

BOOK OF ABSTRACTS

NORDIC WINTER SPORTS CONFERENCE

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ORAL PRESENTATIONS

Development and Numerical Evaluation of an Open-Air Flight Simulation Facility for Ski Jumping Aerodynamics

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Aim: The aim of this study was to develop and numerically evaluate a dedicated open-air flight simulation facility located in the vicinity of a ski jump, enabling controlled and repeatable investigations of aerodynamic conditions during the jumping and in-flight phases of ski jumping, as suggested by Schwameder [1]. A further objective was to achieve realistic wind velocities of up to 100 km/h [2] under laboratory conditions.

Methods: A conceptual facility design was developed using a staged Computational Fluid Dynamics approach. Two-dimensional simulations were first applied to define fundamental flow characteristics and design constraints, followed by three-dimensional simulations for detailed assessment and optimisation. Key parameters were analysed iteratively. All simulations were conducted at velocities relevant to ski jumping flight conditions.

Results: The numerical results demonstrate that the proposed facility concept is capable of generating a realistic and homogeneous inflow as well as a representative surrounding flow field around an athlete mannequin. Optimised fan spacing and targeted geometric modifications improved velocity uniformity within the region of interest. The final configuration showed stable and reproducible flow conditions suitable for aerodynamic investigations. Furthermore, the numerical results directly supported the construction of the real flight simulation facility.

Practical Application: The developed flight simulation facility represents a novel experimental infrastructure for systematic aerodynamic research in ski jumping. It enables controlled testing of equipment, body positions, and measurement systems and can be used to simulate both the take-off and in-flight phases of ski jumping, supporting future biomechanical and aerodynamic studies under reproducible laboratory conditions beyond real-world constraints.

References

[1] H. Schwameder, „Biomechanics research in ski jumping, 1991–2006“, *Sports Biomechanics*, Vol. 7, Nr. 1, p. 114–136, Jan. 2008, doi: [10.1080/14763140701687560](https://doi.org/10.1080/14763140701687560).

[2] M. Virmavirta, „Aerodynamics of Ski Jumping“, in *The Engineering Approach to Winter Sports*, F. Braghin, F. Cheli, S. Maldifassi, S. Melzi, and E. Sabbioni, ed., New York, NY: Springer New York, 2016, p. 153–181. doi: 10.1007/978-1-4939-3020-3_6.

PRESENTATION: Wednesday, April 22 at 13.45 (Oral Presentation 1)

Towards an AI-accelerated sports aerodynamics pipeline

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Aim: This study presents work towards a fast pipeline for sports aerodynamics using image-to-3D reconstruction for the 3D model and a cloud-CFD (computational fluid dynamics) platform or surrogate modelling for the flow simulation. The objective is to replace the traditional sequential workflow of 3D scanning, manual geometry processing, meshing, and CFD with an automated, scalable pipeline capable of delivering aerodynamic feedback within seconds.

Methods: Athlete geometries are reconstructed from a single image using segmentation-driven image-to-3D methods. Both use of a cloud-native CFD platform and the use of neural-operator based surrogate models are used to simulate the resulting geometries. The performance of the pipeline is evaluated in representative winter sports scenarios, including downhill skiing and speed skating postures.

Results: The integrated workflow enables geometry generation and surrogate-based aerodynamic predictions in seconds. The results show that current technology enables predictions within 10 % of the baseline, both for image-to-3D compared to 3D scanning, and surrogate modelling compared to full CFD simulation. The relative performance differences between postures remain consistent.

Practical application: This framework may provide broader access to aerodynamic optimization across performance levels and sports. An AI-driven real-time aerodynamic pipeline may enable simpler testing of sports aerodynamics using cameras instead of expensive wind tunnels. Additionally, the technology could open for new uses of drag predictions, e.g. in dynamic TV broadcast visualizations, or in applications for amateurs for posture improvements.

PRESENTATION: Wednesday, April 22 at 14.00 (Oral Presentation 1)

The Aerodynamic Influence of Arms while Cornering During a 5000 m Speed Skating Race

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INTRODUCTION: Aerodynamic drag is crucial in speed skating accounting for ~90% of the opposing force [1]. To reduce drag, focus is often paid on apparel [2]. However, technique changes could also reduce drag, for example movements of arm [3]. Recently, skaters have started maintaining both arms on the back while cornering on long-distances. This benefit was highlighted this season when Timothy Loubineaud set

a new World Record on 5000 m. Two months later, Sander Eitrem became the first ever under 6 minutes (05:58.52), with the same strategy. Due to this paradigm shift, the aim is to highlight the aerodynamic influence of utilizing both arms on the back while cornering on 5000 m.

METHODS: Drag measurements were collected dynamically, mimicking speed skating movement, with arms on back and one arm loose on Sander Eitrem. A power balance model [4] was then used to simulate the power production and dissipation on Sander's 05:58.52 run. Afterwards drag values were changed in various conditions to understand the aerodynamic effect.

