Muscle mechanical efficiency in cycling versus running

Gisela Sjøgaard1, Lars Vincents Jørgensen2, and Ernst Albin Hansen2

1National Institute of Occupational Health, Copenhagen, Denmark;
2Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark

Introduction
Running efficiencies of 30-50 % are reported in the literature while during cycling efficiencies are reported to be around or below 25% in spite of similar movement cycle times, i.e. around 0.7-2 Hz for stride frequency and pedal rate, respectively. One major reason for this diversity is the difference in estimation of power output that during running has been estimated from kinematic and/or kinetic data and includes energy changes of body segments. In contrast during cycling generally only the external work rate (EWR) is included that during horizontal running is nil. In the present study power output during cycling was estimated based on methods developed for analysis of running in order to elucidate if differences in efficiency could be due to conceptual and methodological differences.

Methods
Sixteen males (73.7±8.2kg, 1.77±5.1m) cycled on a motorized Woodway ELG 70 treadmill (Woodway Gmbh, Weil am Rhein, Germany) at 40% and 70% of VO2max with 61, 88 and 115 rpm. EWR was adjusted by changing the mass of a weight magazine, which was connected to a wire, running over a pulley - placed behind the treadmill, and tied in behind the bicycle. VO2 and EWR were measured with the Douglas bag technique and a SRM crank dynamometer (Schoberer Rad Messtechnich, Jülich, Germany), respectively. Additionally, power output due to limb segment energy changes was calculated based on kinematics (Willems PA et al., 1995) and is here termed internal work rate (IWR). Muscle mechanical efficiency was calculated as apparent efficiency between 40% and 70% VO2max.

Results & discussion
Based on EWR and VO2 mean values (±SD) of gross efficiencies with increasing pedal rate were: 20(±2)%, 19(±2)%, and 15(±2)% at 40% VO2max (~ 150W), and 22(±2)%, 21(±1)%, and 18(±2)% at 70% VO2max (~260 W). Based on the kinematics the IWR was estimated to be 26(±4)W, 59(±10)W, and 121(±23)W at 61, 88, and 115rpm, respectively, differences in IWR between 40 and 70 % VO2max being within 10% of the mean values. Consequently, the total work rate (EWR + IWR) could be calculated at 40% VO2max to amount to 176W, 209W, and 271W with 61, 88, and 115 rpm, respectively. Based on these total work rates and the corresponding VO2 values the gross mechanical efficiencies were: 23(±2)%, 26(±2)%, 27(±4)%. Similarly, for 70% VO2max the total work rates were 286W, 319W, and 381W with 61, 88, and 115 rpm, respectively, resulting in gross mechanical efficiencies of 24(±2)%, 26(±2)%, and 27(±2)%, respectively. Apparent efficiency was as a mean

Figure 1: left side figure shows the original setup in the study by Lloyd & Zacks 1971 and right side figure the setup in the present study.
26±3\% and independent of pedal rate. No significant difference between these 7 different estimates of efficiency was found.

Inclusion of power output due to changes in limb segment energies (IWR) during cycling significantly increased efficiency, however, it remained lower than reported for running. Interestingly, the efficiencies based on total power output (EWR + IWR) were similar to the apparent efficiency, implying that estimates of IWR for evaluation of muscular mechanical efficiency is of physiological significance. A further correction of gross mechanical efficiency for resting VO2 (~ 0.004 l/s) to obtain net muscular mechanical efficiency would be even more comparable with apparent efficiency. The overall mean value of net muscular efficiency was 28±3\% indicating that during cycling IWR was slightly overestimated by the present model that was originally validated for running (Willems et al. 1995).

Apparent efficiency for running was 36\% as measured in an experimental setup corresponding to the present for cycling (Lloyd BB & Zacks RM, 1971). This variable is independent of estimates of IWR – that may vary widely based on the model used- and the present findings are in support of mechanical efficiency to be lower in cycling than running; a finding not to be explained by differences in methodology.

References: