December 2023

Physiological and Biomechanical Response to Indoor Cycling with and without the Ability to Sway

Alina P. Swafford
University of Nevada, Las Vegas

PHYSIOLOGICAL AND BIOMECHANICAL RESPONSE TO INDOOR CYCLING WITH AND WITHOUT THE ABILITY TO SWAY

By

Alina P. Swafford

Bachelor of Science – Sport and Exercise Science
Ithaca College
2016

Master of Science – Sport and Exercise Science
University of Central Florida
2018

A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy - Interdisciplinary Health Sciences

The Graduate College

University of Nevada, Las Vegas
December 2023

UNLV | GRADUATE COLLEGE

Dissertation Approval

The Graduate College
The University of Nevada, Las Vegas

November 27, 2023

This dissertation prepared by

Alina P. Swafford

entitled

Physiological and Biomechanical Response to Indoor Cycling with and without the Ability to Sway

is approved in partial fulfillment of the requirements for the degree of

Doctor of Philosophy - Interdisciplinary Health Sciences
The Graduate College

John Mercer, Ph.D.
Examination Committee Chair

Julia Freedman Silvernail, Ph.D.
Examination Committee Member

James Navalta, Ph.D.
Examination Committee Member

Nancy Lough, Ph.D.
Graduate College Faculty Representative

Alyssa Crittenden, Ph.D.
Vice Provost for Graduate Education &
Dean of the Graduate College

Abstract

Introduction: Bicycles have been around since the early 19th century. Since the invention of the bicycle, it has taken on several purposes. People have used bicycles as a means of transportation, leisure, exercise, and sport. The number of individuals who participate in a cycling event per year has increased. With the increase in popularity, research related to cycling has also increased. Research related to the physiology and biomechanics of cycling are of particular areas of interest. Balance is a crucial component of understanding why we cycle a certain way. Some research has labeled balancing on a bicycle as cycling sway. However, limited research has examined the influence of balance on the physiology or biomechanics of cycling. Therefore, the purpose of this study was to understand whether or not the potential to sway influences physiological and biomechanical measures. Methods: Thirteen participants (age = 24.9 ± 6.5 years; height = 1.7 ± 0.1 m; body mass = 64.7 ± 11.2 kg; mean ± SD) volunteered for the study. The participants completed two submaximal-graded cycling tests on a stationary smart bike placed on a rocker board. One condition allowed the participants to cycle freely and maneuver the bike side-to-side (unblocked). The second condition had blocks placed in the rocker board to keep the bike stationary (blocked). The order of the conditions was counterbalanced. Prior to completing the two cycling protocols, participants performed a preferred power phase. During this phase, participants were informed of the rate of perceived exertion (RPE) scale. Participants were instructed that during this phase, their power output for an RPE of 11 ('fairly light'), 13 ('somewhat hard'), 15 ('hard'), and 17 ('very hard') would be determined. To accomplish this, the researcher increased and/or decreased the power until the resistance felt fairly light (RPE 11) while the participant cycled for roughly one to two minutes at this power while the board was unblocked. Once the power was determined, the participants repeated this two additional times for fairly light and the researcher averaged the three trials. This process was repeated for the other three RPE intensity levels. During the two conditions, participants performed each level of intensity for three minutes and continuously (12 minutes per condition). During each condition, heart rate (bpm), rate of oxygen consumption ($\dot{V}O_2$; $ml \cdot kg^{-1} \cdot min^{-1}$), sway (radians), cadence, speed, power, and RPE (11, 13, 15, 17) were measured. For heart rate and $\dot{V}O_2$, the last minute of the three minutes was averaged. For sway data, 30 seconds were recorded for each intensity. From the 30 seconds, local maximums in each direction (i.e., right, left rotations) were identified for each intensity level. The right and left sway maximums were each averaged. Results: Sway reported a statistically significant difference in the main effect of condition ($p<.001$). The rate of oxygen consumption, heart rate, and speed reported statistically significant differences in the main effect of intensity levels ($p<.001$). For sway, the VO_2, heart rate, speed, distance, and cadence, there was no statistical interaction between condition and intensity ($p>.05$). Conclusions: Physiological measures were not influenced by the ability to sway with power matching. Sway was different between SWAY conditions regardless of INTENSITY. For the rate of oxygen consumption, heart rate, speed, and distance, values increased between INTENSITY levels (RPE 11, 13, 15, 17) for each condition. These findings are reasonable due to the graded cycling protocol and the blocked/unblocked conditions. Sway was different between conditions since the blocked condition restricted the bike's lateral movement and the unblocked allowed sway movement. Power increased between each intensity level and since the intensity levels were performed continuously, adapting to the change in power led to increases in physiological demand. While this study allowed for any experience of cyclists, the majority of subjects were novices. Future studies should consider examining different levels of experienced cyclists to see if they respond similarly.

Acknowledgments

I want to acknowledge several people that without their support this dissertation and degree would not be possible. First, I want to express my extreme gratitude to my mentor, Dr. John Mercer. He welcomed me to the University of Nevada, Las Vegas and during my time here has given me ample opportunities to excel. Without him, I would not have been able to teach, be involved with research projects, and evolve as an academic. When I shifted my focus to biomechanics, I knew I wanted to be mentored by Dr. Mercer. Without him, I would have never gone out of my comfort zone and experienced participating in a triathlon. His years of knowledge and experience have enriched my doctoral experience.

Secondly, I would also like to acknowledge my committee, Dr. James Navalta, Dr. Julia Freedman-Silvernail, and Dr. Nancy Lough. You have each provided incredible support, advice and patience during my dissertation. I would like to especially thank Dr. Silvernail who over the years has been a great teacher and who joined my committee when I needed it most. I want to thank all the students I taught, my professors, and my colleagues. Each of you shaped my experience at UNLV and I am forever grateful. Lastly, I would like to thank all of my amazing friends and family. All of you have been by my side cheering me on as I have gone through this journey. I cannot thank you all enough for being a part of my life.

Dedication

To my parents, Frances and Timothy Swafford, I am beyond thankful for you. Throughout my life, they have been exceptionally supportive and loving. I would not be the person I am today without them. Thank you for pushing me, taking me to all of my gymnastic practices, and being there for me when I needed you. This degree is not just for me, but for us. I would like to especially thank my father. He has always been the biggest supporter of my education. I am grateful for all of the science experiments we did in the garage. He also instilled a love for math in me. Without him, I would not be the scientist I am today.

I would also like to dedicate my dissertation to my partner, Connor. He has been an incredible inspiration to me. His unrelenting support and unconditional love have allowed me to persevere through my degree. Connor has experienced all the tears, stress, and happy moments with me, and I do not take it for granted. His positivity and uplifting light inside him make my worst days better. Thank you for all that you do for me and the belief that I could make my dreams come true. This is for you, for us.

Table of Contents

Abstract iii

Acknowledgments v

Dedication vi

List of Tables x

List of Figures xi

Chapter 1 1

Introduction 1

Chapter 2 3

Literature Review 3

Introduction 3

Cycling Performance 3

Cycling Sway 5

Experience Level on Cycling Sway 7

Seated vs Standing Sway 9

Power Output during Cycling 10

Training and Competition Zones 10

Power Meters 11

Laboratory-Based Power Measurements 13

Oxygen Consumption during Cycling ... 14

Heart Rate Measurements during Cycling ... 16

Rate of Perceived Exertion ... 17

Gaps in the Literature ... 18

Conclusion ... 20

Chapter 3 ... 23

Methods ... 23

Participants ... 23

Procedures ... 25

Data Reduction ... 28

Statistical Analysis ... 31

Chapter 4 ... 33

Results ... 33

Sway ... 33

VO_2 ... 36

Heart Rate ... 37

Cadence ... 37

Speed ... 38

Chapter 5 ... 39

Discussion ... 39

VO_2 and Heart Rate 43

Cadence 44

Speed 45

Limiting and Confounding Factors 45

Future Research 46

Conclusions 48

Appendix A: Informed Consent 50

Appendix B: Cycling Information Survey 54

Appendix C: Rate of Perceived Exertion Scale 55

References 56

Curriculum Vitae 61

List of Tables

Table 1. Distances for triathlon events. 5

Table 2. Means and standard deviations of main dependent variables. 34

Table 3. Means and standard deviations for cadence for both conditions. 45

List of Figures

Figure 1. Important parts of a bicycle 12

Figure 2. Visual representation of bicycle sway 22

Figure 3. Bike-board System and Rotary Device Set-up 25

Figure 4. Experimental design 28

Figure 5. An example of sway data for an RPE of 11, 13, 15, and 17 for the unblocked condition 30

Figure 6. An example of sway data for an RPE 11, 13, 15, and 17 for the blocked condition.... 31

Figure 7. Right sway means and standard deviations for both conditions 35

Figure 8. Left sway means and standard deviations for both conditions 35

Figure 9. VO_2 means and standard deviations for both conditions 36

Figure 10. Heart rate means and standard deviations for both conditions 37

Figure 11. Speed means and standard deviations for both conditions 38

Chapter 1

Introduction

In 2017, approximately 47.5 million people in the United States participated in bicycling, also known as cycling or biking (Gough, 2021). Each year more people cycle, whether it is for leisure, transportation, or sport. When it comes to cycling as a sport, in 2018 more than 160 million people attended a cycling event in the U.S. (Gough, 2021). Some types of sports cycling include cyclocross, track, mountain, and road. For road cycling events, some of the major competitions that draw spectators include the Tour de France, Ironman, and the Olympic Games.

Over the past few decades with the increased interest in cycling, there has been a growth in cycling research. Researchers have examined physiological and biomechanical measures to evaluate cyclists' performance. For example, there is a wealth of research on cycling power (Denham, Scott-Hamilton, Hagstrom, & Gray, 2020; Passfield, Hopker, Jobson, Friel, & Zabala, 2017), heart rate (Lucia et al., 1999, Vogt et al., 2007), oxygen consumption (Denham et al., 2020), and rate of perceived exertion (Parry et al., 2011; Mieras, Heesch, and Slivka, 2014) during cycling. Much of this research has been conducted in a laboratory on a fixed stationary cycle. However, it is well known that the skill of cycling involves balancing (Cain, Ashton-Miller, & Perkins, 2016). There is limited research on the influence of balancing a bike on physiological and/or biomechanical measures. A measurable component of balance is the amount of sway that occurs during cycling. The term 'sway' represents amount of deviation (lateral rotational movement) from the center the bicycle moves during cycling (Figure 1). Since balancing is a crucial component to propelling a bicycle, it should be thoroughly researched to understand the effects sway may have on the physiological and biomechanical parameters while cycling.

Therefore, the purpose of the current study was to understand whether or not cycling sway influences physiological measures when power was matched. The overarching goal of this study was to understand why we cycle a certain way. The information derived from this study may have implications on whether sway is beneficial to the physiological demand on the body and biomechanics while cycling. It is hypothesized that sway may be an important factor that influences heart rate and the amount of oxygen consumption required when cycling when power is matched. Specifically, since sway is a natural component of cycling, it is hypothesized that restricting sway on a fixed cycle trainer coincidentally increases the intensity of cycling as it would interfere with the natural sway component. It is hypothesized that HR and VO_2 will decrease for a given cycling resistance when sway is allowed.

This study aims to extend the current research on cycling sway by examining additional parameters of heart rate and VO_2. The proposed study introduces a novel progression on identifying factors that may affect cycling performance. Understanding sway helps us determine how we maneuver and balance on a bicycle. Therefore, having a greater understanding of sway may reveal ways to optimize cycling performance.

Chapter 2

Literature Review

Introduction

Bicycles have been around since the early 19^{th} century. Since the invention of the bicycle, it has taken on several purposes. People have used bicycles as a means of transportation, leisure, exercise, and sport. The number of individuals who participate in cycling events per year is upwards of 47.5 million people (Gough, 2021). With the increase in cycling events and participation each year, there has become more interest in cycling research over the decades. There has become specific interest in enhancing cycling performance. Some ways researchers have examined enhancing performance is through physiological and biomechanical parameters. Topics such as cycling sway, power output, oxygen consumption and heart rate.

The purpose of this literature review is to evaluate studies on cycling sway, cycling power, heart rate, and oxygen consumption as it pertains to cycling performance. A secondary outline will discuss the use of a rate of perceived exertion (RPE) scale as a tool in cycling to determine self-perceived exertion levels (Borg, 1982). The overall goal will be to address the gaps in the literature of cycling sway, cycling power, heart rate, and oxygen consumption and how it can influence cycling performance.

Cycling Performance

A range of road bicycling events occurs throughout the world each year. Some events are solely bicycling events (e.g., Tour de France, Giro d'Italia, and the Vuelta a España) while others are multidisciplinary events such as the triathlon. Specifically, in triathlon events, there are four main distances: Sprint, Olympic, Half Ironman, and Ironman. Distance measurements are displayed in Table 1. Though these are standard distances, the distances may vary depending on terrain (e.g., flat v. mountainous). Each ‘leg’ of a triathlon (swim, bike, and run) and the transition periods in between are important to overall performance. Overall performance is important to an athlete and determines whether they earn a medal or qualifies for an important race. This literature review will focus on the examine of the cycling portion of a triathlon and cycling events.