RESULTS: Wind tunnel data showed that drag increased by ~8% when swinging one arm, compared to having both on the back. Simulation of the current World Record run indicated an average power output of 7.60 W/kg. Swinging one arm while cornering, increased the total time by 5.82 second. Highlighting the aerodynamic benefit of maintaining both arms on the back while cornering in 5000 m.

PRACTICAL APPLICATION: This investigation demonstrates the practical importance of maintaining both arms on the back while cornering in long-distance speed skating.

REFERENCES:

[1] Spoelstra, A., Terra, W., & Sciacchitano, A. (2023). On-site aerodynamics investigation of speed skating. *Journal of Wind Engineering and Industrial Aerodynamics*, 239, 105457.

[2] Sætran, L., & Oggiano, L. (2008). Skin suit aerodynamics in speed skating. In *Sport Aerodynamics* (pp. 93-105). Vienna: Springer Vienna.

[3] Giljarhus, K. E. T., Reid, R., Liland, F. F., Oggiano, L., & Elfmark, O. (2022). Aerodynamic influence of an alpine skier's arms. *Sports Engineering*, 25(1), 20.

[4] De Koning, J. J., Foster, C., Lampen, J., Hettinga, F., & Bobbert, M. F. (2005). Experimental evaluation of the power balance model of speed skating. *Journal of Applied Physiology*, 98(1), 227-233.

PRESENTATION: Wednesday, April 22 at 14.15 (Oral Presentation1)

Elastic energy innovations in speed skating suits

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Aim: Although aerodynamic suits are essential for speed skaters, this study aims to demonstrate that the elastic properties of fabrics also exert a measurable influence on skaters' performance and may be systematically optimized.

Methods: A Nike 2002 Olympic suit (NIKE02) and a modified suit with strong elastic bands (MOD) were examined in detail for material hysteresis and tested in squat jumps¹. Based on fabric-elongation measurements across different body regions and hysteresis data from several polyurethane materials, the Norwegian 2018 Olympic suits were subsequently modified for a few skaters. Qualitative observations and key insights from this development process will be presented.

Results: Overall elongation from an upright to a skating posture was 16 (1) percent. The within-suit material-forces in the skating posture were estimated to 98 N and 122 (9) N

for NIKE02 and MOD, respectively, with only MOD affecting the knee joint. Jump height increased by 4.6 (0.8)% and 7.0 (1.1)%, respectively¹.

A manual process for integrating polyurethane across the knee was successful for a few skaters prior to the 2018 Olympics, storing elastic energy without compromising aerodynamics, causing discomfort, or adding much weight. However, the labor-intensive method has not been continued.

Practical application: This study claims that elastic energy has influenced skaters' performance since the 2002 Olympics, and that a significant improvement—including the knee joint—was achieved in the 2018 Olympic season. Newer technology and increased awareness of these effects may lead to further non-aerodynamic, individually tailored suit optimizations, or potentially to modifications of rules and regulations.

References:

1. Myklebust, H. (2008). *Mekanisk avlastning av muskulatur i skøytestilling med elastisk materiale*, <https://hdl.handle.net/11250/171938>

PRESENTATION: Wednesday, April 22 at 14.30 (Oral Presentation 1)

Dynamics of heart rate time series during progressive high intensity roller ski skating in undulating field conditions

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Aim: To assess how terrain-dependent fluctuations during whole-body, interval-based skate roller skiing influences metabolic and cardiovascular regulation.

Methods: Nine biathletes (3F) completed four 3.3-km roller-ski intervals, progressively increasing intensity to a target blood lactate (bLa) of 4–6 mmol·L⁻¹ while self-pacing. bLa was measured after each interval, and continuous heart rate (HR) time series was recorded at 1 Hz and further processed to determine HR and the short-term scaling exponent alpha 1 of detrended fluctuation analysis. GNSS-derived position and speed were synchronized with HR data. Mixed linear models assessed lap effects on HR, speed, time, and bLa, while SPM 1D one-way ANOVA examined instantaneous HR responses across laps and terrain segments - Uphill (UH), Downhill (DH), Undulating (UN1/2).

Results: bLa was lower in lap 1 than in lap 2, 3, and 4 ($p < .01$). HR (%max) did not differ between laps, while HR recovery during rest was slower in lap 4 compared to lap 1, 2, and 3 ($p < .01$). DFA a1 showed no differences across laps or recovery periods. Speed and time showed no lap differences. SPM analysis identified significant differences along the track ($p < .05$) for DFA a1 (UN1, UN2), for HR (%max) (UN1, UH, DH), and for speed (UN1, DH, UN2).

Practical Application: HR recovery demonstrated a delayed impairment despite stable exercise HR, whereas bLa increased after lap 1 and remained elevated across subsequent laps. Instantaneous DFA a1 dynamics revealed significant differences at the start of the course (UN1) and reduced autonomic recovery across laps in UN2, likely reflecting recovery processes following DH.

