Global Navigation Satellite System receiver (Leica Viva CS15, Leica, CH) while a second one was placed close to the start area as a fixed base station. Data were fused offline to calculate the position of the receiver carried by the skier (Supej, 2010).
The motion data from the XSens system were expressed in a hip-fixed coordinate system, exported to C3D format. A Matlab routine using the Biomechanical Toolkit (btk) toolbox was implemented to add the GNSS sensor displacement to the C3D file. Subsequently, the resulting C3D file was imported to Visual 3D to calculate displacements, joint angles and center of mass (CoM) paths. Following reference measurements and the initiation of data recording, the two systems were synchronized by a double jump movement carried out by the athlete prior to moving into the start gate.
The experience of the coaches involved in this study was used as motivation for exemplary 'interventions', characterized by individualized instructions for technique alterations. The main idea of the intervention was to reduce knee and hip extension at the bottom of the Wu-Tang to avoid a too high velocity at the end of it to minimize the time needed to cross the highest point and prevent a potential flight phase. Additionally, trials without ski poles were included to remove the potential effects of using them to push. Four trials per condition were recorded and averaged.

RESULTS: Due to availability of athletes only three were tested indoors with mean and maximum impulses presented (Table 1). Out of these three the one with the highest momentum getting out of the gate seems ends with the fastest completion time while the ranges of completion times over interventions vary. Four out of five athletes completed in a shorter time for the intervention while individual kinematic data show that not all of athletes succeeded in changing knee angles according to instructions. For two of the athletes, we recorded a 'faulty' trial which ended with a jump over the crest after the Wu-Tang resulting in an approximately 0.2 s longer completion time (values not shown).

DISCUSSION: In this study, an experimental protocol to assess the interaction of movement technique in the start gate and subsequent body actions to negotiate course features in Ski

Cross was developed. This method was then applied to assess the effects of different coaching instructions or exercises, in five elite skiers, on skiing performance determined by taking the time the skiers needed to complete the first approximately 30 m of a Ski Cross course.

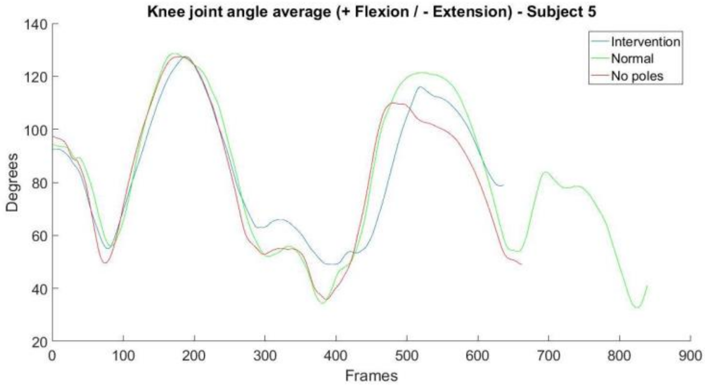

Figure 2: Mean curves of knee angle for Subject 5. The 2nd trough in the curve shows the bottom of the Wu-Tang.

Table 1: Mean values for indoor start test and outdoor test for 5 participants.

	Indoor			Outdoor						
	Kinetics			Start		Pre-Jump		Jump		Completion
	Resultant	Horizontal		Max hip	Max knee	Min hip	Min knee	Max hip	Max knee	Time
	Momentum [Ns/kg]			angle [deg]						t [s]
Athlete 1	N/A	N/A	Intervention	105	129	26	27	120	123	4.06
			Normal	110	129	32	27	122	126	4.16
			No poles	103	126	31	31	120	112	4.12
Athlete 2	3.44	3.14	Intervention	83	124	21	25	104	132	4.12
			Normal	82	126	23	23	105	126	4.19
			No poles	73	129	17	28	111	135	4.18
Athlete 3	3.67	3.05	Intervention	83	124	29	64	94	123	4.04
			Normal	86	130	5	41	101	121	4.04
			No poles	89	133	10	36	101	120	4.08
Athlete 4	4.07	3.40	Intervention	98	141	22	31	110	130	4.03
			Normal	98	143	34	53	104	124	3.99
			No poles	97	143	34	58	106	123	4.04
Athlete 5	N/A	N/A	Intervention	88	128	16	49	88	116	3.98
			Normal	88	129	1	34	102	121	4.00
			No poles	91	127	11	36	105	110	4.23

Results indicate that elite athletes are capable of executing coaching instructions without an extensive time of practice. For the one who did not succeed in this experiment the feedback provided by the system may be helpful. Due to the limited number of athletes tested it remains difficult to present generalizable recommendations or guidelines. However, if applied to more and different skiers as well as to different course designs, this approach might help to better understand the way hip and knee flexion/extension over slope features influence performance. A variable of interest which might be introduced in a single-trial analysis is the skier's vertical velocity when leaving the ground on the Wu-Tang top and on the top of the crest after the Wu-Tang, which is directly proportional to the vertical linear momentum. It should be investigated whether the mentioned kinematic quantities have an effect on the skier's vertical velocity during the negotiation of obstacles or jumps and how this velocity affects the performance.

Another variable of interest which should be further investigated is the anterior-posterior distance between the foot and the skier's CoM (or the pelvis): it is of great interest for the coaches because it could help them in detecting and therefore correcting potential mistakes in the athletes' anterior-posterior balance during a Ski Cross run.

It has to be noted that the XSens system provides several advantages in respect to optical motion capture systems when conducting biomechanical tests outdoors (Nedergaard et al., 2015), e.g., shorter set-up time and the possibility to measure over a larger area while one challenge is to provide GNSS data of sufficient precision without further post-processing of the positional data. We are currently experimenting with smaller and more compact sensor systems to overcome this limitation.
While an experimental approach as illustrated in this study will always be beneficial to coaches and athletes it is needed to advance biomechanical models of skiing as each new course design might require special and individually different adaptations of the athletes. If such models could be developed a more effective preparation for competitions may be achieved. On the other hand, simulations can also be used to estimate limitations of course design or even course related injury potential.
One limitation of this study was that the kinetics within the start gate were tested on a separate day in a different environment. However, as has been demonstrated previously (Nedergaard et al., 2015) indoor and outdoor results are comparable, while an integration of the existing start gate would be possible without further problems.

CONCLUSION: This study was the first, to our knowledge, to demonstrate a setup for a full coverage of skier technique in the Ski Cross start including the generation of momentum while in the gate, and the first 30 m of skiing on a designated training or race course. Applying this approach to various ski courses or other winter sport disciplines with different athletes will be of benefit for the development of the sport and improve the assessment of performance and coaching efforts the like.

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