# Title

The Effect of Bicycle Lean on Maximal Power Output During Non-Seated Cycling

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TBC

# Abstract

# Introduction

Clues can be drawn from maximal power output achieved during jump squats using free-weights versus in a smith machine.

Our primary objective was to...

We compared three bicycle-lean conditions: 1) using a preferred amount of bicycle lean (“ad libitum”), 2) , and 3) .

Based on previous experimental results (Wilkinson, Cresswell, and Lichtwark, unpublished findings), we hypothesised that during a 5-s sprint, maximal power output would decrease in an ordered fashion from locked to ad libitum and then to self-restricted.

We statistically tested the null hypothesis that there would be no differences in maximal power output between the three bicycle-lean conditions.

# Material and methods

## Experimental design

Twenty-six healthy adults voluntarily completed this study (? men/? women, age:  ±  years, height: ±  m, mass: ± kg). All subjects gave written informed consent according to the procedures approved by the University of Colorado Boulder’s Institutional Review Board. Participants were asked to avoid intense exercise in the 12 h before each session.

Testing was performed on a friction-loaded ergometer equipped with a crank-based mechanical power meter (Quarq DZero, SRAM, Corp, Chicago, IL, USA) with 172.5 mm long cranks. Participants wore their own cycling shoes that clipped into the pedals.  ﻿The geometry of the ergometer was matched to the participant’s bicycle. Resistance at the pedals was provided by a rope wrapped around the circumference of a rotating flywheel, with a hanging weight attached at one end (See Figure 1A). The hanging weight was coupled to resistance at the pedals due to the friction force of the rope sliding on the fly wheel. Cadence was measured using a crank-mounted sensor. Power and cadence were recorded by a cycling computer mounted to the handlebar (Edge 1000, Garmin Ltd, Olathe, KA, USA). The power meter was calibrated prior to each testing session. Based on the differences in the calibration factor and cadence of 120 rpm, the precision of the power meter between sessions was estimated to be ± 3.4 W. The friction-loaded ergometer was modified to either constrain or allow side-to-side lean in the frontal plane (See Figure 1A). The ergometer was mounted atop a hinged platform, which provided motion in the frontal plane. In the constrained condition, no movement in the frontal plane could occur as the platform’s pivot joints were braced using additional pieces of aluminum framing. In the lean and self-restricted conditions, springs attached to the rear legs of the ergometer provided a restoring force proportional to the lean angle of the bicycle. This spring mechanism was designed to replicate the lateral dynamics of a bicycle, which can be reduced to the equations of motion for an underdamped simple harmonic oscillator. Participants warmed up for the laboratory test by cycling at a low-intensity for 15 min followed by three short (5-s) maximal sprints, each separated by 3-min recovery. These warm-up sprints were performed under the lean condition, which familiarized the participant to the side-to-side movement of the ergometer and also allowed the resistance of the ergometer to be individualized for each participant to ensure valid maximal 1-s power output test results. A further 10-min recovery was given after the warm-up, before participants performed nine maximal 5-s sprints from rest in a non-seated posture, with 3-min recovery between each. The order of the trials was quasi-randomized to eliminate the effect of trial order.

## Data analysis

Torque (𝑇) was calculated from the recorded power (𝑃) and cadence (𝐶) data using Equation 1.

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| --- | --- |
|  | (1) |

In the above equation 𝑇 is in units of Newton meters, P is in Watts, and C is in revolutions per minute. Linear regression analyses were performed to determine the torque-cadence relationship for each participant using each data point during the 5-s sprint. This torque-cadence relationship was then used to construct the power-cadence relationship using Equation 2.

