Energy Fluctuations in Double Poling
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Introduction
For walking and running the fluctuations of mechanical energy (E_{kin}) of the center of mass (CoM) are well depicted as inverted pendulum (out-of-phase) and a spring-mass (in-phase) models respectively (Cavagna, 1975). Diagonal stride roller skiing was recently found to be a unique movement where the energy fluctuations only shared minor similarities with walking and running (Kehler et al., 2014). Double poling (DP) is another unique skiing technique where all the propulsive forces are generated solely through the poles. Still the lower limbs have been shown to utilize around 50 % of the metabolic work in DP (Rud et al., 2013), which have been suggested to be caused by the utilization of potential (E_{pot}) and rotational (E_{rot}) energy of the body during the repetitive up-and-down movement. However, this aspect has not yet been fully investigated. To further understand how power is produced during DP, the present study investigated the various energy fluctuations during increasing DP intensities.

Methods
Nine male XC skiers (age 24±5 yrs, body mass 81.7±6.5 kg, VO2max 5.45±0.64 L min⁻¹) completed three 4-min submaximal (low, moderate and high) intensities and one 3-min all-out test on a modified Concept2 SkiErg. Reflective markers (Qualisys motion capture system) were positioned on anatomical landmarks and segment masses and inertia parameters were estimated based on DeLeva (1996). The horizontal (E_{kin}) and vertical (E_{pot}) kinetic energies, the gravitational potential energies and the rotational energies of all segments (foot, leg, thigh, trunk+head, arm and forearm) were added to yield energies of the total center of mass. E_{tot} was defined as the sum of all the energies.

Results and Discussion
During the first two-thirds of the poling phase in DP all joints (except shoulder) were flexed until CoM reached its lowest height. This resulted in a decrease in E_{pot} but a corresponding increase in E_{rot} and E_{kin} (mainly because of the forward rotation of the trunk). In the last phase of poling, extension began in the lower limbs and started a heightening of the CoM that subsequently led to an increase in E_{rot} E_{pot} and E_{tot}. At the start of the cycle, E_{kin} and E_{rot} fluctuated out-of-phase with E_{rot} thereby conserving E_{pot} (inverted pendulum). E_{kin}, E_{rot} and E_{pot} then fluctuated in-phase (spring-mass) creating the rapid decrease and then increase in E_{tot}. E_{kin} was almost zero during the entire cycle, resembling near constant speed in real skiing.

Based on the literature, E_{tot} fluctuations in ergometer DP resembles that of running more than walking. However, DP is essentially different to running, walking and also diagonal stride: no propulsive forces are generated at the feet and external work is performed simultaneously with the rapid decrease in E_{tot} ending around minimum E_{tot}. In DP large amounts of E_{rot} can be transferred directly to perform external work, opposite to walking, running and also diagonal stride. In those locomotion forms specific joints act as breaks during E_{rot} decrease (energy absorption) and accelerators of CoM during E_{rot} increase (energy generation). In DP there is a mixture, where some of E_{rot} is absorbed by joints acting as energy absorbers, but not as breaks with regard to horizontal displacement. At the same time some of E_{pot} is transferred to external work. The high metabolic work in the legs can thus be partly explained as a functional way of increasing and/or maintaining the transfer of E_{pot} to external work. In conclusion, DP is a unique locomotion form where athletes need to utilize large amounts of potential and rotational energy to produce high external power.

References