Cyclists, especially at the elite level, that are competing in time-trial races are concerned with performance. Cyclists will use completion times as an indicator of overall performance. At the elite level, the margin for error is narrow due to the competitive race times each athlete can produce during every leg of the triathlon. For example, at the 2021 NOOSA triathlon in Australia, the men’s top three finishers had bicycling times that were within approximately 13 seconds of each other (1^{st}—00:54:12; 2^{nd}—00:54:25; 3^{rd}—00:54:24) and the female’s top 3 were within 30 seconds (1^{st}—01:01:09; 2^{nd}—01:00:46; 3^{rd}—01:00:39) (*NOOSA Triathlon (2021) Results*, 2021). In a triathlon, an athlete’s performance can be affected by the course terrain, climate conditions (e.g., dry v. humid), proper training, nutrition, illness, injury and many more factors.

When it comes to improvements, cyclists train to have faster completion times in a variety of ways. This can be through nutrition and supplementation, physical training, crossover training, mental training, and changes in equipment. Due to the vast number of variables that could influence bicycling performance during a triathlon, the extent of this paper will examine the mechanical adaptations related to cycling performance specifically through bicycle sway, bicycling power, and attentional focus.

Table 1. Distances for triathlon events.

Distance	Swim	Bike	Run
Sprint	750 m	20,000 m	5,000 m
Olympic	1,500 m	40,000 m	10,000 m
Half Ironman	1,900 m; 1.2 miles	90,000 m; 56 miles	21,100 m; 13.1 miles
Ironman	3,800 m; 2.4 miles	180,000 m; 112 miles	42,200 m; 26.2 miles

Cycling Sway

A bicycle is a seemingly simple human-powered vehicle, but the dynamics necessary to maneuver a bicycle are complex. Research dating back as early as the late 1800s have explored the complexities of the bicycle and bicycle-rider system. The research investigated by Whipple pioneered the understanding of the bicycle-rider system in terms of lateral stability and coordination through mathematical concepts and equations (Whipple, 1899). In summary, the Whipple model considers the bicycle-rider system a rigid body. This means the rider's movements are insignificant and the rider is connected to the rear frame creating a single rigid body (Whipple, 1899; Kooijman, J., & Schwab, A., 2013; Schwab, A., Meijaard, J., & Kooijman, J., 2012).

As bicycling research continued, the vast complexities involving bicycle-rider stability became more apparent. In the early 1970s, research began to shift from the Whipple model. For example, Jones (1970) rejected the idea of a single rigid body with his creations of "un-rideable" bicycles to demonstrate that the rider's manipulation of the bicycle plays a role in stabilization. Research into the bicycle-rider system continues because a bicycle lacks lateral stability (Jones, 1970; Kooijman, J., & Schwab, A., 2013; Schwab, A., Meijaard, J., & Kooijman, J., 2012). Since the research performed by Jones, research continues to examine the importance of the rider's role in the ability to maneuver and stabilize a bicycle.

Road cycling is a sport that requires balance to operate the single-tracked vehicle (Kooijman, & Schwab, 2013). When cycling, the bicycle can be maneuvered from side-to-side, which we will term bicycle sway. For this paper, bicycle sway is analogous to 'lean', lateral movement, or side-to-side movement of the bicycle. In current existing research, cycling sway is addressed as bicycle lean (Cain, Ashton-Miller, & Perkins, 2016) and lateral or bicycle sways (Bouillod et al., 2018). Bicycle sway is considered the natural lateral movement that occurs when a person is riding a bicycle. Figure 1 below displays the concept of bicycle sway. In this figure, the center position would be when the cycle is standing upright. When the bicycle is maneuvered to the left or right of the center, this will be considered bicycle sway.

There is a growing body of research in the area of cycling sway. Bicycle sway can be divided into two perspectives. From the first perspective, sway is a parameter that appears to decrease as a cyclist becomes more experienced. Research has attempted to identify the difference in sway between experience level within motorcycling and cycling (i.e., novice vs experienced) (Rice, 1978; Prem, 1983; Cain, Ashton-Miller, & Perkins, 2016). Research from motorcycles is important due to the similar manipulation of a motorcycle and a bicycle. The second perspective occurs when an experienced cyclist is in a competition setting and they purposefully maneuver the bicycle from side-to-side to generate more power. In the second perspective, cyclists tend to stand up from the staddle (the bicycle seat) to produce greater power outputs (Miller, Wells, Martin, 1988; Swain, Wilcox, 1992; Bouillod et al., 2018). Bicycle sway from both perspectives can influence a cyclist's performance. A large amount of research has been performed on bicycle lateral dynamics and bicycle-rider stability. Limited research has explored lateral dynamics in the sport of bicycling and its effect on performance.

Experience Level on Cycling Sway

The range of bicycle sway can vary depending on experience level and the intended purpose of that bout of bicycling. Anecdotally, novice or beginner riders' cycle with large, sporadic, uncoordinated movements. Since balance is a necessary skill to ride a bicycle, novice cyclists will have extreme bicycle sway as they learn to balance and maneuver the vehicle. Once a cyclist becomes experienced, minimal lateral movement of the bicycle can be detected unless the intended purpose is to produce greater power output. In this case, the cyclist will stand up while bicycling, and the bicycle will move with large degrees of lateral movement. These visible differences between experience levels could be due to the findings that researcher Jones concluded. Jones stated that with slower speeds a bicycle-rider system experienced greater lateral movement and less lateral movement at higher speeds (1970). A novice cyclist rides a bicycle much slower in comparison to their experienced counterpart which would lead to more lateral movement.

The magnitude of bicycle sway is related to a cyclist's ability to balance. Anecdotally, novice and experienced riders' cycle with different levels of balance and coordination. Novice riders experience greater bicycle sway in attempts to propel the bicycle forward. The comparison of novice and experienced riders within cycling performance is more prevalent in motorcycle research than in bicycle research. In motorcycle research, sway is referred to as body lean. In this research, novice riders experience different body lean and steering torque when attempting lane changes and corner turns in comparison to experienced riders (Rice, 1978, as cited in Cain, Ashton-Miller, & Perkins, 2016). More specifically, novice motorcyclists performed lane changes and corner turns with less body lean and steering torque. Another study by Prem (1983), found similar findings where novice riders would couple lean and steering torque when performing evasive maneuvers whereas experienced riders could perform the two movements separately. Even in motorcycle research, the differences in balance and coordination are evident between experience levels. Motorcycle research can be used as a reference for bicycling research because both are single-tracked vehicles (Kooijman, & Schwab, 2013).

Due to the gap in knowledge regarding skill level, Cain, Ashton-Miller, and Perkins (2016) examined the different skill levels of cyclists (novice and experienced) and their ability to balance on a bicycle. Results determined that at lower speeds both groups experienced similar bicycling patterns. At higher speeds, the more experienced riders were able to maintain greater balance due to their ability to maneuver the bicycle with more lateral movement. Cain, Ashton-Miller, and Perkins (2016) concluded that the more experienced riders were able to successfully ride at higher speeds not due to increased balance demands, but due to the ability to adopt more lean control.

In a competition setting with more experienced cyclists, it appears that lean or sway may be related to cycling performance, specifically, cycling power. In competitions, especially when an athlete cycles on a gradient, the cyclist will stand up and manipulate the bicycle in a lateral movement pattern with the intent to generate more power to endure that bout of cycling. Experienced riders may also encounter undesired sway during the long stretch of cycling in a competition. Environmental factors such as wind and rain or physiological factors such as fatigue and illness could influence an athlete's ability to balance leading to more sway which could affect their overall performance or lead to injury.

Seated vs Standing Sway

In experienced cyclists, their ability to balance translates to their ability to produce smooth coordinated movements. An experienced rider generates negligible movement in the upper torso and at the hips while bicycling. Bicycle sway or ‘lean’ is an important skill developed by experienced riders to help them generate power to cycle uphill or sprint. It would seem that balancing a bicycle is related to cycling performance as measured by power. Research with experienced riders have examined bicycle sway in seated vs standing positions (Miller, Wells, Martin, 1988; Swain, Wilcox, 1992; Bouillod et al, 2018). With experienced riders while in a seated position, there is minimal lateral sway. Whereas with a standing position, an experienced rider will elicit more lateral movement with the bicycle for the purpose of producing more power.

A study by Bouillod et al. (2018) found that bicycling uphill in a standing position led to an increase in lateral sway and ultimately an increase in power output. In an experiment by Wilkinson and Kram (2021), the researchers investigated whether bicycle lean during sprinting would increase maximal power output. They found that having cyclist lean ad libitum did not increase power output compared to no lean but minimizing lean led to a decrease in power output. Though Wilkerson and Kram’s findings did not show that a standing position with lateral sway increased power output, the restricted the potential to sway did hinder the participant’s ability to produce power. Both studies would suggest that a standing position coupled with bicycle sway or lean could be beneficial to cycling performance under certain circumstances, but within a certain range of sway.

Power Output during Cycling

Power is the measurement of the amount of work done over a period of time and measured in Watts. The mathematical equation traditionally used for power is $P = W/t$ (P—power; W—work; t—time). For cycling, due to the application of force at the pedal resulting in angular movement with the intended goal of forward propulsion, the power equation used is $P = F * v$ (F—force; v—velocity). Another important power equation used in cycling is the critical power model represented as $P(t) = W'/t + CP$ (W′—anaerobic work capacity; CP—critical power) (Passfield et a., 2016; Leo et al., 2021). The critical power model is typically performed by completing several exhaustive cycling bouts then the mean power output is determined for each bout. This equation/model can be a helpful measurement for cyclists since the severe exercise intensity with which this test is performed is equivalent to the intensity that majority of road race and time trials are performed at (Vogt et al., 2006). The invention of the power meter calculates power then displays and stores this data via Bluetooth to a computer or cyclo-computer. Power is a variable that cyclists use due to the strong association between power output and endurance cycling performance (Amann, Subudhi, & Foster, 2006; Coyle, et al., 1991; Jeukendrup, Craig, & Hawley, 2000). Due to this relationship, cyclists will use maximum sustained cycling power output as a performance quality (Denham et al., 2020).

Training and Competition Zones

During competitions, the course design and location can influence an athlete's power demands during the race. For example, the Tour de France is a multi-day cycling race whose course terrain involves flat, semi-mountainous, and mountainous landscapes. Vogt and researchers examined the power output demands for this race with the changes in terrain. They found that the power demands increased as the terrain became more mountainous (flat: 218 ± 21

W [3.1 ± 0.3 W/kg], semi-mountainous: 228 ± 22 W [3.3 ± 0.3 W/kg], and mountainous: 234 ± 13 W [3.3 ± 0.2 W/kg]) (Vogt et al., 2007). Sanders et al. (2019) found similar findings in power outputs with changing terrain when examining results from a cycling Grand Tour. The researchers found that with the flat and semi-mountainous terrains athletes had higher short-duration outputs and the mountainous and time trials had longer durations of maximal power outputs (Sanders et al., 2019). The findings from these studies can be implemented into training so athletes can gauge the appropriate power output zones while training on certain gradients to prepare for the physical demands of competition.

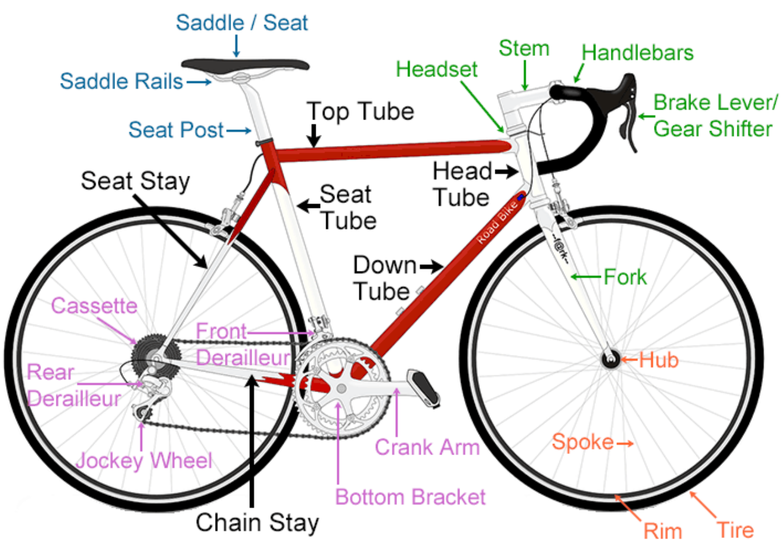
Power Meters

The introduction of the first patented spider-based power meter was in the late 1980s with the company Schoberer Rad Messtechnik (SRM) designed by the engineer Ulrich Schoberer (Passfield et al., 2016; *History*, n.d.). Spider-based power meters record the total power output from both legs as opposed to individual measurements per leg. In 1988, SRM continued pioneering power-based inventions by creating the bicycle computer to record cycling power data (*History*, n.d.). Since the original creation by Schoberer and subsequent instruments, a wide range of hi-tech power output measurement devices have been designed.

Power meters have been designed to fit on different parts of a bicycle depending on the desired needs. For example, power meters can be mounted on the bicycle's crank spindle, crank arm, pedal spindle, rear wheel, chain, and bottom bracket axle (Maier et al., 2017; Passfield et al., 2016). A cyclo-computer or a cycle computer is typically mounted on the handlebars that is directly connected or connected via Bluetooth© to display power output readings. These readings will allow an athlete to gauge the appropriate power zone they need to be in while training or during competition. Figure 2 displays an illustration of a bicycle highlighting important parts (Ellis, 2021). The purpose of this illustration is to show the placement of power meters.

Power meters use strain gauges that ultimately measure torque (force about an axis) and angular velocity to then calculate power (Leo et al., 2021). Whereas some power instruments such as insoles measure through pressure or force. The type of power meter an athlete requires may be based off of their demands (Passfield et al., 2016). Hub-based power meters measure total power output; whereas pedal meters can measure each leg and reveal asymmetries. An example stated by Passfield et al. (2016), track sprinters may be more interested in torque at the pedal or crank due to the demands of their sports. Triathletes may be more interested in overall power output measures to determine the appropriate zones to train in. Due to a large number of power meter designs, accuracy is important (Maier et al., 2017).

