

8th INTERNATIONAL
CONGRESS ON



SCIENCE AND SKIING

March 11–15, 2019
Vuokatti, Finland

Book of Abstracts

Edited by
M. Karczewska-Lindinger
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S. Lindinger



**Abstract Book of the
8th International Congress
on Science and Skiing**

Editors

Magdalena Karczewska-Lindinger

Anni Hakkarainen

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Preface

The Vuokatti Sports Technology Unit of the University of Jyväskylä is proud to present the Abstract Book of the 8th International Congress on Science and Skiing (ICSS 2019), held in Vuokatti, Finland, March 11–15, 2019. The scientific programme offers a broad interdisciplinary spectrum of current research in Nordic and Alpine skiing.

The Abstract Book includes altogether 61 oral presentations of which five are keynotes, 13 are invited and 10 are in the Young Investigator Award Competition. In addition there are 20 poster presentations. The entire scope of relevant topics in skiing will be covered by these presentations. The highlights of the congress will be the five keynotes, presented by Erich Müller (Austria), David Bacharach (USA), Øyvind Sandbakk (Norway), Maarit Valtonen (Finland), and Walter Herzog (Canada).

In order to maintain a high scientific standard required of this congress, a peer review process was utilized in the selection of the papers. Each abstract was sent to at least one member of the scientific committee to be reviewed. The papers were examined regarding content, topics and structure according to the guidelines of ICSS. Most of the abstracts were accepted, some of them after minor improvements. We want to thank the members of the scientific committee for the work they did reviewing the abstracts.

In addition to the Abstract Book the Proceedings will be published by Meyer&Meyer in 2020. All keynote and invited speakers as well as all oral and poster presenters will be invited to submit their papers by August 31st, 2019.

Magdalena Karczewska-Lindinger
Anni Hakkarainen
Vesa Linnamo
Stefan Lindinger

Vuokatti, March 2019

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Memorial lecture

EMERITUS PROFESSOR PAAVO KOMI MEMORIAL LECTURE

Vesa Linnamo

Faculty of Sport and Health Sciences, University of Jyväskylä, Finland

KEY WORDS: Cross-country skiing, ski jumping, stretch shortening cycle

Professor Paavo V. Komi (1939-2018) dedicated his professional life to studying human movement and developing novel methodologies to understand the mechanisms behind different phenomena. For example, the buckle transducer and optic fiber techniques, as well as the sledge apparatus to examine the stretch shortening cycle, became known to the scientific community all over the world. He received seven honorary doctorates and numerous international and national prestigious awards, and served as president in organizations such as the International Society of Biomechanics (ISB), World Commission of Sports Biomechanics, International Council of Sport Science and Physical Education (ICSSPE), and European College of Sport Science (ECSS).

Komi published over 300 original articles and over 90 books/book chapters, of which approximately 30 were related to cross-country skiing or ski jumping. As was the case in his other studies, in Nordic skiing he was a forerunner in introducing new measurement technologies. Starting already from the late 1970's, he used velocity measurements, force plates under the snow, force transducers attached to cross-country skis, pole force measurements, and plantar pressures to study different aspects of these sports, both in the laboratory and in the field. In ski jumping, measurements were performed at a total of six Winter Olympic Games. Scientific knowledge that he obtained was also converted into practice, and Komi was without a doubt one of the important people behind Finnish success in Nordic skiing in the 1980's and 1990's.

15 years ago he played a significant role in establishing the Sports Technology Unit in Vuokatti, and until about five years ago he was still actively participating in skiing research. One of the memorable moments some years ago was when we measured stretch shortening cycle behavior of muscle tendon units during skiing using a portable ultrasound device in Vuokatti ski and snowboard tunnels.

In many cases the technologies used in today's research world have developed from the decades before, but it is important to understand history and respect the pioneers who have started the work. I was honored to be first a student and later a colleague and friend to Professor Paavo Komi, whose research history with national and international partners in skiing I am proud to present in this memorial lecture.

Keynote lecture

SCIENCE IN SKIING (ICSS): PAST - PRESENT - FUTURE

Erich Müller

Department of Sport and Exercise Science, University of Salzburg, Rif, Austria

KEY WORDS: Wintersport research, publication rate, interdisciplinarity, internationalization

If we analyze the research output in the area of Alpine and Nordic skiing since the seventies of the last century, we find an enormous increase of publications per year. Between 1970 and 1996 (when the first ICSS was organized) on average 50 – 100 papers per year had been published. Around the year 2000, the amount of publications has increased to about 200 per year, whereas today we find 500 and more papers per year. In addition to the increase in amount of papers, we find a clear tendency of publications with large groups of authors per paper. Between 1992 and 1996 about 30% of all publications were published by only one author and only 10% of all publications had 4 or more authors. In the period 2014 – 2018 only 4% of the publications had only one author, whereas more than 57% of all publications were published by more than 4 authors. This development might be explained by the increase of complexity and the inter-/multidisciplinarity of the study designs. A third, from my point of view, very important development is the increase of numbers of research groups with members coming from different research organizations, even from different countries. In the period 1992 – 1996, 60% of all publications were published by authors from only one institution and only 15% of the papers were established by authors from 3 or more institutions. In the period 2014 – 2018 more than 60% of all publications were published by authors from at least 3 institutions, many of them from different countries.

It seems to be very likely that the installation of the ICSS movement in 1996 has at least partly been responsible for this huge improvement of quantity and quality of science in skiing. At the 1st ICSS in 1996 almost all leading scientists in this research area had accepted to participate and to present keynotes and invited lectures: Bengt Saltin, Paavo Komi, Benno Nigg, Jochen Mester, Carmelo Bosco, and others. Their presentations were published in the congress proceedings book. Many of them have reached a high amount of citations. Within the last 23 years, 8 ICSS congresses were organized, 6 of them in St. Christoph a. Arlberg, Austria. For all of them congress proceedings books were published. On average about 250 scientists from 25 nations worldwide participated at the congresses, many of them regularly. This movement created an international network of scientists from many different institutions and scientific disciplines from all over the world, all of them interested in skiing. Many of the above mentioned high quality projects with multidisciplinary study designs and big international working groups might have been started during one of these congresses.

To continue with this positive development, I suggest to officially found an “International Society of Science in Skiing” with the main vision and mission to further develop the quality of science and the international network of especially young scientists!

Young Investigator Award (YIA) competition

Monday, 11th of March: 16:00–19:15

KNEE JOINT LOADING DURING LOADED SQUAT JUMP LANDING

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KEY WORDS: Joint loading, overuse injury, landing technique

INTRODUCTION: Leg muscle power is a key factor for athletic performance in alpine and nordic skiing (Müller et. al, 2000). Large numbers of unloaded and loaded jumps are performed to improve this skill. Overuse joint injuries are associated with frequent landing impacts (Lian et al., 2005). Therefore, loaded jumps might pose an increased overuse injury risk due to the additional load during landing. The aim of this study was to analyze the effect of loaded jumping on the knee joint loading during landing.

METHODS: Twelve male athletes participated in this study. Testing included jumping with four additional loads. Peak joint power was calculated for the assessment of the joint loading using an inverse dynamics approach. Furthermore, joint angle at initial contact (AIC), range of motion (ROM) and landing duration (LD) were calculated for the kinematic landing description. One way ANOVAs with repeated measures and post hoc t-tests were conducted to test for the effect of additional load on the calculated variables.

RESULTS: Peak knee joint power decreased with increasing load (Fig. 1). AIC decreased and LD increased with increasing load. No changes were found regarding the ROM (Table 1).

DISCUSSION & CONCLUSION:

Loaded jumping even decreased the knee joint loading during landing. This was achieved by a combination of the naturally decreased jump height and an altered landing technique. Landing was performed in a more erect position without changes regarding the ROM resulting in a decreased peak flexion angle. Therefore, the lever arm at the knee was reduced, which mainly determines the magnitude of the joint moment. The constant ROM in combination with an increased landing duration resulted in a decreased joint angular velocity and consequently in a decreased peak joint power. Considering the sensitivity of the knee joint loading to the landing technique, particular attention should be paid to it during loaded jumps to avoid overuse injuries in alpine and nordic skiers.

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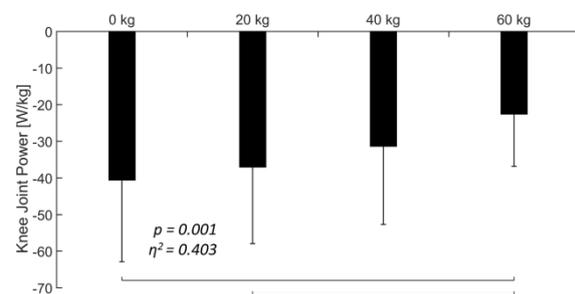


Fig. 1. Peak knee joint power

Table 1. Kinematic landing description

	AIC [°]	ROM [°]	LD [s]
0 kg	31 (14) ^{#,§}	60 (13)	0.21 (0.06) ^{#,§}
20 kg	26 (9) [§]	59 (11)	0.23 (0.09) [§]
40 kg	22 (10) ⁺	63 (10)	0.28 (0.06) ⁺
60 kg	19 (8) ^{+,~}	63 (12)	0.33 (0.10) ^{+,~}
<i>p</i>	<0.001	<i>ns</i>	0.001
<i>η</i> ²	0.50	0.158	0.48

⁺different from 0 kg, [~]different from 20 kg, [#]different from 40 kg, [§]different from 60 kg

TORSO AND HIP FLEXIONS INFLUENCE SKI JUMP LANDING IMPACT

Veronica Bessone, Johannes Petrat, Wolfgang Seiberl, Ansgar Schwirtz

Department of Biomechanics in Sports, Technical University of Munich, Germany

KEY WORDS: Injury prevention, kinematics, technical suggestions, force insoles, inertial sensors

INTRODUCTION: In jumping sports, injuries are frequent and mainly involve the knee joint (Dufek and Batek, 1991). In ski jumping, although the kinematics before landing influences the impact kinetics and, therefore, the injury risk (Greimel et al., 2009), few studies focused on the biomechanics of this phase. This study aims to discover which kinematic variables during landing and its preparation correlate with lower impact forces.

METHODS: One athlete performed nine jumps on the hill HS106 of Oberstdorf (DE) during summer training, landing with telemark. The subject jumped wearing 16 inertial sensors *aktos-t* (myon AG, Schwarzenberg, CH) on each body segment, and force insoles *loadsol* (Novel GmbH, Munich, DE). Correlations were calculated between impact kinetics and lower body angles recorded during impact and at 0.10 ($t_{0.1}$), 0.40 ($t_{0.4}$) and 1.00 ($t_{1.0}$) s before impact.

RESULTS and DISCUSSION: Focusing on the kinematics of the torso and of the hip of the telemark front-positioned leg, correlations were found between maximal impact force F_{max} and, torso and hip flexions during landing preparation ($t_{0.1}$: torso $r=.710$, hip $r=-.685$; $t_{0.4}$: hip $r=-.847$; $t_{1.0}$: torso $r=.681$, hip $r=-.700$; all $p<0.05$). Therefore, a more extended torso during landing preparation could lead to lower impacts. Greater hip flexion ($r=-.670$, $p<0.05$) and smaller knee internal rotation ($r=.689$, $p<0.05$) during the impact are correlated with a smaller F_{max} , with a possible reduction of the risk of anterior cruciate ligament rupture (Blackburn and Padua, 2008). Hip flexion (Fig. 1) showed to be important for injury prevention as in alpine skiing (Heinrich et al., 2014).

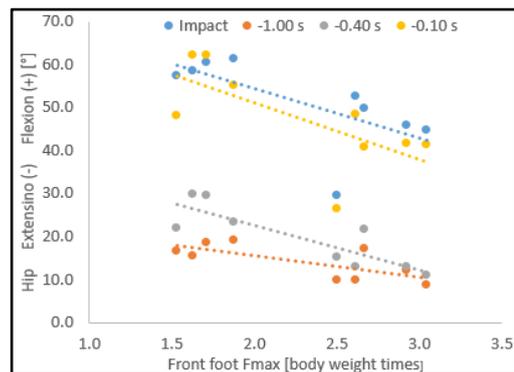


Figure 1. Correlations ($n=9$) between F_{max} and hip flexion during impact and at 0.10, 0.40 and 1.00 s before impact

CONCLUSION: Based on preliminary results, during telemark landing and its preparation, athletes should flex more the hip of the front positioned leg for reducing the impact force. Knowing the kinematic predictors that lead to lower impact force can be important for giving technical support to the athletes, in order to improve safety. Further studies should include more participants and the analysis of the parallel landing.

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MAGNITUDE AND RELATIONSHIP BETWEEN FORCE OUTPUT AND PERFORMANCE IN GIANT SLALOM

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KEY WORDS: Biomechanics, force-plates, ground reaction forces

INTRODUCTION: An enhanced capacity for force production is generally accepted as a necessary physical component for ski athletes. However, while some evidence suggests advanced athletes exhibit a greater ability to produce force (Keranen et al. 2010), the relationship is likely more complicated (Supej et al. 2011). Data on the subject is rare, and often features limitations due to technology and the complex nature of collection in an alpine environment. Using validated force plates (Falda et al. 2016) we aimed to (i) compute magnitudes and balance of force produced on a giant slalom course, and (ii) test the relationship between performance and force measures.

METHODS: 13 athletes (club to world cup level) performed a 16-gate giant slalom course while equipped with a custom force plate system. 14 turns were isolated using the point of minimal vertical GRFs, and resultant force produced by the two limbs was calculated per turn. Individual data were combined as peak (F_{peak}) and mean (F_{mean}) force, and the absolute difference in mean force between limbs was calculated and expressed as a percentage of F_{mean} (F_{diff}). The mean data were tested for a relationship with total course time (T) using Pearson's correlation coefficient.

RESULTS: The mean and peak force produced across the turn cycles were the equivalent of 1.80 ± 0.16 and 4.95 ± 0.62 BW, respectively. Mean and peak force output were found have large and very large correlations to performance, respectively. The difference in output between limbs was 32 ± 6 % of F_{mean} and was not significantly correlated to T .

Table 1. Correlation matrix

	T	F_{mean}	F_{peak}
F_{mean}	-0.631*	—	
F_{peak}	-0.763**	0.577*	
F_{diff}	0.213	-0.646*	-0.312

* $p < .05$, ** $p < .01$

DISCUSSION & CONCLUSIONS: The average and peak GRFs measured in this study are substantial, and comparable to that reported in the literature. The large to very large correlations observed between the force developed by the skier's limbs and the total run performance may indicate better athletes present greater force production ability. However, ongoing investigation is required to clarify the exact bounds of this relationship. In any case, these results corroborate a baseline requirement of advanced force production capabilities in ski racers.

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KINETIC AND KINEMATIC TURN SWITCH DETECTION IN GIANT SLALOM

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KEY WORDS: Biomechanics, force-plates, GNSS, Turn switch

INTRODUCTION: Biomechanical analyses of alpine skiing performance typically separate data into distinct events determined as the period between ‘turn switch’ (TS). Among several methods, a TS can be detected using kinetic data as the minimum summated vertical ground reaction force (vGRF) exhibited over a given turn cycle (Nakazato et al. 2011; Method 1), or from kinematic data as the inflexion point of the center of gravity trajectory defined as the sign change in the twice derivative position signal over time (Fasel and Gilgien 2016; Method 2). The aims of this study were to (i) determine the difference between methods 1 and 2 for detecting each TS, and (ii) test the effect of varying turn and skier characteristics on any measured difference.

METHODS: 13 mixed-level skiers (club to world cup competitors) performed a timed 16 gate giant slalom course. Skiers were equipped with validated 3D force platforms (Falda et al 2016) synchronized with a lumbar mounted GNSS/IMU unit (MacLloyd, Paris, FRA) with factory fusion computations. Methods 1 and 2 were applied to their respective data kinetic and kinematic data, and the difference in time between each TS was computed per turn. A total of 267 turns were analyzed, and the data were compared using Bland-Altman plots, and systematic and random errors (as mean \pm SD of differences). Pearson’s correlations were performed between measured errors and the turn-averaged slope, radius, length of the turn, speed of entry and vGRF.

RESULTS: Method 1 consistently detected the turn earlier than Method 2 (Table 1). No correlation was found between the lag between the two methods and turn characteristics (slope, radius, length of the turn, speed of entry, vGRF applied during turn). The mean of individual random error was 0.06 ± 0.001 s. No correlation was observed between the systematic error and the mean speed of entry of a skier, nor the race time.

	Syst. error	Random Error
Lag (s)	0.304	± 0.109
Lag (% cycle)	19.1	± 7.7

DISCUSSION & CONCLUSION: Time of turn shifted depending on the method used, with each TS detected earlier using kinetic methods than with a kinematic approach. Based on this finding, trajectory appears a consequence of the skier’s action, which must be considered when integrating the methods into research and practice. Lower individual error than global error might highlight that the personal strategic and technical approach of each athlete may explain some magnitude of errors observed. A deeper analysis of vGRF pattern could better clarify these findings, and the relationship between technical strategy and observed lag.

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AUTOMATIC 3D MOTION CAPTURE IN ALPINE SKIING USING DEEP LEARNING AND COMPUTER VISION

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KEY WORDS: Alpine skiing, motion estimation, computer vision, deep learning

INTRODUCTION: Up to this point, 3D motion capture in alpine skiing data had to be manually annotated or collected using body-worn IMU and GPS sensors. As an alternative, we propose to train a vision-based deep pose estimator to detect 2D joint positions that are then used to triangulate global 3D kinematic data.

METHODS: To this end, a new alpine skiing dataset was created by sampling 1982 images from semi-professional skiing video sequences and annotating 24 joint positions for each frame by hand. For 2D pose estimation, two deep neural networks [4,5] were trained on only the aforementioned new dataset to first detect the athlete and then predict 2D joint locations. This algorithm was then applied to different multi-view recordings with calibrated cameras [1,2], without needing additional annotation. 3D joint locations were triangulated by minimising a reprojection error and additional smoothing priors [3]. Finally, the 3D pose estimation by the suggested computer vision-based method was compared to the ground truth (i.e. manually annotated, video-based 3D kinematics as described earlier in [1,2]).

Cameras	2	3	4	5	6
Joint position	1.63 \pm 1.58	0.77 \pm 0.59	0.48 \pm 0.45	0.45 \pm 0.43	0.43 \pm 0.40
CoM	0.63 \pm 0.54	0.30 \pm 0.34	0.20 \pm 0.23	0.17 \pm 0.13	0.16 \pm 0.11

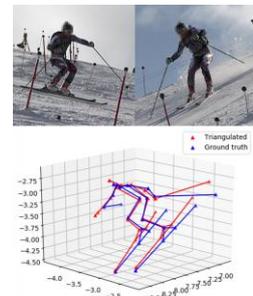


Figure 1. Example triangulation

RESULTS: 2D pose estimation over six trials (totalling 5584 frames) resulted in a percentage of correct key points (PCK) of 62.69%, taking the head to neck distance as a threshold. Triangulation results with different numbers of cameras taken are shown in Table 1.

DISCUSSION: While the automatic joint detection suffered from substantial outliers, Center of Mass (CoM) position can be considered sufficiently accurate for detecting meaningful differences in various contexts of alpine skiing. Having more than 2 cameras greatly improves the detection accuracy.

CONCLUSION: This study demonstrates that using task-specific, medium-sized datasets, global 3D ski pose estimation can be conducted with reasonable performance. Future work should focus on approaches using less calibrated cameras and on applying the proposed methods to other winter sports like cross-country skiing or snowboarding.

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DEVELOPMENT OF AN AUTOMATIC ALPINE SKIING TURN DETECTION ALGORITHM BASED ON A SIMPLE SENSOR SETUP

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KEY WORDS: Algorithm, ski, turn, sensor, IMU, gyroscope; algorithm

INTRODUCTION: In order to gain insight into alpine skiing performance, it is necessary to determine where each ski turn begins. Several methodologies have been proposed to determine turn switches. However, those methodologies are not yet feasible to use in a regular basis. The aim of this study was to develop a simple sensor set up for daily usage and an algorithm to accurately detect turns during alpine skiing.

METHODS: Ski turn imitations were performed on a ski-ergometer at different turn durations and slopes. An IMU was attached to the posterior upper cuff of each boot. Turn detection algorithms were developed to analyze multiple IMU signals. Expert raters assessed the point of the turn switch based on video recordings to establish the most accurate algorithm. The selected signal and algorithm was used for the in-field measurements. Eleven expert skiers performed a minimum of 10 turns for each of the styles assessed e.g. carving long, carving short and parallel to validate and fine tune the algorithm, ratio and adapted confusion matrix were used. The ratio is the relation between the number of detected and the number of actual turns. The confusion matrix assesses the precision (how many detected turns are true turns) and recall (how many real turns are detected).

RESULTS: Acceleration signals showed less consistent behavior and lower accuracy values during the in-lab situation and were consequently discarded for further algorithm development. Within the gyroscope data, the anterior-posterior (roll) axis with a cutoff filter of 3 Hz showed the best agreement with expert evaluation. The algorithm developed was based on accurately detect the point of maximum angular velocity which due to the pendulum like behavior of the skiers, corresponds with the point of turn switch. Ratios and confusion matrix are shown in Table 1.

Table 1. Evaluation metrics. AT, actual turns.

Turn Sequence	AT	Ratio	Precision	Recall
Short carved turns	231	0.996	0.996	0.991
Long carved turns	143	1.007	0.993	1
Parallel	132	0.833	1	0.833

DISCUSSION: The results indicate that the developed system is valid and accurate for carved turns. For parallel turns, while all the turn detected are real, some real turns are missing. Further development needs to be done to enhance the robustness for parallel turns and to include other techniques such as snowplough.

CONCLUSION: This study developed a new system to accurately (95 %) detect turn switches using a simple and unobtrusive set up that is feasible to use on a regular basis.

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A COMPARISON OF PHYSIOLOGICAL VARIABLES BETWEEN CHINESE NATIONAL CROSS-COUNTRY SKIERS AND LONG-DISTANCE RUNNERS

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KEY WORDS: Physiological variables, cross-country skiers, long-distance runners

INTRODUCTION: Both cross-country skiing and long-distance running are kind of sports based on endurance and require strongest aerobic capacity compared with other sports (Holmberg et al. 2007). The purpose of this study was to determine and compare physiological variables of Chinese national long-distance runners and cross-country skiers to provide some suggestions to Chinese talent transfer selection.

METHODS: 16 male and 16 female cross-country skiers, 12 male and 12 female long-distance runners who were all national-level participated in this study. All subjects underwent the anthropometric data collection, body composition assessment (Inbody770, Korea), VO₂max test (Metamax 3B[®] Metabolic Measurement system, German), and anaerobic power test (Watt bike, UK). Statistical evaluation was performed using SPSS 17.0 program. An alpha value of < 0.05 was considered significant.

RESULTS: Age, height, weight, physical and physiological variables of participants are provided in Table 1.

Table1. Physical and physiological variables of cross-country skiers and long-distance runners

		Age (years)	Height (cm)	Weight (kg)	BMI (kg/m ²)	PBF (%)	VO ₂ MAX (ml/kg/min)	Anaerobic Power (w/kg)
male	XC	19.4±2.2	177.4±5.5	66.2±6.1	21.1±1.8	9±1.8	70.9±5.7	8.6±0.75
	LD	18.2±2.8	180.2±2.8	68.7±7.8	21.2±2.1	10.1±2.1*	62.4±5.0*	8.5±0.75
female	XC	18.7±3.4	166.4±5.7	55.7±3.3	20.1±1.3	15.5±3	59.9±2.7	6.9±0.6
	LD	20.1±3.8	163.9±5.2	51.3±5.7*	19.1±1.4*	17.4±4*	58.8±5.5	6.2±0.7*

* P<0.05;XC, cross-country skiers; LD, long-distance runners; PBF, percent of body fat

DISCUSSION: We found that the PBF of male and female XC skiers was lower than LD runners significantly, the male VO₂MAX of XC skiers was about 8 ml/kg/min higher than LD runners, and female XC skiers' anaerobic power was higher than LD skiers'. Besides, it might be concluded that there are no significant differences at the anthropometric indexes and some physiological variables.

CONCLUSION: we can make a try to transfer long-distance runners to cross-country skiers to provide some talents to the cross-country skier talents tool.

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HEART RATE VARIABILITY IN YOUNG ATHLETES: WHEN SHOULD WE MEASURE IT AND DOES IT RELATE TO PERFORMANCE?

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KEY WORDS: Heart rate variability, young athletes, performance, recovery

INTRODUCTION: Young athletes are encouraged to train intensely and the demand to provide high-level physiological support to young athletes is increasing. Heart rate variability (HRV) is a non-invasive assessment tool that can be used for monitoring recovery (Plews et al., 2013). The purpose of this study was to collect HRV values during sleep and morning orthostatic tests to investigate their relationship and determine its connection to performance tests.

METHODS: Eleven well-trained young endurance athletes -7 males (16±1 years) and 4 females (16±1 years) from the Vuokatti-Ruka Sports Academy were recruited for this study. HRV analysis for stress/recovery status was collected using a morning supine orthostatic test (Polar) and ballistocardiographic sleep tracking device (EmfitPM) for evening and (Emfit AM) for morning values. Performance tests included submaximal running test for heart rate (HR) and blood lactate, as well as counter movement jumps. All tests were conducted at week 1, 2 and 4 during the training and racing season (Nov - Dec 2017).

RESULTS: Both nocturnal HRV values correlated significantly ($P < .01$) with Polar HRV values (Table 1). EmfitAM HRV values were 70±14 (week1), 73±16 (week 2) and 74±15 (week4) and Polar HRV 91±36 (week1), 105±46 (week 2) and 99±38 (week4). For both EmfitAM and Polar, only the change from week 2 to week 4 was statistically significant ($P < .01$). The relative HRV change of EmfitAM correlated with the respective values measured with Polar ($r = .803$, $P < .01$). No significant changes were observed in treadmill HR or lactate or jumping test between the weeks and the changes in HRV did not correlate with any of the changes in the performance test results.

