

TITLE**: The Effect of Lateral Bicycle Dynamics on Maximal Power Output**

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# **PRINCIPAL INVESTIGATOR (PI)**:

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# KEY PERSONNEL

**Name**: Rodger Kram

**Role in project**: Co-investigator

# GENERAL RESEARCH STAFF

Two undergraduate research assistants will assist with this protocol. The PI will ensure that the appropriate CITI and protocol specific training are maintained. General Research Staff responsibilities will include communicating and recruiting subjects via emailing flyers and assisting with laboratory-testing. They will only perform laboratory-testing of subjects with the accompaniment of the PI or Co-investigator.

# OBJECTIVES

The primary **objective** of this project is to quantify the effects of lateral bicycle dynamics on a rider’s maximal power output during standing cycling. We will use a crank-based power meter to measure maximal power output of riders in response to variations in lateral bicycle dynamics during 5-s maximal effort sprints in a non-seated posture. We will test the primary null **hypothesis** that there is no effect of lateral bicycle dynamics on a rider’s maximal power output in a non-seated posture.

The secondary **objective** of this project is to quantify the effects of lateral bicycle dynamics on the non-muscular contribution to maximal power output during standing cycling. We will use a single inertial measurement unit (IMU) to estimate each rider’s center of mass motion in response to variations in lateral bicycle dynamics during 5-s maximal effort sprints in a non-seated posture. We will test the secondary null **hypothesis** that there is no effect of lateral bicycle dynamics on a rider’s range of vertical center of mass displacement during non-seated sprint cycling.

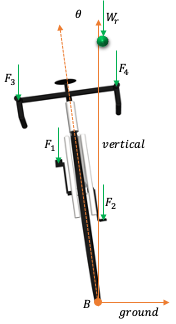
# BACKGROUND AND SIGNIFICANCE

When riding off the saddle to accelerate and sprint, cyclists appear to coordinate the rhythmic, vertical oscillations of their center of mass (CoM) with leaning the bicycle from side to side. Is the coordination of these two motions a strategy to increase stability or could it also be a strategy to generate more crank power?

It is clear that bicycle lean is important for maintaining dynamic balance, but it is unclear how self-restricting bicycle lean (e.g. by a rider) or constraining lean (e.g. by an ergometer) affects how maximal power is generated during non-seated cycling.

The use of cycling ergometers in research has limited our current understanding of optimal strategies to generate maximal power output during over-ground cycling. This is because ergometers constrain lateral dynamics of the bicycle which result from forces imparted by the rider at the pedals and handlebar. Thus, it is also difficult to associate any difference in maximal power output between outdoor and ergometer cycling solely to the change in lateral bicycle dynamics due to a number of confounding variables (e.g. environment, inertia, etc.).

To address this problem, we have modified a friction-loaded ergometer to either allow or constrain side-to-side lean of the bicycle, which will facilitate a controlled comparison of maximal power output under three lean conditions: 1) riders use their preferred amount of lean, 2) riders attempt to restrict lean, and 3) the ergometer constrains lean.



***Figure 1.*** *Frontal plane diagram of reference coordinates and vertical forces imparted by the rider on the bicycle. Bicycle lean angle is represented as , which is the counterclockwise angle relative to vertical. represents rider weight; the force due to gravity acting on the mass of the rider. represents the wheel-ground axis, around which an imbalance of torque due to forces imparted by the rider will act to perturb the system.*

# PRELIMINARY STUDIES

Research shows that the bicycle leans from side to side at the same frequency as pedaling (Hull, Beard, & Varma, 1990; Soden & Adeyefa, 1979), while the CoM rises at twice this frequency (Hull et al., 1990; Soden & Adeyefa, 1979; Wilkinson, Cresswell, & Lichtwark, 2020). During non-seated treadmill cycling, peak lean angles of 11º from vertical have been observed and occur when each crank is close to bottom dead center (180º) (Duc, Bertucci, Pernin, & Grappe, 2008; Hull et al., 1990). Studies of outdoor and ergometer cycling show the rider’s CoM rises by up to 13 cm as the crank transitions from the downstroke to upstroke for each leg (Soden & Adeyefa, 1979; Wilkinson, Cresswell, et al., 2020). The amplitude of bicycle lean and vertical CoM displacement appear to be positively related to crank torque requirements (Duc et al., 2008; Hull et al., 1990; Soden & Adeyefa, 1979; Wilkinson, Cresswell, et al., 2020), but the relationship between these two motions remains unclear.