Figure 1. Important parts of a bicycle



Note. Bicycle Anatomy (Ellis, 2021).

Laboratory-Based Power Measurements

Prior to these inventions, cyclists would measure power in a laboratory setting. Laboratory testing is not an accurate representation of the changes in power that occur in training sessions or competitions. The invention of the power meter bridged the gap between laboratory and field testing.

Laboratory testing is hindered by the controlled environment and does not accurately represent the cycling demands and changes that occur during training and race conditions. Prior to the power meter invention, power output was measured in the laboratory on cycle ergometers (Stein et al., 1967). In research by Mieras et al. (2014), investigators found that cyclists riding a known distance outside produced greater power outputs in comparison to performing the same distance in an indoor setting. The study by Mieras et al. demonstrates the importance of field data collection and how these power output measurements can provide insight into planning appropriate training and competition protocols. The invention of the power meter aided in bringing laboratory measurements into the field.

Prior to the invention of the power meter, indirect measurements (e.g., heart rate and speedometers) were used for training and competition purposes (Lucia et al., 1999; Montain et al., 1998; Mieras et al., 2014; Vogt et al., 2007). The problem with using measurements such as heart rate and speedometers is that it does not give appropriate real-time indications of overall cycling performance and can be affected by other variables. For example, heart rate can measure how hard the heart is working during a bout of exercise which can aid in helping an athlete gauge what training zones to practice or compete in. Though heart rate is a widely used physiological parameter to measure cycling performance (Lucia et al., 1999; Vogt et al., 2007), it can be affected by factors like stress, fatigue, hydration levels, hyperthermia, and the use of stimulants which may not accurately represent performance (Montain et al., 1998; Mieras et al., 2014; Vogt et al., 2007). The use of a power meter allows for direct, real-time, continuous measurements of power output that are not affected by other factors.

There are other physiological measurements cyclists use to determine their performance such as blood lactate measurements and maximal oxygen consumption testing. With these types of tests, the equipment needed may be expensive and require unique expertise to use. In comparison, power meters are less expensive and can be used in indoor and outdoor training settings. Also, power meters are more accessible to cyclists which allows for a greater number of athletes to have the ability to gauge cycling performance regularly (Denham, Scott-Hamilton, Hagstrom, & Gray, 2020; Passfield et al., 2016). Measuring these physiological parameters may interfere with an athlete's ability to cycle properly whereas the power meters will not.

Oxygen Consumption during Cycling

Maximum oxygen uptake or consumption (VO_2 max) is a metric used by cyclists to gauge their aerobic fitness and endurance performance. In short, this metric is defined by the body's ability to transport and consume oxygen during exercise (ACSM GETP, 1986; Lippincott, Williams & Wilkins, 2013). VO_2 max is expressed in relative values (mL * kg^{-1} * min^{-1}) as opposed to absolute values (mL * min^{-1}) (Lippincott, Williams & Wilkins, 2013). By using relative values, individuals can be compared with differing body weights. The equation for VO_2 max is VO_2 max = Q * a-vO_2 difference. Q is cardiac output (liters of blood per min) and a-vO_2 is the arterial-venous oxygen difference (milliliters of oxygen per liter of blood). This equation can also be seen as VO_2 max = (HR * SV)* a-vO_2 difference. HR is heart rate and SV is stroke volume.

Understanding VO_2 max helps in determining the heart's and other physiological systems capacities to perform moderate-to-intense physical activity. To determine $VO_{2\ max}$, graded exercise testing or incremental exercise testing performed maximal or submaximal in a laboratory setting is used. These tests are deemed the gold standard for testing cardiorespiratory fitness (Denham, 2020; Lippincott, Williams & Wilkins, 2013). In cycling research, VO_2 max has been an important variable to measure to understand cycling performance.

For measuring oxygen consumption during cycling, the American College of Sports Medicine (ACSM) created a guideline outlining the specific equation necessary to measure VO_2 while cycling on a cycle ergometer (ACSM GETP, 1986; Lang, Latin, Berg, & Mellion, 1992; Lippincott, Williams & Wilkins, 2013). The ACSM metabolic equation encompasses the following parameters: pedaling frequency, the distance the flywheel travels, applied resistance to the flywheel, and an estimation of the resting metabolism to predict oxygen cost (ACSM GETP, 1986; Lang, Latin, Berg, & Mellion, 1992). The equation for VO_2 for cycling on a cycle ergometer is VO_2 (ml * min^{-1}) = 3.5 ml/kg/min+1.8 * work rate/bm+3.5 ml/kg/min [work rate= power (watts); bm = body mass]. With this equation, you can determine a person's oxygen consumption while cycling a certain power output with their specific body mass.

As endurance cycling research has grown, researchers have explored measuring VO_2 as a means of understanding why riders cycle a certain way. Denham et al. (2020) examined the relationship between functional threshold power and VO_2max while performing certain aerobic and anaerobic cycling tests. VO_2 has been studied with other cycling parameters such as speed (Pugh, 1974), cadence and uphill cycling (Swain & Wilcox, 1992), and standing vs seated cycling (Bouillod et al., 2018; Swain & Wilcox, 1992). Since VO_2 is associated with endurance performance, it will continue to be researched within cycling due to its relationship to other physiological and biomechanical parameters and overall cycling performance.

Pugh (1974) measured VO_2 with speeds ranging from 12 km/hr to 41 km/hr outside and performed comparative measures of VO_2 to work rates on a cycle ergometer. The results discovered that VO_2 had a curvilinear relationship with speed when cycling outside and a linear relationship between VO_2 and work rates on a cycle ergometer. Swain & Wilcox (1992) and Bouillod et al. (2018) have examined some measure of VO_2 while seated and standing during cycling. Swain & Wilcox (1992) investigated oxygen consumption and heart rate measures while cycling at 11.3 km.hr on a 10% grade during three conditions (84 revolutions per minute (rpm) while sitting, 41 rpm standing, 41 rpm sitting). The authors found that VO_2 and heart rate were significant lower during 84 rpm sitting than 41 rpm sitting and standing. They concluded that when cycling uphill it is economical to have a higher cadence than lower. In Bouillod et al. (2018), the researchers discovered that the energy cost (oxygen consumption and speed) was not significant different between seated and standing positions with different slopes and intensities. The differences in Bouillod et al. (2018) and Swain & Wilcox (1992) may be due to study design. In Bouillod et al. (2018), the participants cycled on a bicycle allowing for lateral movement whereas in Swain & Wilcox (1992) the experiment was performed on a Monarch cycle ergometer which did not take into consideration the potential importance of bicycle lateral movement.

Heart Rate Measurements during Cycling

Since VO_2 max relates to the heart's capabilities during exercise, within research there is a linear relationship between heart rate and VO_2 max (Lucia, Hoyos, Carvajall, & Chicharrol, 1999). The linear relationship between heart rate and oxygen consumption means as heart rate increases the rate of oxygen consumption is likely to increase. Measuring oxygen consumption requires specialized equipment, training and typically performed in a laboratory setting. Whereas, heart rate monitors have become increasingly more accessible to measure due to the vast amount of equipment available on the market today. Heart rate, measured in beats per minute, has an association with a person's ability to perform under taxing exercise bouts.

Due to heart rate being a physiological response to exercise, especially endurance exercise, it is a common measurement amongst cyclists. Heart rate, like with power output, can aid cyclists in competition to determine how much effort they should be engaging in during certain parts of a race. As the amount of exercise increases, heart rate will most likely increase. Since oxygen consumption is a measurement of the heart's capabilities, heart rate can be measured directly and then predictions of oxygen consumption can be calculated.

Lucia et al. (1999) found that during the Tour de France cyclists reported increased heart rate during time-trials and during stages of high-mountainous terrain. Indicating that during these bouts of cycling there is greater demand on the body and an increase in oxygen consumption. In a study by Mieras et al., (2014) researchers found that when cycling outdoors participants had greater heart rate measurements in comparison to cycling indoors. This may indicate that the environment plays a role in a person's ability to perform a task. Heart rate, though a standard measurement practice, can fluctuate due to certain circumstances. The presence of stress, fatigue, stimulants, and more can all affect heart rate measurements (Montain et al., 1998; Mieras et al., 2014; Vogt et al., 2007).

Rate of Perceived Exertion

Borg's Rate of Perceived Exertion (RPE) Scale is a tool used to measure intensity (Borg, 1982). This scale ranges from 6-20 and assists in determining a person's self-perceived exertion while performing an exercise. The scale starts at a level of 6, which indicates no exertion, and reaches a level of 20, which is maximal exertion (Borg, 1982). RPE is typically used in conjunction with exercise testing, especially, submaximal testing. When performing a submaximal test, the subjective RPE scale can provide insight into the relationship between an individual's exertion levels and work rate. The Borg's RPE scale correlates to other physiological measurements such as heart rate, power output, and blood lactate (Groslambert, & Mahon, 2006; Mieras et al., 2014; Steed, Gaesser, & Weltman, 1994). Cycling research has implemented the use of the Borg's RPE scale to have a better understanding of cycling performance.

Within cycling research, RPE has been used as a tool to determine exercise intensity between indoor and outdoor cycling. Mieras, Heesch, and Slivka (2014) found that despite having similar indoor and outdoor environments participants cycled at a higher intensity outdoors. Thus, leading to the conclusion that the RPE determined while cycling indoors should be increased to acquire the same benefits while cycling outdoors (Mieras, Heesch, & Slivka, 2014). As with heart rate, RPE measured in an outdoor environment may affect the measurements.

Gaps in the Literature

Mental and physical fatigue during long endurance races such as triathlons could lead to compromised form while executing tasks. Filipas et al (2019) examined the effect of mental fatigue on time-trial cycling performance. The results indicated that cognitive fatigue led to an impairment in physiological (e.g., mental demand, fatigue, vigor, effort, frustration) and physical function (e.g., mean power output, cadence). Kinematics and kinetics during cycling are important to study for performance and injury prevention. With fatigue, kinematics such as thorax and pelvis orientation will experience greater lateral movement (Sayers, & Tweddle, 2012). Martin and Brown (2009) found that fatigue during cycling reduced joint power at the ankle, knee, and hip. Research related to fatigue while cycling covers a range of topics, but research on the effect of fatigue on bicycle lateral movement or sway has yet to be examined.

Environmental factors such as terrain (e.g., flat, semi-mountainous, mountainous) and climatic conditions (e.g., humid, dry) can affect an athlete's performance during training and in competition. The effect of these environmental factors, especially landscape, on physiological factors such as heart rate, cadence, and power output during competitions have been investigated (Lucia et al., 1999; Montain et al., 1998; Mieras et al., 2014; Vogt et al., 2007). Research has shown that when climbing a gradient with a bicycle to produce greater power output more lateral movement is necessary (Bouillod et al., 2018; Wilkinson, & Kram, 2021). In the studies analyzing physiological and mechanical changes during cycling events, the examination of bicycle sway during these events may indicate its influence on physiological and mechanical parameters.

Cycling power is a known parameter used for training and competitions. Power is measured in watts and athletes can gauge their wattage to optimize their training and competitions. Environmental factors such as gradient can affect an athlete's power output. Power output will be less when cycling on a flat grade and greater on mountainous terrain (Vogt et al., 2007). To produce greater power during bouts of cycling, especially in uphill cycling, additional training or incorporating other means such as bicycle sway may be necessary. Research should explore bicycle sway interventions to examine the effects of these parameters on cycling power outputs.

Heart rate and oxygen consumption measurements can be used to indicate an individual's cardiorespiratory fitness. As a person cycles with an increased intensity, heart rate and oxygen consumption will subsequently increase. These measurements are used in cycling to understand an individual's overall cycling performance while executing an exercise task. Drawback to heart rate and oxygen consumption measurements include fatigue, environment, caffeine/supplement intake, and stress. Research has yet to study the effect of cycling sway on heart rate and oxygen consumption. Cycling research has shown that individuals move their bicycles side-to-side when seated or standing, but studies have yet to examine the effects sway has on physiological variables. There may be a correlation between heart rate and oxygen consumption (physical demand on the body) and an individual's ability to freely move their bicycle. This may give insight on whether sway is important to cycling performance.

Conclusion

Cycling is a sport that requires balance for optimal performance. Cycling balance skills vary between the different skill levels of cyclists. For novice riders, balancing is a skill that is acquired with practice. When a novice cyclist begins to maneuver a bicycle, the bicycle will sway or move laterally as they attempt to propel the bicycle forward. This is due to the multiple demands required to ride a bicycle. For instance, some of these demands include balancing on the bicycle, keeping the handlebars horizontal, and simultaneously having to push on the pedals to rotate the tires to propel the bicycle forward. On the other hand, with experienced cyclists, bicycle lateral movement may be wanted for times when generating more power is necessary such as uphill cycling or sprinting. Regardless of skill level, balancing a bicycle may affect other cycling parameters (e.g., power output) and in turn, affect overall performance.