Table 1. Correlation between nocturnal HRV values (Emfit) and morning HRV (Polar) values during orthostatic test

Week	1	2	4
Emfit AM	$r = 0.742^{**}$ $P = 0.009$	$r = 0.801^{**}$ $P = 0.003$	$r = 0.757^{**}$ $P = 0.007$
Emfit PM	$r = 0.623^*$ $P = 0.041$	$r = 0.876^{**}$ $P = 0.000$	$r = 0.757^{**}$ $P = 0.007$

* $p < 0.05$, ** $p < 0.01$, $N = 11$

DISCUSSION: Although differences were found in nocturnal and morning HRV, both methods showed similar trends. Nocturnal values exclude all external factors which may explain why values behave similarly but do not fully correlate. Changes in HRV and performance test between weeks were too small for a valid prediction of performance to be made.

CONCLUSION: Nocturnal and morning HRV may be able to reflect smaller changes in stress levels of young athletes than performance tests can.

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MEASURES OF IMPAIRMENT IN CROSS-COUNTRY SIT SKIING

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KEY WORDS: K-means, strength, trunk control, paralympics

INTRODUCTION: To date, classification in cross-country sit skiing is performed by a panel of classifiers. Even though classifiers are experts, a subjective decision making process is involved and there is a need for a new classification system based on scientific evidence (Tweedy 2011). The aims of the study were: (i) to assess if able bodied athletes and athletes with impairment performed differently in a new testing device and (ii) to identify minimum set of variables that would cluster athletes according to their impact of impairment.

METHODS: Five able bodied skiers and 14 elite sit skiers (LW10.5=1, LW11=2, LW11.5=3, LW12=8) volunteered. Athletes performed two strength (MVC) tests, without (MVC_{wo}) and with (MVC_w) a backrest, and one trunk control test that include forward and backward stimuli at 1 m/s² on the testing device (Figure 1). An anterior force sensor was used to assess forces in MVC_{wo} and ratio between forces MVC_{wo}/MVC_w. Two inertial sensors were used to calculate trunk range of motion in backward and forward stimuli. Correlations between variables were evaluated and cluster analyses (k-means) including strength and trunk control variables in different combinations were run.

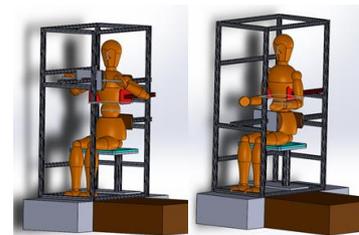


Figure 1. The new testing device

RESULTS: The ideal number of clusters was three and able bodied athletes were clustered together with athletes with low impact of impairment. Force in MVC_{wo} correlated with ratio ($r=.61$, $p<.01$) and with trunk range of motion in backward ($r=-.60$, $p<.01$) and forward ($r=-.53$, $p<.05$) stimuli. A very high correlation was also found between kinematic variables ($r=.95$, $p<.001$). The highest accuracy (equal to 95%) in clustering athletes was found when the four variables - anterior force in MVC_{wo}, ratio, and trunk range of motion in backward and forward stimuli were considered.

DISCUSSION: The three clusters identified represented high, middle, and low impact of impairment. Able bodied athletes and athletes with low impact of impairment were clustered together, suggesting that the new testing device evaluated impairment of upper body, limiting lower limbs contribution. Despite some correlations, the best accuracy was obtained when force and kinematic variables were used, defining this set as the minimum set of variables to cluster athletes.

CONCLUSION: Performing three tests and evaluating four variables allowed clustering athletes according to their impairment of strength and trunk control. After a validation on a larger data set, the new testing device may be considered in an evidence-based classification system.

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THE ATTRACTOR METHOD – A NOVEL TOOL TO HIGHLIGHT SUBTLE DIFFERENCES IN CROSS-COUNTRY SKI SKATING TECHNIQUES (V1 VS. V2)

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KEY WORDS: Cross-country skiing, skating technique, attractor method, roller skiing

INTRODUCTION: Distinguishing between various types of techniques in cyclic sports is essential in technical and tactical analyses. Applying the Attractor Method, and using all data from 5-minute intervals in two different cross-country skiing techniques (V1 & V2), generates data sets containing unique characteristics of each performance. This method allows a practical, cost-effective implementation into daily training procedures.

METHODS: Nordic skiers (8 female / 8 male) roller-skied on a treadmill for two 5-min intervals of V1 and V2, separated by a 5-min break. Grade and speed were determined by a previous VO_{2max} test.

Raw data were collected with five inertial sensors (RehaWatch by Hasomed) attached to both lateral malleoli, wrists, and at the TH6 vertebrae representing the torso. Acceleration data were collected at 8 G and 500 Hz (Fig 1.). Analysis for each interval was performed via the Attractor Method (Vieten, Sehle & Jensen, 2013) and Statistical Parametric Mapping (SPM; see Pataky, Robinson & Vanrenterghem, 2016).

RESULTS: Differences were found primarily at the extremes of movement between the techniques. The V2 technique was symmetrical while for V1 the dominant side was clearly evident for both arms and legs, but not for the torso ($p > 0.05$). V1 had more movement to the extremes, for both the arms and the legs, except for the arms moving up/down and side-to-side, where V2 moved more ($p < 0.05$).

DISCUSSION: Global characteristics of each technique across the skiers were similar, however, specifics of the technique between skiers were able to be visualized (i.e. symmetry). For example, longer drive and glide phases could be seen in an elite versus junior level skier. The latter's stride was shorter and more to the side than the elite.

CONCLUSION: The Attractor Method proved to be a sensitive means to analyze skiing motions and serves as a practical and cost-efficient tool to help coaches and scientists to get a deeper insight into athletes' performance. SPM enabled us to identify and highlight specific differences between the two skating techniques and individuals. This illustrates the advantage of using assessments, which are time and cost effective to analyze skating kinematics.

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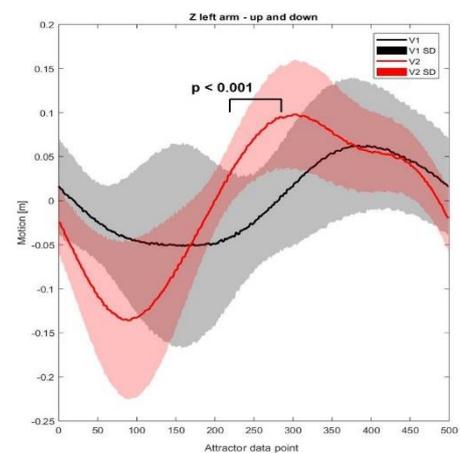


Fig. 1. Vertical wrist motion analyzed by SPM

Biomechanics in Alpine Skiing

Tuesday, 12th of March: 9:00–12:25

Keynote lecture

BRIDGING THE GAP BETWEEN SCIENCE AND PRACTICE IN WINTER SPORTS

David W. Bacharach

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KEY WORDS: Science, practice, winter sports, survey, gap

INTRODUCTION: Clearly from the time of Galen in 150 AD, and most likely before that, research has attempted to bridge the gap between science and practice. Impressive were August Krogh who won the 1920 Nobel prize for his work on capillary blood flow at rest and exercise as well as Per Olaf Astrand's seminal paper on physiological work capacity. But at no other time than present, have we witnessed an unprecedented acceleration in technology that could help bridge such a gap. This presentation will explore the perceptions of coaches and scientists as to the factors that help narrow a gap as well as barriers to overcome a gap between science and practice in worlds of Alpine and Nordic ski racing.

METHODS: From the initial survey in the Delphi technique, over 100 coaches and/or scientists, from 26 countries provided anonymous information about their background, experience, gender, education and their perceived factors and barriers to bridging the gap between science and practice. All data were compiled using Qualtrics.com survey procedures and relevant data were then coded and extracted from the responses.

RESULTS: The top ten (10) recorded factors that help bridge the gap between science and practice, in alphabetical order are listed in column A. The top ten (10) barriers to overcome a gap, in alphabetical order, are listed in column B.

Column A: Top 10 factors that help bridge a gap	Column B: Top 10 barriers to overcome a gap
Access to athletes by researchers	Antiquated information and resources
Assessment assistance for athletes	Athlete/coach driven research questions
Data base for fitness and training	Better model for sharing information
Education for coaches/athletes	Communication of coaches and scientists
History of embracing science to practice	Fear of losing the "old standard"
Improved technologies applied by coaches	Improved validity and application to athletes
Nutritional assistance	Making research understandable
Provide/participate in regional/national projects	Out of touch researchers
Rapid transfer of research to coaches	Provide funding for research efforts
Strong relationship between coaches and scientists	Reduce scientific language barrier

DISCUSSION: In the context of the model presented by Bishop (2008), results from the ranking by the experts will be presented as well as considerations from additional literature as it relates to the rank of each top 10 factors and barriers. Comparisons when appropriate may also be presented as it relates to differences between scientist, coach, experience, gender, and sport type.

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REVIEW ARTICLE

Invited lecture

APPLICATION OF POWER-FORCE-VELOCITY PROFILING TO “ICSS” DISCIPLINES

Josef Kröll, Isabella Fessl, Julian Fritz

Department of Sport and Exercise Science, University of Salzburg, Rif, Austria

KEY WORDS: P-F-v Profiling, performance diagnostics, alpine skiing, XC-skiing, ski-jumping

INTRODUCTION: The ability to produce high mechanical power output during ballistic push-offs is one of the main physical performance determinants in various skiing disciplines covered by the ICSS. Ballistic performances are determined by both the maximal power output (P_{max}) and their individual force-velocity (F-v) mechanical profile. Therefore, power-force-velocity (P-F-v) profiles are used increasingly more for the purpose of performance assessment of lower and upper limb anaerobic capacity (Morin et al. 2016). The promising aspect of these approaches is, that they allow for an accurate evaluation, monitoring, as well as (most important) a more individualized training practices (Jimenez-Reyes P., et al. 2017). The purpose of the current presentation will be twofold: i) To derive and present potential applications of the “Morin/Samozino” P-F-v-Profilng method for several skiing disciplines; ii) To compare lower limb P-F-v-Profiles of young elite athletes from alpine skiing (AS), cross-country skiing (XC) and ski-jumping (SJ) on group level, but also on individual level.

METHODS: In total 27 young elite AS, XC and SJ athletes (1.82 ± 0.06 m, 70 ± 7 kg, 17.9 ± 1.1 yr) performed vertical maximal squat jumps without loads and against four extra loads ranging from 20% to 80% Bodyweight. All trials were performed on a force plate. According to a standard data processing method (Samozino et al. 2008 & 2012), a P-F-v-Profile (P_{max} , F_0 , v_0 , Slope) was calculated for each athlete. Differences between the disciplines were assessed by one-way ANOVA.

RESULTS: As shown in Table 1, SJ and AS performed with similar Power but different F_0 - v_0 profiles as represented by the slope (AS F_0 dominant; SJ v_0 dominant). The XC Group performed with

Table 1. P-F-v-Profile parameters of different disciplines

	P_{max} [W/kg]	F_0 [N/kg]	v_0 [m/s]	slope [N.s/m/kg]
AS	$21.8_{\pm 2.3}^{XC}$	$33.5_{\pm 2.4}^{XC,SJ}$	$2.6_{\pm 0.4}$	$13.2_{\pm 2.8}^{SJ}$
XC	$17.1_{\pm 2.9}^{AS,SJ}$	$30.6_{\pm 3.6}^{AS}$	$2.2_{\pm 0.4}^{SJ}$	$14.0_{\pm 2.7}^{SJ}$
SJ	$20.9_{\pm 2.6}^{XC}$	$29.4_{\pm 2.4}^{AS}$	$2.9_{\pm 0.4}^{XC}$	$10.5_{\pm 2.2}^{AS,XC}$

lower Power and similar slope compared to AS. Individual results depicted, that athletes with similar power potentially show differences in F_0 and v_0 of up to 25%.

DISCUSSION & PRACTICAL APPLICATION: The main interest of the current approach is that the diagnostics and resultant training periodization are discipline specific, individualized and can easily be monitored. “ICSS”-discipline specific features were explored and individualization of the training is possible as shown above. Within the presentation, literature based examples of “upper body” P-F-v-Profilng as well as a novel approach of “strength-endurance profiling”, which both seem to be of high importance for XC and AS, will be presented too.

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MUSCLAR RESPONSES TO SKI WIDTH WHEN SKIING ON GROOMED AND POWDER SNOW CONDITIONS

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KEY WORDS: Ski width, powder skiing, EMG

INTRODUCTION: Wide skis (WS) were originally designed to be used in powder snow conditions where the design of the ski does not allow the skier to sink as deep into the snow as narrow width skis (NS). Previous work (Seifert et al., 2016) reported EMG responses were greater on WS than NS. However, that study was performed on groomed snow. The purpose of this study was to compare the EMG responses from different width skis skiing on groomed (GR) and powder (POW) snow.

METHODS: Three expert level skiers completed runs on groomed snow and in 33 cm of POW. The snow had a reported water content of 4.5%. Underfoot widths for NS and WS were 67 mm and 95 mm, respectively. EMG was collected from four turns once skiers reached stable skiing speed. RMS analyses were performed on *gluteus medius* (GM), *gluteus maximus* (GX), *rectus femoris* (RF), *vastus lateralis* (VL), and *biceps femoris* (BF). Turns were divided into 3 phases (P1, P2, P3).

RESULTS: Skiing in POW generally led to greater muscle activity than GR. GM activity was highest for WS in P1,P3 and highest in P2,P3 for NS during POW and GR. GX activity was consistent except for high activity during P1 for WS in POW. RF activity was highest in P1, P3 for WS in POW and P2, P3 for NS in POW. VL activity was high in P3 on GR and POW for WS and high during P2 on GR and POW for NS. BF was highest in P3 for WS in POW and during P1 in GR and POW for NS.

DISCUSSION: Skiing in POW generally elicited greater EMG activity than GR for both skis. Rotary action was dominant during P3 for WS and in P2, P3 for NS. There appeared to be greater loading at the end of the turns for WS as noted by high activities in P3 but these activities generally occurred in P2 for NS. Muscle activity was usually lower during P2 of the turn for WS whereas it was elevated in P2 for NS.

CONCLUSION: There were substantial differences in EMG activity between NS and WS. It is assumed that the high activity levels seen for NS occur near the apex of the turn whereas they occur late in the turn with WS due to turn shape. This may be due to the WS characteristic to rise in the snow surface during a fall line turn.

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BIOMECHANICAL ANALYSIS OF JUMP LANDINGS IN COMPETITIVE ALPINE SKIERS: CROSS-SECTIONAL OBSERVATIONS FROM YOUTH TO ELITE LEVEL

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KEY WORDS: Athletes, alpine ski racing, vertical drop jump, neuromuscular performance, dynamic valgus, injury prevention

INTRODUCTION: Competitive alpine skiers are prone to suffer from severe injuries, such as a rupture of the anterior cruciate ligament (ACL).¹ In this connection, limited neuromuscular control (i.e. dynamic valgus) is considered to be a key injury risk factor.² The aim of the present study was to provide reference data on medial knee displacement (MKD) during vertical drop jumps in competitive alpine skiers.

METHODS: 142 competitive alpine skiers were investigated: 108 youth athletes (45 female, 63 male; age: 13.8 ± 0.60 y) and 34 elite athletes from the Swiss Ski national teams (18 female, 16 male; age: 22.3 ± 2.7 y). By the use of a skin marker-based 3D motion capture system (*Vicon Motion Systems Ltd, UK*), athletes' MKD during vertical drop jumps (VDJ) were assessed (Figure 1). Differences in mean MKD during jump landing were tested for significance ($p < 0.05$) using a one-way analysis of variance (ANOVA), including post hoc testing with Bonferroni correction for pairwise comparison. Pearson correlations between mean MKD, maturity offset (in youth athletes only), body height and weight were calculated.

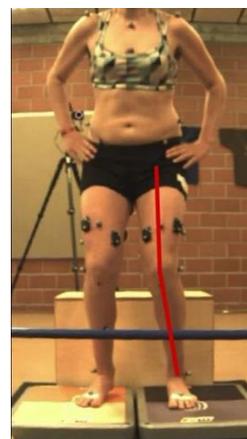


Figure 1. Medial knee displacement during a vertical drop jump (VDJ).

RESULTS: In youth athletes, mean MKD was found to be significantly larger in females (26.2 ± 1.7 mm) than in males (19.0 ± 1.4 mm). In elite athletes, no gender differences were observed. Moreover, in both female and male youth athletes, mean MKD significantly correlated with body height, weight and maturity offset, while in elite athletes no correlations with anthropometrics were observed. No differences in MKD were found between youth and elite athletes.

DISCUSSION: The results demonstrate a larger MKD in youth female skiers than in males and a positive relationship between mean MKD, body height, weight and maturity offset in youth competitive alpine skiers in general. Interestingly, there is no improvement of medial knee stability in the course of an athlete's career from youth to elite level.

CONCLUSION: Particular caution should be taken in finding training solutions to circumvent knee instability already in younger age, especially for females. This could potentially tackle future knee stability problems at older age.

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SKICROSS-STARTING FACILITY: INDOOR VS. SNOW STARTS**Carlo Denier^{1,3}, Fabian Mösching¹, Silvio Lorenzetti², Björn Bruhin^{1,2}**¹ Swiss-Ski, Muri bei Bern, Switzerland² Swiss Federal Institute of Sport Magglingen SFISM, Magglingen, Switzerland³ Department of Sport, Exercise and Health, University of Basel, Switzerland**KEY WORDS:** Skicross, start performance, force measurements

INTRODUCTION: The start of the ski cross is an important factor to master (Argüelles, De la Fuente, Tarnas & Dominguez-Castells, 2011) in order to dominate during the competition. In the summer, the skiers of the Swiss national team have the opportunity to train their starts in an indoor facility. It is crucial to ensure that indoor training closely simulates the training on the snow.

METHOD: In addition to time parameters (start time, runtime), the force of the skiers on the handles of the start gate during takeoff and the speed immediately after takeoff were measured in a volunteer group of 14 members of the Skicross National team (9 men, 5 women). The measurements were carried out, in each case, at two different starting positions: a start on steep terrain and a start on a flat track (maximum 5 meters flat) with a subsequent terrain transition. In order to compare the two start tests on the indoor unit and on snow, correlations of the different force parameters were calculated.

RESULTS: The maximum force and the maximum force increase correlated strongly in both conditions with the runtime. The speed seemed to be less correlated to force parameters and runtime on the indoor facilities.

Tab. 1. Correlation coefficients between run time, exit speed, and maximum (Max) force and rate of force development (RFD).

Place	Condition	Start Setup	Run time		exit speed	
			Max Force	RFD	Max Force	RFD
Biel	Indoor	steep	-0.63	-0.70	0.40	0.45
Saas Fee	Outdoor	steep	-0.47	-0.51	0.45	0.48
Biel	Indoor	flat	-0.68	-0.64	0.67	0.67
Balzers	Indoor	flat	-0.45	-0.56	-0.03	0.05
Saas Fee	Outdoor	flat	-0.53	-0.55	0.40	0.37

DISCUSSION: A limiting factor, especially in the indoor facilities, was the missing technical elements after the start. These could have possibly influenced the launch technique, as it is possible that the athletes aimed to achieve the best starting results, and then neglected the track after the initial measurements.

CONCLUSION: Start training on the indoor system simulates the start on snow well. The lower correlation of maximum force and maximum power increase with speed on the indoor facilities can be explained by the greater friction on the ground. On steep starts, when the start transitions from flat to steep terrain, the technical ability to manage the transition plays an important role in the skier's speed.

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PERFORMANCE OF THE POLE-PUSH DURING STARTS IN ALPINE SKIING

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² Department of Sport, Exercise and Health, University of Basel, Switzerland

KEY WORDS: Alpine skiing, start performance, force measurements

INTRODUCTION: Performances between athletes during their start sections can demonstrate a substantial difference, and can influence the finishing time (Supej & Cernigoj, 2006). Skate-pushes and pole-pushes are the predominant parts of the start movements. The aim of this study was to analyse the key parameters of the pole-pushes at the starts.

METHODS: During preparation for the 2018/2019 skiing season, eleven female members of the Swiss alpine skiing Europa Cup Team (age: 21.9 ± 1.7 y; weight: 62.2 ± 5.5 kg) practiced starts on a slope with a 22° inclination, on average. Each athlete performed four starts with three pole-pushes. The peak force, impulse and contact time were measured for every pole-push, with transducers located in the handles of the poles. Time was measured by a standard photocell system. Velocity was monitored with Global Navigation Satellite System (GNSS) sensors.

RESULTS: The 3 impulses showed significant differences from each other (27822.6 ± 5578.0 Ns vs. 7057.9 ± 2611.7 Ns vs. 3614.8 ± 1026.8 Ns) ($p = 0.00$). Post-hoc tests showed that only the first trial's peak force (709.4 ± 175.9 N) and the first trial's contact time (0.70 ± 0.12 s) were significantly higher and longer, respectively, than during the second and the third pole-pushes ($411.1 \text{ N} \pm 102.9 \text{ N}$ vs. $375.4 \text{ N} \pm 73.3 \text{ N}$; $0.29 \text{ s} \pm 0.07 \text{ s}$ vs. $0.18 \text{ s} \pm 0.02 \text{ s}$) ($p = 0.00$). No correlation was found between the force data that was measured in the pole (impulse, peak force and contact time) and time, or with the speed data.

DISCUSSION: The kinetic data of the pole forces did not explain the time and the speed of the starts. This observation may support the importance of the performance of skating steps and the strategy that is utilised (Supej et al., 2018; Kröll et al., 2012)

CONCLUSION: The present study showed the kinetic data of the pole forces during pole-push starts of alpine skiing, for the first time, and the data was implemented as a training tool during start training. Further studies should integrate the analysis of the direction of force during pole-pushes, combined with the data of the skating steps.

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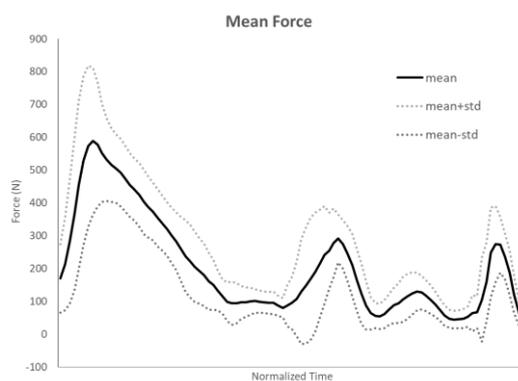


Fig. 1. The summed force data of all trials over the start section with ± 1 SD.

BIOMECHANICAL EFFICIENCY OF DIFFERENT STARTING TECHNIQUES IN SKI CROSS

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KEY WORDS: Ski cross, kinematics, pulling force, starting technique

INTRODUCTION: Previous investigations in ski cross concerned the influence of pre-activation, the start slope inclination and other aspects (Ebenbichler 2012, Nedergaard 2014). The aim of this study was to investigate the influence of the height of the handles and the use of specific technique strategies during the starting phase.

METHODS: Force transducers (3-axial, 200 Hz) acquired the forces applied to both the handles. Two cameras (50Hz) recorded the lateral and frontal motion sequences. A photocell system (Microgate) recorded the time performance for the first 5 m (T_Mgate, slope of 34°). After the start, athletes also performed a supplementary pushing with their poles. 3 techniques were chosen: personally free (PF_T); with prevalent arm and shoulder impulse (AS_T) and with a previous full body vertical extension (BE_T). The handles were located at 3 different heights (H= 82, 88 and 92 cm). Six elite athletes of the Italian national team were involved (20,2 Y, 178,3 cm, 78,2 kg). They had to perform 3 attempts for each possible grouping factor.

RESULTS: The main kinematic and dynamic results are shown in Table 1. Best T_Mgate was obtained with PF_T technique, while the handles heights showed no significant effects. Maximal resultant velocity after start (Vm_Gait) was highest for AS_T technique and for H-2 handle's height (88cm). Maximum resultant force and normalized force impulse were observed for BE_T and H_1. In order to evaluate the efficiency, we defined the biomechanical cost as the ratio between the force impulse and the obtained CG velocity, for both the resultant and horizontal component (Irel/VCG, Irel/VxCG). The lower this value, the higher the efficiency. Thus, according to the resultant CG velocity, the AS_T technique and the H_3 height show the better values.

Table 1. Kinematics and dynamic parameters grouped for techniques and handgrips height

Parameter		PF_T	AS_T	BE_T	H_1	H_2	H_3
T_M-Gate	s	1,52 ± 0,05	1,56 ± 0,06	1,55 ± 0,04	1,55 ± 0,05	1,54 ± 0,05	1,54 ± 0,06
T_react	s	-0,06 ± 0,03	-0,06 ± 0,04	-0,06 ± 0,05	-0,05 ± 0,04	-0,05 ± 0,05	-0,07 ± 0,03
Vm_Gait	m/s	3,76 ± 0,36	3,88 ± 0,34	3,84 ± 0,37	3,87 ± 0,38	3,89 ± 0,35	3,72 ± 0,32
Vm_Final	m/s	4,74 ± 0,20	4,71 ± 0,16	4,69 ± 0,19	4,71 ± 0,17	4,74 ± 0,18	4,68 ± 0,19
V_ELBO_flex	Deg/s	-179,7 ± 69,8	-215,8 ± 80,6	-115,6 ± 55,7	-131,6 ± 57,5	-170,5 ± 82,7	-205,0 ± 83,6
V_ELB_est	Deg/s	158,0 ± 96,6	228,1 ± 128,6	112,1 ± 57,3	146,2 ± 69,4	155,4 ± 114,6	195,7 ± 129,4
Fmax_tot	N	1007,6 ± 112,9	944,2 ± 136,0	1024,0 ± 132,5	1017,5 ± 95,3	985,3 ± 138,3	975,0 ± 151,2
IFR/BW	N/kg	4,64 ± 0,61	4,18 ± 0,53	4,80 ± 0,56	4,79 ± 0,12	4,57 ± 0,84	4,27 ± 0,67
Irel/VCG		1,41 ± 0,16	1,25 ± 0,12	1,45 ± 0,11	1,43 ± 0,15	1,36 ± 0,16	1,32 ± 0,14
Irel/VxVG		1,51 ± 0,16	1,40 ± 0,14	1,52 ± 0,11	1,54 ± 0,13	1,48 ± 0,15	1,42 ± 0,15

DISCUSSION/CONCLUSION: Technique PF_T show better total time performance. On the other hand, technique AS_T shows an overall better biomechanical efficiency, whereas technique BE_T produces the greatest force impulse. It seems that an optimal combination of the elbow flexion with the hip extension should generate a maximal VCG with minimization of the VyCG. Highest handles heights induce the greatest loss in velocity and in vertical forces.