However, bicycle lean is important for maintaining dynamic balance (Meijaard, Papadopoulos, Ruina, & Schwab, 2007). In the frontal plane, greater pedal forces result in greater imbalances in the moments about the line of contact between the wheels and the ground (Soden & Adeyefa, 1979). A rider can correct these imbalances using a combination of: 1) counter-steering into the fall to bring the line of contact underneath the CoM, 2) leaning the bicycle to bring the driving pedal over the line of contact, 3) generating a balancing torque at the handlebar, and 4) moving the CoM laterally (Cain, Ashton-Miller, & Perkins, 2016). Thus, maintaining dynamic balance when sprinting in a non-seated posture requires coordinated motion and a complex interaction of forces between the rider and bicycle.

Evidence suggests vertical CoM motion and upper limb muscles can amplify crank power (Wilkinson, Cresswell, et al., 2020) and help riders achieve greater maximal power output (Baker et al., 2002; Doré et al., 2006). During non-seated cycling, peak pedal forces reach magnitudes greater than two times bodyweight in each downstroke (Dorel, 2018; Soden & Adeyefa, 1979; Wilkinson, Cresswell, et al., 2020). Without the action of the arms at the handlebar, vertical pedal forces greater than bodyweight result in lifting the CoM rather than generating power on the pedal, which can cause a 22% decrease in maximal power output (Baker et al., 2002). The arms also act to give the CoM downward velocity, resulting in the CoM losing mechanical energy at a rate equivalent to 18% (3.9 ± 0.9 W·kg-1) of peak instantaneous crank power (Wilkinson, Cresswell, et al., 2020). Thus, using the arms to either resist or cause accelerations of the CoM is an important strategy for generating high pedal force and power output during non-seated cycling.

The use of cycling ergometers in research has limited our current understanding of optimal strategies to generate maximal power output during non-seated cycling. For instance, a recent study suggested a novel forward crouching posture known to limit bicycle lean during sprinting does not impair maximal power output (Merkes, Menaspà, & Abbiss, 2020). However, the use of an ergometer ignores lateral dynamics of the bicycle which result from forces imparted by the rider at the pedals and handlebar. Given CoM movement and arm power contribute to crank power, and bicycle lean likely influences the rise and fall of the CoM, it is unknown how self-restricting lean (e.g. by a rider) or constraining lean (e.g. by an ergometer) impacts how maximal power is generated during non-seated cycling.

We propose to use our knowledge and experience to conduct a safe and systematic investigation on the effects of lateral bicycle dynamics on the biomechanics of non-seated sprint cycling. The Locomotion Lab has conducted numerous studies of the biomechanics and energetics of ergometer, treadmill, and outdoor bicycling. In more than 25 years of research, Prof. Kram has not had a single serious accident in his laboratory. The proposed study builds upon the success shown by previous researchers in the Locomotion Laboratory.

# RESEARCH STUDY DESIGN

Repeated measures within-subject design with one factor (Bicycle Lean) and three levels (Preferred, Self-Restricted, and Constrained). Each condition will be completed three times in a quasi-randomized order (See Figure 2). The order of conditions will be randomized within each of the three trials using a random permutation function with MATLAB. This will ensure that any variability due to the order of conditions is minimized.



***Figure 2.*** *A schematic of the quasi-randomization process whereby the order of trials will be randomized within each block.*

The effect of bicycle lean on maximal power output and vertical center of mass displacement will be 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 will be required to detect both the expected true effect size of 0.8 and the smallest effect size of interest of 0.44 (Faul et al., 2007, Lakens, 2014). The estimated duration of the study (recruitment through data analysis) is one year allowing for current and possible future delays due to the outbreak of COVID-19.

During each experimental trial, we will measure cadence, crank power, and center of mass motion of the rider.