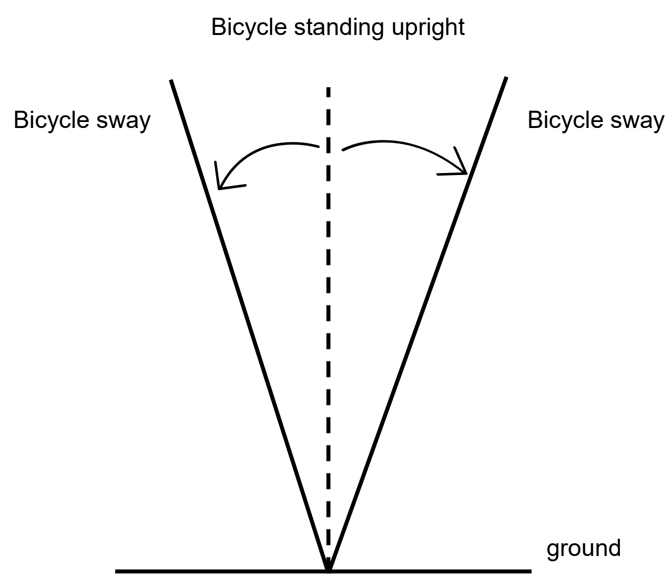
Cycling power is a parameter that majority of athletes use to gauge their performance outcomes. This measurement is widely used due to the equipment readily available to athletes. The invention of the power meter allows cyclists to have continuous, real-time power data displayed while they cycle. From this data, athletes can target certain power output zones during specific portions of their ride. For example, different types of terrain may be navigated during a competition (e.g., flat, semi-mountainous, mountainous) which requires various power demands. Research has shown that with more mountainous terrains greater power demands are needed (Sander et al., 2019; Vogt et al., 2007). Therefore, the power measurement and the power meter are an integral part of cycling performance.

Oxygen consumption is the gold standard to measuring a person's cardiorespiratory fitness and endurance performance. Heart rate and oxygen consumption have a linear relationship with both measurements indicating an individual's physiological capabilities to perform moderate-to-strenuous exercise. Both types of measurements are used in cycling research because it can determine a person's ability to perform certain cycling protocols. This aids in researcher's understanding of cycling performance and then interventions or changes can be made that can help cyclists in training or in competition. Limited research has examined these two measurements conjunction with sway. There may be a link between a person's ability to maneuver a bicycle laterally and the effects it has on physiological parameters.

The Borg's RPE subjective scale is a tool used to determine an individual's self-perceived exertion levels. Though a standard measurement tool used in research, the measurements may vary depending on the environment that data was collected in. There may be confounding variables such as perception and the ability to perform the task differently that alter a person's perceived exertion levels. RPE has been correlated to physiological measurements such as heart rate and power output but has yet to be studied on cycling sway. Since an individual is able to move a bicycle side-to-side as they cycle, hindering a person's ability to move their bicycle freely may alter their perceived exertion levels.

Cycling performance enhancements can be a challenging feat for any level of cyclist. To improve performance, we need to have a better understanding of all the components of cycling that could potentially have an effect on overall performance. The purpose of the proposed study is to understand why cyclists cycle a certain way. We will specifically examine the effect of sway on performance. In the proposed study, we will examine how hindering sway may have an effect on heart rate and rate of oxygen consumption/cycling economy. We hypothesize that if we block a person's ability to move the bicycle laterally (sway), then it will affect heart rate and rate of oxygen consumption showing that sway is an important component to cycling performance.

Figure 2. Visual representation of bicycle sway



Note. The bicycle standing upright is the center point of the bicycle. Bicycle sway is the lateral movement (left and right) of the bicycle away from the center.

Chapter 3

Methods

Participants

Individuals were recruited via flyers posted throughout the University of Nevada, Las Vegas campus, social media advertisements, word-of-mouth, and verbal announcements made in classes.

Thirteen participants (age = 24.9 ± 6.5 years; height = 1.7 ± 0.1 m; body mass = 64.7 ± 11.2 kg; mean ± SD) volunteered to participate in the study. Participants were deemed apparently healthy as per ACSM Guidelines and following a brief health history questionnaire (Physical Activity Readiness Questionnaire for Everyone, PAR-Q+). Only participants who answered 'no' to the first seven screening questions were able to participate in the study. All participants reported they were comfortable riding a bicycle. Participants were not allowed to have any current medical restrictions for exercise or have any injury that would interfere with their ability to cycle, could they be pregnant or think they could pregnant, or have any electronic implanted devices (e.g., pacemaker) due to the use of bioelectric impedance to measure body composition.

Instrumentation

Anthropometric measures of height, weight, and body composition (InBody USA, Cerritos, CA) were recorded. The participant had a heart rate monitor (Wahoo Fitness, Atlanta, GA) placed on them. The placement of the monitor was instructed to be right below the chest muscles. The participants were given a wet paper towel to wet the band, placed the monitor in the appropriate position, snapped the band in the front and tightened the band so that it was comfortable but would not fall off.

All cycling conditions were completed using a smart trainer bike (Wahoo KICKR Bike, Wahoo Fitness). The smart bike measures cycling parameters such as power, cadence, speed, and distance. The resistance of the smart bike was controlled by the researcher. The smart bike was placed on a rocker board (KOM Cycling) (Figure 3). The rocker board allows for side-to-side rotation while using the stationary smart bike. The ability of the board to rock is controlled by two inflatable balls, one on each side of the rocker board. These balls were inflated to 20 psi. Due to the asymmetrical weight distribution of the bike due to the flywheel (left leaning), 6 lbs of weight were added to the right side of the board. A level was used to ensure the board was balanced prior to data collection. A custom rotary sensor (Pasco Scientific, Roseville, CA) was secured on the back of the rocker board where the axis of rotation of the board and rotary switch were aligned.

The rotary sensor set-up was connected to a computer wirelessly via Bluetooth. Pilot work was completed to confirm the ability of the rotary sensor to measure sway. This work consisted of comparing rotary sensor output to digitizing and inclinometer methods while placing the rocker board in specific rotations.

Rotary sensor data were recorded using data acquisition software (Pasco Scientific) at a sample rate of 250 Hz. The smart bike and hear rate monitor have Bluetooth capabilities that measured and recorded with data recorded at (1 Hz through specific data acquisition software (Wahoo Fitness). The metabolic system (Parvo Medics) and software were used to measure and record oxygen consumption (1 sample every 5 sec; 0.025 Hz) data during each cycling condition.

Figure 3. Bike-board System and Rotary Device Set-up

Procedures

Participants gave signed informed consent (Appendix A) and completed the PAR-Q+ and all necessary paperwork prior to data collection. Participants completed a cycling information survey prior to data collection to address the amount of cycling participants were engaging in (Appendix B). Prior to data collection, the participants were asked to perform a 5-minute self-selected warm-up. Warm-up could be running, cycling, or any exercises the participant felt comfortable with prior to collection. After the warm-up, the bike was fitted properly for the participant. After the bike fitting, a researcher demonstrated the proper technique for riding the smart bike. Participants were asked to maintain the same posture (e.g., hand position, head position) during all cycling conditions. Emphasis was given to staying seated during the entire data collection and not to stand-up. In addition, participants were instructed not to change gears on the bike as they performed the data collection. After the demonstration, participants were given time to cycle on the bike-board system until they are comfortable. This was considered the equipment familiarization process.

Following the equipment familiarization process, participants were informed of the testing conditions and instructed in using the Borg's 6-20 point Rating of Perceived Exertion Scale (RPE) (Appendix C). The participants were informed that the RPE scale is a tool to gauge subjective exercise intensity. Participants were instructed that an RPE of 6 is no exertion and an RPE of 19-20 is maximal effort. Participants were informed that their testing protocol included 4 levels of RPE: RPE of 11 ("fairly light"), RPE of 13 ("somewhat hard"), RPE of 15 ("hard"), and RPE of 17 ("very hard"). Participants were notified that they will cycle for 3 minutes at each of these levels for the two conditions and each level will be performed continuously. Participants were not required to cycle at a particular cadence, but cadence was recorded.

Participants were informed that they would complete all intensity levels during two conditions: *unblocked vs blocked*. The unblocked condition would allow the participant to sway laterally freely as they cycle. The blocked condition would have blocks placed within the rocker board to inhibit the participant's potential to sway the smart bike.

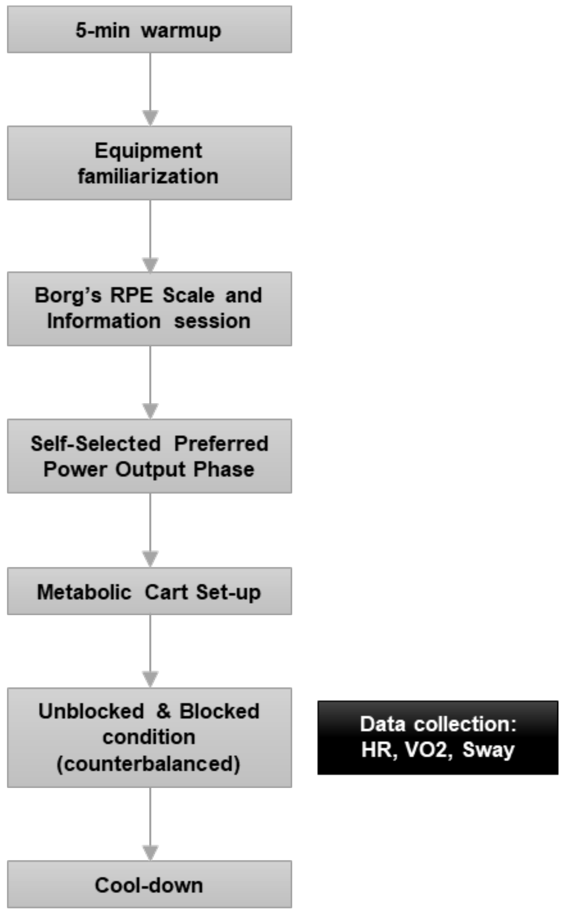
After the explanation of the study protocol, participants went through a self-selected preferred power output phase. During this phase, participants were instructed to cycle at an RPE of 11 for 1 to 2 minutes. The participant would tell the researcher to increase or decrease the resistance until he/she indicated that the RPE is 11. The participant would not be able to view their power during this process. Once the subject indicated he/she was at RPE 11, the researcher recorded the power that was produced and the subject will be asked to stop pedaling. This process was repeated two more times and the average of the three power measurements was used as the set power during data collection. This was repeated for RPE levels of 13, 15, and 17. During this phase, there were no blocks in the rocker board and the participant was able to cycle normally. The preferred power measurements found at each level of RPE were used in the subsequent experiment to elicit four levels of exercise intensity.

After determining the preferred power for each RPE was identified, participants were given time to rest. At this point, participants were fit with a face mask so that expired air could be recorded. Resting measurements of oxygen consumption and heart rate were recorded over six minutes while the participant rested in a seated position.

Following the resting measurements, the participant was informed of the order of the sway conditions (i.e., blocked, unblocked). The order of the conditions was counter balanced. For the experiment, the participant completed a continuous graded test progressing from RPE 11, 13, 15 to 17. The resistance for each intensity level was set as per the preferred power phase.

Each intensity level was continuous and lasted for three minutes. The participant was given a rest period in between each condition (i.e., blocked and unblocked) to minimize fatigue. Sway (radians), heart rate (bpm), oxygen consumption (VO_2, $ml \cdot kg^{-1} \cdot min^{-1}$), cadence, speed, power were recorded during each condition. At the conclusion of the study, the participant was allotted time for a cool-down. The experimental design is illustrated in figure 4.

Figure 4. Experimental design



Data Reduction

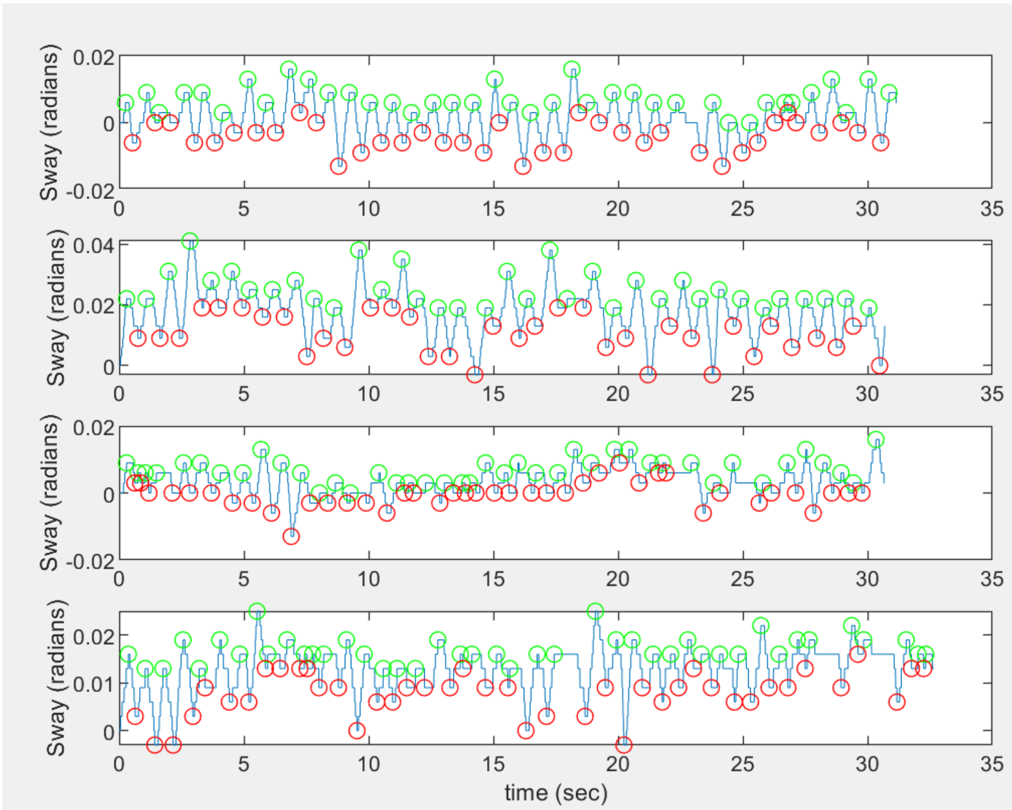
Data were analyzed through custom programs (MathWorks MATLAB, Natick, MA) and spreadsheets (Excel, Microsoft Inc.). All raw data were graphically inspected through MATLAB. After visual inspection of the raw data files, several data points were excluded from the analysis due to data recording issues. For both right and left sway, 4 of the 104 data points (i.e., all subject-condition data points) were excluded. For heart rate data, cadence, and speed, 3 of the 104 data points (i.e., all subject-condition data points) were excluded.