PRESENTATION: Wednesday, April 22 at 16.00 (Oral Presentation 2)

The relationship between the pole force ratio and gross efficiency in cross-country skiing: a pilot study

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Background: In cross-country skiing, the pole force ratio (PFR) can be defined as the ratio of the propulsive force and axial pole force [1, 2]. Research has shown that during constant-power-output (CPO) double poling, the PFR can be described as a nonlinear function of incline, suggesting that it might explain the variance in the physiological response to exercise [2].

Aim: This study aimed to investigate the feasibility of modeling gross efficiency (GE) and heart rate (HR) during cross-country skiing using the PFR.

Methods: The participant performed a submaximal and two CPO double-poling tests, at 70% of the power output associated with the second lactate threshold (i.e., 4 mmol/L), on a motor-driven treadmill. The CPO test consisted of 10 × 2 min stages between 1° and 7° inclines, performed in both increasing and decreasing incline orders. Axial pole force was measured using ski poles with integrated strain gauge force sensors. Respiratory variables and HR were assessed throughout all tests.

Results: GE and HR were accurately modeled by quadratic polynomials ($GE = -85.5PFR^2 + 105.6PFR - 15.6$ and $HR = 607.1PFR^2 + 721.8PFR + 343.3$), with PFR explaining 95% of the variance in both indices until a 3.7° incline.

Practical application: The findings indicate that scaling power output by the PFR could provide a training load assessment approach which accurately reflects exertion during double poling at inclines below the transition incline [3]. Further investigation of the PFR may enhance the understanding of GE and improve pacing optimization algorithms.

References:

[1] Thomas Stoggl and Hans-Christer Holmberg. “Double-poling biomechanics of elite cross-country skiers: flat versus uphill terrain”. In: *Medicine & science in sports & exercise* 48.8 (2016), pp. 1580–1589. doi: 10.1249/MSS.0000000000000943.

[2] Marton Horvath et al. “Effects of speed and incline on double-poling biomechanics [Unpublished manuscript]”. In: *In review* (2026), pp. 1–16.

[3] Erik Andersson et al. "Energy system contributions and determinants of performance in sprint cross-country skiing". In: Scandinavian journal of medicine & science in sports 27.4 (2017), pp. 385–398. doi: 10.1111/sms.12666.

PRESENTATION: Wednesday, April 22 at 16.15 (Oral Presentation 2)

From lab to field – The metabolic demand of a cross-country skier

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Aim: Determine 1) propulsive power during on-snow skiing using a power balance approach, 2) aerobic mechanical power using indirect calorimetry and laboratory-derived gross efficiency values and 3) anaerobic mechanical power production by subtracting aerobic mechanical power from propulsive power.

Methods: Laboratory (gross efficiency) and field measurements (location, velocity, sub-technique utilization, ambient conditions, snow friction coefficient, respiratory data) of two female skiers were collected to feed a power balance model. The power balance model described a cross-country skier during a 10-km time trial on snow (37:39 and 29:10 minutes). Propulsive power was estimated from the power lost to air drag and snow friction, gravitational power and change in kinetic energy. Aerobic mechanical power was estimated from the respiratory data and speed/sub-technique specific gross efficiency values. Anaerobic mechanical power was estimated by subtracting aerobic mechanical power from propulsive power. A local sensitivity analysis highlighted influential input parameters for propulsive power and anaerobic mechanical power.

Results: A high anaerobic mechanical power was found during uphill sections, with signs of recovery during flat or downhill sections. The effective drag area and snow friction coefficient had a notable influence on propulsive power and anaerobic mechanical power across the expected range of measurement uncertainty.

Practical applications: Insight into race-specific propulsive power, aerobic mechanical power and anaerobic mechanical power outlines the demands of skiing. Knowledge about energy system contributions and influential input parameters (i.e. effective drag area and snow friction coefficient) can guide forward dynamics power balance models, that aim to predict performance and opportunities for performance improvement.

PRESENTATION: Wednesday, April 22 at 16.30 (Oral Presentation 2)

Accuracy of commercial global navigation satellite system receivers during alpine ski training: a multi-device comparison

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AIM: Given continuous hardware and algorithmic improvements, testing the latest sports-targeted technology is critical [1]. The aim of this study was to compare the positional, distance, speed, and acceleration accuracies of four receivers designed for sports in a challenging alpine-skiing setting.

METHODS: Two athletes wore four receivers and a gold-standard geodetic-grade reference (post-processed kinematic, 20 Hz) separated by 25–35 cm [2]. Receivers included: Emlid Reach M2 (RTK, 10 Hz), ZXY Arena (RTK, 10 Hz), STATSport Apex Pro (standalone, 10 Hz), and Garmin Forerunner 255 (standalone, 1 Hz). Data from 74 giant slalom runs at Juvass, Norway, were time-synchronised to compute errors. Results are median [interquartile range].