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| --- | --- |
| Name of procedure/instrument/tool | Purpose (i.e., what data is being collected?) |
| Quarq DZero power meter | Measures crank angular velocity, torque, and power at 1Hz |
| Garmin Edge 1000 cycling computer | Collects and stores data from the Quarq power meter via Bluetooth at 1Hz |
| iMeasureU BlueThunder Inertial Measurement Unit | Sensor containing an accelerometer, gyroscope, and magnetometer for measuring acceleration, angular velocity, and magnetic flux in three orthogonal planes at 100 Hz. |
| iMeasureU IMU Research Application | Records data from the IMU at 100 Hz via Bluetooth. |
| Apple iPhone 6S | Hardware with operating system required to run the IMU Research Application. |

# FUNDING

This study is supported by an International Society of Biomechanics (ISB) Student International Travel Grant awarded to Ross Wilkinson.

# ABOUT THE SUBJECTS

We plan to recruit and enroll 30 participants. Based on our experience, we anticipate that <10% of participants who are enrolled will elect to withdraw or be unable to complete the protocol due to the intensity of cycling. However, to be conservative, we seek permission to enroll up to 30 participants. Participants will be between the ages of 18-49, of any gender, and any ethnicity.

We will screen for apparently healthy adults (18-49 years of age) who self-report of currently cycling at least 4 hours per week, and meet the guidelines set forth by the American College of Sports Medicine (ASCM, 2017). The latest American College of Sports Medicine guidelines indicate that a medical exam and diagnostic exercise testing are not warranted prior to beginning a vigorous exercise program for apparently healthy individuals who already participate in regular exercise and do not have any signs or symptoms of cardiovascular, metabolic, or renal disease. We will use a screening form to determine if these criteria are met (see Screening Form included with eRA submission).

The day prior to attending the laboratory for testing, participants will be screened over the phone for COVID-19 infection and exposure according the procedures outlined by the Department of Integrative Physiology.

Inclusion criteria:

* 18-49 years of age
* Apparently healthy and cleared to participate in physical activity
* Self-report of currently riding at least 4 hours per week.
* Own their own clip-in cycling shoes and pedals

Exclusion criteria:

* None.

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| --- | --- |
| Subject Population(s) | Number to be enrolled in each group |
| Apparently healthy adults | 30 |

# VULNERABLE POPULATIONS

We will not enroll any vulnerable populations. We will potentially enroll CU students which should not pose an issue since Professor Kram no longer teaches classes.

# RECRUITMENT METHODS

The candidate population for this study will consist of volunteers recruited by word of mouth by the investigators, flyers, and emailing flyers (Flyer and sample email attached). Flyers will be posted on the CU campus and at local bicycle stores. The flyer will also be emailed to friends, local cycling clubs/message boards etc. After obtaining verbal consent, participants will undergo the normal screening process and a testing session will be scheduled. In the 24 hours prior to the scheduled testing session, we will screen participants via telephone for COVID-19 infection, exposure, and risk using the attached screening form titled “IPHY Human Subjects Research Participant COVID-19 Visit Screening”. Participants will then be screened upon arrival for testing using the attached screening form. If the initial screening is done via telephone, participants will subsequently complete the screening form in person, in writing, when they first come to the laboratory before completing the consent form.

The recruitment materials provide an email address for the study (culocomotionlab@gmail.com). The investigators will monitor that email address and reply to candidate participants initially via email. Via email, the investigator will coordinate a phone conversation. For example, the investigators will reply via email with a message stating:

“Hello, thank you for your interest in our study about maximal power output in cycling. Please call me at (XXX) XXX-XXXX so that I can describe the study to you, determine if you might be eligible and schedule a time for you to participate in the study. Alternatively, you can provide me with your phone number, and I can call you. Thank you, [Investigator Name.]”

Pre-consent language: At the beginning of the phone conversation, the investigator will ask: “Do I have your permission to ask you a few questions about you and your health to determine if you are eligible to participate in this study?”

All participants will complete the physical activity readiness screening form in writing when they first come to the study site. The investigator will examine their answers on the screening form and determine if they are eligible before asking them to read and complete the consent form.

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| List recruitment methods/materials and attach a copy of each in eRA |
| 1. Flyer |
| 1. Email |

# COMPENSATION

Participants will be compensated for their time and effort with one $25 Amazon gift card. Participants will receive the gift card even if they choose to withdraw before completing the study protocol. We will hand the gift card to the participant at the end of the experimental session.