|  |  |
| --- | --- |
|  | (2) |

The CoM motion of each rider was estimated using a single 9-axis Inertial Measurement Unit (BlueThunder Sensor, IMeasureU, Auckland, New Zealand) secured to the rider's skin at the intersection of Tuffier’s line and lumbar spine midline (L4 spinous process) using double-sided tape. A self-adhesive bandage was then wrapped around the IMU and the torso of the rider to limit soft-tissue artifact. The IMU Research Application (IMeasureU, Auckland, New Zealand) was used to record inertial measurement data from the IMU at 100 Hz via Bluetooth to an iPad (Apple, California, United States). The IMeasureU 9-axis sensor contained an accelerometer (±16 g), gyroscope (±2000º·s-1), and magnetometer microelectromechanical system technology (MEMS, ±1200 µT) mounted in a tri-axial arrangement on a small circuit board. The sensor logged acceleration, angular velocities, and magnetic flux data in the three orthogonal planes. Raw data from the IMU was imported into MATLAB (R2020a, The MathWorks Inc., Natick, MA, USA), where it was passed through the Madgwick filter (Madgwick, Harrison, & Vaidyanathan, 2011) to calculate the global orientation of the sensors. A static trial was collected to provide an initial estimate of the heading direction of the sensor. This estimate was then used to adjust for any drift in the orientation produced from the filtering process. Rotation matrices were then applied to the raw data in order to calculate linear accelerations in a global reference frame. Linear accelerations were then integrated to velocity and then to displacement in each axis. The beginning of each sprint trial was identified within the IMU data by creating an artificial spike in the resultant acceleration by lightly tapping the sensor with a pen at the same time as giving a “Go!” command to the rider. CoM power was calculated as the change in total mechanical energy of the rider’s CoM (potential + kinetic) divided by the change in time. Kinetic energy of motion (a scalar quantity) was accounted for in all axes by using the square of the resultant velocity of the CoM in x, y, and z axes multiplied by half mass. Kinetic energy due to angular motion of the CoM was deemed negligible.

## Statistical analysis

The effect of bicycle lean on maximal power output and vertical center of mass displacement was analyzed using a one-way repeated-measures analysis of variance (ANOVA) within MATLAB (R2020a, The MathWorks, Inc., Natick, MA, USA). We performed a conventional power analysis (alpha = 0.05, power = 90%) to determine that a sample size of 23 was required to detect both the expected true effect size of 0.8 and the smallest effect size of interest of 0.44 (Faul, Erdfelder, Lang, & Buchner, 2007; Lakens, 2013). Sphericity of the data was checked using Mauchly’s test and p-values were corrected using the Greenhouse-Geisser method when necessary. P-values for multiple comparisons were corrected using the Dunn-Sidak method. The F-statistic (𝐹), p-value (𝝆), and generalized eta squared (G2) have been provided for main effects. For multiple comparisons the t-statistic (𝑡), corrected p-value (𝝆), 95% confidence intervals (95%CI [Low to High]), and corrected effect size (Hedge's gav) are provided. Descriptive data are presented as mean ± standard deviation.

## Rider-ergometer system

We want the springs to exert a torque that is proportional to the lean angle itself:

Kp is a constant whose optimal value may be determined via simulation and experimentation.

If Kp is greater than , then the angular acceleration of the system about the wheel-ground axis is in the opposite direction of the lean angle. Specifically, when the ergometer leans one way, it will accelerate in the opposite direction. When the ergometer moves to the other side of the equilibrium point, the angular acceleration will then switch directions to move the ergometer back toward equilibrium. This is a “stable equilibrium”, which means when the system is perturbed from the equilibrium position, it will restore itself back toward equilibrium.

Solving the differential equation, we have a solution in the form:

The above

# Results

## Pmax Test

## Maximum 1-s Power Output

## Maximum 1-s Cadence

# Discussion

# Conflict of interest statement

At the time of this study RDW and RK were paid consultants to Specialized Bicycle Components, Inc.

# Acknowledgements

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# References

# Figures, tables, and captions



Figure 1. Average 1-s power output as a function of hanging weight during the Pmax Test.



Figure 2. Individual (color) and group mean (thick black) maximum 1-s power output during the three experimental conditions.



Figure 3. Individual (color) and group mean (thick black) maximum 1-s cadence during the three experimental conditions.



Figure 4. Individual (color) and group mean (thick black) range of bicycle lean angle during the three experimental conditions.

|  |  |  |  |
| --- | --- | --- | --- |
| Table 1. Group results (n=17) in each condition during all-out 5-s cycling sprints in a non-seated posture. See Table 2 for more detailed statistical results. | | | |
|  | ad libitum | Self-restricted | Locked |
|  | m + sd | m + sd | m + sd |
| Range bicycle lean angle (deg) | 10.0 | 3.8 | 0.9 |
| Maximum 1-s power output (W) | 999.1 | 953 | 1011 |
| Maximum 1-s power output (W/kg) |  |  |  |
| Maximum 1-s cadence (rpm) | 112.4 | 109.9 | 114.7 |
| a statistical difference between ad libitum and self-restricted (p<0.05).  b statistical difference between locked and self-restricted (p<0.05). | | | |

Table 2. Statistical analysis of group results (n=15) shown in Table 1. Multiple comparisons were corrected using the Dunn-Sidak method.