RESULTS: Both RTK receivers (ZXY; Emlid) performed similarly: horizontal position errors were 0.28 [0.24–0.33] and 0.30 [0.26–0.36] m, speed errors 0.03 [0.01–0.06] and 0.04 [0.02–0.08] m/s, and acceleration 0.11 [0.05–0.19] and 0.12 [0.05–0.24] m/s². STATSport showed larger position errors (1.74 [1.23–2.50] m) but comparable speed (0.05 [0.02–0.10] m/s) and acceleration (0.12 [0.05–0.22] m/s²). Garmin had substantially larger errors (position: 11.05 [5.34–17.07] m; speed: 0.81 [0.35–1.66] m/s; acceleration: 1.50 [0.61–3.17] m/s²). Distance error was <1% for all except Garmin (–1.05%).

PRACTICAL APPLICATION: Practitioners must align equipment choice with their specific analytical goals. RTK systems provide the precise spatial mapping required for tactical line and technique analysis. However, for monitoring physical exertion parameters, 10 Hz standalone trackers offer a reliable, cost-effective alternative. Standard 1 Hz consumer devices are inadequate for dynamic high-speed sports.

REFERENCES:

- [1] Torres-Ronda, L., Beanland, E., Whitehead, S., Sweeting, A., & Clubb, J. (2022). Tracking Systems in Team Sports: A Narrative Review of Applications of the Data and Sport Specific Analysis. *Sports medicine - open*, 8(1), 15. <https://doi.org/10.1186/s40798-022-00408-z>
- [2] Gilgien, M., Spörri, J., Chardonens, J., Kröll, J., & Müller, E. (2013). Determination of External Forces in Alpine Skiing Using a Differential Global Navigation Satellite System. *Sensors*, 13(8), 9821–9835. <https://doi.org/10.3390/s130809821>

PRESENTATION: Thursday, April 23 at 11.00 (Oral Presentation 3)

How Can Vision-Based Artificial Intelligence Be Used for Technique Assessment in Cross-Country Skiing?

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Aim: Vision-based artificial intelligence (vision AI) offers potential for objective technique assessment in cross-country skiing. This includes markerless motion-

capture systems, where vision AI is a key component. The presentation provides an overview of the current state of vision AI in cross-country skiing and explores perspectives, future directions, and practical possibilities for coaches and practitioners.

Methods: Literature on vision AI for skiing technique assessment was reviewed. This was supplemented by first-hand experience from the United States Cross-Country Ski Team, which conducted a large-scale markerless-capture campaign across their national team, and our ongoing applied initiative in this field.

Results: Although peer-reviewed literature in this field remains sparse [1], master's theses and applied development projects indicate that multiple groups are actively working in this space [2,3]. Existing systems range from treadmill-based multi-camera markerless setups [1,2] to a field-deployable AI feedback system based on a single camera [3]. One of the most mature applications is the Finnish Vuokatti environment [1,2], where vision AI forms part of the broader Coachtech coaching feedback platform. The United States team's campaign illustrates applied interest beyond research groups, with insights into scalability, data quality, and practitioner adoption. Overall, accuracy and robustness in controlled settings appear promising, while field deployment remains a key challenge.

Practical Application: Vision AI tools offer the potential to move technique assessment in cross-country skiing from subjective coach observation toward objective, reproducible biomechanical analysis. Coupling technique assessment with physiological efficiency measurements and examining technique changes under fatigue represent particularly promising directions for applied use.

REFERENCES:

1. Torvinen et al. (2024). Detecting skier pose on treadmill by machine learning. *Bioengineering*, 11(2), 136.
2. Hulkkonen (2022). Detecting skier pose on treadmill by machine learning. Master's thesis, University of Eastern Finland.
3. Wilde & Lundin (2025). Improving Cross-Country Skating Technique with AI-Based Feedback. Master's thesis, Luleå University of Technology.

PRESENTATION: Thursday, April 23 at 11.15 (Oral Presentation 3)

PET imaging technology as a tool to elucidate cardiac function in endurance athletes

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Aim: The heart contributes importantly to determine the endurance exercise performance. Proper cardiac function critically depends on its oxygen supply, thus blood flow, which may be one of the limiting factors for exercise performance [1]. In our previous [2-5] and recent studies we have elucidated this phenomenon by studying the heart of highly trained endurance athletes at rest and during exercise and during pharmacological, adenosine-induced vasodilation.

Methods: Athletes have been mostly, but not solely cross-country skiers whose heart has been studied by positron emission tomography (PET) imaging.

