**Accurately measuring mechanical power output during cycling using a treadmill**

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**Abstract**

**Purpose:**

**Methods:**

**Results:**

**Conclusion:**

**Key Words:**

**Introduction**

It is easy to accurately measure mechanical power output using a stationary cycle ergometer, but stationary cycling is different than actual road cycling. On an ergometer, there is no need for balance and there are no hills. With the advent of inexpensive, on-board, power-measuring hubs, pedals and cranks, it is possible to measure power output in the field on real bicycles. However, some of these devices are of dubious accuracy (REFS Maier et al https://www.ncbi.nlm.nih.gov/pubmed/28482367).

Power meters are typically calibrated using a motor that applies a constant torque at the crank (Refs), however even the best riders do not apply a constant torque throughout the crank cycle (Refs). Furthermore, on a freely moving bike a rider will likely apply forces outside the plane of the cranks, for instance when rocking the bike sideways during a climb or sprint.

Outdoor cycling is “noisy” due to variations in road surfaces, incline, velocity and wind. These variations can be eliminated when riding a treadmill in a lab setting where surface, incline and velocity can be controlled and wind is absent. However, overcoming air resistance, the major determinant to the power demand in overground cycling, is also absent during treadmill cycling. Two common strategies to increase the external power demands of treadmill cycling are increasing the incline or applying a resistive force.

Thus, we explored if a large, inclined motorized treadmill could allow realistic simulation of overground cycling under highly controlled conditions. We were inspired by the great Swedish exercise physiologist, P.O. Åstrand who studied treadmill bicycling in 1953 [1] and humorously noted that his measurements remained particularly consistent “so long as the rider remained on the treadmill”.

Uphill:   
Heil 1998 https://www.ncbi.nlm.nih.gov/pubmed/9760331 VO2 per body mass or combined (M+m) mass

Resistive force:

Zacks 1973 efficiency

Bijker et al 2001 efficiency

<https://www.ncbi.nlm.nih.gov/pubmed/26094819>

<https://www.ncbi.nlm.nih.gov/pubmed/23180213>

Here, we describe our method for using a treadmill to measure mechanical power output and then highlight its utility with three application examples. First, we compared the power required for riding uphill in a seated vs. standing climbing position. Then, we quantified the mechanical power losses due to a novel road bike suspension system. Finally, we used the treadmill to validate a crank-based power measuring device.

**Methods**

We quantified each factor that contributes to the total external mechanical power output required to ride a bicycle uphill on a treadmill: the power to overcome rolling resistance, the vertical power involving the increase in potential gravitational energy and the power demand to overcome drivetrain losses. Note that overcoming air resistance, a major determinant of the total external mechanical power output during overground cycling, does not contribute to power output during treadmill cycling because the rider is stationary relative to the surrounding air.

First, we measured the coefficient of rolling resistance (CRR) for the test bicycle with a rider on the treadmill at incline ϑ (Figure 1). To do so, we attached a cord to the head-tube of the bicycle frame. The cord ran parallel to the treadmill deck and passed over a low-friction pulley mounted in front of the treadmill. We hung weights at the end of the cord and turned on the treadmill to 3.35 m/sec. The rider held on to the side railing of the treadmill until the belt reached its goal velocity. Then the rider let go of the side railing and coasted without pedaling while maintaining balance. We manipulated the amount of the hanging weight (FHang) until the freewheeling rider was in equilibrium, neither drifting forwards nor backwards. In that case, the force to overcome rolling resistance (FRR) is equal to FHang minus the component of the gravitational force parallel to the treadmill surface. The component of the gravitational force parallel to the treadmill surface (FP) equals the total mass (rider mass, M, plus bicycle mass, m) multiplied by gravitational acceleration (g = 9.81 m/s2) and the sine of the inclination angle ϑ:

FP = (M + m) · g · sin (ϑ) (Equation 1)

CRR is equal to the ratio of the force to overcome rolling resistance and the force perpendicular (normal) to the treadmill surface (FN):

CRR = FRR / FN (Equation 2)

Where FN can be calculated similar to FP:

FN = (M + m) · g · cos (ϑ) (Equation 3)

Note that, with this setup, CRR includes spoke churn and hub bearing losses in addition to the rolling resistance of the tires on the treadmill surface. With the CRR determined, we calculated the rolling resistance force and knowing the velocity (vtreadmill), we calculated the power (P) to overcome rolling resistance:

PRR = (M + m) · g · cos (ϑ) · CRR · vtreadmill (Equation 3)



*Figure 1 (draft from ASB poster)*

The major determinant of the total external mechanical power output during uphill treadmill cycling is the vertical power involving the increase in potential gravitational energy. The vertical power required to ride a specific velocity (vtreadmill) up an incline (ϑ) against gravity (g), depends on the masses of the rider (M) and the bike (m):

PVERT = (M + m) · g · vtreadmill · sin (ϑ) (Equation 4)

Finally, in order to account for 2% drivetrain losses, we multiplied the sum of the vertical and rolling resistance powers by 1.02 (Martin et al., 1998):

PTOT = (PVERT + PRR) · 1.02 (Equation 5)

Third, we evaluated the accuracy and precision of six individual units of a newly developed 4iiii precision power® crank-based power meter. We inclined the treadmill to 4.1° degrees and adjusted treadmill speed to achieve 5 power outputs starting at 150W and incrementing 50W every 2 minutes up to 350W. We compared the crank-measured mechanical power to our reference calculated power. We determined an average absolute error of 1.56% (Table 1).

Treadmill bicycling is a more realistic and useful simulation of outdoor riding that controls for multiple environmental factors which facilitates collection of accurate and reproducible data.