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LETTER TO THE EDITORS

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Comments on "Influence of pedalling rate on the energy cost of cycling in humans"

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In a recent article, Belli and Hintzy (2002) addressed the influence of pedaling rate on the energy cost of cycling (Cr), defined as the metabolic energy spent (above resting) per unit distance traveled (di Prampero 1986). The apparent disconnection between the pedaling rate at which oxygen consumption ($\dot{V}O_2$) is minimized (50–60 rpm), and the pedaling rate typically employed by both trained cyclists and fit non-cyclists (90–100 rpm), has received much attention in the research literature (e.g., Marsh and Martin 1997; Seabury et al. 1977). Belli and Hintzy (2002) compared the cadences at which was ($\dot{V}O_2$) minimized (mean of 57 rpm) with the cadences at which the Cr was minimized (mean of 101 rpm). The Cr at each cadence was determined by dividing the rate of energy expenditure by flywheel velocity. The authors noted that preferred pedaling rates adopted during cycling in the field agreed well with the pedaling rates they found to minimize the Cr. They further suggested that during overground cycling individuals select pedaling rates primarily to minimize the Cr. While these results would seem to explain the tendency for individuals to choose high pedaling rates, there is a fundamental problem with the analysis that weakens the impact of their results. Specifically, the energy–speed and energy–cadence relations have been confounded, due primarily to the way in which speed, cadence, and resistive forces co-vary in overground cycling versus laboratory ergometer cycling.

Belli and Hintzy (2002) acknowledged the different manner in which mechanical power output is produced in overground cycling versus ergometer cycling; however, the authors seem to have confused these important issues in their analysis and interpretation of the results. The overground cycling speed corresponding to a specific laboratory ergometer situation can be determined by careful consideration of the factors that contribute to power output in road cycling (e.g., air resistance, road grade, rolling resistance). In the discussion that follows, the relations between overground cycling speed and power output were determined using the model equation derived and validated by Martin and colleagues (1998). Necessary model parameters (rider and bicycle mass, air density, drag coefficient, rolling resistance coefficient, etc.) were taken from values provided therein.

The important issue is that for any given overground cycling situation (i.e., a particular wind speed, road grade, and bicycle and rider characteristics), a particular mechanical power output corresponds to a single, specific speed of progression. Belli and Hintzy (2002), however, assumed that the speed of progression was equal to the ergometer flywheel speed (actually the tangential velocity of the flywheel rim), even though the power output was the same (150 W) for all cadences. The speeds used to calculate the Cr were not given in the article, but can be determined from the power output and frictional loads used, or from the fixed gear ratio and flywheel radius of the Monark ergometer. For subjects attempting to pedal at 40, 60, 80, 100, and 120 rpm, the corresponding speeds would be approximately 4, 6, 8, 10, and 12 m s^{-1}. Data presented by the authors suggest that these were in fact close to the speeds used in calculating the Cr. Given the fixed gear nature of the Monark ergometer, these would indeed be the actual overground speeds if the ergometer was traveling on wheels with the same radius as the flywheel. However, the resistive forces encountered with increasing speed would be very different from the linearly decreasing frictional loads used on the Monark ergometer. In overground cycling with zero wind speed and zero road grade, the power output would increase substantially when speed is increased from 4 m s^{-1} to 12 m s^{-1} (see first two columns in Table 1). In the laboratory protocol used by Belli and Hintzy (2002), however, the power output remained constant over this same range of

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Table 1 Mechanical power required to travel overground at different cycling speeds with zero wind speed and zero road grade; and wind speeds and road grades required to produced a power output of 150 W at various cycling speeds. Negative values denote tailwinds or downhill grades

Speed ($m\ s^{-1}$)	Power with zero wind and grade (W)	Wind producing 150 W ($m\ s^{-1}$)	Grade producing 150 W (%)
4.0	23.1	10.20	3.50
6.0	55.3	5.33	1.75
8.0	112.2	1.57	0.52
10.0	202.1	−1.65	−0.58
12.0	333.2	−4.58	−1.69

"speeds". Given that the power output was constant for all cadence conditions, the Cr should have been calculated by dividing by a single speed, corresponding to 150 W, for all cadence conditions.

For zero wind speed and zero road grade, the overground speed is approximately 9 $m\ s^{-1}$ at a mechanical power output of 150 W, regardless of cadence. The differences in cadence would simply represent different gear ratios selected by the rider at this fixed speed. This does not mean, however, that it is impossible to cycle at different speeds for a particular power output. For example, cycling against a 10 $m\ s^{-1}$ headwind at 4 $m\ s^{-1}$ results in a power output of approximately 150 W. A similar power can be obtained at 4 $m\ s^{-1}$ by pedaling up a 3.5% gradient. Traveling 12 $m\ s^{-1}$ at 150 W, on the other hand, requires a tailwind of 4.5 $m\ s^{-1}$, or a slight downward grade of about 1.5%. The complete series of wind speeds and road grades required to produce 150 W power output at the approximate speeds assumed by Belli and Hintzy (2002) are provided in Table 1. While it is therefore possible to have a constant power output but different speeds of progression by employing changes in wind speed or road grade, this does not seem to be the comparison the authors intended. The findings presented in the article could simply be interpreted to mean that the Cr of pedaling 40 rpm while traveling 4 $m\ s^{-1}$ into a strong headwind is higher than the Cr of pedaling 100 rpm while cycling 10 $m\ s^{-1}$ with a slight tailwind. Overall, the experimental design does not seem to allow for a very realistic or complete assessment of the Cr–pedaling rate and Cr–speed relations.

The manner in which the energy cost of cycling, or any form of locomotion for that matter, varies with cycle rate, speed, grade, and resistive forces is a matter of considerable interest. However, the data presented by Belli and Hintzy (2002) seem too limited to address these interrelationships adequately. Furthermore, their assumption that ergometer flywheel velocity adequately represents the comparable overground cycling speed, regardless of power output, is not justified. If the metabolic energy rate data are divided by a constant speed, say 9 $m\ s^{-1}$, then the Cr at 150 W has a minimum at the same cadence at which ($\dot{V}O_2$) is minimized (57 rpm). In contrast to the view held by the authors, this leads to the conclusion that in the current situation, and perhaps most cycling situations, cyclists in the field do not self select the cadence which minimizes the energy cost of cycling (Cr). As suggested by many previous investigators (e.g., Marsh and Martin, 1997; Seabury et al. 1977), preferred pedaling rates are considerably higher than energetically optimal pedaling rates, and some other factor(s) must be the primary determinant(s) of pedaling rates in the field.

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