Results: The results indicate that myocardial blood flow (MBF) is lower, but oxygen extraction is higher both at rest and during exercise in the endurance-trained athletes' than in untrained subjects. Thus endurance athletes have limited capacity to increase myocardial oxygen extraction and they rely almost solely on increased MBF to deliver oxygen, especially during maximal exercise. MBF is however very hard to measure during maximal exercise, but adenosine-induced MBF studies indicate that endurance athletes do not have improved MBF reserve. Further, in our recent studies we have tried to estimate, based on submaximal exercise intensities, maximal exercise MBF. These results also suggest that peak MBF is not higher in the endurance-trained heart, but that peak MBF in humans might be in general higher than previously considered.

Practical application: These results, obtained by non-invasive imaging technology as heart is difficult to study otherwise, provide complementary information to cardiac ultrasound studies trying to increase the understanding of the function and performance of the athlete's heart.

References

1. Heinonen I. Cardiac output limits maximal oxygen consumption, but what limits maximal cardiac output? *Exp Physiol* 2025; 110(5):666-674.
2. Heinonen I, Kudomi N, Kempainen J, Kiviniemi A, Noponen T, Luotolahti M et al. Myocardial blood flow and its transit time, oxygen utilization, and efficiency of highly endurance-trained human heart. *Basic Res Cardiol* 2014; 109(4):413.
3. Heinonen I, Nesterov SV, Liukko K, Kempainen J, Nagren K, Luotolahti M et al. Myocardial blood flow and adenosine A2A receptor density in endurance athletes and untrained men. *J Physiol* 2008; 586(21):5193-5202.
4. Kalliokoski KK, Nuutila P, Laine H, Luotolahti M, Janatuinen T, Raitakari OT et al. Myocardial perfusion and perfusion reserve in endurance-trained men. *Med Sci Sports Exerc* 2002; 34(6):948-953.
5. Laaksonen MS, Heinonen I, Luotolahti M, Knuuti J, Kalliokoski KK. VO₂(peak), myocardial hypertrophy, and myocardial blood flow in endurance-trained men. *Med Sci Sports Exerc* 2014; 46(8):1498-1505.

PRESENTATION: Thursday, April 23 at 11.30 (Oral Presentation 3)

Mapping Open Innovation Strategies among Sports Start-ups in Europe

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Aim: This study analyses the Open Innovation (OI) strategies adopted by sports start-ups and how they structure collaborations with key actors in the Open Innovation Ecosystem (OIE). The paper also explores how these choices of openness influence innovation management.

Methods: Descriptive analyses and cluster analyses have been used on survey data of 209 sports start-ups in Europe.

Results: The results show that the sports start-ups show generally low openness to external collaboration. The sports start-ups display the deepest intensity of openness to Users and Customers. In terms of OI strategies, the sports start-ups favour the outside-in and coupled strategies. Openness to Universities and Research Institutions and Intermediaries and Knowledge Brokers represent the lowest scores, with the inside-out approach being the least common OI strategy. The cluster analysis identified four distinct configurations of openness: (1) Market-User Oriented Openness, (2) Institutional-Corporate Openness, (3) Investor-Driven Openness and (4) Technology-Provider Openness. These configurations reveal heterogeneous OI paths through which sports start-ups access resources, build legitimacy and manage constraints.

Practical applications: At the managerial and practical level, the results indicate the need for support tools capable of strengthening the sports ecosystems and helping start-ups overcoming the liability of newness and smallness. The main contribution consists of identifying different configurations of openness among start-ups giving them a useful tool to understand how deeply and broadly they collaborate with other players in the ecosystem.

PRESENTATION: Thursday, April 23 at 11.45 (Oral Presentation 3)

Curvature creates speed: a new perspective on speed skating technique

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Background: The classical model of speed skating assumes that the skate travels in a straight line at constant forward velocity, while sideward push-offs generate a velocity increase of the skater's centre of mass (CoM) perpendicular to the skate^{1,2}. However, experimental data suggest that the CoM also gains forward velocity during each stroke³.

Aim: This study examines the effect of a curved skate trajectory on skater velocity. We hypothesized that as the skater leans inward while the skate follows a curved path, the CoM gains forward velocity.

Methods: To test this, we developed a simplified inverted, extendable pendulum model in which the CoM maintains constant height while the leg extends and tilts inward⁴.

Results: When the skate is constrained to a circular path, the model predicts an increase in forward CoM velocity during the stroke—an effect absent under the straight-line assumption.

Practical implications: With these findings, common coaching cues such as “finding pressure” gain a concrete mechanical interpretation. In the curved-path model, pressure reflects the generation of centripetal acceleration: only when the skate follows a curved trajectory and the skater leans inward does the CoM acquire an additional forward velocity component. In the straight-path case—analogous to running—maximum forward velocity is primarily limited by maximal leg extension velocity. In contrast, the curved-path model predicts that the same resultant skating speed can be achieved with lower peak leg extension velocities and reduced peak instantaneous

power, at the cost of higher extension forces. A trade-off, speed skaters are acutely aware of in practice.

