

Incorporating internal mechanical power into performance models in cycling

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Abstract

Background: A number of models have been developed to establish the energy cost of cycling. These models have become better refined to account for the various energy demands, including air and rolling resistances. Among the established models, however, there does not appear to be sufficient consideration for changes to internal mechanical power (IP), the rate of energy to move the limbs against gravitational and inertial forces. Values up to 100 W have been reported for IP in cycling for cadences between 80 and 115 rev · min⁻¹, and so the inclusion of IP in performance prediction models is arguably warranted. Quantifying IP has previously been done using either 1) a physiological approach (IP_{met}), in which the metabolic counterpart of the external mechanical power (power applied to the cranks) was subtracted from \dot{E} (energy expenditure) to equal the metabolic equivalent of IP_{met}, which was then multiplied by delta efficiency (DE) to yield the IP_{met}; or 2) a biomechanical approach (IP_{mech}), which used an inverse dynamics analysis of the kinematics and kinetics of cycling. Both approaches have notable advantages and limitations, which is why quantifying a range for IP, delimited by IP_{met} and IP_{mech}, has been proposed by this research group.

Purpose: The aim of this study was to assess whether incorporating a range of values for IP into an established performance model would provide a better prediction of \dot{E} than when IP was not included.

Methods: Steady-state \dot{E} was measured (K4 b², Cosmed, Rome, Italy) for 10 elite male cyclists who cycled for 5-6 min at 200 W at 80 and 110 rev · min⁻¹ on the flat duckboard of an outdoor velodrome in calm conditions. Steady-state \dot{E} was compared to \dot{E} predicted by the established model (Equation 1) (di Prampero et al. 1979: Journal of Applied Physiology, 47(1), 201-106; Olds et al. Journal of Applied Physiology, 75(2), 730-737):

$$\dot{E} = \frac{\left(\frac{1}{2} C_{drag} A_{frontal} \rho v_w v_{ss} \right) + \left(C_{rr} \cos(\arctan S) \times (m_{body} + m_{bicycle}) \right) \times v_{ss}}{DE}$$

and \dot{E} predicted by the model that includes IP (IP_{met} and IP_{mech}) (Equation 2):

$$\dot{E} = \frac{\left(\frac{1}{2} C_{drag} A_{frontal} \rho v_w v_{ss} \right) + \left(C_{rr} \cos(\arctan S) \times (m_{body} + m_{bicycle}) \right) \times v_{ss} + IP}{DE}$$

where the first term of both equations represents the cost due to air resistance and includes a coefficient of drag (C_{drag}), the projected frontal surface area (A_{frontal}), the air density (ρ), the velocity of the wind (v_w) and the steady-state velocity of the cyclist (v_{ss}). The second term represents the cost due to rolling resistance, where C_{rr} is the coefficient of rolling resistance, S is the angle of terrain, m_{body} and m_{bicycle} are the masses of the participant's body and bicycle, respectively. IP_{met} and IP_{mech} were determined in the laboratory for each cyclist in an identical cycling position to that adopted in the outdoor trials.

Results: Mean (± s) measured \dot{E} at 80 rev · min⁻¹ was 866 W (± 78 W) and at 110 rev · min⁻¹ was 937 W (± 75 W). The mean difference (± 95% limits of agreement) between measured \dot{E} and \dot{E} predicted by Equation 1 was -98 W (± 214 W) at 80 rev · min⁻¹ and -185 W (± 191 W) at 110 rev · min⁻¹. When IP_{met} was included in the prediction (Equation 2), mean differences (± 95% limits of agreement) were 125 W (± 192 W) and 182 W (± 153 W) at 80 and 110 rev · min⁻¹, respectively. The mean differences (± 95% limits of agreement) between measured \dot{E} and \dot{E} predicted by Equation 2 incorporating IP_{mech} were -48 W (± 201 W) at 80 rev · min⁻¹ and -148 W (± 274 W) at 110 rev · min⁻¹.

Discussion: Energy expenditure (\dot{E}) predicted using an already-established model was shown, in this study, to fall short of the \dot{E} measured from respiratory gas during outdoor cycling for most participants at 80 rev · min⁻¹ and for all at 110 rev · min⁻¹. Inclusion of IP_{mech} into the performance prediction model resulted in values closer to the measured \dot{E} , however they were not sufficiently large enough to account for the entire deficit from the original prediction model (Equation 1) at either cadence. When the upper limit of the IP range, IP_{met}, was incorporated it more than compensated, in almost all cases, for the deficit from Equation 1. That is to say, the \dot{E} measured during outdoor cycling fell within the range of values that was predicted for \dot{E} when estimates of IP were considered in the model.



Conclusion: Based on these results, it is recommended that future predictions of cycling performance include a cost for IP.

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