For heart rate and VO_2, the last one minute of the three minutes for each intensity level was averaged.

To quantify sway, the local maximum rotation in each direction (Right, Left) were identified. These local maximums were then averaged for each direction resulting in Right sway and Left sway data of each intensity level for unblocked (Figure 5) and blocked (Figure 6) conditions.

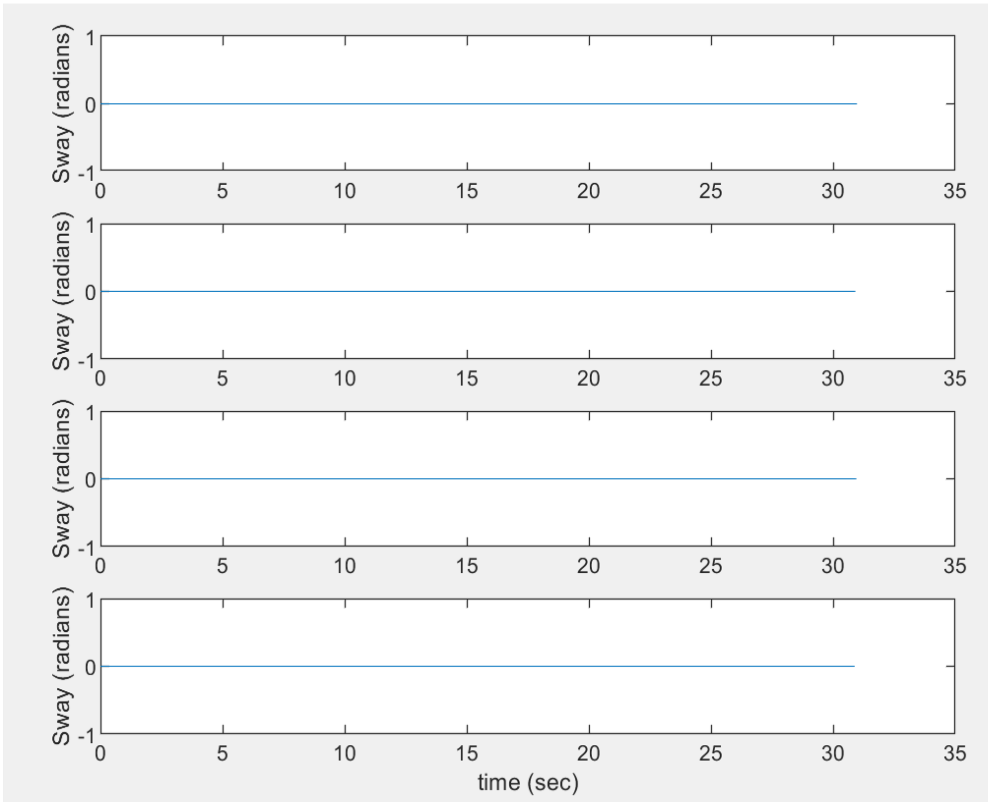
Power was controlled and set to the target power identified during the preferred power phase. Speed and cadence were each averaged for each 3-min intensity.

Figure 5. An example of sway data for an RPE of 11, 13, 15, and 17 for the unblocked condition



Note. This figure is an example of one subject's raw data file with both right and left sway data. The order of intensity levels from top to bottom in the figure is an RPE of 11, RPE of 13, RPE of 15, and RPE of 17.

Figure 6. An example of sway data for an RPE 11, 13, 15, and 17 for the blocked condition



Note. This figure is an example of one subject's raw data file with the blocked condition. The order of intensity levels from top to bottom in the figure is an RPE of 11, RPE of 13, RPE of 15, and RPE of 17.

Statistical Analysis

The dependent variables were: right sway, left sway, cadence, power, speed, heart rate, and VO_2. The independent variables were Intensity (RPE 11, 13, 15, and 17) and Sway condition (blocked, unblocked).

Each dependent variable was analyzed using a 2 (Sway: blocked vs unblocked) x 4 Intensity: RPE 11, 13, 15, 17) repeated measures analysis of variance (ANOVA). All statistical analyses were conducted using IBM SPSS version 28 at an alpha level of 0.05. If Mauchly's Test of Sphericity was violated, then the degrees of freedom, F-ratio and p-value were adjusted using

Greenhouse-Geisser. When the F-ratio was found to be significant, a planned pairwise comparison analysis was performed using a Bonferroni correction to analyze significant differences between conditions. Furthermore, effect size ($\eta 2$) was reported and determined small at 0.01, medium at 0.06, and large at 0.14.

Chapter 4

Results

Physiological and biomechanics data for all conditions are presented in Table 2 (means ± standard deviations).

Sway

Right sway was not influenced by the interaction of SWAY and INTENSITY ($F(3,30) = 2.01$, $p = .134$, partial $\eta^2 = .167$). Right sway was influenced by SWAY condition regardless of INTENSITY ($F(1,10) = 12.326$, $p = .006$, partial $\eta^2 = .552$). Right sway was not influenced by INTENSITY ($F(3,30) = 2.162$, $p = .113$, partial $\eta^2 = .178$).

Left sway was not influenced by the interaction of SWAY and INTENSITY ($F(1.105,11.049) = 1.747$, $p = .215$, partial $\eta^2 = .149$). Mauchly's Test of Sphericity was violated and the F-ratio was adjusted using Greenhouse-Geisser because ($p < 0.05$). Left sway was influenced by SWAY condition regardless of INTENSITY ($F(1,10) = 5.856$, $p = .035$, partial $\eta^2 = .369$). Left sway was not influenced by INTENSITY ($F(1.108,11.075) = 1.625$, $p = .231$, partial $\eta^2 = .140$).

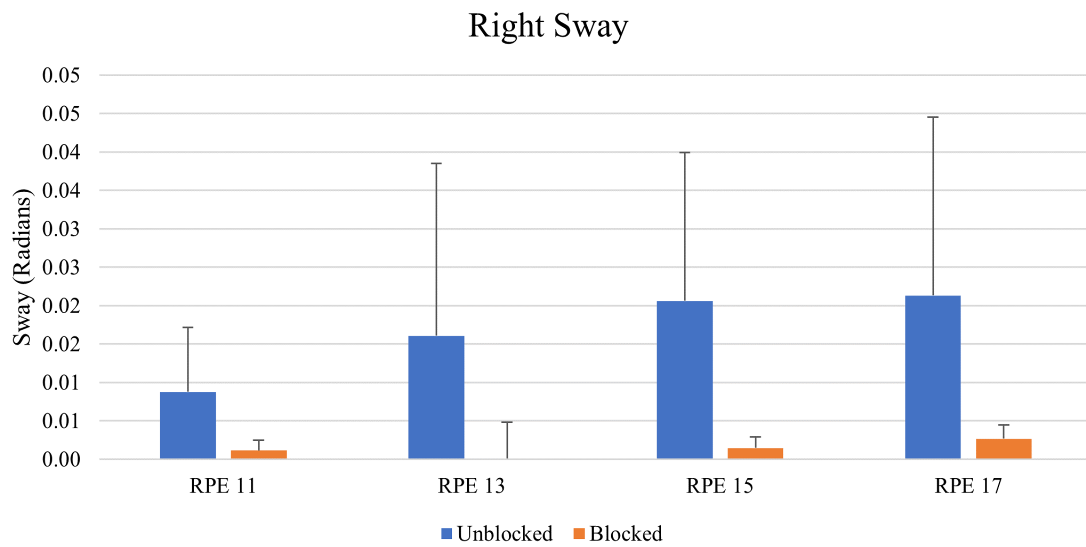
The right and left sway means and standard deviations per intensity for each condition are displayed in Table 2.

Table 2. Means and standard deviations of main dependent variables.

	Unblocked Condition				Blocked Condition			
Dependent Variables	RPE 11	RPE 13	RPE 15	RPE 17	RPE 11	RPE 13	RPE 15	RPE 17
Right Sway (radians)	0.01±0.01	0.02±0.02	0.02±0.02	0.02±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Left Sway (radians)	-0.01±0.01	-0.01±0.01	-0.01±0.01	-0.03±0.07	0.00±0.00	0.00±0.01	0.00±0.00	0.00±0.00
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	17.7±6.2	20.5±7.0	23.8±7.9	27.4±10.2	18.1±6.4	21.0±7.7	24.1±8.7	27.2±10.8
Heart rate (bpm)	111.2±16.3	122.3±17.1	134.6±18.4	145.2±20.5	116.5±18.6	129.1±22.6	137.0±22.6	147.0±23.7
Cadence (rpm)	74.4±14.2	71.2±15.8	72.3±15.2	72.5±17.9	73.8±15.0	73.7±16.0	73.4±16.6	71.9±16.4
Speed (mph)	13.4±5.1	17.7±5.6	21.0±5.5	23.5±5.1	13.1±5.2	17.60±5.8	21.0±5.6	23.5±5.1
Power (Watts)	56.5±32.6	76.7±37.9	92.9±42.8	110.7±51.7	56.5±32.6	76.7±37.9	92.9±42.8	110.7±51.7

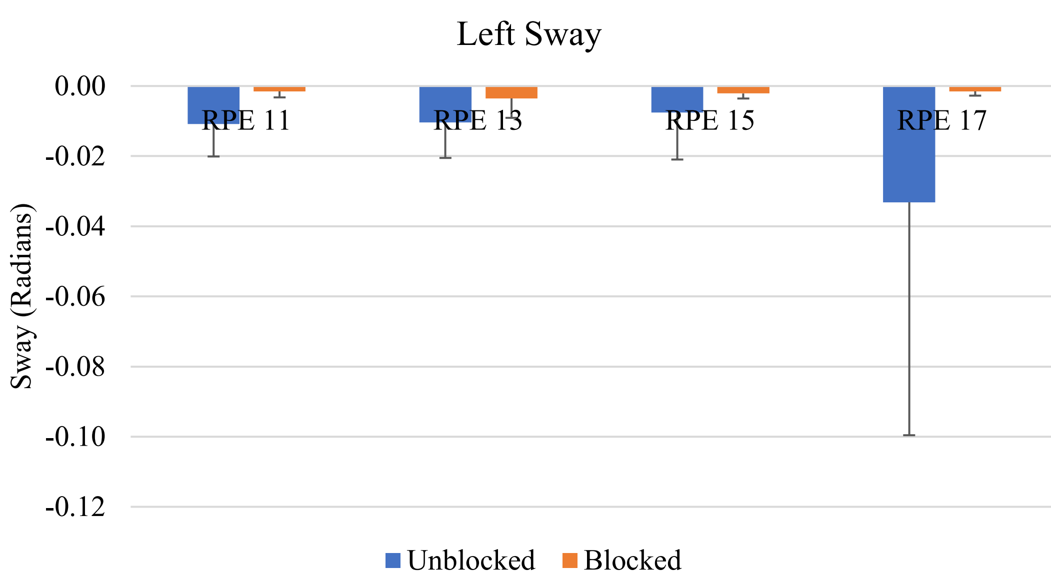
Note. The data represented in this table includes means and standard deviations for all intensities.

Figure 7. Right sway means and standard deviations for both conditions



Note. There was no interaction for SWAY and INTENSITY, no main effect of INTENSITY, but there was a main effect for SWAY.

Figure 8. Left sway means and standard deviations for both conditions

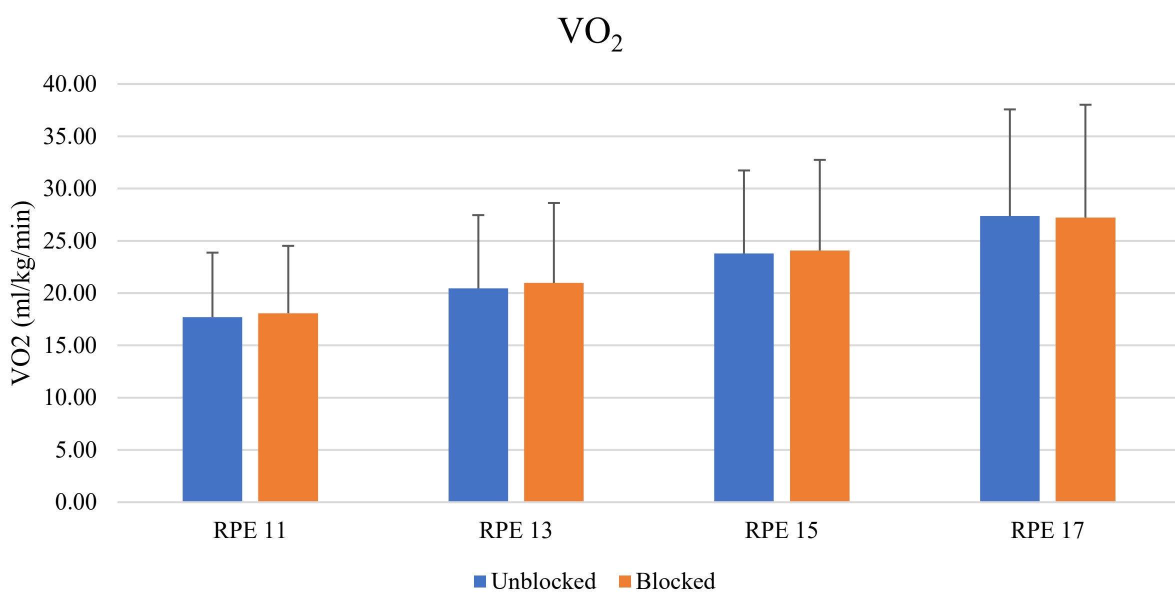


Note. There was no interaction for SWAY and INTENSITY, no main effect of INTENSITY, but there was a main effect for SWAY.

