PHYSIOLOGICAL AND BIOMECHANICAL FACTORS DETERMINING CROSS-COUNTRY SKIING PERFORMANCE

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Abstract

Cross-country (c.c.) skiing is a complex sport discipline from both physiological and biomechanical perspectives, with varying course topographies that require different proportions of the involved sub-techniques to be utilised. A relatively new event in c.c. skiing is the sprint race, involving four separate heats, each lasting 2-4 min, with diverse demands from distance races associated with longer durations. Therefore, the overall aim of the current thesis has been to examine the biomechanical and physiological factors associated with sprint c.c. skiing performance through novel measurements conducted both in the field (*Studies I-III*) and the laboratory (*Studies IV* and *V*).

In *Study I* sprint skiing velocities and sub-techniques were analysed with a differential global navigation satellite system in combination with video recording. In *Studies II* and *III* the effects of an increasing velocity (moderate, high and maximal) on the biomechanics of uphill classical skiing with the diagonal stride (DS) (*Study II*) and herringbone (HB) (*Study III*) sub-techniques were examined.

In *Study I* the skiers completed the 1,425 m (2 x 712 m) sprint time trial (STT) in 207 s, at an average velocity of 24.8 km/h, with multiple technique transitions (range: 21-34) between skiing techniques (i.e., the different gears [G2-7]). A pacing strategy involving a fast start followed by a gradual slowing down (i.e., positive pacing) was employed as indicated by the 2.9% faster first than second lap. The slower second lap was primarily related to a slower (12.9%) uphill velocity with a shift from G3 towards a greater use of G2. The maximal oxygen uptake ($\dot{V}O_{2max}$) was related to the ability to maintain uphill skiing velocity and the fastest skiers used G3 to a greater extent than G2. In addition, maximal speed over short distances (50 and 20 m) with the G3 and double poling (DP) sub-techniques exerted an important impact on STT performance.

Study II demonstrated that during uphill skiing (7.5°) with DS, skiers increased cycle rate and cycle length from moderate to high velocity, while cycle rate increased and cycle length decreased at maximal velocity. Absolute poling, gliding and kick times became gradually shorter with an elevated velocity. The rate of pole and leg force development increased with elevated velocity and the development of leg force in the normal direction was substantially faster during skiing on snow than previous findings for roller skiing, although the peak force was similar in both cases. The fastest skiers applied greater peak leg forces over shorter durations.

S*tudy III* revealed that when employing the HB technique on a steep uphill slope (15°), the skiers positioned their skis laterally (“V” between 25 to 30°) and planted their poles at a slight lateral angle (8 to 12°), with most of the propulsive force being exerted on the inside forefoot. Of the total propulsive force, 77% was generated by the legs. The cycle rate increased across all three velocities (from 1.20 to 1.60 Hz), while cycle length only increased from moderate to high velocity (from 2.0 to 2.3 m). Finally, the magnitude and rate of leg force generation are important determinants of both DS and HB skiing performance, although the rate is more important in connection with DS, since this sub-technique involves gliding.

In *Studies IV* and *V* skiers performed pre-tests for determination of gross efficiency (GE), $\dot{V}O_{2max}$, and V_{max} on a treadmill. The main performance test involved four self-paced STTs on a treadmill over a 1,300-m simulated course including three flat (1°) DP sections interspersed with two uphill (7°) DS sections.

The modified GE method for estimating anaerobic energy production during skiing on varying terrain employed in *Study IV* revealed that the relative aerobic and anaerobic energy contributions were 82% and 18%, respectively, during the 232 s of skiing, with an accumulated oxygen (O_2) deficit of 45 mL/kg. The STT performance time was largely explained by the GE (53%), followed by $\dot{V}O_2$ (30%) and O_2 deficit (15%). Therefore, training strategies designed to reduce energetic cost and improve GE should be examined in greater detail.

In *Study V* metabolic responses and pacing strategies during the four successive STTs were investigated. The first and the last trials were the fastest (both 228 s) and were associated with both a substantially larger and a more rapid anaerobic energy supply, while the average $\dot{V}O_2$ during all four STTs was similar. The individual variation in STT performance was explained primarily (69%) by the variation in O_2 deficit. Furthermore, positive pacing was employed throughout all the STTs, but the pacing strategy became more even after the first trial. In addition, considerably higher (~ 30%) metabolic rates were generated on the uphill than on the flat sections of the course, reflecting an irregular production of anaerobic energy. Altogether, a fast start appears important for STT performance and high work rates during uphill skiing may exert a more pronounced impact on skiing performance outdoors, due to the reduction in velocity fluctuations and thereby overall air-drag.

Keywords: cycle characteristics, energy cost, energy yield, incline, joint angles, kinematics, kinetics, mechanics, Nordic skiing, oxygen deficit, oxygen demand, technique transitions, total metabolic rate