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ANALYSIS OF THE FIRST ACCELERATION PHASE OF THE FEMALE DOWNHILL WORLD CUP IN GARMISCH-PARTENKIRCHEN 2018

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KEY WORDS: Biomechanics, alpine skiing, start performance

INTRODUCTION: In alpine ski racing, every athlete and coach put a lot of effort into optimizing the equipment and skiing technique to gain hundredths of a second. The start out of the gate and the acceleration phase is part of the race and can make, depending on discipline and steepness of the race slope (Supej et al.; 2018), the difference about winning or losing the race. Kröll et al. (2010) observed differences in start performances and the potential influence on the race performance. He and his colleagues recommend for example the training of basic xc-skating elements, like leg push off or poling action. This study investigate the strategies and techniques used during the starting phase of a female World Cup downhill race.

METHODS: All 43 athletes of the women FIS World Cup downhill race 2018 in Garmisch-Partenkirchen have been recorded with four synchronized high-speed cameras. With the software Simi motion (Simi Reality Motion Systems GmbH, Munich, Germany) and the DLT (Direct Linear Transformation) method, the velocity during the first 50m of the start phase were calculated.

RESULTS/DISCUSSION: The number of pole strokes differ between two and five. The speed after 50m is with 17,8m/s slightly higher with more strokes, compared to 17,4m/s, but not significant. In a qualitative analysis, huge differences have been observed. The number of skating steps varies greatly, as well the technical quality during the acceleration phase is very different between the athletes and makes an objective evaluation difficulty. The frequency of the pole strokes is also a factor for an effective start.

CONCLUSION: This analysis shows that in World Cup racing different starting strategies and techniques are used. The number of pole strokes varies greatly, with affecting speed and time. An objective evaluation is due to the different quality of the technical execution difficult.

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Physiology and Training in Cross-Country Skiing & Biathlon

Tuesday, 12th of March: 14:30–16:55

Keynote lecture

MODERN TRAINING CONCEPTS IN CROSS-COUNTRY SKIING

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Cross-country skiing competitions demand interval-based, high-intensity endurance efforts, while employing a multitude of different sub-techniques across the hilly terrain. To overcome these demands, the world's best skiers have developed some of the highest aerobic powers ever measured in humans, in combination with a fine-tuned skiing technique. Accordingly, endurance training is indeed the major component of an elite cross-country skier's program. However, the sport has developed tremendously over the last decades, and the new competition formats require complex technical and tactical skills as well as the ability to master high-speed attacks and the finish-sprint of competitions. Skiers therefore need to design their training to concurrently improve their aerobic endurance capacity and high-speed ability, as well as technical and tactical expertise. In this keynote, I will discuss the evolution of training concepts in cross-country skiing.

Among the best skiers, the major component of the 750-950 hours of annual training is endurance, of which around 80% is performed as low-, 4-5% as moderate- and 6-8% as high-intensity training. Low- and moderate intensity training provide a physiological and technical foundation that seems to be needed for long-term development, and since this comprise 85% of the overall training time, consciousness of training quality also during these sessions are of particular importance. Competitions account and long intervals (>3 min) make up around 40% of the annual high-intensity sessions, whereas the remaining 20% include a combination of short and sprint intervals. In all cases, a main emphasis should be on the choice of exercise mode and terrain. Accordingly, an integrative understanding of physiological, biomechanical, tactical and mental aspects is required to concurrently develop these factors during all sessions.

Cross-country skiers have also shown a unique ability to build up and sustain a relatively large and strong muscle mass whilst, at the same time, having an outstanding endurance capacity. Accordingly, this keynote will provide examples and discuss how world-class skiers implement strength and speed training in their long-term endurance training schedule, in order to build up strength and power in the preparation period and to maintain strength and develop speed in the competition period. This is done using individualized, movement-specific strength programs aiming to improve speed abilities, skiing technique, exercise economy/efficiency and to delay fatigue.

In all abovementioned cases, the daily decision-making process, leading to minor adjustments in the training program, is imperative for optimizing both training quality as well as training-adaptations to the unique characteristics of each skier. Here, new technological solutions might provide decision-support and help us to further enhance performance. To achieve optimal adaptations from these sessions we additionally need to understand and optimize recovery, and remember the fact that elite athletes are humans with daily-life struggles, emotions and health issues like the rest of us. While all these factors can be difficult to control or predict, they need to be taken into consideration in the training process. This holistic approach to training and recovery might be the most important to implement in future training concepts.

Invited lecture

BIATHLON – HAS THE SPORT CHANGED DURING THE PAST DECADES AND CAN SCIENCE KEEP UP?

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KEY WORDS: Rifle carriage, shooting, skiing, technique,

The biathlon is an Olympic sport that combines rifle marksmanship and cross-country skiing with the skating technique while carrying a rifle. Biathlon is a demanding endurance sport requiring extensive aerobic capacity and involving other considerable physiological demands similar to those associated with competitive cross-country skiing (Hoffman and Street, 1992; Holmberg, 2015; Sandbakk and Holmberg, 2014). The technical complexity including wide range of speeds and slopes involved requires biathletes to alternate continuously between and adapt different skating sub-techniques during competitions, and thus, places a premium on efficiency. At the same time, precise fine motor control for fast and accurate shooting under mental pressure is required (Vickers and Williams, 2007). Therefore, many different factors, including body sway, triggering behavior, and even psychology, influence the shooting performance.

Since its introduction in Olympic Games at 1960 many new events such as sprint, pursuit, mass-start and different relay competitions have been introduced. The development of the skating technique in the 1980s (Smith, 1990), in combination with substantial improvements in equipment, track preparation, and training, has increased the average skiing speeds in biathlon competitions considerably (Laaksonen et al. 2018). Meanwhile, the time spent on the shooting range has decreased together with minor improvements in shooting accuracy among the best biathletes. Thus, the competition level seems also to be tighter.

Regardless of the popularity of biathlon and its complexity, the scientific research in biathlon is lacking behind. Today, the Pubmed database provides approximately 8-fold less scientific publications related to biathlon in comparison to cross-country skiing or rifle shooting. Although much of that knowledge is probably applicable to the biathlon, carrying the rifle and shooting under stress make biathlon somewhat unique. Thus, research on several different aspects of biathlon is needed.

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Invited lecture

LIMITING CARDIOVASCULAR FACTORS OF CROSS-COUNTRY SKIING PERFORMANCE

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University of Turku, Finland**

KEY WORDS: Heart, skeletal muscle, endurance, performance, cross-country skiing

Although the importance of other elements has also increased, maximal oxygen consumption remains to be one of the most important variables determining endurance exercise performance, including cross-country skiing. Maximal oxygen consumption is strongly genetically determined, but is also affected by total blood volume, particularly red blood cell (hemoglobin) mass and it appears that training performed at early childhood has an important effect on hemoglobin mass.

Research has also importantly shown that when more than half of the whole body skeletal muscle mass is engaged in maximal exercise, muscle oxygen consumption is limited by oxygen supply. This means that especially in cross-country skiing muscular oxygen consumption and thus performance is largely determined by the maximal blood pumping capacity of the heart (Lundby et al. 2017). As maximal heart rate is not much affected by training or is even reduced in highly performing endurance athletes, the main factor determining maximal cardiac output, and thus maximal blood pumping capacity, is stroke volume. Stroke volume may be at least partly genetically determined, but can also be improved by endurance training. However, different exercise training modes affect cardiac adaptations differently, and if training leads to concentric type of cardiac enlargement, this may not be favorably associated with endurance performance. Pronounced cardiac hypertrophy may namely associate negatively with myocardial circulatory variables and it remains to be confirmed whether heart's own blood flow is the main limiting factor for cardiac output, and thus ultimately for maximal oxygen consumption and endurance exercise performance.

Nevertheless, during submaximal exercise endurance-trained athletes document reduced blood flow both in heart and skeletal muscles, as oxygen extraction and blood mean transit times are higher (Heinonen et al. 2014; Koga et al. 2014). These adaptations reduce circulatory demands during submaximal exercise, and together with high stroke volume, explain classical endurance training adaptations such as reduced heart rate during exercise. Thus, also peripheral oxygen extraction can be improved by endurance training, but this adaptation still plays a limited role in comparison to systemic (largely cardiac) features explaining limiting factors of endurance exercise performance also in cross-country skiing.

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INFLUENCE OF TORSO MOVEMENT DEVIATION ON METABOLIC ECONOMY DURING V1 AND V2 SKATE TECHNIQUES

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KEY WORDS: Attractor method, nordic skiing, roller skiing

INTRODUCTION: Speed and efficiency of Nordic skiing may be influenced by technique-specific ski-cycle alterations (Sandbakk et al., 2012). Skate techniques affect the propulsive forces generated from poling and may ultimately affect the metabolic economy of performance (Millet et al., 1998). Importantly, the consistency of effective movement patterns that are characteristic to the V1 and V2 skate technique may be related to the metabolic cost of the movement. Thus, the purpose of this study was to determine if a relationship exists between the economic cost and movement variability measured during the V1 and V2 skate techniques.

METHODS: Elite Nordic skiers (n = 17) performed two, 5-min skating bouts at a consistent workload using the V1 and V2 techniques. Metabolic economy was defined as the mean oxygen consumption (VO_2 ml/kg/min) of the final minute of work. The deviations from average movement paths were calculated using the Attractor method (Vieten et al., 2013). Data were gathered with inertial sensors (8 G, 500 Hz) placed above both malleoli and wrists, and the 6th thoracic vertebrae (torso). Correlations of absolute differences in V1 and V2 economy (δVO_2) and movement deviation (δD) were analyzed for each body part.

RESULTS: Torso attractor δD was significantly associated with δVO_2 ($p = 0.018$, $r = +0.565$). There were no significant correlations for the legs or wrists ($p > 0.05$).

DISCUSSION: Positive correlations suggest that metabolic economy differences between V1 and V2 techniques are associated with torso movement variability. Because core and torso musculature has a high force generating capacity, this association may indicate that torso movement variability affects the skier's ability to apply an effective propulsive force to the poles. Greater cycle time spent in the propulsive poling phase is associated with high speeds and grades (Millet et al., 1998), and may allow for higher developed forces in the musculature.

CONCLUSION: A skier's ability to utilize both the V1 and V2 techniques without sacrificing metabolic expenditure is an important element of performance. Thus, economical torso movement patterns to maximize propulsion may be a determinant to competitive performance in elite Nordic skiers.

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ANALYSIS OF THE U23 CROSS-COUNTRY SKI WORLD CHAMPIONSHIP 2018 SPRINT: RELATIVE TERRAIN PERFORMANCES AND SEX DIFFERENCES

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KEY WORDS: Cross-country ski sprint, pacing strategy, terrain performance, sex difference

INTRODUCTION: The cross-country ski sprint prologue involves a 2 – 4 minute long effort on varying terrain with only the top 30 skiers advancing to the subsequent heats. Qualification success not only depends on physiological and technical capacity, but also on optimal pacing strategy and appropriate relative efforts in the various terrains (Sandbakk et al., 2011).

METHODS: During the U23 Cross-Country Ski World Championships 2018 freestyle sprint prologue in Ulrichen (SUI), skiing performance in flat, uphill and downhill terrain was analyzed for female (N = 43) and male (N = 64) skiers using time-synchronized video recordings. Relative performance indices for the three different terrains were calculated ($V_{\text{terrain}} / V_{\text{average}}$). A Spearman’s rank order correlation for the terrain indices ranking and overall prologue ranking was calculated and potential sex differences regarding performance in the various terrains were analyzed by ANOVA.

RESULTS: Terrain index rank correlations are shown in Table 1. Male skiers demonstrated higher uphill indices than females 0.62 ± 0.01 vs. 0.57 ± 0.02 ($p < .001$), with no significant differences found for flat and downhill terrain indices (both $p > .05$).

Table 1. Spearman’s rank correlation coefficients for terrain index rank and overall prologue performance and corresponding level of statistical significance.

	Overall prologue rank	
	Women	Men
Flat index rank	-0.42**	-0.24
Uphill index rank	0.59***	0.57***
Downhill index rank	-0.39*	-0.50***

* $p < .05$; ** $p < .01$; *** $p < .001$

DISCUSSION: A higher relative skiing effort for uphill terrain appeared to be correlated to overall rank in the investigated cross-country ski sprint prologue for both female and male skiers. At the same time, relative skiing performance in flat and downhill sections were negatively correlated to overall rank in the prologue, indicating a smaller relative effort and/or significance. Furthermore, male skiers demonstrated higher relative skiing velocities in the uphill track sections compared to female skiers, which was not observed regarding relative flat and downhill terrain efforts.

CONCLUSION: The current study identified higher relative velocities invested during uphill terrain in faster skiers compared to slower skiers at an international freestyle sprint skiing competition, supporting the importance of performance indicators for uphill terrain. In addition, the difference in the relative effort investment between female and male skiers appeared to be only present in uphill terrain, indicating a sex differences in performance concerning uphill relevant performance factors and/or pacing strategy.

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SEX-BASED DIFFERENCES IN SPEED AND SUB-TECHNIQUE SELECTION DURING AN INTERNATIONAL COMPETITION IN CLASSICAL XC-SKIING

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KEY WORDS: Competition analysis, sex differences, endurance sport

INTRODUCTION: Previous research has shown that the well-known diversity in anthropometric and physiological capacity between men and women leads to differences in skiing speed, sub-technique selection and temporal patterns during cross-country (XC) skiing training and competitions. However, the position devices utilized have had limited accuracy, and data from world-class skiers in international competitions are lacking. Therefore, the main aim of this study was to investigate sex-based differences in speed, sub-technique selection and temporal patterns in an international FIS regulated competition.

METHODS: Eight men and eight women skied three laps (men) or two laps (women) in the classical style on a 4.6-km competition track while wearing an integrated 10-Hz GNSS and inertial measurement unit (Optimeye S5, Catapult Innovations, Melbourne, Australia) in a pocket in the upper part of the race bib. The elevation profile was measured using a high-end differential, multi-frequency and multi-GNSS receiver (Alpha-G3T, Javad, San Jose, CA, United States). Sub-technique classification was done using a K-Nearest Neighbour algorithm with per-distance classification accuracy of 96%.

RESULTS: Women/men spent 32/45, 45/30 and 5/3% of the time and 35/43, 27/16 and 4/2% of the distance in the sub-techniques double poling (DP), diagonal stride (DIA) and DP with kick (DK), while the remaining time/distance was spent in miscellaneous sub-techniques (MISC), including tucking and turning. Here, there were significant differences between sexes for DP and DIA (both $P < .001$). Men skied 16% faster than women overall ($P < .001$), but within the different sub-techniques there was no difference in average speed for DP (both 5.6 m/s), and DK (4.0 vs 3.9 m/s, $P = .10$), whereas 6% and 9% differences were found for DIA (3.2 vs 3.0 m/s, $P = .04$) and MISC (10.4 vs 9.3 m/s, $P < .001$), respectively. Men and women had different preferred sub-technique on 20% of the overall distance (i.e., 11% for inclines $< 2^\circ$, 54% for inclines between 2 and 5° , 7% for inclines $> 5^\circ$). A higher speed threshold was found for transitions from DIA to DP for men than women (4.0 vs 3.7 m/s, $P = .01$), but not from DP to DIA (3.6 vs 3.9 m/s, $P = .14$). However, men transitioned at a steeper incline both from DP to DIA (2.5 vs 1.3° , $P = .02$) and DIA to DP (5.4 vs 4.4° , $P = .002$). The steepest uphill climb had a near-constant incline, in which the final transition to DIA occurred later for men compared to women (81 m vs 32 m, $P < .001$).

CONCLUSION: The higher speed in men compared to women is associated with men's ability to apply "high-speed" sub-techniques in larger parts of the course. More specifically, these men utilize DP instead of DIA in hills with an incline between 2 and 5° , due to transitioning both from DIA to DP and from DIA to DP at steeper inclines, and due to a later transitioning to DIA in hills with constant incline.

BLOCK VERSUS TRADITIONAL PERIODIZATION OF HIT: A COMPARISON OF TWO ROADS LEADING TO ROME FOR THE WORLD'S MOST SUCCESSFUL CROSS-COUNTRY SKIER

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KEY WORDS: Endurance training load, training intensity, intensity distribution

INTRODUCTION: Block periodized (BP) high-intensity training (HIT) is shown to be an effective strategy in short-term studies. Still, long-term studies, and detailed investigations of the micro, meso- and macro periodization utilizing BP of HIT in world-class endurance athletes is currently lacking. In a recent study, we showed that the most successful XC-skier ever utilized two different periodization models with success throughout her career (Solli et al., 2017), namely an extensive use of BP of HIT, and a traditional method (TRAD). In this case-study, the main aims are to compare the long-term utilization of BP of HIT and TRAD in two successful seasons by the world's best XC skier, and to provide a detailed description of her long-term utilization of BP of HIT.

METHODS: The participant is the most decorated winter Olympian with 8 Olympic gold medals, 18 world championship titles and 114 world cup victories. Training data was systemized as previously described (Solli et al., 2017) and combined with qualitative interviews.

RESULTS: No significant difference was found in the weekly endurance-training load (ETL) between the BP-year (1058±368 TRIMP) and the TRAD-year (1084±339 TRIMP). Average weekly training volume during the TRAD-year was higher compared to the BP-year (18.0±6.7 vs. 15.2±5.8 h, $P=0.001$), which could mainly be explained by more LIT time (14.8±5.3 vs. 12.6±5.2 h/wk, $P=0.003$), and in particular more LIT sessions >90 min (4.7±2.5 vs 3.3±2.4 sessions/wk). The total number of MIT sessions was higher in the TRAD-year (38 sessions) compared to the BP-year (12 sessions), and accordingly weekly MIT time was higher (0.6±0.6 vs. 0.2±0.3 h/wk, $P<0.01$) in the TRAD-year. In contrast, the number of HIT sessions was higher in the BP-year (157 sessions) compared to the TRAD-year (77 sessions), and the weekly HIT time was higher (1.6±1.1 vs. 0.7±0.6 h/wk, $P<0.01$). Seven HIT-blocks with a duration of 7-11 days including 8-12 HIT sessions were performed during the general- and specific preparation phase in the BP-year, with the average time between HIT-blocks being 27±12 days. The HIT sessions performed during HIT-blocks was distributed as 33% running, 25% running with poles, 11% double pooling and 19/16% skating/classical skiing or roller skiing.

CONCLUSION: This study gives novel insights into the utilization of two different periodization models by a world class XC-skier. The study highlights that more than one way of organizing HIT sessions can be successfully used in XC-skiing.

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EFFECTS OF UPPER-BODY MAXIMUM STRENGTH TRAINING ON DOUBLE POLING PERFORMANCE ON FEMALE SKIERS

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KEY WORDS: Strength training, double poling

INTRODUCTION: Skating and modern double poling require great upper-body power output and thus it has become one of major success factors in contemporary cross-country skiing (Sandbakk & Holmberg 2014). However, a recent study by Skattebo et al. (2016) suggests that increased upper-body strength after linear strength training has no effect on DP performance in young female skiers. The aim of the present study was to examine if double poling performance could be improved by a specific upper body nonlinear strength training program of eight weeks in female participants.

METHODS: 7 female cross-country skiers (age $21,5 \pm 4,9$ years) were split into two groups, one performing 8 weeks of nonlinear heavy maximal upper body strength training ($n=3$) and the other acting as a control group ($n=4$). Both groups also carried on their normal training schedule but control group was advised to avoid heavy strength training. All subjects underwent pre- and post intervention tests measuring body composition, reference maximal oxygen uptake ($VO_{2maxREF}$), upper body strength (BP_{1RM} , BP_{VOL} and PD_{1RM}), maximal DP velocity (V_{max}) and maximal oxygen uptake during DP (VO_{2maxDP}), DP intra-cycle timings, blood lactate concentration (BL) on 3-minute intervals and skiing time (DP_{TIME}) during double poling on a treadmill. All tests except $VO_{2maxREF}$ were repeated after the intervention. Shapiro-Wilk test was used as a test of normality for each variable and based on its results either nonparametric Wilcoxon-test or a t-test was used.

RESULTS: No significant changes in body mass or fat percent were detected in either group. Strength training group (S) managed to improve on every strength test (BP_{1RM} +15 % ($p < 0,05$), BP_{VOL} +26,8 % and PD_{1RM} +14,7 %) whereas control group (C) showed changes of -2,5 %, -14,0 % and +4,6 % respectively. Both S and C improved their end time on short and long tests, but S had bigger gains (+51,0 % ($p = 0,005$) vs. +24,3 % ($p < 0,05$) and +18,9 % ($p < 0,05$) vs. +5,3 %). Relative VO_{2maxDP} increased 0,3 % (S) and 9,6 % (C). BL decreased on every measure point for both groups except for BL_{PEAK} which increased for both S and C. BL_{POST} was significantly lower than BL_{PRE} for S on 12th and 15th minute of the long DP test ($p < 0,05$).

DISCUSSION/CONCLUSION: Contrary to the study of Skattebo et al. (2016) increased strength of group S was accompanied with improved double poling performance indicated by better (higher) long test end time and only small change to VO_{2maxDP} . Differences might be explained by differences in the strength training method (nonlinear vs. linear) and by testing method (treadmill vs. DP ergometer).

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Posters: Nordic Skiing - Alpine Skiing - Technology

Tuesday, 12th of March: 17:10–18:30

Topic: Nordic Skiing

BIOMECHANICAL EFFICIENCY IN ELITE ATHLETES OF SPRINT ROLLER SKI

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KEY WORDS: Skiroll, sprint, kinematics, technique

INTRODUCTION: international competition in sprint roller ski (SRS) represent an interesting investigation field, also for possible comparison with the corresponding performance in sprint cross-country skiing (SCCS). Previous investigations analyzed the kinematic and kinetic characteristics of SCCS and SRS under laboratory conditions (Stoeggli, 2010, 2014) but not under competitions. According to previous classification (Sandbakk 2014) the technique used here corresponds to the V2-alt (also G4), i.e. where the poling movement is synchronized with the leg push-off on one side (the strong side). Thus, in the present study, we collected the data at the final World Cup Competition 2016 in Trento. The aim of this study was to investigate the biomechanical characteristics of elite athletes.

METHODS: The total competition distance (154m) was divided in 10m sections with markers on the floor. Each athletes performing his qualification trial was filmed with two systems. One camera (50Hz) was positioned at 7m height from the ground and at about the middle of the entire distance; this permits to calculate the average velocity of each 10m section and, consequently, the whole time-history of CG velocity.

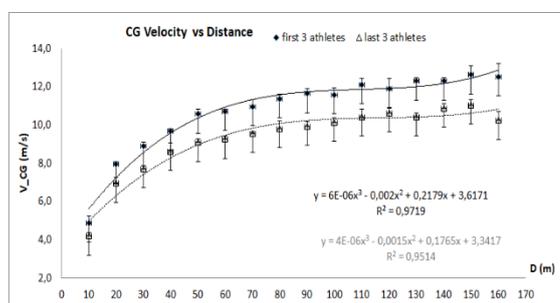
For 3-D kinematic analysis (full body and tools stick; 24 points) two other cameras (50Hz), located ahead of the 100m marker (i.e. at maximal velocity), recorded the lateral and frontal motion sequences along a 30 m section. 13 athletes were taken into the analysis (26,3±6,7 Y, 180,2±7,2 cm, 73,8±8,1 kg). Anthropometric measures were also taken for later correlation analysis.

RESULTS: The CG velocity development in the whole distance for the best 3 and the last 3 athletes is shown in fig.1 (top). Higher acceleration in the first 50 m, as well an increment of final CG velocity is achieved by the best athletes. Among the relevant 3-D parameters we found a significant correlation between the VCoG velocity and: total cycle time, cycle frequency, pushing time of the strong leg, recovery time of the arm, and trunk angle at pole plant (fig. 1 bottom)

DISCUSSION/CONCLUSION: Frequency cycle and timing of elbow flexion-extension seem to be a discriminant between best and weak performances. No significant relationships were founded between VCoG velocity and the antropometric parameters.

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CL (m) (cycle length)	10,0±0,7
CT (s) (cycle time)	0,90±0,11
CF (Hz) (cycle frequency)	1,1±0,1
TApr (s) (time arm propulsion)	0,21±0,08
TAre (s) (time arm recovery)	0,72±0,11
TLSp (s) (time strong leg propulsion)	0,61±0,10
TLWp (s) (time weak leg propulsion)	0,40±0,11
VCGave (m/s)	10,2±0,6
VCGmax (m/s)	12,1±0,8
Acc_CG_ave (m/s ²)	0,5±0,1
Acc_CG_max (m/s ²)	2,4±0,4

Fig.1 most relevant 2-D (top) and 3-D (bottom) kinematic parameters

EFFECTS OF DRAFTING ON VO₂ IN DOUBLE POLING XC-SKIING**Mats Ainegren¹, Vesa Linnamo², Stefan Lindinger^{3,4}**¹Sports Tech Research Centre, Mid Sweden University, Östersund, Sweden² Faculty of Sport and Health Sciences, University of Jyväskylä, Finland³ Center for Health & Performance, Department of Food and Nutrition and Sport Science, University of Gothenburg, Sweden⁴Department of Sport and Exercise Science, University of Salzburg, Rif, Austria**KEY WORDS:** Wind tunnel, drafting, oxygen uptake

INTRODUCTION: XC-skiing is a sport where the skiers are often in the immediate vicinity, in front of or behind, with their fellow competitors in the track. Thus, the aim of this project was to investigate the influence of drafting on energy expenditure and air drag in double poling cross-country skiing.

METHODS: 10 XC-skiers of each gender took part in the study carried out in the wind tunnel at Sports Tech Research Centre, Mid Sweden University (Ainegren et al. 2018). Two skiers were roller skiing at the same time on the large

treadmill and in line with the flow (Figure 1), one skier in the front and the other skier behind (drafting), using the double poling technique on low to high speeds ranging from 3 to 6 m/s for females and from 3 to 7 m/s for males. After a 30 min break the skiers changed place with each other and the same protocol was repeated. Skiing economy (VO₂) was measured with Douglas bags simultaneously from both skiers.

RESULTS: VO₂ was lower at all skiing speeds for both genders when drafting but for men the difference was significant only from 5 m/s and for women at 6 m/s (Table 1). At the highest speed (men 7m/s, women 6 m/s) VO₂ was 3.8 ± 0.3 % lower in men and 2.2 ± 0.4 % lower in women when drafting.

