Introduction
Sprint cross-country skiing begins with a time-trial qualification, followed by three knock-out heats. Today’s world-class sprint skiers achieve higher peak oxygen uptake, greater efficiency, longer cycle length, and higher maximal speed compared to national level sprint skiers. However, the specific influence of physiological characteristics on different terrains within the sprint heats should be examined more extensively. This investigation was designed to analyze the time-trial (STT) in an international cross-country sprint skiing competition for 1) overall STT performance and relative contributions of time spent in different sections of terrain, 2) work rate and kinematics on uphill terrain and 3) relationships to physiological and kinematic parameters while treadmill roller skiing.

Methods
Twelve elite male sprint cross-country skiers, including three World Champions, volunteered to participate in this study. Initially, a time-trial for an international FIS sprint skiing competition in cross-country skiing was investigated with respect to overall performance and time spent in nine different sections of terrain, as well as kinematics and estimated work rates for one representative uphill section of terrain. The kinematics were examined by analyzing video and work rates estimated from the combined contribution of work against gravity, gliding friction and air resistance. One week later, the subjects performed treadmill roller skiing in the laboratory and were assessed for 1) gross efficiency (GE) in a submaximal test; 2) peak oxygen uptake (VO2peak), treadmill performance and kinematics in a ~5-min incremental test and 3) peak treadmill speed (Vpeak) in a ~1-min incremental test.

Results
- Times on the last two uphill and two final flat sections were correlated to overall STT performance (r = -0.80, P < 0.001).
- For the selected uphill section, speed was correlated to cycle length (r = -0.75, P = 0.01) and the estimated work rate was approximately 16% of peak aerobic power.
- VO2peak and GE, Vpeak and peak cycle length were all correlated to STT performance (r = -0.85, P < 0.001).
- More specifically, VO2peak and GE were correlated to the last two uphill and two final flat section times, whereas Vpeak and peak cycle length were correlated to times in all uphill, flat and curved sections except for the initial section (r = -0.80, P < 0.01).

Discussion
The current findings reveal that the times spent on uphill and flat terrain, especially during the latter part of the race, correlate to STT performance, indicating that the ability to maintain speed is crucial. On a treadmill better sprint skiers demonstrate higher peak oxygen uptake, more efficient technique, and greater speed, as well as longer cycle lengths. VO2peak and GE are important determinants of performance on uphill and flat terrain during the latter part of the race, whereas Vpeak and peak cycle length are of great significance for performance on flat, uphill and curved terrain throughout the race, with the exception of the initial section (S1). Superior time-trial performance in sprint skiing is therefore characterized by a greater ability to generate and maintain speed. The current results show that the most significant determinants of STT performance can also be applied to the total competition ranking after the man against man knock-out heats. However, the importance of the final section of a race might be particularly important during the knock-out heats.