VO_2

VO_2 was not influenced by the interaction of SWAY and INTENSITY (F(1.750, 20.996) = .932, p = .398, partial η^2 = .07). Mauchly's Test of Sphericity was violated and the F-ratio was adjusted using Greenhouse-Geisser because ($p < 0.05$). VO_2 was not influenced by SWAY condition (F(1, 12) = 0.248, p =.627, partial η^2= .020). VO_2 was influenced by INTENSITY (F(1.144, 13.732) = 49.971, p < .001, partial η^2=.806). Pairwise comparison showed mean differences between intensities (p<.05). That is, each intensity was different from the subsequent intensity.

Figure 9. VO_2 means and standard deviations for both conditions

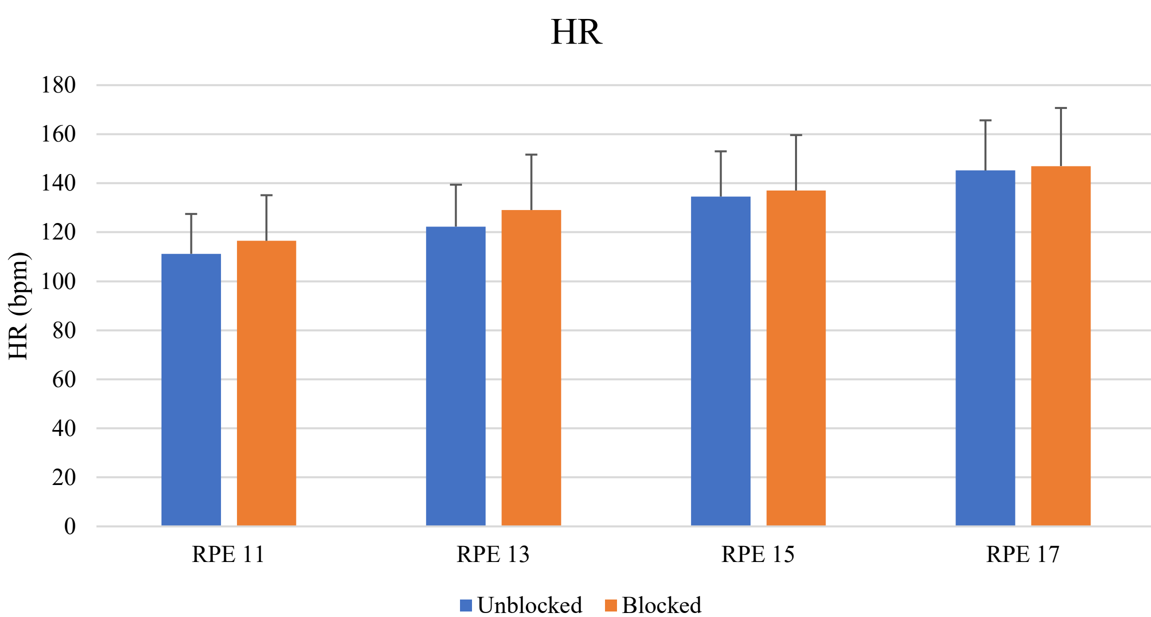


Note. There was no interaction for SWAY and INTENSITY, no main effect of SWAY, but there was a main effect for INTENSITY.

Heart Rate

Heart rate was not influenced by the interaction of SWAY and INTENSITY (F(1.203, 12.026) = .929, p = .373, partial η^2= .085). Mauchly's Test of Sphericity was violated and the F-ratio was adjusted using Greenhouse-Geisser because ($p < 0.05$). Heart rate was not influenced by SWAY condition F(1, 10) = 1.644, p = .229, partial η^2= .141. Heart rate was influenced by INTENSITY F(1.620, 16.203) = 104.621, p < .001, partial η^2 = .913).

Figure 10. Heart rate means and standard deviations for both conditions



Note. There was no interaction for SWAY and INTENSITY, no main effect of SWAY, but there was a main effect for INTENSITY.

Cadence

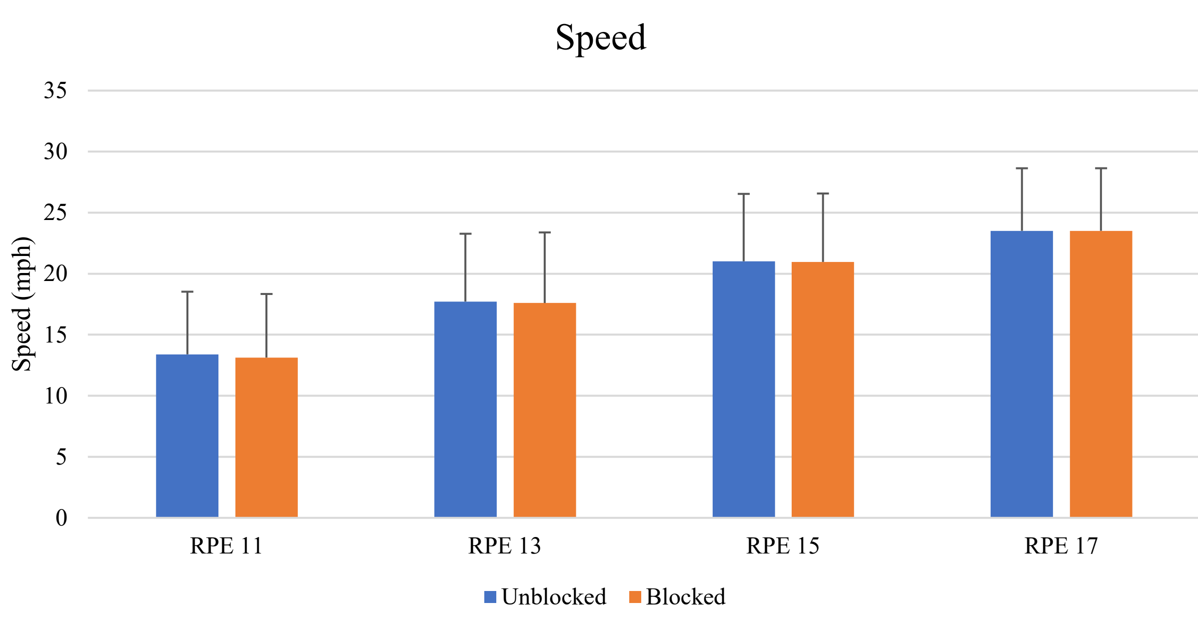
Cadence was not influenced by the interaction of SWAY and INTENSITY (F(1.332, 13.316) = .319, p = .645, partial η^2= .031). Mauchly's Test of Sphericity was violated and the F-ratio was adjusted using Greenhouse-Geisser because ($p < 0.05$). Cadence was not influenced by

SWAY condition (F(1, 10) = .923, p =.359, partial η^2= .084). Cadence was not influenced by INTENSITY (F(1.767, 17.673) = .275, p =.736, partial η^2=.027).

<u>Speed</u>

Speed was no statistically significant by interaction of SWAY and INTENSITY (F(1.005,10.045) = .556, p = .474, partial η^2= .053). Mauchly's Test of Sphericity was violated and the F-ratio was adjusted using Greenhouse-Geisser because (p < 0.05). Speed was not influenced by SWAY condition, F(1, 10) = .401, p =.541, partial η^2=.039. Speed was influenced by INTENSITY (F(1.632, 16.324) = 92.148, p <0.001, partial η^2=.902). Pairwise comparison showed mean differences between each intensity regardless of condition (p<.001).

Figure 11. Speed means and standard deviations for both conditions



Note. There was no interaction for SWAY and INTENSITY, no main effect of SWAY, but there was a main effect for INTENSITY.

Chapter 5

Discussion

The most important observation of this study was that physiological and biomechanical parameters were not influenced by sway. The hypothesis that the potential to sway the bike would decrease heart rate and rate of consumption was refuted. As expected, VO_2, heart rate, power, and speed increased with intensity whereas cadence did not. However, none of these parameters were different between sway conditions. Overall, the potential to sway did not influence the measurements.

This study sought to investigate whether the potential to sway a bike was influential to physiological demand while cycling. In this experiment, we investigated the potential to sway during two conditions (unblocked, blocked). We discovered that sway was different when the participants were cycling on a rocker board that allowed sway vs. having the rocker board blocked to prevent sway. These results make sense due to the unblocked condition allowing participants the opportunity to sway and the blocked condition restricting a participant's ability to maneuver the bike (Figure 10 and 11). It should be noted that prior to this experiment, we categorized the unblocked condition as "potential to sway". Due to the novelty of this study design, it was not certain if participants would sway the bike or not during the unblocked condition. Based upon the observations in this study, participants did employ sway when it was allowed. However, that sway did not influence VO_2, heart rate, or cadence used during cycling at a target power.

Although this study is unique and there are no direct published results of sway measured during using a rocker board set up using a stationary cycle, there are some parallel studies that are in line with the results of the present study. For example, in a study by Cain et al. (2016), reported that at higher speeds more experienced riders exhibited more rider lean while seated than their less experienced counterparts. It should be noted that in Cain et al. (2016), classified rider lean as the participants torso lateral movement and bicycle roll angle as the bicycle's lateral movement. In this study, it was stated that rider lean and bicycle roll angle were negatively correlated. This indicates that as the bicycle moved laterally in one direction, for example to the right, the rider would lean the opposite direction, to the left. In our study, we specifically examined the bikes' magnitude of sway from side-to-side, not the person's lateral movement. In addition, cycling experience level was not controlled in our experiment. Even though experience was not a criterion and torso movement was not measured for this study, we identified that when given the opportunity to participants did sway the bike, but the magnitude of sway was not different between intensity levels (which would be a proxy for different speeds).

Based upon the results, it is now hypothesized that there is a limit that may exist for sway to be beneficial. If there is too much sway, a cyclist may lose balance/control of the bicycle and/or be detrimental to generating power. Instead, there may be an optimal sway zone for a given power. There is no research comparing the influence of magnitude of sway on physiological and/or biomechanical parameters while seated. Interestingly, there seems to be research comparing sway between seated vs standing positions (e.g., Bouillod et al., 2018; Swain & Wilcox, 1992) or just standing (e.g., Wilkinson & Kram, 2021) during cycling– which would seem to be situations that elicit a large amount of sway. It is believed that due to the changes in mechanics (e.g., change in center of mass, increased engagement of the upper body, additional weight due to lack of saddle support, increased sway of the bicycle and body) during standing allows cyclist to generate more lateral movement which may be beneficial for cycling performance especially during uphill cycling (Duc et al., 2008) or sprinting (Wilkinson & Kram, 2021).

In Bouillod et al., (2018), they discovered that cycling at varying slopes and intensities while standing resulted in increased bicycle sway, increased mechanical cost, and increased heart rate vs seated. In their conclusion, they advised that since a relationship exists between bicycle sway and mechanical cost, cyclists should decrease their bicycle sway in order to reduce the mechanical cost of locomotion (Bouillod et al., 2018). The authors suggested that there may be optimal amounts of bicycle sway while standing at different intensities and slopes. With our experiment, we sought to investigate whether or not sway while seated would be different at different intensity levels. However, sway did not differ between intensities. Nevertheless, further research is needed to see if sway differs at different magnitudes of slope. With the smart bike used in the present study, there is the capability to increase and decrease the slope. It would be interesting in future studies to examine sway while seated with no slope vs. with a slope.

In Wilkinson and Kram's (2021) study, they expounded on the bicycle sway conclusion state in Bouillod et al. (2008). The purpose of this study was to understand the different magnitudes of sway and its effect on power while standing. In this experiment, participants completed three 5-s maximal sprints while standing for three conditions (ad libitum, minimal lean, and no lean). The results detected a decrease in power (5%) when sway was minimized vs ad libitum and locked positions. The findings from this study may suggest an optimal zone for sway while standing during cycling. This may have carryover to seated cycling like in our experiment. In the Wilkinson and Kram study, participants were able to move the cycle ergometer as much as possible during the ad libitum condition. Our study was constrained in the range of lateral movement due to the inflation of the balls in the rocker board. With the pilot work, we found that the rocker board had upward limits of 0.22 radians of rotation. In our study, participants did not use maximum sway of the board. The limited range may have caused our participants to have more minimal lean than ad libitum lean which may have resulted in sway not being different between intensity levels and not influencing VO_2, heart rate, cadence, and speed.

A potential confounding factor in this study was that the power for each intensity level was determined during the unblocked condition (i.e., sway was allowed). We do not know if subjects would have selected different powers for the blocked (i.e., no sway) condition. However, the experiment was designed around the idea that power would be controlled during blocked and unblocked conditions. We do not know if we would get a different result if subjects were able to self-select a unique power for blocked and unblocked intensity levels.