Table 1. Results of VO₂ (L/min) for leading and drafting, men and women. Mean \pm SD.

Speed m/s	Men		Women	
	leading	drafting	leading	drafting
3	1.63 \pm 0.11	1.60 \pm 0.13	1.36 \pm 0.13	1.31 \pm 0.14
4	2.06 \pm 0.13	1.98 \pm 0.16	1.74 \pm 0.15	1.68 \pm 0.16
5	2.59 \pm 0.14	2.48 \pm 0.19*	2.33 \pm 0.22	2.27 \pm 0.26
6	3.45 \pm 0.19	3.23 \pm 0.21*	3.20 \pm 0.37	3.09 \pm 0.38*
7	4.77 \pm 0.32	4.48 \pm 0.30*		

* Significant difference vs leading.



Figure 1. Two xc-skiers being tested.

DISCUSSION/CONCLUSION: It is clear that drafting in double poling has a positive influence on skiing economy especially at racing speeds where the influence of air drag is more substantial. Due to larger body size and higher racing speeds, the influence of drafting is greater for men. This may give new insights for tactical race perspectives, how to run training sessions and how to define testing and race profiles on treadmills due to the influence of wind.

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SAME BUT DIFFERENT. ARE THERE DIFFERENCES IN TECHNIQUE AMONG TRAINING AND COMPETITION IN YOUTH CROSS-COUNTRY SKIING?

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KEY WORDS: Cross-country skiing, technique, double poling, junior elite sports

INTRODUCTION: In cross-country (XC) skiing technique is an important performance prerequisite and an essential feature of long-term athlete development (1). Focus on improving the technique lies mostly in training, but the transfer in the competition is rarely examined. The aim of this study is to evaluate technical characteristics of young XC skiers in training and competition to determine biomechanical differences.

METHODS: Approximately 100 young XC skiers (14-15 years) will be captured in an official training and a 2km race of the German Youth Cup in January 2019. Three high-speed cameras (Canon HFG30) will record the athletes from a sagittal view while performing double poling on a 20m flat part of the track in three different settings: a) training: focus on optimal technique at self-selected speed, b) training: focus on skiing at maximum speed, c) competition. Training settings are divided into a) and b) considering the influence of speed (2). To eliminate effects on technique due to fatigue (3) the measurement section is located 20m after the start of the competition. The section time will be measured in all settings by two light barriers. Markers are going to be placed on anatomical landmarks of the subjects. A 2D video analysis (Mess-2D, IAT, Leipzig, Germany) based on the marker positions enables identification of four key variables: *range of trunk motion, pole contact length and pole angle, location of the centre of mass at pole contact* (3, 4). The mean of three cycles is going to be analysed. A multivariate ANOVA of repeated measures will be applied to check for statistical differences between the different settings (a, b, c).

RESULTS: Results can be shown after the analysis in January 2019. We expect biomechanical differences in skiing technique between training with focus on technique (a) and competition (c). We also assume to find variations while skiing with either focus on technique (a) or on speed (b). A further assumption is that the best-ranked athletes show a more stable technique with fewer differences between the settings than the lower ranked athletes in the competition (4).

DISCUSSION & CONCLUSION: The results will be discussed against the backdrop of previous literature and experience of successful XC skiing coaches. Identifying the causes in execution (e.g. attentional focus, speed, coach instructions) is the subject of further investigation. The outcomes will aim at supporting the methodology of technique training and the design of a technique assessment in youth XC skiing.

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DEVELOPMENT OF A FRAMEWORK FOR INVESTIGATING PERFORMANCE, PHYSICAL AND TECHNICAL DEMANDS IN PARA CROSS-COUNTRY SIT SKIING: A CASE STUDY

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KEY WORDS: Paralympic, race course analysis, GPS

INTRODUCTION: Most of the endurance-training done by cross-country (XC) sit skiers is low-intensity training (LIT), whereas high-intensity training (HIT) sessions are performed 1 to 3 times each week to develop competition-specific technique and related physiological capacities. In order to better understand the physiological and technical demands of both LIT and HIT, as well as performance demands in XC sit skiing, this pilot study aimed to provide a framework for investigating speed, technique and heart rate across the different terrain sections of a race course.

METHODS: We tested a XC sit skiing athlete of the LW12 class with a single above-the-knee amputation (age: 46 years, body mass + sit ski, skies, poles: 68 + 4.2 kg, VO_{2peak} : 52.7 mL·kg⁻¹·min⁻¹, peak heart rate: 195 beats·min⁻¹, pull-down 1RM: 115 kg). The athlete was equipped with a Garmin Forerunner 920XT GPS and heart rate monitor and an inertial measurement unit (IMU) at the right forearm. Two 20-m maximal speed (V_{max}) tests in both flat and uphill terrain were performed, followed by three laps of 1.9 km at LIT and HIT in varying terrain. Ski-snow friction was determined before and after skiing and air drag was measured for various body positions in a wind tunnel. Power output was calculated during the V_{max} -tests, and in the same uphill and flat section during LIT and HIT, as the sum of power against gravity (P_g), ski-snow friction (P_f) and air drag (P_d).

RESULTS: 51, 28 and 21% of the time during HIT and 53, 28 and 19% of the time during LIT were spent in the uphill, flat and downhill terrain, respectively. Maximal speed was 4.0 and 6.2 m·s⁻¹ in the uphill and flat section, respectively, and maximal power output was 331 W (P_g : 65%, P_f : 31%, P_d : 4%) and 253 W (P_g : 17%, P_f : 65%, P_d : 19%), respectively. The % of maximal speed did not differ between the uphill and the flat section (HIT: 66 vs 67%, LIT: 47 vs 50%, both $p>0.51$). The % of maximal power output tended to be lower in the uphill than flat section (HIT: 63 and 76%, LIT: 45 and 55%, both $p<0.11$). However, the absolute values of power output were not significantly different between the uphill and flat section (HIT: 228 vs 206 W, LIT: 160 vs 149 W, both $p>0.29$). Furthermore, cycle rate was significantly higher for HIT than LIT (59 vs 48, 60 vs 45 and 60 vs 52 cycles·min⁻¹, respectively, in the uphill, flat and downhill terrain, all $p<0.04$). In contrast, cycle length was not different in HIT and LIT (3.1 vs 3.0, 5.5 vs 5.4 and 6.6 vs 5.8 m, respectively, in the uphill, flat and downhill terrain, all $p>0.1$). Furthermore, % of peak heart rate was significantly higher in HIT than LIT (90 vs 78, 85 vs 67 and 88 vs 66%, respectively, in the uphill, flat and downhill terrain, all $p<0.001$).

CONCLUSION: Both in HIT and LIT, most time was spent in uphill terrain and heart rate fluctuations across varying terrain were greater in LIT, whereas a more stable heart rate was seen for HIT. In more detail, the increase in speed from LIT to HIT was mainly due to increases in cycle rate, whereas cycle length showed to be less affected by intensity. The integrative framework developed in this study can be used in future investigations of performance, technical and physical demands in standing and sitting Para XC skiing and similar sport activities.

AIMING ACCURACY IN BIATHLON STANDING SHOOTING PERFORMANCE

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KEY WORDS: Aiming, triggering, optoelectronics, postural balance, technique

INTRODUCTION: Ihalainen et al. (2018) observed stability of hold, cleanness of triggering and postural balance to be related to biathlon standing shooting performance. The present study investigated, whether aiming accuracy and timing of triggering, which in air rifle shooting have been observed to be important (Ihalainen et al. 2016), would be related also to biathlon standing shooting performance.

METHODS: 23 biathletes (12 men and 11 women, 20.0 ± 3.8 years old) fired 8x5 standing shots at rest (REST) and 2x5 shots during a race simulation of 2x5 min at 95% of maximal heart rate (RACE). Mean values in both conditions were calculated for shooting performance (SP, distance of the hit point from the center of the target), horizontal and vertical (DevY) stability of hold (standard deviation of the aiming point 0-0.6 s before the shot), aiming accuracy (COG, mean distance of the aiming point 0-0.6 s before the shot), cleanness of triggering (ATV, distance travelled by the aiming point 0-0.2 s before the shot), timing of triggering (TIRE, time period when the mean location of the aiming point is closest to the center of the target: 0-0.2 s before the shot = 3, 0.2-0.4 s = 2, 0.4-0.6 s = 1), and postural balance (PB) of the whole body and each leg (SDY_R, rear leg sway in shooting direction).

RESULTS: The most important components related to SP were ATV, DevY, COG and SDY_R (table 1). PB, especially SDY_R, was related to ATV, DevY and COG, and decreases in DevY, COG and PB were related to increases in TIRE.

Table 1. Pearson correlations to shooting performance.

Variable	REST	RACE
ATV	0.75***	0.63**
DevY	0.57**	0.56**
COG	0.52*	0.45**
SDY_R	0.63**	0.58**

***p<0.001, **p<0.01, *p<0.05

DISCUSSION/CONCLUSION: The present study confirmed findings of the study by Ihalainen et al. (2018), as cleanness of triggering, holding ability and PB were observed to be among the most important technical components for a controlled shooting process, and PB had also an indirect effect due to its relationship to ATV and DevY. In addition to those, the present study showed that also aiming accuracy is related to SP and PB. Further, decreased balance and technical abilities may alter pre-shot processes. In addition to holding ability and cleanness of triggering, it may be beneficial to focus on aiming accuracy, which could be accomplished by bringing the aiming point as close to the next target as possible already before holding breath. Further, a continuous development of postural control is recommended.

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COMPARISON OF GLIDING AND GRIP PROPERTIES OF DIFFERENT TYPES CLASSICAL CROSS-COUNTRY SKIS

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KEY WORDS: Cross-country skiing, static friction, kinetic friction, ski waxing, force production

INTRODUCTION: Various methods such as skin-skis, nanogrip skis and also grip tape exist to replace the normal grip waxing in classical cross-country skiing. The aim of this study was to examine how these different skis and the grip tape influence skis' gliding and grip properties and skiers' leg force production in different conditions.

METHODS: The dry old and wet snow field tests were carried out on Vuokatti ski tracks and the dry artificial snow field test was carried out in Vuokatti ski-tunnel. The laboratory tests were conducted at the dry and the wet old snow conditions with a linear tribometer (Linnamo et al. 2008). Two active cross-country skiers (75 kg and 85 kg) tested grip waxed, grip tape, skin and nanogrip skis. Skiing times were measured with a photocell timing system on a same terrain point on a constant 47,5 meter up- or downhill (in the ski track 4,4° and in the ski tunnel 4° without poles) zone. In the grip tests the cycle characteristics and the legs force production were collected over 10 sequential cycles with the force plates attached to ski bindings (Ohtonen et al 2013).

RESULTS: Snow humidity resulted to differences between the skis (Table 1). For example, in the wet old snow condition the time of nanogrip skis in a gliding test decreased by 66,6% and the grip tape skis horizontal force producing capability decreased by 54,7% when comparing to the dry artificial snow condition.

Table 1. Gliding times (s), maximum uphill horizontal force (N) and friction coefficient (μ) in different conditions

Ski	Glide time (s)			Max. uphill horizontal force (N)			Kinetic friction (μ)	
	dry old snow (75/85kg)	wet old snow (75/85kg)	dry artificial snow (75/85kg)	dry old snow (75/85kg)	wet old snow (75/85kg)	dry artificial snow (75/85kg)	dry old snow (75/85kg)	wet old snow (75/85kg)
Normal	9.92 / 9.64	9.40 / 9.45	11.27 / 10.70	222 / 285	331 / 325	263 / 248	0.0465 / 0.0466	0.0351 / 0.0329
Tape	9.77 / 9.61	9.23 / 9.40	11.15 / 10.55	215 / 323	113 / 161	250 / 251	0.0573 / 0.0517	0.0396 / 0.0326
Skin	10.37 / 10.25	9.25 / 9.24	11.48 / 10.77	227 / 231	219 / 243	239 / 241	0.0683 / 0.0662	0.0543 / 0.0528
Nano	21.70 / 15.09	12.01 / 11.44	22.04 / 14.54	244 / 297	295 / 300	139 / 160	0.0542 / 0.0512	0.0540 / 0.0424

DISCUSSION/CONCLUSION: Gliding properties were somewhat similar in all ski types expect for nano which was the slowest and most affected by air humidity. With a grip tape, especially for heavier skier, it was possible to get good grip properties for the rough and the artificial snow condition. For active cross-country skiers skiing should be enjoyable with enough grip and skis preparation before skiing should not take too much time from skiing itself. Therefore, when making a ski selection, conditions where the skis will be used should be considered.

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Topic: Alpine Skiing

THE POWER PROFILE OF THE MAXIMUM ANAEROBIC POWER OF ALPINE SKIERS

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KEY WORDS: Alpine skier, anaerobic power, power profile, force type/speed type

INTRODUCTION: Alpine skiers require both aerobic and anaerobic capacity particularly for explosive power and stretching-shortening cycle exercise performance capacity (Raschner et al. 2013). We classified the power characteristics of the force velocity relation generated during counter movement jump utilizing various additional loads generating two divergent profiles: speed type and force type (Hoshino 2013). The purpose of this study is to clarify the force-velocity characteristics of alpine skiers by classifying the maximum anaerobic power into force type and speed type by brief dynamic exercise using a bicycle ergometer which excludes the stretch-shortening cycle. In other words, we will clarify whether one power profile--speed or force type--are more prevalent or desirable for successful alpine athletes.

METHODS: This study consisted of seven subjects in alpine skiers. Maximum anaerobic power tests were measured at the using a Power Max V II stationary bike. Subjects performed 10-second pedaling at 3%, 5%, 7.5%, 9%, 11%, 13%, 15% load per body weight. The rest period between each pedaling exercise was 2 minutes. Maximum anaerobic power was measured three times: at the end of the 2017 competitive season (June 2017), at the beginning of the 2018 competitive season (September 2017), and at the end of the 2018 competitive season (June 2018).

RESULTS: Fig. 1 shows the average power values for each % load studied and the resulting power profiles indicative of speed and force types. Table 1 shows the averages of the seven athlete's maximum anaerobic power and corresponding load values obtained during the three trials.

DISCUSSION: The maximum anaerobic power values at the end of the two studied competitive seasons than the values obtained at the end of the summer training session (table 1).

CONCLUSION: The data suggests that competitive alpine skiing develops force type power, while off-season training develops speed type power. It seems that force type power development would best enhance alpine skier performance.

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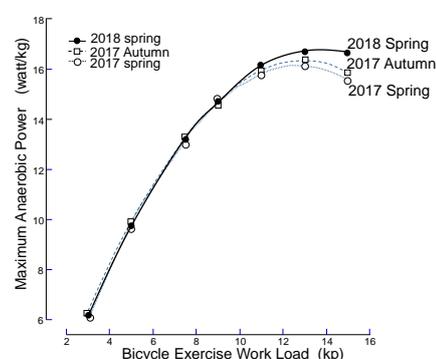


Fig. 1. Average power values for each % body weight load are show.

Table 1. The maximum anaerobic power and corresponding load values.

Date of measurement	Maximum Anaerobic Power (watt/kg)	Load Value at Peak Maximum Anaerobic Power (kp)
2017 June	17.6±1.5	10.2±2.0
2017 September	16.9±1.3	9.2±1.0
2018 June	18.0±2.5	10.5±1.8

Mean value ± SD

LONG-TERM MONITORING OF POWER CAPABILITIES OF PRE PUBERTY AGE SPORTSMEN IN ALPINE SKIING

Kamil Povrazník

Magnet Sport Consulting, Diagnostic Centre of Sports, Poprad, Slovakia

KEY WORDS: Relationship between fitness and techniques, force dysbalance, long-term follow-up of athlete, dynamic changes in hip and lower limb dysbalance, health prevention

INTRODUCTION: Long-term monitoring of athletes' performances and their development during the annual training cycle but also in the long-term sporting training create assumption for: prevention of injuries to the athlete, individual management of sports training, optimization of sports training preparation load, correct choice of testing methodology and diagnostics for given sport

METHODS: A total of 14 alpine skiers aged between 10 and 15 (7 girls and 7 boys) were included in the long-term diagnosis of power capabilities. Power skills control was performed 3 times during the training year: A total of 12 control measurements were performed from 3.5.2014 to 3.11.2018. Measurement of isometric power is performed by the Mobil Power Test System, which is based on the principle of registering the muscular power with a strain gauge power sensor. We chose to diagnose the isometric power of the straight abdominal muscles, the spine deflectors, the four-headed thigh muscle and thigh retractors, the Illinois test, and the optojump.

RESULTS:

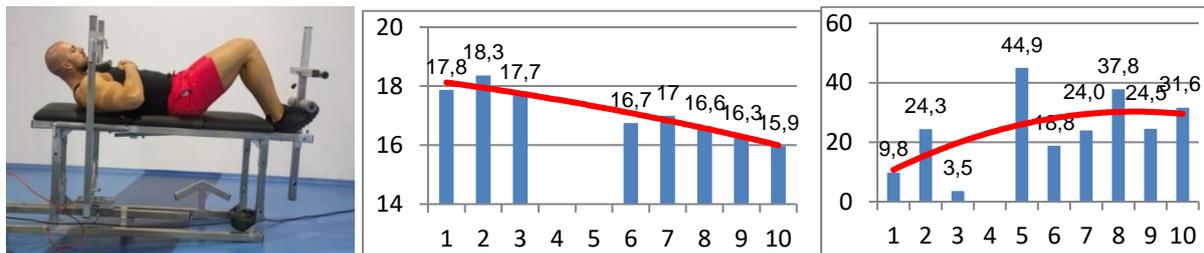


Fig. 1. Measuring device, Coordination Test, Strength Dysbalance / Backbon

All monitored athletes experienced a gradual improvement in coordination skills over the period under review. The evaluation of the dysbalance of the maximum isometric power output between the direct abdominal muscles and the spine marker points to the very dynamic nature of the muscle work ratio during the diagnosis period.

DISCUSSION: These results indicate:

1. importance of long-term multiple diagnosis of fitness during the training year
2. the existence of power dysbalance already in the pre-puberty age of the athlete
3. changes in the level of the upper and lower limb dysbalance
4. the importance of regular diagnostics for the management of the sports training methodology

BALANCE AND RECREATIONAL ALPINE SKIING ARE IN A CAUSATIVE RELATIONSHIP

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KEY WORDS: GYKO, ski school, motor ability, development

INTRODUCTION: Alpine skiing is characterized by non-standardized movements. To manage the ski turns and improve technique, specific motor abilities are required. We aimed to determine importance of balance during initial phases of learning as well as the influence of alpine skiing on balance.

METHODS: 96 participants were randomized into two equal groups. Balance was assessed for both groups on a balance board enabling movements in the antero-posterior (AP) way. Gyko instrument was positioned in the central, part of the standing surface. Variable assessing balance was absolute AP displacement of instrument from starting point either to anterior or posterior direction in centimetres. Participants performed test with ski boots on. After testing, experimental group participated in 10-day ski-school, while controls refrained from physical activity. Two days after experimental group completed ski-school, test was repeated for all participants.

RESULTS: Participants' baseline characteristics were comparable. There were no differences in initial balance results. Differences in the initial and final test were insignificant for the controls. Experimental group achieved better results after ski-school (IN-35.93 ± 12.62, FIN- 27.68 ± 9.70; p=0.00). Improvement was evident for participants with poor (IN-47.36 ± 11.11, FIN-32.86 ± 10.90; p=0.00), and with better initial results (IN-27.77 ± 4.93, FIN-23.98 ± 6.78; p=0.02).

DISCUSSION: Ski-school affects balance in recreational skiers. Experimental group improved while control stagnated in balance, suggesting skiing was responsible for positive effects. The essence of ski technique is controlling skies during dynamic conditions. To be successful, skier must attain balance. Ski-school includes learning lateral and circular movements in legs and proper timing of moving center of gravity and its return to central position. To maintain balance, skier must direct inner forces from the center of body mass to the foot and outer ski, where the contact with surface should be placed. Skiing provides the opportunity for constant balance, which leads to its development. Ski boots are important for shielding the ankle and foot from injuries, directing skies and finding balance on skies. But they limit the movements which negatively affects the ability to maintain central balance position while skiing. Therefore, beginners usually have a wider position on skies and a larger support surface. As they improve, they are better in maintaining balance in narrower position.

CONCLUSION: Balance is important for learning ski basics, and vice versa, ski school improves balance.

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ALPINE SKIING STARTS ON SNOW VERSUS ON MATT PLANTS

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KEY WORDS: Alpine skiing, start technique, biomechanical analysis, force measurement

INTRODUCTION: Alpine skiing races are often decided by hundredths of a second (Pozzo, Canclini, Cotelli, Martinelli, & Röckmann, 2001). One important part of an alpine skiing race is the start. Only a few scientific papers have analysed this part of the race. The objective of this study was to compare alpine skiing starts on the snow versus on a matt plant.

METHODS: Five female members of the Swiss alpine skiing Europa Cup Team practised starts on both setups. The athletes performed four starts on each setup. Pushing forces were measured with transducers that were located in the handles of the poles. Time was measured by photocells for the following two parts of the track (16.1m and 68.8m from the start on the matt plant; 23.85m and 102m from the start on snow): a high-speed video camera recorded the release of the start gate and another camera recorded the whole track. Coaches and scientists provided instant feedback to the athletes at the end of each trial. The collected data was statistically analysed with Pearson correlation coefficient.

RESULTS: The correlation of rank between the two setups was high (0.80, $p < 0.05$), meaning that fast starters on the matt plant were fast starters on the snow, as well. Both setups showed significantly negative correlations between the force at the gate push-off and the time at which the skiers finished (-0.52, $p < 0.05$ on the matt plant; -0.48, $p < 0.05$ on snow). The mean correlations of force and time were higher for the matt plant than for snow. The mean start gate push-off force was significantly higher on the snow (329.4 ± 75.6 N vs. 282.5 ± 73.1 N, $p < 0.05$) and the mean force of the skiers' pole-push, on the second and third pole-push, were significantly higher on the matt plant (195.8 ± 57.4 N vs. 168.4 ± 35.7 N, $p < 0.05$; 199.6 ± 71.6 N vs. 139.9 ± 30.7 N, $p < 0.05$).

DISCUSSION: The starts on the snow and on matt plant were very similar. Pole pushing forces seemed to be more important on the matt plant. This can be explained by the higher resistance of the matt plant and can be utilised as an additional stimulus in training. The influence of the skating steps can only be estimated. The decreasing correlations of pole force and time indicated a greater importance of the skating steps on faster surfaces, such as snow.

CONCLUSION: This study showed that alpine skiing starts that are on a matt plant and on snow depend on similar performance parameters. This indicates the high value of training on the matt plant in preparation for the winter.

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3D KINEMATIC ANALYSIS OF DIAGONAL STRIDE IN ELITE SKI MOUNTAINEERING (SKIALP) DURING WORLD CUP RACES

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KEY WORDS: Ski alp, 3d reconstruction

INTRODUCTION: In recent years the ski mountaineering (SKIALP) has become more and more popular, and SKIALP skiers improved their technical and physiological performances. Due to the complex multiparametric environment conditions (air and snow temperature, track, techniques, gradients, boots, ski) and the relatively recent development of the discipline, there is a lack of specific studies especially under race conditions. On the other hand, technique and physiological analysis comparing normal race and treadmill conditions have been undertaken (Canclini 2007, Haselbacher 2014, Tosi 2009, Pozzo 2016). The purpose of this study is to investigate the kinematics of elite skiers during high level competition.

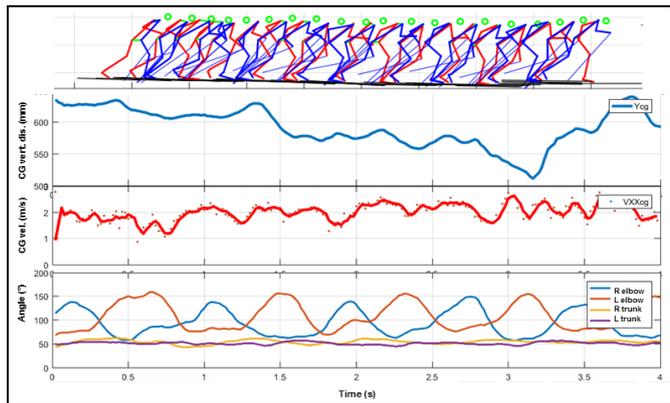


Figure 1. Stick diagram and kinematic parameters

METHODS: Data collection was performed in 2016 and 2017 during two World Cup sprint qualifications. Dedicated software for video analysis (DLT method) was used (Baroni 1998). For each race, a minimum of 5 top male skiers were analyzed on an uphill section (21°-11°) where the athletes performed Diagonal Stride (DS).

RESULTS: Figure 1 shows an example of stick diagram model, along with the typical patterns of the main kinematic parameters. Specific kinematics parameters were calculated for each athlete and with respect to the left/right symmetry patterns (Table 1) and were reported as the mean value averaged on 4 movement cycles. Angles-vs-angles plots were used to investigate individual coordination patterns.

DISCUSSION/CONCLUSION:

Table 1. kinematic parameters

Some of the considered parameters seem to correspond with those related to classical cross/country performance (e.g. CL, CT, Vave). However, the inter-subject variability in SKIALP is greater than in CC (Canclini 2007). This

Terrain/ Technique – gear	Uphill 21°/38% - DS	Uphill 11°/20% - DS
Subject N – number of	N = 5 - 4 cycles	N = 5 - 4 cycles
CL (m) (cycle length)	1.75 ± 0.10	2.56 ± 0.37
CT (s) (cycle time)	0.87 ± 0.05	0.91 ± 0.20
% Time-Poling / CT	61% ± 2%	49% ± 4%
CoG Vert. Displacement (m)	0.07 ± 0.02	0.10 ± 0.02
Vave (m/s)	2.00 ± 0.06	2.85 ± 0.33
Elbow Angle (°) at PP	90 ± 23	80 ± 7
Elbow Angle (°) min	75 ± 6	73 ± 7
Trunk Angle (°) at PP	50 ± 4	32 ± 5
Poles Angle (°) at PP	51 ± 3	52 ± 4

investigation represents a preliminary global biomechanical analysis of SKIALP during a competition. The obtained results need to be reinforced by additional data to be collected about selected elite skiers.

