# Title

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

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## Word Count

TBC

# Abstract

# Introduction

Paragraph 1

Some cyclists lean the bicycle from side to side when sprinting out of the saddle, while others restrict this lean. But is one technique superior to the other for generating maximal power output? Here we used a custom-made cycling ergometer to compare maximal 1-s power output generated by cyclists during all-out maximal standing sprints under three different lean conditions: 1) ad libitum lean, 2) self-restricted lean, and 3) externally constrained lean. We expected that the findings from this experiment could be applied specifically to maximising cycling sprint performance, but also provide broader insights into rider-bicycle interactions and the effects of instability on human power generation.

Paragraph 2

Clues from cycling research

Comparisons of maximal power output have been made between ergometer and over-ground cycling using a non-seated posture.

Rider-bicycle interactions have been compared during high-power output cycling in a non-seated posture under ad libitum and self-restricted conditions.

Paragraph 3

Clues from other human movements – Rowing

Paragraph 4

Clues from other human movements – Squat jumps

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

Paragraph 5

Hypotheses and statistical analysis

Based on previous experimental results (Wilkinson, Cresswell, and Lichtwark, unpublished findings), we hypothesised that during a 5-s sprint, maximal power output would decrease in an ordered fashion from locked to ad libitum and then to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

We also performed a statistical analysis to confirm our supplementary hypothesis that riders would be able to significantly self-restrict the range of bicycle lean compared to the ad libitum condition.

# 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.

## Rider-ergometer system

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. 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

## Experimental protocol

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.

|  |  |
| --- | --- |
|  | (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.

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|  | (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 was analyzed using a one-way repeated-measures analysis of variance (ANOVA) and post-hoc multiple comparisons within MATLAB (R2020a, The MathWorks, Inc., Natick, MA, USA). P-values for multiple comparisons were corrected using the Dunn-Sidak method. We performed a conventional power analysis using G\*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) to determine that a sample size of 19 was required to detect the expected true effect size of 0.8 between the “ad libitum” and “self-restricted” conditions at 90% power and alpha of 0.05. This resulted in a smallest detectable effect size of 0.48 () (Lakens, 2013). The F-statistic (), p-value (), and generalized eta squared () have been provided for main effects. For multiple comparisons the t-statistic (), corrected p-value (), 95% confidence intervals (), and corrected effect size () are provided. The strength of main effects () were assessed against benchmarks of small (0.02), medium (0.15), and large (0.35) (Cohen, 2014a). The strength of corrected effects () were assessed against benchmarks of small (0.2), medium (0.5), and large (0.8) (Cohen, 2014b). Pairwise differences are presented with their corresponding pairwise standard error of the mean (SEMpairedDiff)(Franz & Loftus, 2012). Descriptive data are presented as mean ± standard deviation.

# Results

Descriptive statistics of maximum 1-s power output, bicycle lean range, and cadence are presented in Table 1. Statistical analyses of maximum 1-s power output and bicycle lean range are presented in Table 2.

## Maximum 1-s Power Output

Individual and group mean maximum 1-s power output results are shown in Figure 1A. Pairwise differences in maximum 1-s power output between all conditions are shown in Figure 1B. There was a large main effect of condition on maximum 1-s power output (F=25, p<0.001, =0.6). On average, there was a large increase in maximum 1-s power output of 45 W (4.8%) in the ad libitum condition compared to self-restricted and a large increase of 58 W (6.2%) in the fixed condition compared to self-restricted. On average, there was a trivial decrease of 13 W (1.3%) in the ad libitum condition compared to fixed.

## Bicycle Lean Range

Individual and group mean bicycle lean range results are shown in Figure 2A. Pairwise differences in bicycle lean range between all conditions are shown in Figure 2B. There was a large main effect of condition on bicycle lean range (F=39, p<0.001, =0.76). On average, there was a 6.1 deg (159%) increase in bicycle lean range in the ad libitum condition compared to self-restricted and a 9 deg (920%) increase in the ad libitum condition compared to fixed. On average, bicycle lean range in the self-restricted condition was 2.9 deg (294%) higher in the self-restricted condition compared to fixed.

# Discussion

# Conflict of interest statement

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

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# Figures and tables

Diagram, engineering drawing

Description automatically generated

Figure 1. Diagram of dynamic cycling ergometer, which was designed to allow frontal-plane motion but could also be fixed to prevent frontal-plane motion using additional rigid struts (not shown). The extension springs acted to provide a restoring force proportional to the lean of the ergometer.



Figure 1. A. Individual (color) and group mean (thick black) maximum 1-s power output during the three experimental conditions. B. Pairwise differences between all conditions.



Figure 2. A. Individual (color) and group mean (thick black) range of bicycle lean angle during the three experimental conditions. B. Pairwise differences between conditions.

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| Table 1. Group results (n=18) in each condition during all-out 5-s cycling sprints in a non-seated posture. | | | |
|  | ad libitum | Self-restricted | Fixed |
|  | m + sd | m + sd | m + sd |
| Maximum 1-s power output (W) | 980.3 ± 227.7 | 935.3 ± 237.5 | 992.9 ± 246.7 |
| Range bicycle lean angle (deg) | 10.0 ± 5.0 | 3.9 ± 1.8 | 1.0 ± 0.6 |
| Maximum 1-s power output (W/kg) | 6.5 ± 1.2 | 6.2 ± 1.2 | 6.6 ± 1.3 |
| Maximum 1-s cadence (rpm) | 112.4 ± 8.8 | 110.0 ± 11.3 | 114.8 ± 11.1 |

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| --- | --- | --- | --- |
| Table 2. Statistical analysis of group maximal 1-s power and bicycle lean (n=18) between all conditions. Multiple comparisons were corrected using the Dunn-Sidak method. | | | |
|  | ad lib. v S-R | Fixed v S-R | ad lib. v Fixed |
|  | *t, p, 95%CI, ES* | *t, p, 95%CI, ES* | *t, p, 95%CI, ES* |
| Maximum 1-s power output (W) | 5.3, <.001, 23-67, 1.2 | 7.6, <.001, 38-78, 1.7 | 1.3, .485, -38-12, 0.3 |
| Range bicycle lean angle (deg) | 5.4, <.001, 3-9, 1.4 | 6.3, <.001, -4to-2, 1.7 | 6.7, <.001, 5-12, 1.8 |
| ES, Hedge’s gav effect size; S-R, self-restricted | | | |