Furthermore, in our study a stationary bike was used. Even though the stationary bike was placed on a rocker board to simulate natural riding style outdoors, this setup was still not equivalent to riding an actual bicycle. A stationary bike is rigid creating more stability while vs cycling on a bicycle outdoors requires dynamic balance. This requires a complex interaction between the cyclist and bike in order to not only maintain the balance of the bike while riding on changes in surface, turning, riding uphill, etc.

In this experiment, we examined the potential to sway (sway and no sway) whereas the vast majority of research examining sway has only examined cyclists while have the ability to sway their bicycle. Further research should investigate the potential to sway as a means of balance and its possible influence on cycling performance. However, in the present study, allowing participants the opportunity to sway did increase sway but that sway had no influence on VO_2.

VO_2 and Heart Rate

As expected, there was a main effect found between intensities for VO_2 and heart rate. Specifically, VO_2 and heart rate increased as the intensity level increased. These findings are appropriate due to the graded cycling testing protocol. The protocol increased power during each intensity. With an increase in power, there is an increase in physiological demand. The rate of oxygen consumption and heart rate have a linear relationship (Lucia et al., 1999) which explains why in this study both variables increase as the power increases. Interestingly, there was no interaction between intensity of cycling and SWAY condition. That is, both physiological parameters changed as expected regardless of sway and they were not different at each level of intensity between SWAY conditions. Another experimental model to use to better understand the relationship between sway and physiological parameters would be to manipulate sway by using different PSI levels on the rocker board balls. The current study filled the balls to their maximum pressure rating. This may have limited the amount of sway the board could laterally move. If the balls were inflated to a lower psi (e.g., 10 psi), the board may have had the potential to move more laterally, creating more of an outdoor ride experience which could have led to physiological differences.

In Mieras et al. (2014), researchers explored the physiological differences between cycling indoor vs outdoor with recreational cyclists. In this study, heart rate and power were higher in the outdoor 40-km cycle condition (on the participants bicycle) vs indoor 40-km cycle condition (participants bicycle place on an ergometer). Additional variables such as RPE and attentional focus were measured and found that these measures were similar for both conditions. Although sway was not measured, it may have been that the ability to sway outdoors was different than when riding indoors on a fixed cycle which resulted in heart rate differences. In our study, we incorporated a novel piece of equipment (rocker board) that essentially bridges indoor and outdoor cycling. The unblocked condition was intended to mimic more of an outdoor riding experience, but the results showed lower heart rate values in the unblocked condition vs the blocked condition. Several factors may play into the difference. First, in Mieras et al. (2014) all participants were recreational cyclists whereas our study was predominately novice cyclists. Experience level may have contributed to the differences in results. Secondly, the instructions provided in the Mieras et al. (2014) study coupled with the experience level may have caused the difference in results. The instructions provided to the participants were, “Exert as much effort as you normally would in a 40-km training ride” (Mieras et al., 2014). RPE was similar in the outdoor and indoor ride believed to be due to the participants experience level, but the participants had increased heart rate and power in the outdoor cycle. In our study, power was determined for the four levels of RPE for each participant only while the board was unblocked. If a single bout of cycling at a targeted RPE was used instead of a submaximal graded cycling test, we may have been similar results in heart rate.

Also, in our study, we controlled power output whereas Mieras et al. (2014) did not. If our experiment was repeated without controlling power, heart rate and VO_2 may have responded similarly to the experiment performed by Mieras et al (2014). Since cycling is an endurance sport, more research should explore sway’s influence on VO_2 and heart rate. Next steps could compare a stationary ride to an outdoor ride measure sway, VO_2, and heart rate.

Cadence

Cadence during this study was not controlled. Participants were allowed to cycle at any revolutions per minute during this experiment. Cadence mean and standard deviation values are displayed in Table 3. Though cadence was a secondary variable measured, the results suggest that regardless of the increase in intensity level, cadence would stay relatively the same through each condition. Since cadence was not controlled in this experiment, a natural progression for this study would be to control cadence at each intensity level.

Table 3. Means and standard deviations for cadence for both conditions.

	Condition	
Intensity Levels	Unblocked	Blocked
RPE 11	74.44 ± 14.15	73.81± 14.99
RPE 13	71.19 ± 15.77	73.73± 16.02
RPE 15	72.28 ± 15.17	73.35 ± 16.58
RPE 17	72.47 ± 17.92	71.86 ± 16.36

Note. The data represented in this table includes means and standard deviations for all intensities.

Speed

A main effect for intensity was found for speed. These findings imply that speed increased as the level of intensity increased. For the unblocked condition, speed increased from 13.39 mph at an RPE of 11, to 17.72 mph at an RPE of 13, to 21.02 mph at an RPE of 15 and to 23.51mph at an RPE of 17 on average. For the blocked condition, speed increased from 13.13 mph at an RPE of 11, to 17.60 mph at an RPE of 13, to 20.97 mph at an RPE of 15 and lastly 23.51 mph at an RPE of 17 on average. An illustration of these means can be viewed in Figure 9. As the intensity levels increased, the participants were able to overcome the increase in resistance by increasing their overall speed.

Limiting and Confounding Factors

A limiting factor that may have affected the study was the experience level of the cyclists. The majority of the participants (N=12) were inexperienced cyclists. Participants reported a wide range of time spent cycling from zero to 15 miles cycled per week in the past year. One subject was an experienced cyclists cycling roughly 150 miles per week. Since the majority of the participants were novice cyclists, it is not clear whether a group of only experienced cyclists would respond similarly. Future research is needed to determine if cycling experience is a factor that must be controlled. In the present study, the majority of the participants were novice and demonstrated sway during the unblocked condition. If the experiment was repeated with experienced cyclists, they may have exhibited minimal sway during the unblocked condition.

A confounding factor for this experiment may have been the understanding and appropriate feelings of exertion related to the Rate of Perceived Exertion Scale. Instructions were provided to participants prior to data collection explaining the protocol is designed to be a submaximal test. Since the majority of the participants were novice, it was challenging for participants to understand the feeling of resistance associated with the different intensity levels (fairly light, somewhat hard, hard, and very hard) while cycling. Nevertheless, since VO_2 was different between conditions, the procedures were adequate for determining unique intensity levels.

This study is limited in the ability to generalize the results to cycling outdoors vs. indoors. Although the rocker board does allow for a degree of freedom of movement in one axis vs. using a stationary, fixed cycle ergometer, cycling outdoors may require control over additional degrees of freedom related to dynamic balance of cycling. However, this study does provide insight into what appears to be no relationship between VO_2 and sway when riding indoors.

Future Research

There are several recommendations that may be beneficial for future studies. Firstly, the rotary device used in this experiment encountered several issues during data collection. At times, the device would become unstable even though weights were used for stability. If the rotary device was able to be anchored to the rocker board, the readings may be more accurate. Also, shorter collection times may elicit higher sampling frequencies. In addition, using another method to measure sway such as 3-D motion capture may record more accurate degree changes.

Secondly, during the blocked conditions movement was still detected due to the bouncing movement of the bike due to the pedaling. Inflatable balls were placed in the rocker board to allow for a stationary bike to move laterally. I believe the inflatable balls may have contributed to the slight bouncing movement seen during data collection. If this experiment were to be repeated again, better measures for blocking the rocker board need to be taken into consideration.

Another recommendation would be to control cadence. In this study, cadence was not controlled allowing participants to cycle at any revolution per minute that felt comfortable. Controlling cadence may produce a different physiological response during the cycling protocol. In future studies, how power is determined for each intensity level could be performed differently. In this study, RPE's of 11, 13, 15, and 17 were used. These levels are fairly close in changes of exertion. Future studies may want to choose a middle ground RPE such as 13 or 15, then add or subtract 10 to 20 watts from the RPE of 13 or 15 to find the power at the other intensity levels. For example, if power at an RPE of 13 is 50 watts, then the researcher would subtract 10 watts to get a power of 40 watts for an RPE of 11, add 10 watts for an RPE of 15, and add another 10 watts for an RPE of 17.

Lastly, our study examined sway on the influence of physiological measures, but there may be a psychological component to sway. At the conclusion of each data collection, I would verbally ask the participants which condition they preferred. All participants reported that the unblocked condition was "easier" and "felt more natural" even though there were no physiological differences between the conditions. Potentially including a Feeling Scale during each intensity may allow researchers to understand the range of feelings (e.g., very good or very bad) a participant may be experiencing during each condition. Additionally, a post survey with questions related to feeling about each condition may be beneficial. Even though the psychological component was not evaluated during this experiment, it should be considered for future research.

Conclusions

In summary, it is known that cycling requires balance to propel the bicycle forward. This balance may play into a person's ability to sway or move the bicycle from side-to-side in an advantageous way. The amount of research related to bicycle sway is limited, especially in only seated cycling studies (Cain et al., 2016). An avenue of research related to bicycle sway or bicycle lean that is more thoroughly studied examines sway while sitting and standing and how it may influence physiological and biomechanical measures (Bouillod et al., 2018; Wilkinson and Kram, 2021). This study adds to the literature because it attempts to understand the concept of sway and its influence on important physiological responses while cycling. This experiment also aids in answering a much larger question of why do we cycle the way that we do.

With cycling research performed in a laboratory while seated, majority were performed on a cycling ergometer which did not allow for the bicycle to laterally move. The use of a rocker board bridges the gap between laboratory and field collections. The board allows researchers to have a controlled environment with results that may mirror that of field/outside data collections.

In this experiment, it was observed that the potential to sway did not influence the rate of oxygen consumption and heart rate when cycling power was controlled. Although sway was not influential, regardless of measuring sway, all participants had the potential to sway. Future studies should take into consideration adjusting the preferred power phase, controlling cadence or speed, including more in-depth instructions on the RPE scale, incorporating different levels of experience and/or implementing a type of measurement to analyze the psychological component of sway. In conclusion, the hypothesis that the potential to sway would positively influence physiological measures was refuted. Understanding the concept of sway may lead to revealing ways to optimize sway and maximize cycling performance and better understand why we cycle a certain way.

Appendix A: Informed Consent

This appendix contains the IRB approved informed consent described in Chapter 4.

Informed consent

Department of Kinesiology and Nutrition Science

Title of Study: The effect of cycling sway on cycling physiology and biomechanics.

Investigator(s): John A. Mercer, Ph.D., Alina Swafford.

For questions or concerns about the study, you may contact John A. Mercer at john.mercer@unlv.edu and Alina Swafford at swaffa1@unlv.nevada.edu.

For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted, contact **the UNLV Office of Research Integrity – Human Subjects at 702-895-2794 or via email at IRB@unlv.edu.**

It is unknown as to the level of risk of transmission of COVID-19 if you decide to participate in this research study. The research activities will utilize accepted guidance standards for mitigating the risks of COVID-19 transmission: however, the chance of transmission cannot be eliminated.

Purpose of the Study

You are invited to participate in a research study. The purpose of this study is to determine if cycling sway has an effect on cycling physiology and biomechanics.

Participants

You are being asked to participate in the study because you are 18 years or older with no injury that would interfere with you cycling. You will need to be comfortable biking. You will be able to participate if you answer ‘no’ to the first 7 questions on the Physical Activity Readiness Questionnaire (PAR-Q).

You will not be able to participate if you have any electric implants (e.g., pacemaker). Women who are pregnant or may think they are pregnant will not be able to participate.
Procedures

All procedures in this study will be conducted on one visit at the University of Nevada, Las Vegas within the Sports Injury Research Center (SIRC). All testing will be indoors on a stationary bike that will be provided for you. If you volunteer to participate in this study, you will be asked to do the following:

1. You will complete the Physical Activity Readiness Questionnaire (PAR-Q). This is a self-screening tool that helps uncover any potential health risks including heart, circulatory, balance, medical, emotional, and/or a joint problem that could make the exercise difficult, or even dangerous for some people. Based on your results from the PAR-Q, if it is determined that you are eligible, you will be asked to complete a 1-day test session (described below). If you are deemed not eligible you will not be able to participate in the study and the data collection will not continue.
2. Anthropometrics: Height, weight and body composition will be recorded. Your body composition will be measured using a special scale (InBody). This scale works by sending a very low-voltage electric signal through your body to determine water content, body fat percentage, and lean (muscle) mass. The voltage is so low that you cannot feel it. This test takes about two minutes.
3. Heart rate monitor: After your height, weight, and body composition have been recorded, you will place a heart rate monitor on yourself.
4. Familiarization session: You'll be given time to get used to the bike-rocker board set up (see picture).
    a. The bicycle-board system will consist of a smart bicycle (Wahoo KICKR Bike) secured on a rocker plate (KOM Cycling Rockr Plate).

    b. Once you are ready, you will be asked to cycle at different resistances that you feel range from fairly light to very hard.
        i. The exercise intensity should never feel maximal.
    c. The next step in the research is to have you breathe into a mask that is connected to a computer so we can measure how much air you breathe in and out during rest and during cycling (see picture).

https://www.vacumed.com/zcom/product/Product.do?compid=27&prodid=8172

d. During cycling, we will have you cycle while the rocker board is free to move (i.e., this allows side-to-side movement) as well as with the rocker board blocked to prevent side-to-side movement.
    i. You'll be asked to cycle at intensities that range from fairly light to very hard (but never maximal effort).
    ii. In total, you'll cycle for about 12 minutes for each condition (24 minutes total).
e. At the conclusion of the study, you will be allotted time for a cool-down.

Benefits of Participation

There may not be direct benefits to you as a participant in this study. However, we hope to learn the importance of the effect of cycling sway on overall cycling performance for future implementation into training and competitive cycling.