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Topic: Technology

ACCURACY AND PRACTICABILITY OF A MAGNET AND MAGNETOMETER-BASED SPLIT-TIME SYSTEM IN SKIING

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KEY WORDS: Race analysis, section times, magnetic field

INTRODUCTION: The official timing companies provide already a small amount of split-times during ski races and the times and mean speeds in specific track sections are measured by expensive photocell systems. Due to the high relevance of detailed split-time information during racing and training there is a need for an accurate low-cost alternative system. First attempts have been done to use magnetometer systems during Paralympic Games 2018. Aim of this study was to investigate the accuracy of a low cost magnetometer split-time system for use in skiing in order to generate detailed time information during racing and training.

METHODS: Split-times were measured by photocells (Ergotest Innovation, NOR) and a magnetometer-magnet system in the LAB (4m). Disk magnets (Supermagnete, GER) were placed at two orientations (perpendicular + parallel to skiing direction) exactly at photocells. The magnet distances were from 0.1 m - 0.5 m (each 0.1 m) to examine this influence. Inertial measurement units (IMU, SparkFun, US; 100 Hz) were fixed on a stick, moved in two velocities (slow and fast) along a runway. Average differences (+SDs) (accuracy) were calculated in each situation (factor 1] magnet position; 2] distance; 3] speed).

RESULTS: The mean absolute difference (to photocell) in all 60 trials was 33 ms. The factor speed did not affect accuracy at all (diff 33.6 ms [at 1.5 m/s] vs 33.0 ms [at 3 m/s]). Magnet orientation showed effects with the perpendicular orientation showing higher accuracy (18,4 ms ± 25,0 ms vs. 51,2 ms ± 41,8 ms). The distance of 10 cm to the magnet showed highest accuracy with 17 ms (vs. 46 ms (20 cm) and 38 ms (30 cm)). The signal peak recognition by Mat lab analysis was best at 10 cm where at 50 cm no spikes could be recognized anymore.

DISCUSSION & CONCLUSION: The placement and orientation of the magnets affected the accuracy of the split-time measurements which gives practical hints how to use those systems during racing and training. While speed had no influence on accuracy, the perpendicular orientation at 10 cm was the most accurate. This set-up can be used in classic cross-country ski races and most likely also in Alpine skiing, Snowboarding and other sports. Further investigations (stronger magnets; further distances) at also faster speeds are required.

SKI TESTER DEVELOPMENT FOR CROSS-COUNTRY SKI TESTING

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KEY WORDS: Ski testing, linear tribometer, gliding, friction coefficient

INTRODUCTION: First version of the skitester (figure 1) was introduced in 2008 (Linnamo et al. 2009). Since that the ski tester has been used for national ski teams to develop the quality of the Finnish ski service. Linear tribometer for cross-country ski testing has also been introduced e.g. in Austria (Hasler et al. 2016), but to the best of our knowledge the present linear tribometer in Vuokatti is exclusively capable to simulate classic kick in addition to sliding friction testing. The aim is to describe how the tribometer has been developed over the past years.



Figure 1. Linear tribometer

METHODS: Environment control: Originally introduced tribometer located inside Vuokatti ski tunnel, where manipulation of environment variables was impossible. Current ski tester locates in an own insulated container where air (cooling 8kW, warming 2kW) and snow (cooling 4kW, warming 2kW) temperature can be selected separately. **Measurement of forces:** Originally forces were measured under the track with force plates (6m). In the current version measurement sensor has been moved to the sledge where the ski is attached. **Measurement area:** Originally position of the sledge was defined only with mechanical switches. Currently sledge position and forces can be defined for over the whole track length (10 m with 0,075 mm accuracy). As an example gliding and grip properties of classic skin and normally waxed skis were measured in -5° and 0°C temperatures.

RESULTS: Skin skis gliding friction changed by -20.8% and grip friction by 101.0% from cold (-5°C) to warm (0°C) temperature In normally waxed skies in the same setup, change in glide friction was similar (-26.7%), but the grip friction change was smaller (14.8%).

DISCUSSION: Adjustable temperatures have opened new possibilities in ski testing such as calculation of the relative changes between two different waxes in two conditions. Changes made to the force measurement have decreased the unwanted changes in track thus improving the quality of the measurements. However, deformation and creation of the snow and lack of humidity control remain as limitations for ski testing with the current linear tribometer.

CONCLUSION: Improvements made to the linear tribometer open new insights for ski and wax testing despite the limitations in snow condition. Better ski track simulation is the aim of further development.

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A FEEDBACK SYSTEM TO TRAIN START PERFORMANCE IN SKI CROSS

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KEY WORDS: Force measurement, fast feedback, coaching, winter sports

INTRODUCTION: The importance of a successful start in ski cross has been stressed in observational studies. Biomechanics studies have identified at least two fundamentally different starting techniques using divergent segmental sequencing during the start action (Nedergaard et al., 2015). This study aimed at using feedback from force measurements to tune the start in elite athletes. It was hypothesised that force feedback alone would improve start performance.

METHODS: Ten elite ski cross athletes from the Swedish and Finnish national teams (height 177 ± 8 cm, mass 77 ± 12 kg) were tested on repeated occasions over a period of 3 months. They were provided with feedback on kinetic parameters as measured by force sensors built into the handles of a training start gate (Figure 1). Force data were recorded by DasyLab software and immediately imported into MatLab, providing visual and numerical feedback for the athlete and coach immediately after each start action. Descriptive statistics were used to compare between tests.



Figure 1. Skier in the start gate with coaches handling the feedback system in the foreground.

RESULTS: On average there were no substantial or significant changes in any of the force parameters analysed for this comparison. Out of the 10 athletes only 4 improved their starting performance as assessed by force measurements and a standard timing gate system.

DISCUSSION: The chosen feedback derived from grip force measurements was not successful in altering the performance for this group of athletes. However, some individuals improved their horizontal impulse by 10% which is substantial. Obvious limitations are that the required coaching instructions are unknown and that the athletes were elite such that changes may remain small.

CONCLUSION: Despite the current result such a feedback may be of particular benefit during reconditioning following injuries. Especially, in combination with kinematic assessments fed into biomechanical models a better foundation for the type of coaching instructions may be achieved.

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HOW CAN XSENS KINEMATIC SUIT ADD TO OUR UNDERSTANDING OF A SLALOM TURN: A CASE STUDY IN LABORATORY AND FIELD CONDITIONS

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KEY WORDS: Alpine skiing, kinematic analysis, model values, ski simulator training

INTRODUCTION: Kinematic analysis with XSENS kinematic suit enables information on body position during every part of a slalom turn, as well as the position of center of mass and position of the inner and outer leg during all phases of a turn. The aim was to investigate technique of a slalom turn.

METHODS: Participant was a 25.1 years old female alpine skier, former competitor. 20 variables for each specific slalom turn were analyzed during 3 situations; on a Pro ski up simulator, free skiing slalom and skiing in a predefined slalom corridor. 26 turns in each situation, 13 in each side were analyzed. Measured kinematic parameters included angles in ankle, knee and hip joints and distance between projection of a body mass and inner and outer foot in relation to the axis of turn rotation. Slalom turn was defined by average duration of slalom turn in predefined corridor. Metronome was used to determine the duration of the turn in free skiing and simulator.

RESULTS: Slalom turn performed on a simulator differs statistically significant in all kinematic parameters from turns performed during free slalom skiing and skiing in a predefined slalom corridor ($p=0.00$). Additionally, we found significant differences between variables hip abduction and flexion ($p=0.00$); knee flexion ($p=0.00$); and distance of the projection of centre of mass relative to the left and right foot in left turn ($p=0.00$); during free slalom turn and slalom turn in a predefined slalom corridor.

DISCUSSION: It should be emphasized that all variables were analyzed during the same position of a ski turn in all 3 situations; while participant was parallel with the fall line of the slope. This is the moment where skies are further apart from the projection of the center of the body mass, measured in centimeters, and it represents the central point of a turn. It was determined in XSENS software which enables frame by frame analysis. At the simulator this is the point in which feet are in the most distant position from projection of center of mass. By using XSENS kinematic suit it is possible to record the whole ski run in a defined corridor and whole duration of a free skiing on the same terrain. Also, XSENS suit does not disturb the athlete and is un-invasive.

CONCLUSION: Results support the differences between the slalom turn performed on a simulator from those during free skiing and skiing in the predefined corridor. Simulator characteristics restrict certain body movements. But, due to similar activation of the muscles in analysed situations Moon and colleagues (2015) advise the use of the simulator in fitness training of alpine ski representatives.

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A STUDY FOR QUANTIFICATION OF ALPINE SKIING TECHNIQUE RELATED TO FASTER SKIING USING SENSOR SYSTEMS

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KEY WORDS: Quantification, technique, faster skiing

INTRODUCTION: Alpine skiing techniques related to faster skiing have been required by many skiers, especially alpine ski racers. The evaluation of alpine skier's technique is mainly qualitative, and the quantitative evaluation in the research is limited number. Therefore, the measurement of a skier on actual snow slopes is important for the quantitative evaluation and the development of the applied training methods, and it is necessary to measure and analyze some skiing techniques that seem to be effective. In this study, I will try to evaluate quantitatively for alpine skiing technique related to improving timings by measurement of actual skiing with using the sensor systems.

METHODS: 3 different kinds of ski techniques which are evaluated by qualitative analysis on a study participant. For quantitative evaluation, the experiment was conducted using the measurement systems of the applied force consisting of 3-axis compact force sensors and the wireless motion sensors attached to the ski boots. The two systems are a synchronized measurement.

Table 1. An explanation of legs movement in 3 different kinds of ski techniques.

Technique	Downhill-turn phase	Uphill-turn phase
Condition A	extension	bending
Condition B	extension	extension
Condition C	no specific move	no specific move

The sampling frequency of these systems is 1 kHz.

RESULTS: There was a difference in acceleration in each condition. Condition A showed the fastest acceleration, followed by condition B. The movement of the 3 different techniques was shown by the force sensors and the wireless motion sensors.

DISCUSSION: It was suggested that it was effective to bend and extend the legs on specific timing for faster skiing. The technique of condition A is used as a racing technique by the subject. The subject has empirically recognized that this skiing technique can give the fastest time. The skill for faster skiing is not simple. It is thought that very complicated factors are involved. This technique could just be one effective means.

CONCLUSION: The technique related to faster skiing was quantitatively shown by using the sensor systems. There was a different acceleration quantified by measurement system among the techniques.

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INTEGRATED SENSOR SYSTEM FOR MEASURING AND ANALYZING POLE WORK IN XC SKIING

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KEY WORDS: Pole force, impulse, sensor system, XC skiing

INTRODUCTION: Key biomechanical factors in cross-country skiing have been little explored due to lack in sensor technology (Pellegrini et al., 2018). Therefore, a novel measurement system has been developed that enables athletes and coaches to measure and record pole forces and analyze pole work in indoor and outdoor conditions. The key component of the system is the instrumented pole handle (Fig 1.) that is easy for the user to calibrate and install on most commercial poles.



Fig. 1. Polar smart pole handle.

METHODS: The system consists of the following parts:

1. Instrumented pole handle with force, acceleration and gyroscope sensors; Bluetooth LE wireless communication.
2. Smartwatch (Polar M600) with route, speed and distance tracking with GPS; data display and recording.
3. Cloud Service with analysis and visualization of recorded data.

RESULTS: The accuracy of the pole force measurement corresponds well to the golden standard measurement with a force plate (Fig. 2). In a 50-meter double poling sprint test the system provided valuable information about the produced pole forces and impulse (Fig 3.).

DISCUSSION: The user-friendly sensor system enables quantitative measurement and analysis of pole work and may contribute to a better understanding of biomechanical factors affecting XC skiing performance.

CONCLUSION: This study describes a novel measurement system that enables laboratory-level measurement of pole work indoors and outdoors to all skiers and coaches. The goal in designing the system have been easy usability, accuracy and compatibility to skier's own poles.

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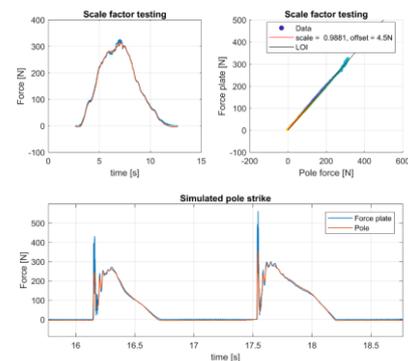


Fig. 2. Agreement between Pole force [N] measured by force plate and by Polar smart pole handle attached to SWIX CT1 poles. We thank the Norwegian School of Sport Sciences for providing this figure.

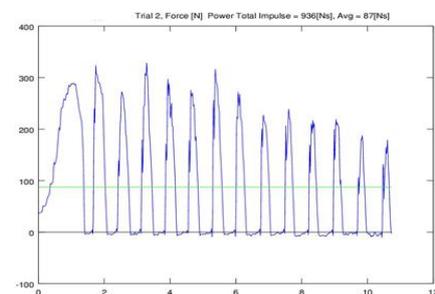


Fig. 3. Force production [N] in a 50m double poling sprint on snow.

VALIDATION OF A SIMPLE SENSOR AND ALGORITHM SYSTEM TO CALCULATE EDGING ANGLE DURING ALPINE SKIING

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KEY WORDS: IMU, alpine skiing, edge angle

INTRODUCTION: Edge angle (EA) during alpine skiing is an important performance variable, however it is methodologically difficult to measure under normal skiing conditions. The purpose of this study was to develop and validate a simple sensor and algorithm system to calculate EA against 3D motion capture.

METHODS: EA was calculated using a custom algorithm based on the input data of two IMU's placed on the posterior cuff of the ski boots. EA was calculated by integration of the angular velocity signal from the roll axis of the boot. Integration drift was corrected on the turn level using a zero-update rule. The EA calculation was validated against a marker-based optoelectric motion capture system (Qualisys) during simulated skiing on a ski-ergometer. One participant completed 30 simulated turns at 1 Hz. Maximum shank angles from each turn were compared between measurement systems using a paired samples t-test. Bias and 95% limits of agreement (LoA) were calculated according to Bland and Altman (1986).

RESULTS: Mean maximum EA measured by motion capture was not different from the calculated EA (19.2°±4.4 vs. 17.7°±2.4, $p=0.420$). The Bias and LoA are presented in Table 1.

Table 1. Bias and LoA (3D vs. Calculated)

Bias (°)	Lower LoA	Upper LoA
1.53	-11.94	14.00

DISCUSSION: The simple system used in this study could provide further information about EA kinematics such as edging magnitude or symmetry, which would be extremely meaningful for training and instruction. Previous studies have demonstrated the potential of similar in-field measurement systems (Yu et al. 2016), however these systems require complex setups. The current system requires only two IMU's, and no information about initial or final conditions, making it suitable for everyday field use. However, it relies on accurate and precise turn switch detection, and assumes a "flat ski" condition at the turn switch point. Further studies should involve more skiers, completing a wider variety of simulated turns to replicate the variety of styles and skills common in everyday skiing.

CONCLUSION: A simple sensor and algorithm system was designed to calculate EA during simulated skiing on a ski ergometer. However, such a system has inherent assumptions, and while useful for providing quantitative information about EA for coaching situations, it may not be suitable for applications requiring a high degree of precision. This will need to be proven during future studies, both in the lab, as well as in the field skiing.

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THE EFFECT OF TRANSCRANIAL DIRECT CURRENT STIMULATION ON IMPROVING CMJ PERFORMANCE

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KEY WORDS: Non-invasive brain stimulation, tDCS, countermovement jump

INTRODUCTION: Transcranial direct current stimulation (tDCS) is a non-invasive brain stimulation technique and has been known to reliably alter motor cortical excitability. Anodal stimulation increases cortical excitability and cathodal stimulation inhibits cortical excitability¹. However, the effects of tDCS on counter-movement jump (CMJ) is currently unknown. The aim of this study was to investigate the effects of tDCS on CMJ performance in healthy men.

METHODS: A double-blinded crossover design was used. Fourteen male subjects (age: 22 ± 2 yrs, height: 174.43 ± 5.74 cm, weight: 68.66 ± 9.47 kg) received three time stimulations, each time an anodal tDCS (a-tDCS) or cathodal tDCS (c-tDCS) or sham tDCS randomly. The electrodes are placed over primary motor cortex (M1) bilaterally and the opposite electrodes pair over the ipsilateral shoulders. Each stimulation lasted 20 min, 48-72 hours apart and current was set at 2mA. Participants were required to get anthropometric measurements and familiar with CMJ in advance. Then, completed five CMJ tests before and after each stimulation, with one minute recovery interval between each test. The best three of the five CMJ in each moment was selected for analysis. Two-way (condition \times time) ANOVA with repeated measures were used for CMJ height, flight time, and initial velocity.

RESULTS: There was a significant interaction between condition and time for CMJ height ($F_{(2,39)} = 7.948$, $p < 0.001$), flight time ($F_{(2,39)} = 8.228$, $p < 0.001$), and initial velocity ($F_{(2,39)} = 8.375$, $p < 0.001$). There were no significant main effects for condition or moment for any of the outcome measures ($p > 0.05$). Post-hoc analysis showed that there were no significant differences between conditions both on pre- and post-stimulation moments ($p > 0.05$). However, post a-tDCS performance was significantly superior to pre a-tDCS for CMJ height, flight time and initial velocity ($p < 0.001$ for all). There were no significant pre-post changes in both c-tDCS and sham-tDCS conditions ($p > 0.05$ for all).

CONCLUSION: Our findings demonstrate that anodal tDCS may be a valuable tool to enhance vertical jumping ability, which is very important for human sport performance.

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TARGET MODELING IN SPORT TRAINING OF HIGHLY SKILLED CROSS-COUNTRY SKIERS

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KEY WORDS: Modeling in sport, elite cross-country skier training

INTRODUCTION: Target [competition] modeling (TM) is the approach to designing elite athletes' training programs over annual or longer training cycles (Matveev 2000). Its effective application was also found in modeling of several performance parameters during preparation of Russian cross-country (XC) skiers – winners of Olympic and world championships (Batalov 2001, Burdina et al. 2007). Yet, numerous varying performance parameters in XC ski pose challenge to plan for peak-performance during long preparation cycles, hence entail risk of not performing at key events as planned. The solution discussed in this study represents technological framework for constructing integrative multi-dimensional training model.

METHODS: 1. Review of studies to select sport specific models used by Olympic and World Champions. 2. Participants: female members of XC-ski Team Russia during 2014-2018. 3. Training and physiological parameters recorded in manual and digital athletes' and coach' diaries during 2014-2018 Olympic cycle.

RESULTS: Technological framework for training towards the best individual performance in XC ski embraces: 1) modeling target performance, incl. "internal" physiological and "external" parameters (such as, for example, the course length, style and speed); 2) modeling effective system of races as an important method and mean in preparation for major international competitions during long training cycles (Burdina et al. 2007); 3) modeling individual training programs and dynamics of physiological capacity (Grushin, 2014). Analysis of participants' actual training parameters against "champions" models.

DISCUSSION/CONCLUSION: The integrative target-based modeling technology for XC-skiers' top-level performance in international championships is individually focused and includes the following inseparable activities: (i) conceptualization of training plan following the identification of target competition activity; (ii) thorough design, calculation and modeling of its key elements; (iii) realization, control and adjustments to plans if needed. Given complexity and varying nature of analyzed parameters, exploitation of digital technology, mathematical tools and interdisciplinary methods is prerequisite for successful management of elite athlete training.

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Talent and Injury in Skiing

Wednesday, 13th of March: 9:00–11:05

Keynote lecture

PREVENTIVE MEDICINE IN ENDURANCE WINTER SPORTS

Maarit Valtonen

KIHU – Research Institute for Olympic Sports, Finland

INTRODUCTION: Elite athletes are commonly considered prone to the common cold due to heavy training load and psychological distress. In addition, air travel and competition are well known risk factors. Exposure to environmental extremes in endurance winter sports, such as altitude, freezing air temperature and low air humidity, enhance the risk of development of respiratory symptoms. However, many previous studies have been uncontrolled, retrospective, based on self-reporting of the respiratory symptoms. Furthermore the possible causative agent of the common cold has been found only in one quarter of the athletes (Spence et al, 2007, Cox et al. 2008). These observations created an idea that most respiratory symptoms in elite athletes may be due to noninfectious airway inflammation.

METHODS: A prospective observational study of the common cold in the Team Finland with molecular POCT diagnostics was conducted during PyeongChang 2018 Olympic Winter Games (OWG). For the first time a fast and automated molecular test for influenza A and B viruses and respiratory syncytial virus was used at site in a major sport event. These viruses caused epidemics in the community at the time of the Games both in Finland and South Korea. Later in laboratory-based testing altogether 16 respiratory viruses were searched for.

RESULTS: Symptoms and signs of the common cold in 45% of the elite athletes during 21 days (median) observation period were recognized and accurate aetiology of the common cold in 75% of the cases was identified in elite athletes. The observations do not support the phenomenon of noninfectious airway inflammation in athletes. We detected nine different respiratory viruses making seven clusters of respiratory infections within the team.

DISCUSSION/CONCLUSION: Common cold is a frequent illness in both elite athletes and other staff members during OWG. Detection of influenza virus infections stress the general use of influenza vaccination in athletes. The findings highlight the clinical implications of molecular POCT diagnostics and suggest that tests detecting comprehensive range of respiratory viruses should be made available in major sport events and health care providers should share the information to all teams. POCT will improve the proper treatment, e.g. decrease unnecessary antibiotic treatment and permit enhanced and timely isolation precautions to decrease the transmission of the respiratory virus infections. Team housing in smaller units and a separate unit for infected subjects prevents virus transmission within a team. Professional cleaning and disinfection should be a standard protocol in major sport events.

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Invited lecture

TALENT DEVELOPMENT IN SKI RACING – CURRENT TRENDS AND PRACTICAL APPLICATIONS

Christian Raschner, Carolin Hildebrandt, Lisa Steidl-Müller

Department of Sport Science, University of Innsbruck, Austria

KEY WORDS: Youth ski racing, fitness training, on-snow training, injury management

INTRODUCTION: More and more scientific contributions underline the importance and the necessity of talent development research in the field of alpine ski racing (Müller et al. 2017; Nilsson et al. 2018; Steidl-Müller et al. 2018). It is undisputed that ski racing demands high levels of physical fitness, ski racing technique and well-developed psychological components in young athletes. However, in contrast, secular trends indicate a decrease in levels of fitness and motor skills from generation to generation.

SELECTED ASPECTS OF FITNESS TRAINING: A systematic approach in resistance training from an early age on is needed to prepare youth athletes in the best possible way for the long-term demands of ski racing. Alternative warm-up and movement sequences in the preparation for strength training sessions should include aspects like neuronal activation, controlled joint rotations, animal walks and movement skills like wall squats or pistol squats. Current trend sports such as Parkour, B-Boying or strength-oriented exercises on a slackline are ideally suited to be integrated into the physical preparation programs. In addition, stabilization oriented strength training and the acquisition of the most important barbell techniques play an important role in this age group. This is highlighted in the three-step model (technical-, speed- and weight-oriented strength training) of the Austrian Ski Federation (ÖSV).

SELECTED ASPECTS OF ON-SNOW TRAINING: The ÖSV's current development plan foresees about 50 days of on-snow training for children at the age of six years (60% free/guided skiing without poles and 40% first experiences with poles and up to five races). This increases continuously up to 100 days for 12- to 13-year-old ski racers including about 40% free/guided skiing without poles, 25% SL turns, 25% GS turns and 10% speed elements (number of competitions 20 to 25). Current data from on-snow training recordings for this age group of a ski boarding school match these requirements or are slightly lower. Compared to youth athletes, the total volume of on-snow training for an Olympic ski racer, who is a specialist in technical events, is about 130 days per season (Gilgien et al. 2018).

ADDITIONAL FOCUS: In the event of an injury, an appropriate injury management system must immediately take effect including the accompanied rehabilitation process. For this purpose, a special injury management concept was developed by the Olympic Training Center Tirol/Innsbruck.

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THE BASE STUDY RESULTS IN U14 CANADIAN ALPINE SKI-RACERS

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²Cumming School of Medicine; University of Calgary, Alberta, Canada

KEY WORDS: U14 alpine ski acers, neuromuscular training program, dry land

INTRODUCTION: Alpine ski racing should be tailored towards neuromuscular (NM) development throughout maturation due to the relationship between injury prevention and performance (Raschner et al., 2017). The BASE (*Balance and Strength Exercise*) study goal was to pilot a NM Training program in U14 racers (Doyle-Baker et al., 2017).

METHODS: Of the 28 clubs within Alberta Alpine Ski Association, 6 met the inclusion criteria, 5 agreed, 2 self-selected to control (C, 14 racers) and 3 to experimental (E, 59 racers) groups. Both the coach-delivered E-NMT warm up and C-warm up, occurred 2X/week for 15-min. for 8 weeks. Pre-post testing outcomes of Star Excursion Balance Test anterior reach distance (SEBTa) and normalized composite score (SEBTcs), Vertical jump (VJ) and predicted peak leg power (LP) were analyzed by dependent t-tests and a Bonferroni correction was applied ($\alpha/\text{number of tests}=0.05/4=0.01$).

RESULTS: No differences, statistically were observed at pre-test, however the E demonstrated significant improvements in the VJ and SEBT at post-testing.

Table 1. Within Group Differences (mean; 99% CI) of Performance Outcomes: Pre and Post-Testing

Outcomes	C (n= 14)			E (n=59)		
	Pre	Post	Difference	Pre	Post	Difference
SEBTa (cm)	55.0 (49.6, 60.4)	55.9 (51.2, 60.7)	0.9 (-2.6, 4.5)	53.0 (51.0, 54.9)	56.9 (53.6, 60.1)	*3.9 (0.3, 7.5)
SEBTcs (%) ^a	79.6 (75.3, 83.9)	78.9 (73.2, 84.6)	-0.7 (-5.9, 4.5)	82.6 (78.4, 86.8)	88.9 (85.8, 92.0)	*6.3 (2.1, 10.4)
VJ (cm)	32.2 (27.5, 37.0)	32.7 (28.1, 37.3)	0.5 (-3.0, 4.0)	31.6 (29.6, 33.6)	33.8 (30.9, 36.6)	*2.2 (0.5, 3.8)
Peak LP (W) ^b	1720.8 (1162.7, 2278.9)	1769.1 (1204.3, 2333.8)	48.2 (-167.1, 263.6)	1653.1 (1457.9, 1848.2)	1818.9 (1559.9, 2077.9)	*165.8 (60.5, 271.2)

Normalized to leg length^a; Predicted peak leg power^b; W, watts; 99% CI, 99% confidence interval; *p <0.01

DISCUSSION: Participants (67%) attended 14 plus sessions over the 8-weeks.