References:

1. van Ingen Schenau GJ, Bakker K. A Biomechanical model of speed skating. *Journal of Human Movement Studies*. 1980;6.
2. van Ingen Schenau GJ, de Boer R, de Groot G. On the technique of speed skating. *International Journal of Sport Biomechanics*. 1987;3. doi:10.1123/ijsb.3.4.419
3. Yuki M, Ae M, Asami T. Re-examination of acceleration theory in speed skating. *Biomechanisms*. 1992;11. doi:10.3951/biomechanisms.11.111
4. van der Eb JW, Yeadon MR. Does the Forward Velocity increase during a Curved Speed Skating Stroke and if so what Is the Mechanism? Submitted 2026

PRESENTATION: Friday, April 24 at 9.30 (Oral Presentation 4)

Within and between season development in performance-determining variables in cross country skiers

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Aims: Longitudinal data on the development of training characteristics and physiological capacities in endurance athletes is currently lacking in the sport science literature. Therefore, this study aimed to investigate longitudinal changes in performance-determining variables and laboratory performance in male and female cross-country skiers within and between seasons.

Methods: 58 male and 19 female national level skiers performed a minimum of two laboratory tests in the general preparation period for analysis of within season effects and a minimum of one laboratory test over two or more years (from 2022 to 2025) for analysis of between season effects. The laboratory tests included a sub-maximal test (for determination of work rate at 4mmol of lactate and corresponding gross efficiency and fractional utilization of VO₂peak) and a maximal test (for determining VO₂peak (ml·kg⁻¹·min⁻¹) and peak power output (PPO; highest one-minute work rate achieved in W)).

Results: Within each season, PPO increased by 17.8±5.3W (p<0.001) and VO₂peak increased by 2.4±1.0 mL·min⁻¹·kg⁻¹ (p=0.020). Gross efficiency at 4mmol of lactate did not change within the season (Δ0.149±0.195 percentage points p=0.445). Between seasons, the average increase in PPO was 10.5±3.0W (p<0.001) and VO₂peak did not increase (Δ0.7±0.6 mL·min⁻¹·kg⁻¹, p=0.255). Gross efficiency at 4mmol of lactate did not change between the season (Δ0.011±0.113 percentage points p=0.920).

Practical applications: Our data indicate that the changes in performance determining variables from season to season in national-level skiers are small and smaller than

within season changes. There no clear differences between men and women in their development although.

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Influence of fatigue on transitions in ski-mountaineering

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INTRODUCTION: This study investigated the execution of the transition in which athletes remove the skins from their skis to change from the uphill to downhill setup (T3). We observed how T3 time changed after exercise at different intensities compared with baseline conditions. We also investigated relationship between rating of perceived exertion (RPE), lactate concentration (La), and transition score (Tr.score) given by the athletes.

METHODS: The main test included a baseline T3 assessment before and after the protocol and a T3 execution performed after each of two stages at each intensity level. Linear mixed models (LMM) and repeated measure ANOVA were used to investigate the differences in T3 times between domains, and any associations between T3 times and RPE, La, and Tr.score.

RESULTS: LMM showed a significant main effect of Domain ($p < 0.001$), with lower values at baseline compared with all exercise conditions. These results were confirmed by the repeated-measures ANOVA ($p < 0.001$, $\eta^2_p = 0.48$). Post hoc comparisons showed that baseline post-test differed significantly from all exercise conditions ($p < 0.01$). No significant association were found between T3 time and RPE or La. T3 time significantly predicted Tr.score, ($\beta = -1.03$, $SE = 0.16$, $p < 0.001$).

PRACTICAL APPLICATIONS: Transition time did not differ between intensity domains during exercise, whereas significant differences were observed between baselines and exercise conditions. T3 training should be performed after an exercise bout, while exercise intensity does not appear to be a determining factor for transition training.

REFERENCES:

1. Bortolan, L., Savoldelli, A., Pellegrini, B., Modena, R., Sacchi, M., Holmberg, H. C., & Supej, M. (2021). Ski Mountaineering: Perspectives on a Novel Sport to Be Introduced at the 2026 Winter Olympic Games. *Front Physiol*, 12, 737249. <https://doi.org/10.3389/fphys.2021.737249>
2. Fornasiero, A., Fornoni, S., Callovini, A., Todesco, B., Savoldelli, A., Schena, F., Holmberg, H. C., Pellegrini, B., & Bortolan, L. (2024). Analysis of Sprint Ski Mountaineering Performance. *Int J Sports Physiol Perform*, 19(2), 155-163. <https://doi.org/10.1123/ijspp.2023-0075>
3. International Ski Mountaineering Federation Rules & Guidelines, 162 (2025).