# INFORMED CONSENT

Candidate participants will be verbally informed of the requirements and goals of the study. If they are still interested in participating, consent forms will be read and signed by the participant before being involved in the study.

A member of the research staff will call study participants within 24 hours prior to their planned study visit to complete the COVID-19 screening tool. Upon reporting to the laboratory and after completing the physical activity readiness questionnaire in person, participants will be provided with a written informed consent form and allowed to read it in a private room with just the investigators present. After the participant reads the form, an investigator will ask them if they have any questions and answer any questions. The investigator will then follow-up with a few questions to get some idea as to whether the subject actually read the consent form (e.g. “What will we be measuring in this experiment?”). If the subject’s responses seem vague, the investigator will ask the subject to re-read the consent form and the investigator will explain any uncertainties. Participants will be given as much time as required to decide on participation and reminded that they may also leave the study at any time.

# PROCEDURES

Participants will report to the front steps of the Clare Small building. All in-person screening and testing procedures will take place at the proposed testing site. Participants will be handed a sanitized clipboard to fill out the screening and consent forms. Researchers and participants will be required to maintain social distancing, wear a face mask and frequently disinfect their hands with an anti-bacterial gel.

While taking the necessary precautions to minimize the risk of spreading COVID-19, participants will complete the physical activity readiness questionnaire, provide informed consent, and then begin the experimental procedure.

Testing will be 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 will wear their own cycling shoes that clip into the pedals. ﻿The geometry of the ergometer will be matched to the participant’s bicycle. Resistance at the pedals will be provided by a rope wrapped around the circumference of a rotating fly wheel, with a hanging weight attached at one end. The hanging weight is coupled to resistance at the pedals due to the friction force of the rope sliding on the fly wheel. Cadence will be measured using a crank-mounted sensor. Power and cadence will be recorded by a cycling computer mounted to the handlebar (Edge 1000, Garmin Ltd, Olathe, KA, USA). The power meter will be calibrated prior to each testing session. Based on the differences in the calibration factor and expected peak cadence of approximately 120 rpm, the precision of the power meter between sessions is estimated to be ± 3.4 W. We modified the friction-loaded ergometer to either constrain or allow side-to-side lean in the frontal plane. Specifically, the ergometer is mounted atop a hinged platform, which allows rotation in the frontal plane. In the “Constrained” condition, no movement in the frontal plane will occur as the platform’s pivot joints will be braced using additional pieces of aluminum framing. In the “Preferred” and “Self-Restricted” conditions, springs attached to the rear legs of the ergometer will provide a restoring force proportional to the lean angle of the bicycle. This spring mechanism has been 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 will warm up 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 will be performed under the lean condition to familiarize the participant to the side-to-side movement of the ergometer and allow the resistance of the ergometer to be individualized for each participant to ensure a valid maximal power output test result. A further 10-min recovery will be given after the warm-up, before participants perform nine maximal 5-s sprints from rest in a non-seated posture, with 3-min recovery between each. The order of the trials will be quasi-randomized to eliminate the effect of trial order. The total time commitment for this session is expected to be <2 hours.

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| Visit # | Procedures/Tools | Location | How much time the visit will take |
| Visit 1 | * Screening and consent (10 min) * Fitting (10 min) * Warm-up (20 min) * Experimental trials (60 min) | Sewall Hall Courtyard, 1725 Pleasant St, Boulder, CO 80310, USA | <2 hours |

# SPECIMEN MANAGEMENT

N/A

# DATA MANAGEMENT

Confidentiality of personal records will be strictly maintained in all published reports and oral presentations resulting from this study. All participants will be given an alphabetic participant code as an identifier for the study. Participant information will be kept in locked cabinets in a locked office (Temporary Building, room 110) under the supervision of Dr. Rodger Kram. Identifiable data will be shared with no one outside of the immediate research team. Data security for storage and transmission for electronic data stored on desktop computers will be managed via a secure network and password access. Data will be retained indefinitely, but the participant code identifier document (paper) will be destroyed in 1 year via shredding.