CONCLUSION: This sport-specific NM training stimuli was sufficient to produce small to moderate improvements in balance and peak leg power during the preseason dryland training. More research with standardized NM training across all alpine ski clubs may add to performance outcomes and potential injury prevention in this population.

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SCALING LATERAL HEEL RELEASE ACROSS A RANGE OF ANTHROPOMETRICS TO ASSOCIATE WITH ACL-FRIENDLY ALPINE SKIING

Rick Howell

Howell SkiBindings, Stowe, Vermont, USA

KEY WORDS: Alpine skiing, biomechanics, technology, ACL integrity

INTRODUCTION: Ski-bindings with additional non-pre-releasing lateral heel release — together with lateral heel release settings — have been presented to address abduction-(valgus)-dominant Slip-Catch injury mechanisms for average males. Lateral heel release settings corresponding to a range of anthropometrics have never been presented in the literature — and must be defined for practical utilization in alpine skiing. A biomechanical relationship is associated with the central position (along the length of a ski) of an applied abduction force that causes a binding with additional non-pre-releasing lateral heel release to release either (a) before torsional tibia fracture or (b) before ACL rupture. This relationship is also a function of the length of the abduction-fulcrum between the snow-surface and the center of the knee. These relationships can be scaled to derive lateral heel release settings across a range of anthropometrics.

METHODS: A range of abduction-fulcrums between the snow surface and the center of the knee (including binding stand-height and boot sole thickness) are derived from published anthropometric data and from commercial bindings and boots. The range of fulcrums are transposed 90-degrees onto a ski aft-ward of the projected-axis of the tibia to define a range of positional-boundary-conditions such that a binding with additional lateral heel release that is set to release torsionally-about-the-tibia at given (fixed, independent) values — will either: (a) release laterally at the heel when an applied-abduction-force enters the ski inside of (short of) the range of positional-boundary-conditions; or (b) release laterally at the toe when an applied-abduction-force enters the ski aft-ward of the range of positional-boundary-conditions — based upon the dependent-variable, the lateral heel release setting. Applied-abduction-force is measured at test-points on the heel of a variable-length ISO 9838 test-sole as a function of the range of torsional release torque settings per ISO 9462 (method, Annex-B).

RESULTS:

Torsional release setting about tibia (daNm)	/	Lateral heel release setting (daN)	
		Females	Males
4.0	/	25	27
6.0	/	34	38
8.0	/	46	52

DISCUSSION: Bindings with non-pre-releasing lateral heel release include specified lateral heel release settings and measurement-values that are scaled to correspond to a range of anthropometrics — to associate, biomechanically, with ACL-friendly skiing.

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TRAINING LOAD CHARACTERISTICS AND INJURY AND ILLNESS RISK IDENTIFICATION IN ELITE YOUTH SKI RACING: A PROSPECTIVE STUDY

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²Department of Sport and Exercise Science, University of Salzburg, Rif, Austria

KEY WORDS: Injury risk factors, training load, youth ski racing

INTRODUCTION: Alpine ski racing is a sport with a high risk of injury. First studies in youth ski racing showed that neuromuscular control, lower limb asymmetries in unilateral leg extension strength, core strength imbalances and biological maturity status represent significant injury risk factors among athletes younger than 15 years. However, training load characteristics have not been investigated with respect to injury and illness risk, even though studies in other types of sport reported significant correlations among these aspects (Watson et al., 2017). Therefore, the aim of the present study was to assess the role of training load characteristics in injury and illness risk identification.

METHODS: Training load characteristics and training contents, as well as traumatic injuries (TI), overuse injuries (OI) and illnesses (IL) of 102 elite youth ski racers (58 males, 44 females; 10.0-14.4 years; 12.0 ± 1.3 yrs) were prospectively recorded over the period of one season. Linear regression analyses were performed (dependent variables: illnesses, injuries; independent variables: weekly training volume, weekly training intensity).

RESULTS AND DISCUSSION: A total of 666 training sessions were analyzed (311 athletic, 355 skiing). Most athletic training sessions were intensive (46.6%), moderate (39.9%) or highly intensive (10.3%). Most skiing specific training sessions were intensive (69.3%) or highly intensive (16.1%). The mean weekly training volume was 680 ± 280 minutes per athlete with in mean 3.6 ± 0.8 training sessions per week. In total, 185 medical problems were reported: 41 TI (0.4 TI/athlete), 12 OI (0.1/athlete) and 132 IL (1.78/athlete). Most TI were classified as moderate (36.6%; time loss: 8-28 days) or mild (31.7%; 4-7 days) and mostly affected the knee (31.7%) followed by ankle and lower leg (12.2% each). Most traumatic injuries occurred during skiing specific training (43.9%). Most overuse injuries were mild (41.7%) and moderate (25.0%) and mostly affected the knee and the ankle (25.0% each). Most illnesses were minimal (55.2%; <4 days) or mild (40.9%). Most illnesses affected the gastrointestinal (48.5%) or respiratory tract (40.2%). Weekly training volume and weekly training intensity did not represent a significant injury risk factor. Weekly training intensity showed to be a significant risk factor for illnesses ($\beta=0.348$; $p=0.044$; $R^2=0.121$).

CONCLUSION: Relatively high rates of TI and IL were present among youth ski racers, whereas only few OI were reported. This finding shows that a lot of preventive measures were applied and that the training load was adequate, which was emphasized by the results of the regression analyses, as well. Training load and intensity seem to not influence injury risk in youth ski racers. However, high weekly training intensities seem to affect the immune system of the athletes, which results in a higher IL rate.

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INJURY-RELATED HEALTH PROBLEMS AND ILLNESSES IN YOUTH ALPINE SKIERS: A 6 MONTH PROSPECTIVE COHORT STUDY OF 167 ATHLETES

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KEY WORDS: Athletes, epidemiology, alpine skiing

INTRODUCTION: Competitive alpine skiing is a sport with a relatively high injury risk.¹ However, little is known on the health problems occurring at youth level.² Accordingly, the aim of this study was to describe the prevalence, duration, severity and location of health problems in youth alpine skiers with regard to gender, age and biological maturity.

METHODS: Over a 6-month period during competition season, the injury-related health problems and illnesses of 167 competitive youth alpine aged 13-14 were prospectively monitored by the use of the Oslo Sports Trauma Research Centre (OSTRC) questionnaire.³ Biological maturity (i.e. the age at peak height velocity - APHV) was estimated according to Mirwald and Colleagues.⁴

RESULTS: Any time during the competition season, 42% of all youth athletes reported a health problem and 20% indicated a substantial health problem (defined as leading to moderate or severe reductions in training/performance, or a complete incapacity to participate)³; see Table 1.

Females had significantly higher rates for sustaining acute and overuse injuries compared to males, and U15 athletes showed a higher prevalence of overuse injury than U14 athletes. Further analysis

Table 1: Average 2-weekly prevalence of all health problems reported

	All (n = 167)	Males (n = 105)	Females (n = 62)	U15 (n = 82)	U14 (n = 85)
All health Problems	42% (38,47)	39% (33,44)	48% (44,52)	45% (41,49)	40% (34,45)
Illness	13% (9,16)	14% (10,18)	11% (8,13)	12% (9,16)	13% (10,17)
Acute Injury	14% (12,15)	10% (9,12)	19% (16,22)	14% (13,15)	13% (11,15)
Overuse Injury	16% (15,18)	15% (13,16)	18% (16, 21)	19% (16, 21)	14% (12,16)
Substantial health Problems	20% (19,22)	19% (17,21)	23% (19,27)	24% (21,26)	17% (15,20)
Illness	6% (5,7)	7% (5,9)	4% (3,5)	7% (5,8)	5% (3,7)
Acute Injury	8% (7,9)	5% (4,7)	13% (10,15)	9% (7,10)	8% (7,9)
Overuse Injury	6% (5,7)	6% (5,7)	6% (4,8)	8% (6,10)	5% (3,6)

values are expressed as percentage of athletes reporting at least one (substantial) health problem, with 95% confidence intervals

revealed that acute and overuse injuries were equally frequent with a similar average duration and severity. Acute injuries primarily affected the knee and tibia, while overuse injuries were mainly related to the knee and the lower back. Accelerated athletes were found to be more prone to acute injuries than retarded athletes.

DISCUSSION / CONCLUSION: In competitive alpine ski skiing, injury prevention at youth level should focus on both acute and overuse injuries. Moreover, since gender, age and biological maturity seem to play an important role, injury prevention should already start before the growth spurt (females: APHV at 12.4 yrs.; males: APHV at 14.3 yrs.; according to our data).

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SINGLE LEG JUMPS AS RESOURCE TO IMPROVE INJURY PREVENTION AND THE RETURN-TO-COMPETITION PROCESS

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KEY WORDS: Alpine ski racing, testing, injury prevention, return-to-competition

INTRODUCTION: Possible relations between ACL injuries and physical fitness were found in core strength (Raschner, Kermer) and eccentric strength (Kermer). Aim of the test is (leg axis and core stability under time pressure) to detect and correct deficits in the injury prevention process and to improve the evaluation of the interventions in the rehab and return-to-competition-process.

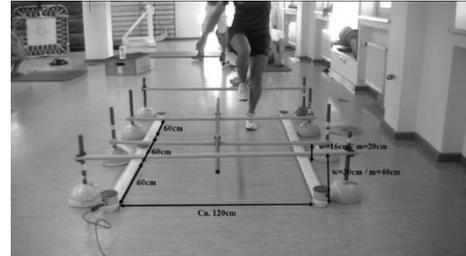


Fig. 1. Single Leg Jumps - Setup

METHODS: The single leg jump test, including 15 jumps and two stabilized landings, was established in 2016. The instruction for the left leg (right laterally reversed) is: Jump from the left foot in the first field (Fig. 1) and stabilize the landing for 2 sec - measurement starts with the first take-off, jump right – left - right, forward – backward – forward, left – right – left, forward – backward – forward, left – right – left, jump over the last hurdle and stabilize the landing for 2 sec. Flight and contact times were measured with a 2m Optojump Next system (Microgate, Bozen, Italy). Additionally, videos of the jumps were recorded. For the qualitative rating of the behavior in the landings, a black dot was painted in the middle of the patella. 77 athletes of the German National Ski team (20.9 ± 3.6 years) conducted 357 tests in 2016 and 2017. In 2017 a questionnaire followed.

RESULTS: Means of flight and contact times are found in figure 2. We found relations between DNF's in race and the test results ($r=0.3-0.4$, n.s.), and in the junior girl group with tolerating high forces and reaction time on imbalances ($r=-.679$, $P<.05$).

DISCUSSION: The single leg jump test illustrates deficits in core and leg axis stability. In the return-to-sport-process this testing was the last one the athlete had to pass because of the challenging character and their insecurity in stabilizing leg axis. Although improving these abilities is supposed to reduce injuries, no obvious changes in injury rates (concerning German ski racers) are found.

CONCLUSION: Relations to skiing indicates high potential not only in injury prevention but also in improving skiing performance. The challenging test character makes it a relevant tool in the final return-to-competition-process.

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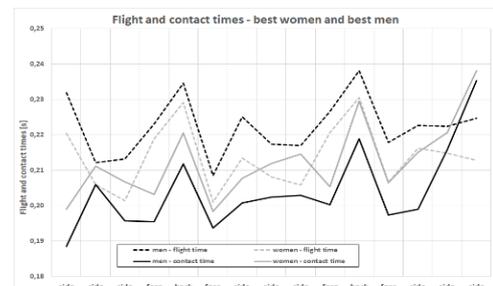


Fig. 2. Means of flight and contact times

Paralympic Skiing

Wednesday, 13th of March: 11:45–12:50

Invited lecture

RACE AND SPLIT TIME ANALYSIS IN PARA NORDIC SIT-SKIING

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KEY WORDS: Section times, percentage system, classification, functional impairment

INTRODUCTION: In Nordic Para skiing, the impact of different impairments on performance may alter over track changes (inclines, curve types, etc.). This impact in those functionally, differently challenging race sections is unknown although being crucial for a correct class assignment (Tweedy et al., 2016) and race %-system. The purpose of the study was to perform a split time analysis, relating impairment and performance in sit-skiers during World Cup and Paralympic races.

METHODS: Split times in World Cup races were measured by by Emit EQ Timing (NOR) and in Paralympic games by magnetometer-based systems (Supermagnete Disc Magnets [20 & 15 mm], GER; "9DoF Razor"-IMU, Spark Fun Electronics, USA; 100 Hz), by Emit EQ Timing (NOR) the and racetrack profiles by a Leica High performance GNSS System (Leica Geosystems AG, SUI). In different Paralympic and WC Biathlon and Cross-Country races, between 25-40 split-time spots were prepared (magnets buried on the snow track) while Magneto-Sensors were mounted close to the binding/ski of the sit-sledge. About 95% of all female/male Elite Para Nordic sit-skiers (classes 10-12) participated in the measurements (~50-60 skiers/race).

RESULTS: As an example of the analysis, here are the results of men's 15km race where the uphill differences were the largest. Diff_{10vs11}:-21.7% (-10.5s), Diff_{10vs11.5}:-25.5% (-12.3s), Diff_{10vs12}:-26.9% (-13s) with further decreases for Diff_{11vs11.5} (-3.8%), Diff_{11vs12} (-5.1%) and Diff_{11.5vs12} (-1.4%). Flat terrain showed smaller changes: Diff_{10vs11}:- 9.0% (-1.9s), Diff_{10vs11.5}:- 13.2% (-2.8s), Diff_{10vs12}:-14.0% (-3.0s) with similar decreases for Diff_{11vs11.5} (-4.2%), Diff_{11vs12} (-5.0%) and Diff_{11.5vs12} (-0.8%). The sharp curve differences were irregular with values of: Diff_{10vs11}:-8.7% (-0.8s), Diff_{10vs11.5}:-18.4% (-1.8s), Diff_{10vs12}:-8.4% (-0.8s) with decreases for Diff_{11vs11.5} (-9.7%) and increases back up for Diff_{11vs12} (0.4%) and Diff_{11.5vs12} (10.1%).

DISCUSSION & CONCLUSION: Uphill sections discriminated most (10 vs.12) with almost half of %-difference in the flat section. Sharp curve and downhill section class differences are lower than 8% and partly show irregularities (low number of skiers in class 11.5). Results partly suggest that the track-profile is influencing time differences and %-system should be adjusted to profiles. The study generates a race analysis methodology, which can be applied repeatedly also to visual and intellectual impaired skiers. The analyses of further races can bring a fairer setting of %-system and classification in combination with other tests.

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Invited lecture

PARALYMPIC ALPINE SKIING – APPLYING APPROACHES FROM MOTORSPORTS TO THE SPORT OF SIT-SKIING

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KEY WORDS: Paralympic athletes, performance, equipment

In Paralympic alpine skiing three categories of visually impaired, standing and sitting athletes compete for medals in their respective classes. As in any other sport, scientists, coaches and athletes aim at enhancing performance. In order to do this, the profile of the sport needs to be established. In alpine skiing, classical fields for optimization are physiology, biomechanics and equipment. For standing and visually impaired athletes it is possible to transfer and apply the knowledge of able-bodied (standing) skiing. However, previous research has shown that sit-skiing athletes display a very distinct sport-specific profile different from standing skiing, which directed the focus on new research fields. The most striking differences between sit-skiing and standing athletes are the sitting posture and the equipment used. This so called monoski or sit-ski is built up of a metal frame with a seat bucket mounted to it and, as the centerpiece, a shock absorber. This unit of a spring and damper can receive, release and modulate external forces and thereby resembles the function of a standing skier's leg. However, unlike the leg's joints with the attached muscles, the shock absorber works as a passive system and therefore athletes can not intentionally choose a concentric, isometric or eccentric mode. Thus, the unit's mode of operation partly explains the differences regarding the physiological demands.



Figure 1. Sit-ski Model (Simpack)

However, further to explaining differences in the sport profiles of sitting and standing skiing, the shock absorber also holds promising potential for performance optimization. Here, the challenge is to match the setup of the shock absorber with the alpine discipline, snow conditions and athletes anthropometry.

For this reason, a sit-ski model was created, evaluated and spring/suspension characteristics were assessed. In a simulation, different spring and suspension settings were analyzed and compared for the respective alpine disciplines. Based on the simulation results a matrix was generated which incorporates the sit-ski type (manufacturer), alpine discipline, and environmental conditions.

Interestingly, results showed that Paralympic sit-skiing benefits from a motorsport approach which in turn indicates that initiatives aiming at performance enhancement in sit-skiing are different compared to standing skiing. However, as the ability of muscle activation and the limitation it causes varies widely between the athletes, any process of performance enhancement regarding equipment needs to be athlete-specific and highly individual.

DETERMINATION OF FACTORS INFLUENCING THE EFFECTIVENESS OF PROPULSION OF PARALYMPIC SITSKIS

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KEY WORDS: Sitskiing, tribology, biomechanics, double poling

INTRODUCTION: The magnitude of propulsion in sitskiing depends on the power of the athlete, the type of sitski, the adequate selection of poles and skis as well as tribology. Depending on the degree of impairment, kneeling and sitting positions can be found. Thus, the particular athletes use differently sized levers and body angles to move their sitski. In addition, skis with different length and stiffness influence propulsion. This contribution used the combined approach of biomechanical analysis and tribology to quantify the effectiveness of propulsion.

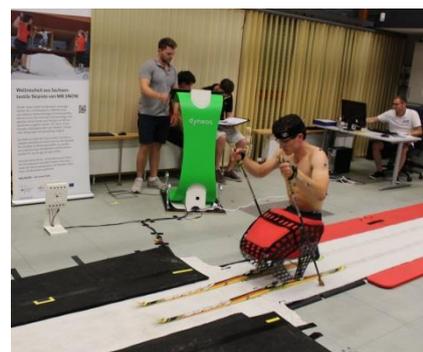


Figure 1. Experimental setup

METHODS: The performing athlete was Martin Fleig (Paralympic gold medal 2018) of the Nordic Paraski Team Germany, who performed double poling movements on textile snow under lab conditions. To be able to analyze his motion patterns and to quantify propulsion speed a motion capture system was used with 37 markers attached to the athlete, sitski, poles and skis. In addition, a high-resolution force measuring plate (2 × 0.5 m, 15,000 integrated sensors) was used to determine the pressure distribution of ski. The length of the track allowed three consecutive double poling movements to be carried out and thereof the middle movement was analyzed. In total, 4 different skis with different flex and torsion were tested. For each ski 2 familiarization trials followed by 5 trials were carried out.

RESULTS: The acceleration of selected markers on athlete, sitski and ski showed differences as function of cycle time. The different skis caused differences in acceleration magnitudes and the temporal behavior of acceleration maxima. One of the skis caused a delay in propulsion of about 10% of the relative cycle duration, i.e. the motion of the ski was significantly retarded. Pressure analysis revealed that this ski showed a larger contact area than the other skis.

DISCUSSION: Since a ski is not a rigid body but responds flexibly upon loading, different contact areas between ski and sliding surface are the result. On a microscopic scale friction force F_f is caused by the product of an intrinsic shear resistance τ and the real area of contact A_c : $F_f = \tau A_c$. The more contact spots appear upon loading, the higher is friction. Thus, confined to the task of decreasing friction, a minimized contact area is mandatory. This can be realized by optimizing the stiffness of the ski. However, issues like ski handling during lane change and downhill motion have to be considered. More detailed analysis is possible by precise evaluations of the markers attached to body and arm of the athlete. The results will be presented in the talk.

Cross-Country Skiing

Thursday, 14th of March: 9:00–12:45

Keynote lecture

CROSS-COUNTRY SKIING AS A MODEL FOR HUMAN MOVEMENT ANALYSIS

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KEY WORDS: Technique selection, cost of transport, pole length, double poling, entrained breathing

INTRODUCTION: Sport biomechanics, and the analysis of sports techniques, is typically used to improve performance of elite athletes, to gain insight into optimal movement, or to determine movement control acquisition. We have often used sport biomechanical and physiological analyses to test basic principles underlying human movement. Here, I will provide three examples where cross-country skiing was used to look at principles underlying gait transitions (or technique selection), to test for cost of transport in cyclic movements, and to investigate the extent to which entrained breathing improves economy of movement.

METHODS: All studies described here (n=7-12) were performed with “elite” skiers. All skiers were either on the National or Provincial Teams and were regular participants at the Canadian Championships. Three of them had represented Canada at Olympic Games. We studied the cost of transport in the so-called 1-skate (V2) and 2-skate (V1) technique with emphasis on elucidating why skiers switched to the 2-skate technique at very high speeds (above 24 km/h on flat terrain), when this technique is usually rejected at intermediate racing speeds. We measured the oxygen uptake and mechanics of double poling at just sub-anaerobic threshold level to identify the interplay between poling frequency, impulse generation and efficiency. Finally, we measured skiers’ oxygen uptake while skate-skiing (2-skate technique) at just sub-anaerobic threshold level while breathing in an entrained and non-entrained manner.

RESULTS: It appears that gait (technique) transitions in skate skiing are dominated by the efficiency of poling, and the muscular requirements of poling at distinctly different frequencies in the 1- and 2-skate techniques. Specifically, the power output and economy of poling in skate skiing appears optimal at intermediate speeds, and that is when skiers rely on the 1-skate technique where more propulsion is produced by the poles than the skis, while the opposite is true for 2-skate skiing. Long poles were more efficient than short poles in skiing at just sub sub-anaerobic threshold which may partially be explained by the high cost of activating and deactivating muscles in cyclic movements. Finally, entrained breathing, compared to non-entrained breathing, was associated with a 5% reduction in oxygen uptake for skiing under controlled conditions, supporting the idea proposed in many animal studies that entrained breathing helps the breathing muscles through the sport specific movement, and thus enhances efficiency.

DISCUSSION/CONCLUSION: Sport biomechanical and physiological analyses may provide insights into basic questions of human movement efficiency and musculoskeletal properties and function under extreme conditions. In this particular case, cross-country skiing helped identify possible reasons for technique and gait pattern selections, and why in some animals (including humans) entrained breathing is coupled tightly with cyclic movement execution.

Invited lecture

RELATIONSHIPS BETWEEN CROSS-COUNTRY SKIING ECONOMY AND ATHLETES' SKILLS

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KEY WORDS: Efficiency, cycle length, FIS points, elite athletes

Skiing economy is defined as the energy required to ski at a given submaximal speed and reflects the ability to efficiently utilize metabolic energy to produce mechanical work. In endurance sport, locomotion economy, together with maximal oxygen uptake and aerobic thresholds, has an important role for performance. When long distance athletes share comparable maximal aerobic power, locomotion economy can be a determinant for competition success. Locomotion economy is a complex concept depending on various modifiable and not modifiable factors, including metabolic, cardiorespiratory, biomechanical, neuromuscular and antropometric factors.

In skiing, a complex movement involving many degrees of freedom, athlete's skill, among other trainable factors, may influence skiing economy. Indeed, elite skiers were seen to be more economical than lower level athletes and to show lower anaerobic contribution. In DP technical reason may be a more pronounced body inclination with higher ability in exploiting the body center of mass to obtain a more effective thrust phase, and in reducing amplitude of non-fundamental motions of body segments. Within elite skiers, better FIS ranked athletes of both genders were shown to have higher skiing efficiency. Moreover, skiing economy was found to change during the year in G3 skating skiing, with better economy, though unchanged $\dot{V}O_2\max$, at peak of competition season. This has been related to improved cycle length, reduced hip vertical acceleration and improved timing of joint motion.

Skiing economy was seen to decrease with fatigue induced by a short maximal effort, with associated shortening in cycle length and ski or pole recovery time, in G3 skating and DP respectively. Despite skiing economy seems to be highly dependent by cycle frequency, freely chosen frequency gives significantly better economy only with respect to large variations of frequency or at near maximal power.

Skiing economy could be improved through training, however a beneficial change in one athlete may be uneconomical in another athlete because of differences in other physiological or biomechanical characteristics

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Invited lecture

ALTERED DEMANDS IN CROSS-COUNTRY SKIING

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KEY WORDS: Sprint double poling, klæbo style, polarized training, strength training, HIT blocks

The introduction of sprint races in the World Cup series in 1998-99, and the increased number of mass-start races has led to altered demands in modern cross-country skiing (XCS). Race tactics, the ability to accelerate in intermediate sprints, recover between sprints, and the ability to reach high speeds in the finishing spurt have become more important, and frequently decide race outcomes. Multiple factors contribute to altered demands: Technical modifications such as sprint double poling (DP)¹⁻³, jumped V2 or double push⁴⁻⁶, running/diagonal stride (Klæbo style)⁶⁻⁸, and the jumped V1⁹ have all been developed within the past year, either due to, or resulting in higher race speeds. These modern XC techniques require high rates of force development and prolonged cycle lengths, which should be considered in strength and conditioning program design (e.g. application of high load or explosive strength training). The DP technique is crucial for success in XCS races involving the classical style^{2, 3, 10, 11}. To date, several elite skiers employ this technique successfully throughout an entire race –especially in the long distance popular races (e.g. Vasaloppet) but also to some extent in the World Cup (three podiums). This development might be based on alterations in skiing technique, increased upper body capacity and equipment². In an attempt to limit this development, FIS implemented the 83% maximal pole length rule and “technique zones” restricting the use of exclusive DP. A recent study demonstrated a great potential with respect to DP especially in female skiers, and particularly in uphill sections¹¹. Along with the development of the DP technique, a marked increase in the upper body / DP capacity can be observed in recent years. In the 1960’s, top skiers were able to achieve 60% upper body / DP V02peak, compared with almost 100% for current athletes.^{11, 12}. Successful XC skiers should be able to perform in all Olympic distances: a moderate to high positive correlation between sprint performance and long distance performance has been observed¹³. From a training methodology perspective, the introduction of the sprint events especially has allowed new training ideas and concepts to enter XCS. In a “polarized” manner, built upon a high base of low intensity training (80-95%) the clear implementation of high intensity training (HIT or SIT 1-3 times/week) across the entire year^{14, 15}, the application of “HIT blocks” every 4-5 weeks¹⁶ and strength training⁶ is recommended.