4. Wagner, C.-M., Röhrs, D., Sandbakk, Ø., Katz, A., Wittke, A., & Keiner, M. (2024). Performance-Determining Variables of a Simulated Skimo Sprint Competition in Elite Junior Skimo Athletes. *Applied Sciences*, 14(5), 1882. <https://www.mdpi.com/2076-3417/14/5/1882>

5. Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*, 14(5), 377-381

PRESENTATION: Friday, April 24 at 10.00 (Oral Presentation 4)

A quantitative study on athletes' willingness to communicate health-related-issues among high-performing Norwegian cross-country skiers

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Aim: High performing athletes are often expected to push their physical limits while simultaneously avoiding unnecessary health risks [1, 2]. Furthermore, there is a significant concern of athletes not reporting health-related-issues to their coach (ComHealth) [3]. Therefore, the current study examines cross-country skiers' willingness to ComHealth to their coach, and how this is associated with athletic-identity and the coach-athlete-relationship.

Method: A total of 206 Norwegian cross-country skiers (52.4% women; mean age = 21.2 years) participated in the study, including both junior and senior athletes. ComHealth (e.g. pain, fatigue and overload) was measured using six items that were subjected to principal-component-analysis and internal-reliability-analysis and found acceptable. Linear regression analyses examined associations between ComHealth and competition level, athletic-identity (Athletic-Identity-Measurement-Scale) [4], and the coach-athlete relationship (Coach-Athlete-Relationship-Questionnaire) [5].

Results: Approximately 25% of the athletes reported low willingness to ComHealth to their coach. Higher competition level (top-30-in-Norway) and stronger athletic-identity were negatively associated with ComHealth ($p < .01$). In contrast, coach-athlete-commitment and complementarity were positively associated with ComHealth ($p < .01$). An interaction effect showed that complementarity had a stronger positive association with ComHealth among sub-top-30-athletes compared to top-30-athletes ($p < .05$).

Practical applications: A strong athletic-identity - a prevalent characteristic among high-performing-athletes - may act as a barrier to health-transparency among cross-country skiers. To counteract this, coaches should prioritize building relationships characterized by commitment and complementarity to facilitate open ComHealth. Such efforts may support both athletes' welfare and long-term performance.

Reference:

1. Nixon, H.L., Accepting the Risks of Pain and Injury in Sport - Mediated Cultural Influences on Playing Hurt. *Sociology of Sport Journal*, 1993. 10(2): p. 183-196.
2. Mayer, J., F. Kühnle, and A. Thiel, Presenteeism in elite sport organisations: a framework for understanding athletes' decisions to practise sport despite health concerns, in *Routledge Handbook of Athlete Welfare*, M. Lang, Editor. 2020, Routledge. p. 81-93.
3. Baugh, C.M., Athlete Concussion Reporting: It Is Time to Think Bigger. *J Adolesc Health*, 2020. 66(6): p. 643-644.

4. Lochbaum, M., S. Cooper, and S. Limp, The athletic identity measurement scale: A systematic review with meta-analysis from 1993 to 2021. *European journal of investigation in health, psychology and education*, 2022. 12(9).

5. Jowett, S. and N. Ntoumanis, The coach–athlete relationship questionnaire (CART-Q): Development and initial validation. *Scandinavian journal of medicine & science in sports*, 2004. 14(4): p. 245–257.

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POSTER PRESENTATIONS

Thursday, April 24th at 14.00

Validation and evaluation of Skisens force sensors for ski poles

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AIM: Reliable cross-country poling force measurements in the field, using movable devices, are notoriously difficult to obtain. Skisens AB (skisens.se) has developed wireless integrated strain-gauge and IMU based sensors for this purpose. Logically, such a device requires validation regarding force measurements. We tested the sensor in poles against force plate recordings.

METHODS: We tested six Skisens sensors that were mounted on specially designed pole handles (provided by Skisens). Raw data from the sensors were collected using the company's application. Benchmark force plate (Kistler model 9286B) data were collected under static (constant forces, pole vertical) and dynamic conditions (imitating actual poling actions), in a total of 36 measurements per sensor. Regression analysis was applied to selected data, evenly spread over the range of applicable pole forces.

RESULTS: Regression analysis revealed good linearity within tests, with some exceptions, $R^2 > 0.99$. Regression of pooled data (over all 36 tests) reduced these values ($R^2 > 0.95$). The inter-variation of sensor gain (volt/N), required to convert raw signal to Newton, was relatively low. Some intra-sensor variability (between tests) was shown to reduce the reliability to some extent. It is believed that this may be caused by the sensor mounting procedure.

PRACTICAL APPLICATION: The system can provide useful force-based information. The systems' between-session precision may be improved by a simple and brief calibration procedure for each training session. Force profiles, indicating technique aspects, are assessed as reliable.

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Correlations between different physical ability tests and linear skating performance parameters in male bandy players

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Aim: The purpose of this study was to investigate relationships between different physical ability tests with linear skating performance parameters in elite bandy players.

Methods: 16 male elite bandy players (age: 19.4±3.3 years; height: 1.80±0.05 m; body mass: 77.6±9.8 kg) performed a linear sprint skating profile over 80 m. distance over time was measured with a laser gun and the maximal force (acceleration), average and peak power and maximal velocity were calculated. As physical ability tests the countermovement jump, squat jump and an isometric squat test, together with a Wingate test were performed. Correlations between the different results of the physical ability tests with the peak force, power and velocity for the linear skating performances were calculated.

