Comparison of models for the estimation of internal work during cycling

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Introduction
During cycling a rise in pedal frequency leads to a rise in oxygen uptake due to a rise in internal work rate (IWR). To estimate IWR two models for cycling have been proposed (Wells et al. 1986, Widrick et al. 1992). These two studies lead to very different results that can be caused by the data material or the model. Models for running have been developed through many decades based on theoretical considerations and empirical validation (Willems et al. 1995). In our study these three models have been compared when applied to cycling.

Methods
Sixteen males (25.8±3.5 yr, 73.7±8.2 kg, 1.77±0.05 m) cycled on a motorized treadmill, model Ergo/ELG70 from Woodway GmbH, Germany. They were equipped with reflective markers placed on anatomical landmarks. A 50Hz video camera (see fig 1) recorded in the sagital plane eight cycling sessions: 61, 88, 115 rpm and a freely chosen pedal rate, each with two external workloads (40\% and 70\% of VO\textsubscript{2}max).

Fig 1. The test persons were equipped with reflective markers and video recorded in the sagital plane.

Five pedal revolutions were digitised using Peak Motus 2000, Peak Performance, USA. A 2D position file containing the x and y coordinates for each marker was used as input for a Matlab program, ErGiLa, developed at our institute. ErGiLa has implemented calculation of IWR from three models: Model 1 (Willems et al. 1995), Model 2 (Wells et al. 1986) and Model 3 (Widrick et al. 1992). Model 1 and 2 are working with a stick figure constructed of 13 segments (three segments in each arm, three segments in each leg and a head-neck-torso-segment) while Model 3 is working with a stick figure constructed of the three leg-segments. Model 1 is based on the König theorem, where movements relative to the centre of mass of the whole body are used, while Model 2 and 3 are using movements relative to the bicycle. Model 1 and 3 are assuming energy transfer between the segments in each limb but not between the limbs, while Model 2 assumes energy transfer between all the segments. In model 1 only the positive work contributes to IWR, while in Model 2 and 3 it is both the negative and the positive work. In Model 3 IWR calculated for the right leg is doubled to calculate the total IWR of both legs.
Results & discussion
The IWR calculated using the three models are highly correlated (R-squared=0.94–0.97) as seen in fig 2 and 3. Model 1 and 2 give similar results while Model 3 gives higher values.
During cycling the IWR is mainly related to the movements of the legs. The similarity between Model 1 and Model 2 is due to the phase conditions during cycling where one leg is moving upwards when the other is moving downwards. Due to changes in both potential and kinetic energy the power is performing two cycles during one pedal revolution. Therefore, it gives similar results whether assuming energy transfer between the legs or not. Model 3 gives higher values due to its algorithm including doubling IWR from one leg to obtain IWR for both legs. It is interesting that Model 1, which is far more advanced and demanding more complex program coding and computer power, supports Model 2 so well. However, these models need further validation including energy consumption and muscular efficiency.

Fig 2. Results from Model 2 plotted against results from Model 1

Fig 3. Results from Model 3 plotted against results from Model 1
References