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SOURCE OF POWER GENERATION DURING DOUBLE POLING AT SHALLOW AND STEEP INCLINES

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Center for Elite Sports Research, Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology, Trondheim, Norway

KEY WORDS: Cross-country skiing, propulsion, technique, preference

INTRODUCTION: To maintain mean speed in treadmill roller-skiing on an incline, the mean power output (P_{mean}) generated must balance power losses to rolling resistance and gravity. Dahl et al. (2017) found that elite skiers prefer double poling (DP) on shallow (5%) but not steep (12%) incline at moderate speeds in which P_{mean} was the same on both inclines. The skiers rated the perceived sense of effort in the arms much higher while DP on steep (RPE ~14) than on shallow (RPE ~11) incline, and energetic cost followed the same pattern. The question then is: Do the arms contribute more (generate more power) to P_{mean} while DP on steep than on shallow incline?

METHODS: Fourteen elite skiers performed treadmill roller-skiing DP at three intensities (low, mod, high) on 5% and 12% incline at speeds set to induce similar P_{mean} . Motion capture and pole force recordings allowed linked-segment modelling to calculate elbow and shoulder joint power. Total instantaneous power output (P_{tot}) was also calculated, and the residual between P_{tot} and elbow+shoulder (ARM) power was interpreted as trunk+leg (T+L) power. The contribution from ARM and T+L towards P_{mean} was calculated, as was power generation and absorption by ARM and T+L throughout the DP movement cycle.

RESULTS AND DISCUSSION: P_{mean} was equal at both inclines (142 ± 7 , 189 ± 9 , 237 ± 12 W), increasing with intensity ($p < .001$). ARM contribution to P_{mean} was 63-66% on 5% and 53-55% on 12% incline (incline effect $p < .001$). Thus, ARM generated less power and did less work on 12% than on 5%, although the skiers perceive the work done by ARM as harder on 12%. This paradox may be related to similar magnitudes of joints moment of force that lasted longer and shorter on 12% and 5%, respectively, due to longer poling time at the steep incline. At both inclines, T+L generated equal amounts of power during the swing phase, raising the body perpendicular to the surface, increasing body energy. During the poling phase, part of the body energy gained during swing was transferred to pole power, driving propulsion together with active ARM power generation. During the poling phase, more negative T+L power occurred on 5% than on 12%, indicating that the T+L absorb more of the body energy gained during the previous swing phase on 5%, and this pattern increased with intensity ($p < .001$). It is debatable whether this is effective or not.

CONCLUSION: During uphill DP, elite skiers rate the effort in the arms as more demanding on steep than on shallow inclines, despite the fact that the arms generate less power and do less work on steep inclines.

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EFFECTS OF FATIGUE ON PROPULSIVE FORCES DURING SKI SKATINGOlli Ohtonen¹, Vesa Linnamo¹, Caroline Göpfert³, Stefan Lindinger^{2,3}¹Faculty of Sport and Health Sciences, University of Jyväskylä, Finland²Center for Health & Performance, Department of Food and Nutrition and Sport Science, University of Gothenburg, Sweden³Department of Sport and Exercise Science, University of Salzburg, Rif, Austria**KEY WORDS:** XC-skiing, skating, propulsion forces

INTRODUCTION: Fatigue effects during cross-country ski racing are essential aspects deciding performance in a race. Earlier studies examined the role of fatigue and race load on performance and biomechanical patterns in different skiing techniques (e.g. Mikkola et al. 2010, Ohtonen et al. 2018). The aim of this study was to examine the influence of the individual physical race load during a 20 km race simulation on pole and leg propulsion mechanisms using the V2-skating technique.

METHODS: Five sub-elite skiers performed 20 km (10 x 2 km) race simulation in Vuokatti ski tunnel. 2D Ski forces (University of Jyväskylä) and axial pole forces (Velomat, Germany) as well as 3D kinematics (Vicon, UK) were recorded before the race (pre), during the race and during final spurt (post) with V2 technique in 100 meter uphill with gradient of 4°. The propulsion of the poles and legs were calculated using the method of Göpfert et al. (2017).

RESULTS: No statistical pre and post differences were found. Individual data analyses gave interest insight into individual mechanisms and Figure 1 shows the behavior of pole and leg propulsion pre-, during and post-race with two extreme cases (subjects S1 and S2) marked in grey. S1 showed highest pole propulsions in pre-test and lowest in post-test while S2 expressed highest leg propulsions during pre-test and lowest during post-test.

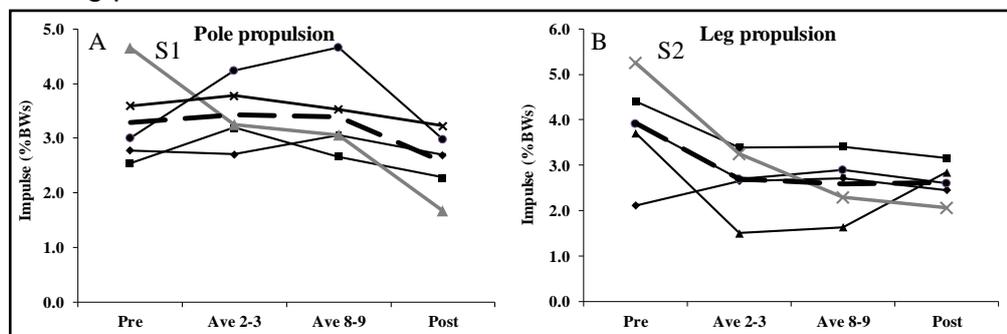


Figure 1. Individual fatigue effects during 20 km simulated race with two extreme cases highlighted

DISCUSSION/CONCLUSION: Large individual differences on how fatigue is effecting on the leg and pole propulsions were observed between the subjects. Pole propulsions are well in line with results acquired by conventional ground reaction forces while leg propulsions show distinctly greater decreases compared to conventional methods (Ohtonen et al. 2018). Propulsion method is likely to give new tools for coaching and athlete performance diagnostics.

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A BIOMECHANICAL ANALYSIS OF A CROSS-COUNTRY SKIING WORLD CUP COMPETITION AT RUKA, FINLAND 2015

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KEY WORDS: Cross-country skiing, split time analysis, video analysis, technique transitions

INTRODUCTION: Different pacing strategies play significant role in time trial type of endurance sports where the duration of the races are more than two minutes. Losnegard et al. (2016) observed that elite skiers adopt a positive pacing strategy and the best male skiers maintain their velocity better than the slower skiers towards the finish line while the women's pacing profiles do not vary significantly. In this study a comparison of split times based on different types of terrain against the competition's finish times was conducted. In addition, different choices of technique strategies and technique transitions ($V1 \Rightarrow V2$ & $V2 \Rightarrow V1$) were examined.

METHODS: The split time analysis was conducted during Ruka, Finland 2015 WC competition (women 5 km, men 10 km) to identify the most important terrain in the race course against the competition results and the pace strategies of the athletes who gained world cup points ($N = 30$). Technique transitions were filmed for video analysis in four locations where they were expected to take place in the beginning ($V2 \rightarrow V1$) and top ($V1 \rightarrow V2$) of uphill. The videos were analyzed to determine each competitor's speeds for both techniques and the location of technique transitions for both techniques used in each filming area.

RESULTS: In the women's race the best 30 skiers' split times correlated with the end times of the race highest in easy and undulating terrain ($r_s = 0.93$; $p < 0.01$). For the compared groups (R1: places 1–10 in the final results; R2: places 11–30) the biggest differences in speed were observed in the uphill (R1: 3.43 ± 0.15 m/s; R2: 3.30 ± 0.05 m/s; $p < 0.01$). In the men's race the highest split time correlations with the end times were observed in the uphill of the 2nd lap ($r_s = 0.70$; $p < 0.01$) and accordingly the biggest differences in speed were observed in the uphill (R1: 3.94 ± 0.09 m/s; R2: 3.82 ± 0.08 m/s; $p < 0.01$). Furthermore, the winners of the both investigated races built their gaps in the uphill. The position of technique transitions correlated statistically significantly with the skiing speed only in one filming location ($V2 \rightarrow V1$): Women: $r = 0.371$, $p < 0.01$; Men: $r = 0.389$, $p < 0.01$ and $r = 0.34$, $p < 0.01$).

DISCUSSION/CONCLUSION: The results showed that in both races the fastest skiers built their gaps mostly in the uphill. The locations of the technique transitions varied a lot individually and significant correlation between the location of the technique transition and skiing speed was found only in one filming area out of four filming areas. The results show that the optimal location for a technique transition depends highly on the terrain characteristics of the skiing track and probably the physiological characteristics of the individual athletes play also a significant role in technique transitions and the decisions of the technique transition are made individually based on these factors.

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HISTORICAL ANALYSIS OF DOUBLE POLING IN HIGH-LEVEL XC SKIING

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KEY WORDS: Cross-country ski, 3d reconstruction, double poling

INTRODUCTION: The cross-country skiing technique evolved significantly starting from the '80s (diversification between freestyle and classical techniques races). During the last decade, a renewed interest in the classical technique have grown everywhere and also in the popular race (PR). This fact, along with improved materials, better track preparation, as well as the increased fitness level, has brought elite athletes to mainly adopt the Double Poling during the race (only DP in the PR). Aim of this work is to summarize the main kinematics parameters collected in a long time period (1999-2017) from recordings and 3D reconstructions of elite skiers engaged in high-level races. In particular, our analysis investigates how the angles motion patterns about DP have evolved during that period.

METHODS: The data were collected from 1999 to 2017 during high level classical races by means of cameras (50 Hz). A dedicated software for video analysis (DLT method) was used (Baroni 1998). A minimum of 5 skiers (males and females, ranking 1-30) were analyzed on different sections where the athletes performed DP.

RESULTS: The main results are shown in Table 1. The kinematic parameters were calculated for each athlete and were reported as the mean value averaged on 2-3 cycles; furthermore angles-vs-angles plots were used to investigate individual coordination patterns.

Table 1. kinematics parameters

Level race	1999 WCh	2003 WCh	2009 WC	2017 Pop	2017 Pop	2009 WC
Race	15 km Ind.	15 km Ind.	15 km Ind.	30 km MS	30 km MS	10 km Ind.
Technique Parameter / Terrain	DP flat	DP flat	DP flat	DP flat	DP Uph 3.5°	DP flat
Gender	Male	Male	Male	Male	Male	Female
Subjects N	11	9	10	5	7	5
CL (m) (cycle length)	7.9 ± 1.1	5.9 ± 0.3	8.3 ± 0.7	7.2 ± 0.5	5.0 ± 0.2	7.3 ± 0.6
CT (s) (cycle time)	1.30 ± 0.14	1.27 ± 0.10	1.16 ± 0.09	1.09 ± 0.07	0.97 ± 0.04	1.07 ± 0.08
Vave (m/s)	5.70 ± 0.25	4.70 ± 0.24	7.08 ± 0.23	6.65 ± 0.6	5.18 ± 0.32	6.71 ± 0.15
% Time-Poling / CT	23% ± 1%	30% ± 1%	23% ± 2%	27% ± 2%	36% ± 2%	24% ± 2%
CoG Vertical Displacement (m)	0.19 ± 0.04	0.16 ± 0.04	0.32 ± 0.02	0.24 ± 0.08	0.25 ± 0.04	0.32 ± 0.02
Elbow Angle (°) at Pole Plant (PP)	111 ± 10	99 ± 12	70 ± 16	72 ± 15	82 ± 10	85 ± 3
Elbow Angle (°) min	91 ± 13	84 ± 11	59 ± 11	53 ± 14	68 ± 10	73 ± 7
Trunk Angle (°) at PP	42 ± 6	40 ± 6	37 ± 7	44 ± 3	39 ± 1	42 ± 6
Poles Angle (°) at PP	17.5 ± 6.4	25 ± 15	10 ± 4	14 ± 2	20 ± 2	13 ± 5

DISCUSSION/CONCLUSION: In accordance with the previous works (Smith 1996), we found that the fastest skiers have longer CL ($r=0.5-0.6$). If we neglect the terrain and other environmental parameters, during the years we notice that the CT decreased from 1.3s to 0.97s. Regarding the key point of the poling, identified as the relative positioning of the upper-body limbs, the skiers adopted different strategies to perform the poling with respect to the trunk, shoulder and elbow rotations.

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VALIDATION, ACCURACY AND PRACTICAL USE OF A POWER MEASUREMENT SYSTEM FOR CROSS-COUNTRY SKIING ANALYSIS – A PILOT STUDY

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KEY WORDS: Double poling, IMU technology, power profiles, propulsive force

INTRODUCTION: Cross-country skiing is a sport with high demands on central and local physical capacity and involves complex biomechanical motion patterns. Such factors were investigated in labs, e.g. VO₂ tests on treadmills for intensity zones. For field assessment of exercise intensity a common method is to measure heart rate (HR) which underlies several problems, e.g. day-to-day variations due to various factors and it too slow to reflect intensities in anaerobic zones. Hence, there was a strong motivation developing a light, versatile system usable for real-time field measurements of propulsive pole forces and mechanical work based on IMUs (pole angle calculations) plus load cells mounted in grips, previously done for ski forces (1). This enables calculation of mechanical power profiles in field and the visualization of all relevant forces and pole angle graphs. Hence, the aim was to validate the developed Skisens technology vs. Golden Standard systems like force plates mounted in a LAB.

METHODS: The validation of the power measurement system integrated in the ski-handles (Skisens, SWE) was done in 3 steps: 1) static tests vs. Kistler force plates (Kistler Messtechnik, GER); 2) dynamic double poling (DP) tests at slow/medium/high speeds vs. plates (compare F_{prop}) and a 3D motion capture system (Qualisys, SWE) (compare pole angle); 3) DP treadmill tests verifying average forces estimated from Skisens vs. expected refraining forces as assessed from treadmill slope and friction. Mean errors for force variables plus similarity coefficients (SC) ($-1 < \text{similarity} < 1$) for time series (Taylor Polynomials) were calculated.

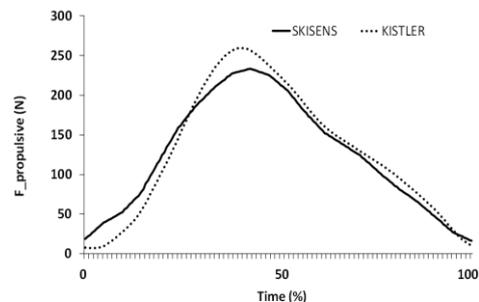


Fig. 1. Mean curves [F_{prop}] from Skisens vs. Kistler from maximal DP

RESULTS: The errors (E) vs. Kistler plates over the entire F_{prop} curve during DP Lab tests were: E_{mean} : -2.7N (1.2%) and $E_{\text{min_max}}$: -29 to 28N (0.8 – 4.3%). The F_{prop_peak} differences were -27N (10%). Mean SCs between the Skisens and Kistler curves over all speeds were high with 0.993 ± 0.025 . Static and treadmill tests showed good agreement of values.

DISCUSSION & CONCLUSION: The Skisens power system can be considered as rather valid and accurate vs. a Golden Standard systems. Algorithms to calculate pole angles from IMUs can be still optimized and pole force sensors have to be further analyzed related to long-term use.

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BIOMECHANICAL ANALYSIS OF G3 SKATING TECHNIQUE ON A TREADMILL OF WORLD-CLASS AND NATIONAL-ELITE FEMALE BIATHLETES

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KEY WORDS: Female, biathlon, technique

INTRODUCTION: G3 skating technique is used in flat terrain as well as during uphill sections. Especially for uphill sections, it was shown that the fastest skiers utilized G3 more than G2 (Andersson et al. 2010). Beside high demands on the athletes' strength capacities, the basic ability is to have a well-educated technique to transfer the applied force into propulsion. The aim of this study was to analyze the G3 technique of world-class and national-elite female biathletes to evaluate possible differences between the groups.

METHODS: 11 female biathlon athletes participated in the study. The elite group (25 ±3 yrs.) consisted of IBU World-Cup starters, whereas the national-elite group (22 ±3 yrs.) consisted of six athletes participating in the IBU-Cup. The mean skiing speed during races was 6.7 ± 0.3 m/s and 6.2 ± 0.2 m/s for the elite and national elite group. Tests were done on a treadmill (Incline: 6%. Speed 5m/s). For the kinematic analysis a 3D motion tracking system was used (Vicon, Oxford, GB) in combination with a customized Plug-in Gait model. For the kinetic analysis pole force measurements were done. Statistics was done using statistic parametric mapping (Figure 1) and unpaired T-tests. The alpha level was set to $p < 0.05$.

RESULTS: For the kinematics, only thorax flexion and elbow flexion showed differences between the two groups. Kinetic analysis showed differences regarding the summed impulse from the left and right pole ($p < 0.05$).

DISCUSSION: It is known that the ability to perform G3 during races affects the result. The kinematic analysis revealed only marginal differences between the groups underlining a good training status of the national-elite group regarding technique. Differences in the kinetics showed a maybe less pronounced strength status of the national elite group.

CONCLUSION: Becoming a world-class biathlete is a combination of technique, strength, endurance and shooting abilities. National-elite athletes showed a technique level comparable to world-class athletes. For the future, those athletes should especially focus on the remaining requirements to further increase their performance level.

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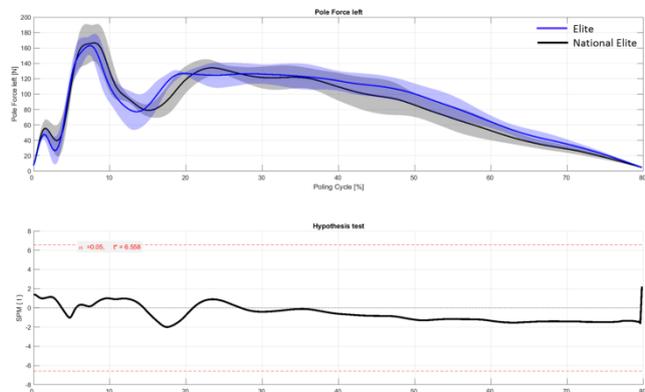


Figure 1. Example pilot of left pole force data using statistical parametric mapping.

KINEMATIC ALTERATIONS OF DOUBLE POLING CYCLE IN GROUPS OF SKIERS WITH DIFFERENT PERFORMANCE LEVELS DURING A LONG-DISTANCE RACE

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KEY WORDS: Fatigue, cycle frequency, cycle length

INTRODUCTION: A massive use of double poling technique during long-distance cross-country skiing classical races is chosen by top-level but also by less-skilled skiers. The present investigation aimed to understand how double poling kinematics is altered by long-lasting double poling in differently skilled cross-country skiers.

METHODS: during a 58 km-long classic competition, the skiers were filmed twice (7 and 55 km after the starting line), on comparable 20-m track sections (0.7- 0.9° of incline) appositely calibrated for the measurements. Considering the first 1000 ranked athletes, the videos of first the 10 skiers for each hundred of athletes (10 groups) that performed DP were analyzed through a tracking software, in both the sections. Pole plant and release were detected for two consecutive DP cycles, to measure poling and cycle durations, duty cycle, cycle length, frequency and velocity. A two way ANOVA test was applied to evaluate the statistical effect of group and section factors on the kinematic parameters.

RESULTS: A significant decreasing trend across groups was found for cycle velocity, frequency and length (all $P < .05$), while an increasing trend was found for cycle and poling time, as well as for duty cycle (all $P < .05$). Between the sections, cycle velocity and length decreased significantly ($P < .05$), duty cycle increased ($P < .05$) while cycle frequency remained unaltered ($P > .05$).

DISCUSSION: The higher the performance level the higher the length travelled at each cycle and movement frequency, resulting in higher locomotion velocity. Moreover, the cycle fraction dedicated to the propulsive action is reduced in better athletes. Muscle strength and power as well as technical skills should determine these results. Fatigue is reflected in reduced cycle velocity and length and increased duty cycle in all the groups. On the other hand, cycle frequency is not influenced by fatigue state.

CONCLUSION: Cycle frequency is maintained in non-fatigued and fatigued conditions by cross-country skiers, independently from their performance level. Movement frequency was suggested to be one of the attention foci on which highly skilled athletes base on, to manage a long-duration effort and to optimize performance.

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KETOGENIC DIETS FOR ENDURANCE ATHLETES: WEIGHING THE PROS AND CONS

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KEY WORDS: Nutrition, diet trends, athletic performance

INTRODUCTION: The debate concerning benefits of a low-carbohydrate 'ketogenic diet' (LCKD) for athletic performance has yielded support of the diet by some and opposition by others.

METHODS: A review of literature spanning between the years of 2000-present was conducted to examine the impact of LCKDs on athletic performance and overall health and to translate current evidence to the cross country ski athlete.

DISCUSSION: LCKDs lead to a significant increase in endogenous fat oxidation compared to moderate or high carbohydrate diets. Peak fat oxidation achieved on a LCKD varies between 0.5-1.5 g/min and is influenced by time on the diet and carbohydrate intake.¹ LCKDs may decrease fat-mass and increase power-to-mass ratio in athletes, improving performance.^{2,3} Conversely, LCKDs may reduce exercise economy and the ability to maintain high intensity activity, impairing performance.⁴⁻⁶ Additional research indicates LCKDs neither increase or decrease performance.^{7,8} Critical analysis of the current literature provides little support for a LCKD improving performance and limitations, such as small sample size, challenge the reliability of findings. Additional considerations of a LCKD should also be examined including diet adherence challenges, impact on inflammation and the gut microbiome, and nutrient deficiencies. For cross country skiers, evidence indicates that LCKDs provide few to no performance improvements and may decrease performance, especially during high intensity sprint competitions, indicating that this diet should be used with caution.

CONCLUSION: Cross country ski athletes should be made aware of the potential benefits, detriments, and challenges of LCKDs. Dietary strategies implemented for skiers should be individualized to meet the specific needs of each athlete.

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Ski Jumping

Thursday, 14th of March: 14:30–15:05

Invited lecture

DO SKI JUMPERS STILL NEED TO BE LIGHT?

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KEY WORDS: Body weight, BMI, equipment, performance, winter sports

INTRODUCTION: The BMI regulation adopted in 2004 by the FIS (International Ski Federation) was intended to reduce the advantage of being light in ski jumping (Schmölzer & Müller 2002). The present study examined the current relationship between body weight, ski length and performance (jumping distance) in ski jumping.

METHODS: Height, weight (measured with suit and boots), BMI and ski length of the 30-60 best athletes in the World Cup ranking were collected from the FIS official data (2008-2018) measured on the competition site (not presented in this abstract). The effect of body mass and ski length on jumping distance was analysed by a model of the complete ski jump: the inrun, take-off and flight. The following parameters were used as input information: total mass and reference area of a ski jumper including skis, air density, coefficient of ski friction, take-off force profile, drag (C_d) and lift (C_l) coefficients for the crouch inrun position, and $C_d(t)$ and $C_l(t)$ for the flight phase.

RESULTS: Table 1 shows the effect of reduced body mass on jumping distance of one jumper (173 cm) without and with the compensatory ski length reduction.

Table 1. The reference jump of 134 m was obtained with BMI 21 allowing max ski length (145 % body height). Take-off force was adjusted to keep the perpendicular take-off velocity (V_p) constant.

BMI (kg/m ²)	V_p (m/s)	Body mass (kg)	Inrun speed (km/h)	Jump distance (m) (*ski length reduced)		Ski length (cm)
22.0	2.78	65.9	91.21	130.5	130.5	251 (145 %)
21.5	2.78	64.4	91.14	132.2	132.2	251 (145 %)
21.0	2.78	62.9	91.08	134.0	134.0	251 (145 %)
20.5	2.78	61.4	91.00	135.6	135.0*	247 (143 %)
20.0	2.78	59.9	90.93	137.2	136.0*	244 (141 %)
19.5	2.78	58.4	90.85	138.8	137.1*	240 (139 %)
19.0	2.78	56.9	90.77	140.4	138.1*	237 (147 %)
18.5	2.78	55.4	90.68	141.8	139.1*	234 (135 %)

DISCUSSION: The results of this study suggest that the weight of the jumper is a more sensitive factor to jump length than ski area (ski length). In fact, sensitivity analysis shows that reducing BMI by 1 % requires a reduction of approximately 2.0 % in ski area to compensate each other. Based on the available information of the complex relationship between body morphology and performance in ski jumping there seems to be no further need for a change in the BMI regulation

CONCLUSION: The BMI regulation adopted by the FIS has reduced the advantage of being light, but despite the use of shorter skis it is still beneficial to be light within certain limits.

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DYNAMICS OF SKI JUMP TAKE-OFF SKILL

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²Olympiatoppen, Norway

KEY WORDS: Skill, ski jump, take-off dynamics

INTRODUCTION: In ski jumping, during the push-off the athlete must generate both linear momentum perpendicular to the take-off table and certain angular momentum. The interplay between the ground reaction force (*GRF*) and moment through the offset, moment arm, *d* of centre of pressure (*CoP*) under the boot to centre of mass (*CoM*) is important for skilled jumping. The manner that these variables develop over time may vary for the same kinematic outcome. The aim of this study was to investigate the relationship of this development and performance level.

METHODS: Eleven male ski jumpers performed 15 consecutive jumps from an indoor take-off ramp. Force cell equipped bindings were used to record dynamics. The athletes were ranked according to expected level of performance prior to testing by three experienced coaches who were well acquainted with all athletes. To relate dynamics of the take-off jump, the original variable time traces were transformed to time traces of Spearman's rank correlation (ρ). Conservative binomial statistics ($\alpha=0.01$) were used to identify significant ρ -trace periods ($|\rho|>0.736$) of long enough duration (0.04 s) to categorise these as meaningful.

RESULTS: The profiles (Fig.1) showed a typical shape that was similar for all jumpers. Velocity depended on performance level only prior to reaching peak velocity. Peak velocity was unaffected by performance level. Angular momentum in the first part of the push-off action (-0.5 to -0.3 s) showed performance level dependence. The final angular momentum at take-off was not related to performance level. Moment and *d* showed significant performance level dependence during an extended period before and at the onset of the push-off action (-1.2 to -0.4 s). The better jumper tended to enter the transition phase between the in-run and the push-off with a smaller *d* and less (backward) angular momentum.