# PROVISIONS TO PROTECT THE PRIVACY INTERESTS OF PARTICIPANTS

We do not foresee this study having any significant impact on a participants’ privacy interests. All experiments will take place outside on the CU Boulder campus. The study site (Sewall courtyard) has low foot traffic. Generally, only the researchers involved in this study are likely be present. Overall, the research activities performed by the subjects will not be private. However, we do not feel that cycling outdoors is an activity that would normally involve privacy. Subjects will wear the same type of athletic clothing that they would wear when bicycling for exercise outdoors in public. We inform the subject in the Consent form that they cannot expect complete privacy during the conduct of the study.

# WITHDRAWAL OF PARTICIPANTS

We do not anticipate any circumstances under which participants will be withdrawn without their consent. Participants who choose to withdraw prior to completing the experiments will be freely allowed to do so.

# RISKS TO PARTICIPANTS

Exercise can cause fatigue and minor discomfort. About 4 in 10,000 average people have chest pain or a heart attack and 1 in 10,000 people die during an exercise test. Fortunately, for an adult without overt heart disease, who exercises regularly, the risk of a cardiac event (heart attack) during exercise is very small, less than 1 chance in every 400,000 person-hours of exercising (approximately equal to exercising for 45 years, 24 hours per day).

Participants could injure themselves by falling off of the ergometer. The likelihood of a fall will be reduced due to the restoring force provided by the ergometer’s spring mechanism. Additionally, the base of the ergometer and pulley system will be weighted down to prevent the risk of tipping. In the unlikely event of a fall, the seriousness of the injury will be mitigated because we will require participants to wear a bicycle helmet.

It is possible that participants could be exposed to COVID-19 during testing. The risk of serious symptoms, hospitalization, and death will be mitigated by following the CDC, CU RIO R2R, and IPHY guidelines. Participants who are deemed eligible for our study will have been screened to be healthy adults between 18-49 years old who self-report being symptom-free and not having close contact with any persons confirmed to have COVID-19. Thus, our participants are deemed low-risk for developing serious symptoms due to COVID-19.

# MANAGEMENT OF RISKS

Bicycling on an ergometer is very low risk, as the rider is not moving relative to their surroundings. Thus, in the unlikely event of a fall, the rider will not collide with any objects with a substantial horizontal velocity. Additionally, all subjects will be required to wear a bicycle helmet. Thus, we are confident that these experiments do not present any undue risk to the participants or investigators. Clearly the risk of participating in this experiment is less risk than outdoor cycling, which participants report as a regular activity.

If a participant experiences a non-life-threatening injury (for example: a cut, scratch or wrist sprain) that requires medical treatment, the experimenters will provide reasonable assistance in getting the subject to Wardenburg Health Center, or Urgent Care at the Boulder Medical Center. Professor Kram has more than 25 years of experience conducting these types of experiments and has never had a subject experience a serious injury during testing.

In the unlikely event of a life-threatening event (e.g. cardiac arrest), the investigator(s) would call 911, begin CPR, and await EMS arrival. Accordingly, all investigators are trained in CPR and AED and at least one investigator will be present during these experiments. A First Aid Kit and AED is always kept within the Locomotion Laboratory.

# POTENTIAL BENEFITS

The only direct benefit is that the participants will experience a moderate amount of physical exercise. This is non-clinical research that will provide new information regarding the effect of lateral bicycle dynamics on maximal power output during non-seated cycling. The results of this study will help cyclists make informed decisions about their cycling technique and help bicycle manufacturers innovate and produce new bicycles and accessories for the customer.

# PROVISIONS TO MONITOR THE DATA FOR THE SAFETY OF PARTICIPANTS

The proposed study is short-term in nature. If a participant reports an injury or substantive discomfort during or after participating, we will review our experimental procedures and take action to minimize/eliminate the risk of such problems.

# MEDICAL CARE AND COMPENSATION FOR INJURY

Research involves minimal risk.

# COST TO PARTICIPANTS

There are no costs to the participants.

# DRUG ADMINISTRATION

N/A

# INVESTIGATIONAL DEVICES

N/A

# COLLABORATIVE STUDIES

N/A

# SHARING OF RESULTS WITH PARTICIPANTS

We intend to prepare the results of this study for presentation at scientific conferences and for publication in a scientific journal. In these ways, study results will be made part of public record and will be made accessible to participants.

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