Results: The main findings were that only countermovement jump height ($r=0.64$) and average power per kg from Wingate test ($r=0.65$) had a significant positive correlation with maximal velocity during skating while no other significant between any of the physical test results with other skating performance parameters were found ($-0.18 \leq r \leq 0.33$).

Practical application: It was concluded that of these physical ability tests only CMJ height and average power per kg produced in Wingate tests can have a predictive meaning for maximal skating velocity and that these tests do not have any relationship with acceleration skating performance.

Differences in metabolic rate between sitting and standing skiing at different work rates

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AIM: To compare the metabolic rate - work rate (MR-WR) relationship for sitting and standing double-poling skiing at 2% and 8% incline in skiers without impairments.

METHODS: Sixteen trained able-bodied cross-country skiers performed treadmill roller-skiing in standing and sit-skiing conditions at 2% and 8% incline, all conditions at three sub-maximal intensities at a self-determined threshold speed. MR was calculated from VO_2 and RER. WR was derived from speed, incline, mass, and rolling resistance. Linear mixed-effects models quantified MR-WR relationships across conditions.

RESULTS: Standing skiing allowed about 45 W higher external work rates than sitskiing (123 vs 168 W). Yet, for a given work rate, sit-skiing resulted in a significantly lower metabolic rate than standing skiing (≈ 95 W lower MR), but the metabolic cost of producing additional external work did not differ between postures (averaging ≈ 4.9 W $\text{MR} \cdot \text{WR}^{-1}$). Incline had a similar WR independent effect: for a given low work rate, the 8% incline required more than 100W extra MR compared to 2% incline. But the MR for increasing WR was lower, leading to MR equivalent crossover points of ~ 155 W (sit-skiing) and ~ 214 W (standing).

PRACTICAL APPLICATION: The potential for producing work rate is limited in sitskiing, even though sitting may be metabolically more economical than standing skiing. Skiing at different inclines had a similar effect regardless of posture. Thus, the profound knowledge of metabolic cost in normal double poling may be transferable to demanding steep uphill sit-skiing for skiers without impairment. The effect of physical impairment needs further investigation.

Reliability and Validity of a 3-Minute All-Out Performance Test for Nordic Skiing: A Pilot Study

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AIM: The 3-minute all-out test (3MAOT) has been suggested as a useful protocol for cycling[1]. The aim of this study was to assess 3MAOT applications in Nordic skiing double poling.

METHOD: Following ethical approval, five Snowsport Scotland Cross-Country Skiing and British Biathlon Union talent squad members (Age: 18 ± 2 years; Mass: 67.0 ± 6.4 kg; Stature: 173 ± 8 cm, Participant Classification Framework Tier[2]: 2), completed four criterion time-trials (3-12 minutes), and two experimental 3MAOTs on a double poling skiing ergometer, in a randomised cross-over design. The 3MAOT end-test power and work done above end test power, were compared against criterion critical power (CP) and work prime (W'), using Pearson's r , intraclass correlation (ICC) and Bland Altman analysis.

RESULTS: The 3MAOT end-test power showed excellent test-retest reliability (ICC: 0.98, Standard Error of Measurement [SEM]: ± 3 W, Coefficient of Variation [CV]: 1.8%, Mean Bias [\bar{d}]: 3.2 W, 95% Confidence Interval [CI]: -1.5, 7.9W), and very large, significant agreement with CP (r : 0.90, p : 0.036, Standard Error of Estimate: ± 11.0 W, CV: 7.5%, \bar{d} : 5.0 W, 95% CI: -18.0, 8.0 W). Work above end test power showed poor reliability (ICC: 0.74, SEM: ± 1.4 kJ, CV: 13.3%, \bar{d} : 0.4 kJ, 95% CI: -2.31, 3.19 kJ).

PRACTICAL APPLICATIONS: The 3MAOT has potential application for assessing double poling CP but not W'. These interpretations are caveated by the underpowered nature of this study, due to the limited sample available in the United Kingdom. Further international collaborative research may clarify these observations.

REFERENCES:

[1]Burnley, M., Doust, J.H. and Vanhatalo, A. (2006) 'A 3-min all-out test to determine peak oxygen uptake and the maximal steady state', *Medicine and Science in Sports and Exercise*, 38(11), pp. 1995–2003.
<https://doi.org/10.1249/01.mss.0000232024.06114.a6>

[2]Morton, S.E., Forrest, L.J., Kavaliauskas, M., Easton, C., Rumley, K. and Macpherson, T.W. (in press) Running Assessed Maximal Oxygen Uptake Increases with Participant Classification Framework Tier in Overall Cross-Country Skiing Performance: A Systematic Review with Meta-Regressions' *Sports Medicine – Open*.