DISCUSSION: The better jumper entered the push-off period with a *GRF* more closely balanced with *CoM*, likely allowing better control over the development of angular momentum. Furthermore, the better jumper did this while showing greater potential for generating linear momentum.

CONCLUSION: All jumpers were able to produce a good final outcome in imitation jumps. The way poorer jumpers achieve this may cause challenges in ski jumping in the hill because of stronger physical and time constraints.

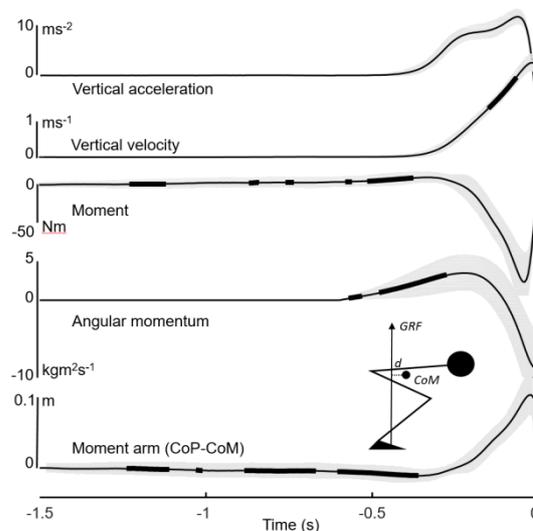


Fig. 1. Time traces of dynamic variables (mean and s.d.). Fat parts indicate significant dependence on performance level ($p<0.01$). Inset depicts mechanical setting.

Air Drag and Aerodynamics in Skiing

Thursday, 14th of March: 15:25–16:30

Invited lecture

AIR DRAG AND AERODYNAMICS IN SKIING

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KEY WORDS: Wind, posture, biomechanics, oxygen consumption, economy

Aerodynamics in skiing deals with the biomechanical-physiological response effected by aerodynamic forces. Drag forces shall be minimized or need to be overcome by corresponding power outputs (e.g. in Nordic skiing; leader vs. drafter). The relevance of aerodynamics or air drag is given in all "ICSS2019" skiing sports but in different ways. During downhill sections or take-off phases, different skiers or jumpers try to minimize air drag, air friction or optimize lift-to-drag ratios by changed posture/anthropometric factors (1-7) or by using special designs of suits, helmets and other equipment (8-9). E.g., Nordic skiers may show relevant physiological-biomechanical effects of drafting, which is hardly investigated (10-11). Compensation strategies in the skiing patterns in case of changing air drag in flat sections or downhills may increase in importance. The purpose of this presentation is to give a systematic overview of research done in these fields in different "ICSS" sports and to provide a structure of relevant topics connected to air effects in all those sports. A special focus is set on Nordic skiing and effects of drafting in different skiing techniques, an aspect getting increasingly important in racing with lacks of knowledge about in theory and practice (10-11).

Starting with a systematic review on different aspects around aerodynamics/air drag in skiing in general, the integrative physiological-biomechanical aspects of drafting (e.g. in Ski Cross or Nordic skiing [technique and race mode dependent]) get into focus. Nordic skiing races carried out in mass start modes create high relevance of examining the safe of force/energy by drafting. Previous studies (5; 10-11) as well as a current study (wind tunnel; treadmill; Douglas bags; pole/leg forces; 3-7 m/s; female/male) showed relevant effects of drafting and air drag with -2 to -7% (drafter vs. leader) VO₂ and -7 to -42% VO₂ (with (leader) vs. without wind) (P<0.05) over speeds, with exponential VO₂ kinetics in leader/drafter position but linear ones in non-wind conditions. Cycle rates increased while cycle lengths and peak and impulses of pole force decreased successively from leader via drafter to non-wind condition (P<0.05) at most of the speeds.

Overall, the aspects of air drag as well as drafting may play an increasing role in all skiing disciplines in the future. In particular, the drafting in Nordic skiing opens up interesting aspects in tactics as regards positioning in races as well as innovative air-drag compensation strategies as regards Nordic skiing technique patterns.

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A CLIMATIC WIND TUNNEL FOR PHYSIOLOGICAL SPORTS EXPERIMENTATION

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KEY WORDS: Aerodynamic drag, rain, treadmill

INTRODUCTION: The aim of this project was to develop a wind tunnel that enables the study of human performance during various types of sports and physical activities by examining the influence of aerodynamic drag, precipitation and gravitational force on uphill and downhill travel on a moving substrate (Ainegren et al. 2018).

METHODS: An overall design for a wind tunnel and working section containing a fan (figure 1) and a large treadmill was drafted, followed by computational fluid dynamics simulations of flow conditions to assess the design's feasibility and select from different geometries prior to its construction. The flow conditions in the completed wind tunnel were validated by measurement at a total of 27 points in the volume above the treadmill using a four whole Cobra Probe instrument (Turbulent Flow Instrumentation Pty Ltd, Tallangatta, Australia), at different flows, speeds and treadmill inclinations. Pilot experiments were carried out using a xc-skier to investigate the effect of aerodynamic drag on oxygen uptake during double poling on a horizontal treadmill and the maximal achieved speed when rolling on a declined treadmill.

RESULTS: The results showed that flow conditions are acceptable for experiments even in worst-case scenarios with maximal inclined and declined treadmill. Results also showed a 50% increase in the skiers energy expenditure when aerodynamic drag was added to rolling resistance during double poling.

DISCUSSION: The big treadmill has space for two cyclists, wheelchair riders or roller skiers in line with the flow, and two side-by-side subjects, to study the effects of drafting in many sports (figure 2).

CONCLUSION: The wind tunnel's overall design, the results of the validation study and initial experiments on a skier shows that a unique and well-designed tunnel has been achieved that is well suited for physiological sports experimentation.

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Figure 1. The wind tunnel fan



Figure 2. The working section

FRONTAL AREA DETECTION DURING SPORTIVE MOTION WITH THE USE OF A 3D CAMERA

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KEY WORDS: Frontal area, aerodynamics, 3D camera

INTRODUCTION: The aim of this study was to develop a Matlab based program, which automatically investigates the frontal area of an athlete during her or his sportive motion on a treadmill or stationary in front of a 3D camera.

METHODS: Earlier research of Ainegren and Jonsson (2018) showed difficulties and measurement errors which appeared by using a 2D color detecting camera running with a Matlab (MathWorks, Massachusetts, USA) interface (MI). To improve this method the idea was to use a 3D camera (Windows Kinects, Microsoft, Washington, USA) also running with a MI which detects the frontal area via depth values of each pixel of each frame. This method allows more accurate mean values of the athlete's frontal area over time and faster fully automatic data processing. The method works by comparing each captured frame with an earlier taken "off-set frame" of the working section without any test-subject in it. Therefore, the MI detects only the athlete and her/his equipment, because of a strong depth change of those pixels.



Figure 1. Cross-country skier captured by the 3D camera.

RESULTS: Pilot tests were made with a cross-country skier and the results show that due to a sampling rate of >5 frames per second even fast changing frontal areas, as for example during cross-country skiing motion, are possible to detect. The results show that objects between 1 to 5 m in front of the camera can be detected with an accuracy of 0,01 m².

DISCUSSION: The frontal area of an athlete is a very important information especially in high velocity sports, as for example skiing sports. Many researchers are used to work with the drag area ($C_D A$) values even though it can be very important to separate the coefficient of drag (C_D) values of the frontal area (A) values, since a frontal area change can affect the C_D values drastically.

CONCLUSION: The user friendliness due to faster and fully automatic data processing combined with a high sampling rate and high area detecting accuracy shows a clear preference for the newly developed 3D camera method. A precise separation of the coefficient of drag and the frontal area during motion in any working section is achieved.

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THE EFFECT OF ATHLETE BODY POSITIONING ON AERODYNAMIC DRAG AND PERFORMANCE IN ALPINE SKI RACING

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KEY WORDS: Alpine skiing, aerodynamic drag, performance

INTRODUCTION: Three external forces determine the alpine skier's trajectory and speed: Gravity (F_G), the reaction force arising from the skier's interaction with the snow surface (F_R), and aerodynamic drag (F_D). A substantial component of the total braking effect on a skier is caused by aerodynamic drag (Savolainen & Visuri, 1994), particularly at the higher speeds of SG and DH. Despite its importance for performance, our understanding of how a skier's body position affects F_D is limited. Therefore, the aim of this series of experimental wind-tunnel studies, in combination with elite-level athlete testing, was to develop our understanding how skier positioning affects their frontal area (A), the drag coefficient (C_D), and the resulting F_D .

METHODS: An empirical model of aerodynamic drag for a range of body positions was developed based on wind tunnel tests of 8 subjects, both male and female, in systematically varied body positions. In addition, a new test rig was engineered that allows adjustment of the ski angles relative to the air flow, to investigate how the skis influence lift and drag during jumps. Testing with elite-level athletes from the Norwegian national team was used to validate experimental findings and to help understand their practical application.

RESULTS: As an illustration of our findings, Figure 1 presents the relative change in C_{DA} for varying arm angle in the skier frontal plane for three subjects. The uncertainty of the resulting numerical model in calculating skier C_{DA} based on body segment angles was $\pm 3\%$. Altogether the model gives us a good understanding of how skier positioning affects A , C_D , and F_D , and furthermore which factors make up for the change.

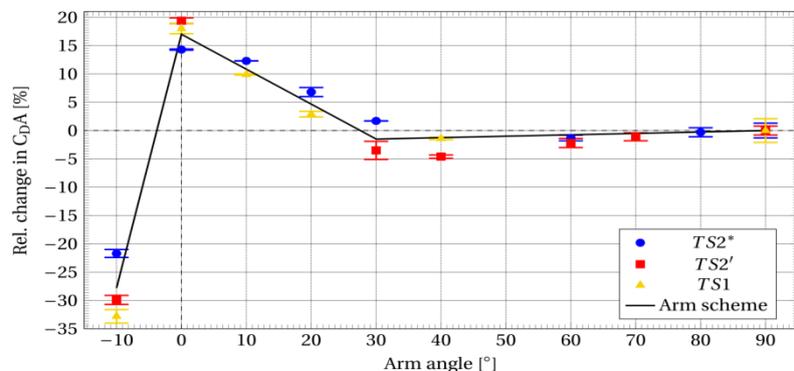


Figure 1. Regression model for the percentage change in C_{DA} based on frontal plane arm angle. 90° was used as the reference position.

DISCUSSION & CONCLUSION:

Interestingly, C_D was surprisingly similar between different subjects standing in the same positions. However, for a given body position, changing the arm angle had a large impact on C_D , as shown in Figure 1. Further testing is required at varying speeds to determine to which degree skier C_D is speed dependent.

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Methodology and Technology in Skiing

Friday, 15th of March: 9:00–10:35

Invited lecture

CLASSICAL CROSS-COUNTRY SKIING TECHNIQUE DETECTION BY HIGH PRECISION KINEMATIC GLOBAL NAVIGATION SATELLITE SYSTEM

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KEY WORDS: Cross-country ski, classical technique, sub-technique detection, kinematic GNSS

INTRODUCTION: The purpose of this study was to detect the various classical style techniques in cross-country skiing using a high-precision kinematic GNSS.

METHODS: For ski style detection a world-class cross-country skier performed a 5.3 km time trial on-snow using the classical style. The skier was instrumented with a 10 Hz high-precision kinematic GNSS (Miyamoto et al. 2018) mounted on the top of the head and a video camera attached to the lumbar region as gold standard for technique detection. The type and number of each classical skiing technique was separately analyzed manually based on the video and GNSS data by two independent persons. The total counts (1 count = 1 cycle) for each technique during trial and the match ratio between the video vs. GNSS evaluation was calculated.

RESULTS: The skiing time, absolute time and relative time for each technique measured by GNSS, and total counts of cycles measured by video and GNSS, and it's match ratio for each technique were shown in Table 1.

Table 1 Characteristics of technique counted by video and GNSS data, and it's match ratio (manual/video) in 5.3 km classical ski time trial. Absolute and relative time was measured and calculated by GNSS data.

Technique	Absolute time (sec.)	Relative time (%)	Counts by video	Counts by GNSS	Match Ratio (%)
Double poling	406" (6'46")	49.6	379	377	99.5
Diagonal	153" (2'33")	18.7	290	292	100.7
Kick double poling	50"	6.1	44	38	86.4
Herringbone	27"	3.3	57	49	86.0
Crouching (downhill)	183" (3'03")	22.3			
Total	819" (13'39")	100.0	770	756	98.2

DISCUSSION: The match ratio between the two methods (video and GNSS) with respect to double poling and diagonal stride were extremely high (~100%), but those of herringbone and kick double poling to a lower extent (~86%). However, almost 50% of the total skiing time was with double poling and only 18.7% with diagonal stride. Therefore, the total match ratio including all 4 techniques was very high (98.2%). The head movement during herringbone was small to clearly distinguish with diagonal stride. Kick double poling was characterized by two successive waves that, however, made it difficult to distinguish with double poling.

CONCLUSION: This study revealed that high-precision GNSS can detect highly accurate the number of techniques in cross-country ski classical style especially with respect to double poling and the diagonal stride.

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VALIDATION OF WEARABLE KINEMATIC GNSS RECEIVER FOR CROSS-COUNTRY SKIING

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KEY WORDS: Differential GPS, low cost GPS, positioning accuracy, static, dynamic

INTRODUCTION: The purpose of this study was to validate positioning accuracy of a wearable high-precision kinematic GNSS receiver, compared with differential GPS receivers commonly used in skiing.

METHODS: Static (10 min stationary position) and dynamic (2.1 km trial on a cross-country skiing track with a snowmobile) positioning analysis have been performed with the wearable kinematic GNSS receiver AT-H-02 (Miyamoto et al. 2018) and four differential GPS receivers (i) Physilog4 GOLD 10D with external antenna ANN-MS-2-005, (ii) Suunto Ambit3, (iii) Polar V800 and (iv) Galaxy S5. For gold standard comparison Trimble R8, a real-time kinematic (RTK) GNSS receiver for land surveying, was used. All receivers were aligned on a rigid T-bar (Figure 1).

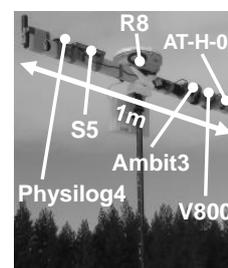


Figure 1. Measurement configuration.

Table 1. Static and dynamic positioning analysis results in horizontal (latitude & longitude) and vertical (altitude) directions. "n/a": The GPS receiver did not output enough data for analysis.

	kine matic GNSS	wear able	1) static analysis		2) dynamic analysis			
			RMS error (m)		RMS error to the gold standard (m)		match ratio within 10cm to the gold standard (%)	
			horizontal	vertical	horizontal	vertical	horizontal	vertical
Trimble R8	✓		0.0067	0.0109	gold standard			
AT-H-02	✓	✓	0.0204	0.0458	0.0630	0.0994	88.2%	60.2%
Physilog4		✓	1.88	1.99	2.70	4.39	2.1%	4.3%
Suunto Ambit3		✓	n/a	n/a	1.70	1.87	3.3%	5.5%
Polar V800		✓	n/a	n/a	1.69	1.53	1.7%	6.6%
Galaxy S5		✓	5.37	3.66	5.15	5.96	0.0%	1.3%

RESULTS & DISCUSSION: Static and dynamic positioning analysis results are shown in Table 1. 1) The AT-H-02 achieved cm-level accuracy, which was 2 orders of magnitude higher than the differential GPS receivers. The AT-H-02 demonstrated 3 to 4 times lower accuracy compared with the gold standard, due to an internal smaller antenna. 2) It was found that position of the AT-H-02 was 88.2% (horizontal) and 60.2% (vertical) matched to the gold standard within 10 cm radius, while the differential GPS receivers were almost never (0.0 - 6.6%).

CONCLUSION: Only the kinematic GNSS receiver achieved cm-level positioning accuracy at a stationary position, and within 10 cm positioning accuracy during dynamic exercise. Since the AT-H-02 is a wearable kinematic GNSS receiver sampling at 10 Hz, and is comparable to land surveying RTK GNSS (1 Hz), it is very useful for sports biomechanics, as for instance cross-country skiing.

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CROSS-COUNTRY TECHNIQUE AND SUB-TECHNIQUE CLASSIFICATION USING A SINGLE INERTIAL SENSOR PLACED ON THE SKI

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KEY WORDS: Activity classification, cross-country skiing, inertial sensors, deep learning

INTRODUCTION: Different sub-techniques characterize XC skiing classic (CL) and skating (SK) techniques. CL is composed of diagonal stride (DS), double poling (DP), double pole kick (DPK) and herring bone (HB), while SK of paddling (G2), double dance (G3), single dance (G4) and skating without poles (G5). Coaches are interested in linking sub-technique distribution to performance, but it is a labor intensive process usually involving manually labelling data based on video recordings. The novelty of this study consists on a single classifier for both SK and CL sub-techniques based on data recorded by a single inertial sensor placed on the ski, since previously publications focused only on SK (Stöggl et al., 2010) or CL (Rindal et al., 2017) with the sensor placed on the chest.

METHODS: Five professional and six amateur skiers performed CL and SK sub-techniques on uphill and flat terrains. One operator who was following the skiers, labeled the data using a mobile application. An inertial sensor (Physilog5, Gait Up™, CH) was fixed on the right ski of each athlete. The recorded data was then classified using deep learning techniques in three steps: technique classification, cycle extraction, sub-technique classification.

RESULTS: Figure 1 shows the CL and SK sub-techniques classification results. A difference was made for G2 and G4 sub-techniques if performed on the right (R) or left (L) leg of the skier. CL and SK sub-techniques were classified on average at 97 % and 92 % accuracy, respectively.

DISCUSSION: The lower accuracy of the SK sub-techniques classification may be due to the fact that these sub-techniques are more similar to each other.

CONCLUSION: This study shows the possibility of using a single inertial sensor as a basis for performance analysis of XC skiing athletes thanks to accurate classification of sub-techniques. Taking advantage of the ski sensor position, additional coaching metrics, such as glide and push-off time, might be extracted in further studies.

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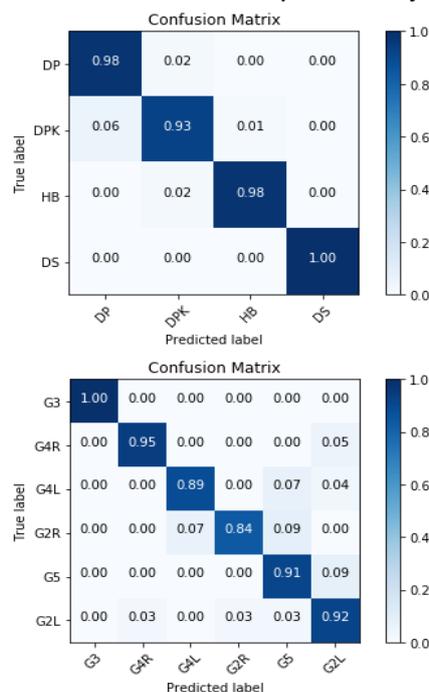


Figure 1. Classic (Top) and Skating (Bottom) sub-technique classification results

FEASIBILITY OF A METHOD TO ASSESS JOINT LOADING IN SNOWBOARD LANDINGS

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KEY WORDS: Snowboarding; jump design; reaction forces; inertial sensors; GNSS

INTRODUCTION: Jump landings in snowboarding have been associated with high injury risk. Therefore, Hubbard et al. (2009) suggested to construct jumps and landing slopes in a way that the effective fall height can be limited. While the concept is plausible it is of interest how landing height and technique affect joint loading. The purpose of this study was to investigate if inertial motion units (IMU) fused with differential GPS data to capture full-body kinematics in outdoor settings would provide kinematics of sufficient quality to apply to musculoskeletal models.

METHODS: Two participants (1/1 female/male, 24/25 years) were equipped with an Xsens motion capture system (240 Hz) and a full body marker set (53 markers) recorded by eight Qualisys cameras (QTM, 240 Hz). The experiment included a selection of simulated snowboard landings in a laboratory setting, e.g., jumping off a box onto a mattress, jumping with the snowboard from a moving roller board or from a swing with a climbing rope, releasing and landing on the mattress. As the IMU system outputs the body movement in a local coordinate system, one marker from the QTM data was used to simulate the GPS system as it would be used during outdoor experiments. After merging these data both sets were applied to a full-body model in Visual3D, to calculate joint angles (ankle, knee, hip, pelvis-trunk) and centre of mass (CoM) position. Data were compared using Bland-Altman plots for discrete values and coefficients of multiple correlation (CMC) for time courses of parameters.

RESULTS: Calculated joint angles followed a similar pattern ($CMC \geq 0.94$) while differences of the mean ranged from 1.5 – 8.9 degrees across all joints and values. CoM position differences of the mean varied from 2.5 – 4.5 cm across all trials.

DISCUSSION: Both approaches provided similar results for kinematics and should therefore be suitable to be applied to inverse dynamics modeling in case a suitable force sensor is integrated into the data capture system for outdoor measurements.

CONCLUSION: The findings of this study illustrate a promising approach to assess joint loading in snowboarding.

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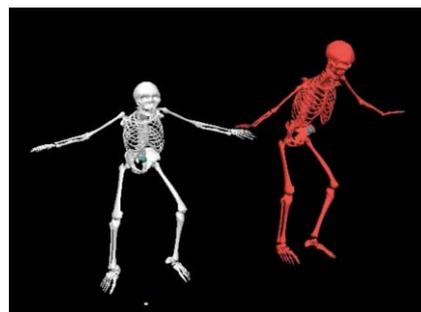


Figure 1. Superimposed model from video data (white) and IMU data (red); offset added for graphical illustration.

SKI CHARACTERISTICS FROM DIFFERENT WIDTH SKIS WHILE POWDER SKIING

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KEY WORDS: Ski width, powder skiing, edge angle

INTRODUCTION: As ski width increases the floatation in powder snow conditions (POW) is enhanced. Although wide skis WS are designed primarily for POW, previous research has dealt with WS only on groomed (GR) terrain (Seifert et al. 2018). The purpose of this study was to measure narrow skis (NS) and WS ski characteristics with regards edge angle on GR and POW conditions.

METHODS: Following approval from the MSU IRB, three elite level skiers completed two runs on GR and in 33 cm POW. The GR run was tilled the morning of testing, following the overnight snow fall. The snow density was reported by the ski area as 45 kg/m³. The NS had an underfoot width of 67 mm while the WS had a width of 95 mm. A motion sensor captured ski data at 100 Hz. Data was collected from four turns once skiers reached a stable skiing speed.

RESULTS: Average turn time was less, peak edge angle occurred earlier, and was greater, and peak angular velocity of the ski rotating around it's longitudinal axis was higher in the NS and the GR condition.

Table 1. Ski characteristics during skiing on groomed and powder conditions (mean (SD)).

	Turn Time (sec)	Peak Edge Angle (°)	% of Turn	Peak Angular Velocity (°)
NS GR	1.11 (0.06)	72 (3)	50.0 (3.0)	273 (3)
WS GR	1.40 (0.33)	59 (2)	53.1 (6.3)	226 (60)
NS POW	0.93 (0.01)	68 (1)	56.0 (2.0)	246 (19)
WS POW	1.00 (0.06)	53 (6)	56.4 (5.0)	205 (45)

DISCUSSION & CONCLUSION: The quantitative measures of ski edging were presented here for a NS and WS in GR and POW conditions. Ski technique reflects the need for greater edge angle as snow conditions become more firm. Peak edge angle is also coincident, albeit not measured here, with maximum pressure in the turn. Since the WS does not achieve as high of an edge angle it is realistic to surmise that the skier is possibly decreasing turn radius slightly to facilitate speed control. With increased lateral torque it is logical that WS is slower when tipping onto its edge.

REFERENCE:

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SKI STYLE CLASSIFICATION AND SCORING IN ALPINE SKIING USING A SIMPLE SENSOR AND ALGORITHM SYSTEM

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KEY WORDS: Alpine Skiing, IMU, carving, drifted turns, snowplow

INTRODUCTION: Alpine Skiing is a complex and dynamic movement with a high degree of variability both within and between skiers. Previous studies have used complex measurement systems to identify turn characteristics that might predict ability of performance¹. In an effort to identify parameters measurable by a simple system, the purpose of this study was to identify variables using a simple sensor system that differentiate between skiing ability within and between skiers.

METHODS: Three expert skiers completed eight runs, performing at least 10 turns in long, medium, and short radius in carving and parallel drifted skiing styles. The seventh and eight runs were steered and pure snowplow turns. Edge angle and g-force were calculated based on 3D inertial sensors (50 Hz) attached to the posterior cuff of both ski boots. Maximum velocity was calculated via GNSS (1Hz) recorded on a mobile phone during each run. Using the mean and standard deviation as of all turns within each style (carving, parallel, snowplow) as a guide, a scoring system was developed such that the highest scores would be observed in carving, the lowest in snowplow, and parallel drifted between.

RESULTS: The scoring system developed using these means is presented in Table 1. The values for score of 10 correspond to “perfect” carving, 6 to parallel drifted turns, and 1 to snowplow.

DISCUSSION: While this study only included three skiers and limited number of turn characteristics, this system represents a first attempt at using simple turn characteristics to discriminate between skiing styles and abilities. Future work should include more skiers, machine learning techniques, and more turn characteristics (timing, acceleration, turn radius etc.) which might better discriminate between skier abilities, but also skiing styles².

CONCLUSION: Skier ability can be determined by a scoring system derived from turn characteristics that can be measured by a simple sensor system.

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Table 1. A Scoring System for Alpine Skiing

Score	Velocity (m*s ⁻¹)	Edge Angle(°)	G-Force
10	≥ 17.0	≥ 54	≥ 2.5
9	15.5 - 16.9	52- 54	2.25 – 2.49
8	14.0 - 15.4	50 – 52	2.00 – 2.24
7	12.5 - 13.9	47 – 50	1.75 – 1.99
6	11.0 - 12.4	44 – 47	1.50 - 1.74
5	9.5 - 10.9	41 – 44	1.25 - 1.49
4	8.0 - 9.5	38 – 41	1.00 - 1.25
3	6.5 - 7.9	34 – 38	0.75 – 0.99
2	5 - 6.5	30 - 34	0.50 - 0.74
1	< 5	< 30	< 0.50

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