Risks of Participation

There are risks involved in all research studies. You may be uncomfortable with your weight and/or body composition measurements. This study may include only minimal risks, such as minor lower extremity injury due to improper cycling technique and/or soreness related to typical training rides indoors. The breathing mask used during data collection may feel uncomfortable at times. You may notify a research team member and adjustments can be made to the mask.

While you are testing, there might be other people in the laboratory who are not part of our research team - they may be observing data collection or collecting data for another study. There is the risk that you may feel uncomfortable with other people in the laboratory. We try to minimize this risk by restricting access to the lab by people who have a specific need (e.g., data collection for another project, instruction, etc.).

If you experience any pain or discomfort during data collection, you will be asked to notify the research team and terminate the testing session. If you do not feel confident in performing one of the included tasks at any point during the session, you can inform a research team member and decide not to participate in the task you are concerned about. You will be monitored throughout the data collection process.

Cost /Compensation

There may not be financial cost to you to participate in this study. The study will take 2-3 hours of your time. You will not be compensated for your time. If needed, a UNLV parking pass will be provided on the day that you participate in the cycling data collection in the SIRC.
Confidentiality

All information gathered in this study will be kept as confidential as possible. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at UNLV for 3 years after completion of the study. After the storage time the information gathered will be destroyed. De-identified, digital data will be stored indefinitely.

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with UNLV. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Participant Consent:

I have read the above information and agree to participate in this study. I have been able to ask questions about the research study. I am at least 18 years of age. A copy of this form has been given to me.

_______________________________________ _______________________

Signature of Participant Date

____

Participant Name (Please Print)

Appendix B: Cycling Information Survey

This appendix contains the cycling information survey taken prior to data collection.

Cycling Information Survey

Have you participated in or trained for any cycling races in the past year?

Yes______ No_______

If yes, how many events have you participated in?

____

How many miles a week do you cycle?

____

How often (days per week) do you cycle?

____

Appendix C: Rate of Perceived Exertion Scale

Rating of perceived exertion: Borg scales continued...

HEART online
Heart Education Assessment Rehabilitation Toolkit

Rating of Perceived Exertion (RPE) Category Scale

6

7 Very, very light

8

9 Very light

10

11 Fairly light

12

13 Somewhat hard

14

15 Hard

16

17 Very hard

18

19 Very, very hard

20

Borg G. Borg's Perceived Exertion and Pan Scales. *Champaign, IL: Human Kinetics, 1998.*

References

Amann, M., Subudhi, A.W., and Foster, C. (2006). Predictive validity of ventilatory and lactate thresholds for cycling time trial performance. *Scand J Med Sci Sports 16*, 27–34.

AMERICAN COLLEGE OF SPORTS MEDICINE. *Guidelines for Graded Exercise Testing and Training*, 3rd Ed. Philadelphia: Lea & Febiger 1986, pp. 162-163.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*, 14(5), 377-381.

Bouillod, A., Pinot, J., Valade, A., Cassirame, J., Soto-Romero, G., & Grappe, F. (2018). Influence of standing position on mechanical and energy costs in uphill cycling. *Journal of Biomechanics, 72*, 99-105. https://doi.org/10.1016/j.jbiomech.2018.02.034

Cain, S., Ashton-Miller, J., & Perkins, N. (2016). On the skill of balancing while riding a bicycle. *PloS One, 11*(2), E0149340. https://doi.org/10.1371/journal.pone.0149340

Coyle, E.F., Feltner, M.E., Kautz, S.A., Hamilton, M.T., Montain, S.J., Baylor, A.M., Abraham, L.D., and Petrek, G.W. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Med Sci Sports Exerc 23,* 93–107.

Denham, J., Scott-Hamilton, J., Hagstrom, A., & Gray, A. (2020). Cycling Power Outputs Predict Functional Threshold Power and Maximum Oxygen Uptake. *Journal of Strength and Conditioning Research, 34*(12), 3489-3497. https://doi.org/10.1519/JSC.0000000000002253

Duc, S., Bertucci, W., Pernin, J.N., Grappe, F., (2008). Muscular activity during uphill cycling: effect of slope, posture, hand grip position and constrained bicycle lateral sways. *J. Electromyogr. Kinesiol.* 18, 116–127.

Ellis, C. (2021, October 31). *Parts of a Bike Diagram: Bicycle Anatomy for Beginners* [Illustration]. https://thebestbikelock.com/parts-of-a-bike/

Garcin, Vautier, J.-F., Vandewalle, H., Wolff, M., & Monod, H. (1998). Ratings of perceived exertion (RPE) during cycling exercises at constant power output. *Ergonomics*, *41*(10), 1500–1509. https://doi.org/10.1080/001401398186234

Gough, C. (2021, Mar 4). *Cycling- Statistics & Facts*. Statistia. https://www.statista.com/topics/1686/cycling/

Groslambert, A &Mahon, AD. (2006). Perceived exertion: Influence of age and cognitive development. Sports Med 36: 911–928.

History. (n.d.). SRM. http://www.srm.de/company/history/

Jeukendrup, A.E., Craig, N.P., and Hawley, J.A. (2000). The bioenergetics of world class cycling. *J Sci Med Sport 3*, 414–433.

Jones, D. (1970). The stability of the bicycle. *Physics Today, 23*(4), 34-40. https://doi.org/10.1063/1.3022064

Kooijman, J., & Schwab, A. (2013). A review on bicycle and motorcycle rider control with a perspective on handling qualities. *Vehicle System Dynamics*, *51*(11), 1722–1764. https://doi.org/10.1080/00423114.2013.824990

Lang, P., Latin, R., Berg, K., & Mellion, M. (1992). THE ACCURACY OF THE ACSM CYCLE ERGOMETRY EQUATION. *Medicine and Science in Sports and Exercise, 24*(2), 272-276. https://doi.org/10.1249/00005768-199202000-00019

Leo, P., Spragg, J., Podlogar, T., Lawley, J. S., & Mujika, I. (2021). Power profiling and the power-duration relationship in cycling: a narrative review. *European Journal of Applied Physiology*, *122*(2), 301–316. https://doi.org/10.1007/s00421-021-04833-y

Lippincott, Williams & Wilkins. (2013). *ACSM's Guidelines for Exercise Testing and Prescription* (9th ed.). Wolters Kluwar Health.

Lucia, A., Hoyos, J., Carvajal, A., & Chicharro, J. (1999). Heart Rate Response to Professional Road Cycling: The Tour de France. *International Journal of Sports Medicine, 20*(3), 167-172. https://doi.org/10.1055/s-1999-970284

Mieras, M. E., Heesch, M. W., & Slivka, D. R. (2014). Physiological and Psychological Responses to Outdoor vs. Laboratory Cycling. *Journal of Strength and Conditioning Research*, *28*(8), 2324–2329. https://doi.org/10.1519/jsc.0000000000000384

Miller, T.A., Wells, C.L., Martin, P.E., (1988). The effect of position and cadence on the cardiovascular response of uphill cyclists. *Med. Sci. Sports Exerc*., *20*, S64.

Passfield, L., Hopker, J., Jobson, S., Friel, D., & Zabala, M. (2016). Knowledge is power: Issues of measuring training and performance in cycling. *Journal of Sports Sciences*, *35*(14), 1426–1434. https://doi.org/10.1080/02640414.2016.1215504

Parry, D., Chinnasamy, C., Papadopoulou, E., Noakes, T., & Micklewright, D. (2011). Cognition and performance: Anxiety, mood and perceived exertion among Ironman triathletes. *British Journal of Sports Medicine, 45*(14), 1088-1094.

Prem, H. (1983). Motorcycle rider skill assesment. Ph.D. Dissertation, University of Melbourne.

Pugh, L. (1974). The relation of oxygen intake and speed in competition cycling and comparative observations on the bicycle ergometer. *The Journal of Physiology, 241*(3), 795-808. https://doi.org/10.1113/jphysiol.1974.sp010685

Rice, R.S. (1978). Rider skill influences on motorcycle maneuvering. *Motorcycle Dynamics and Rider Control*, 79–90.

Sanders, D., & Heijboer, M. (2019). Physical demands and power profile of different stage types within a cycling grand tour. *European Journal of Sport Science, 19*(6), 736-744. https://doi.org/10.1080/17461391.2018.1554706

Schwab, A., Meijaard, J., & Kooijman, J. (2012). Lateral dynamics of a bicycle with a passive rider model: Stability and controllability. *Vehicle System Dynamics, 50*(8), 1209-1224. https://doi.org/10.1080/00423114.2011.610898

Steed, J., Gaesser, G.A., & Weltman, A. (1994). Rating of perceived exertion and blood lactate concentration during submaximal running. *Med Sci Sports Exerc* 26: 797–803.

Swain, D.P., & Wilcox, J.P. (1992). Effect of cadence on the economy of uphill cycling. *Med. Sci. Sports Exerc., 24*, 1123–1127.

Vogt, S., Schumacher, Y., Roecker, K., Dickhuth, H., Schoberer, U., Schmid, A., & Heinrich, L. (2007). Power Output during the Tour de France. *International Journal of Sports Medicine, 28*(9), 756-761. https://doi.org/10.1055/s-2007-964982

Whipple, F.J.W. (1899). The stability of the motion of a bicycle. *Q J Pure Appl Math*; 30:312–348.

Wilkinson, R.D., & Kram, R. (2021). The influence of bicycle lean on maximal power output during sprint cycling. *Journal of Biomechanics*, *125*, 110595–110595. https://doi.org/10.1016/j.jbiomech.2021.110595

Curriculum Vitae

ALINA P. SWAFFORD

Curriculum Vitae

alina.paige94@gmail.com

EDUCATION AND ACADEMIC APPOINTMENTS

University Education

Doctor of Philosophy in Interdisciplinary Health Science August 2018- Dec 2023
University of Nevada, Las Vegas, Las Vegas, NV
Department of Kinesiology and Nutrition Sciences
Mentor: John A. Mercer

Master of Science in Sport and Exercise Science July 2018
University of Central Florida, Orlando, FL
Department of Educational and Human Sciences

Bachelor of Science in Exercise Science with Medical Emphasis May 2016
Ithaca College, Ithaca, NY
Department of Exercise and Sport Sciences

- Tau Sigma National Honor Society Inducted 2014

Academic Appointments

University of Nevada, Las Vegas June- July 2019; June 2022-July 2022

Department of Kinesiology and Nutrition Sciences

- Part-time Instructor

AWARDS

- Master's Student Podium Research Presentation Award, National Strength and Conditioning Association's 41st Annual Meeting (2018) https://www.nsca.com/membership/awards/special-recognition/student-research-award/

RESEARCH: PUBLICATIONS, PRESENTATIONS, AND FUNDING

Publications:

Manuscripts

1. Swafford, AP, Kwon, DP, MacLennan, RJ, Fukuda, DH, Stout, JR, Stock, MS. (2019). No acute effects of placebo or open-label placebo treatments on strength, voluntary activation, and neuromuscular fatigue. *European Journal of Applied Physiology*, *119*(10), 2327–2338.

2. Lim, B., Swafford, A., Conroy, K., & Mercer, J. (2023). Shoulder Muscle Activity While Swimming in Different Wetsuits and Across Different Paces. *International Journal of Exercise Science, 16(1),* 172-181.

3. Swafford, A.P., Lim, B., Conroy K.E., & Mercer, J.A. (2023). Core Temperature While Swimming in Warm Water Wearing a Triathlon Wetsuit. *Science and Sports Journal.*

Presentations at National Meetings

1. Swafford, AP, Lim, B, Mercer, JA. Core Temperature While Swimming In A Wetsuit During 1000-m Race Pace Swim. Poster presentation at American College of Sports Medicine 67th Annual Meeting, 2020, San Francisco, CA.

2. Swafford, AP, Roche, CD, Mercer, JA. Descriptive Kinetics on Unique Skills Performed by a Professional Acrobatic Artist. Poster presentation at the American College of Sports Medicine 66th Annual Meeting, 2019, Orlando, FL.

3. Swafford, AP, Stock, MS, Kwon, DP, MacLennan, RJ, Fukuda, DH, Stout, JR. Effects of placebo versus open-label placebo on fatigue resistance during repeated maximal strength testing: Preliminary results. Oral presentation at the National Strength and Conditioning Association 41st Annual Conference and Exhibition, 2018, Indianapolis, IN.

Published Research Abstracts Presented at National Meetings

1. Masumoto, K., **Swafford, AP**, Roche, CD, Mercer, JA. Influence of running direction on metabolic costs may be attenuated by body weight support. American College of Sports Medicine 68th Annual Meeting, 2021.

2. Swafford, AP, Lim, B, Mercer, JA. Core Temperature While Swimming In A Wetsuit During 1000-m Race Pace Swim. American College of Sports Medicine 67th Annual Meeting, 2020, San Francisco, CA.

3. Lim, B, **Swafford, AP**, Roche, CD, Mercer, JA. Case Study: Shoulder Muscle Activity While Swimming with Different Wetsuit Conditions And Swimming Paces. American College of Sports Medicine 67th Annual Meeting, 2020, San Francisco, CA.

4. MacLennan, RJ, **Swafford, AP**, Kwon, DP, DeFreitas, JM, Stock, MS. Do Decrease in Voluntary Activation Account for Fatigability Differently in Males and Females? American College of Sports Medicine 67th Annual Meeting, 2020, San Francisco, CA.

5. Swafford, AP, Roche, CD, Mercer, JA. Descriptive Kinetics on Unique Skills Performed by a Professional Acrobatic Artist. American College of Sports Medicine 66th Annual Meeting, 2019, Orlando, FL.

6. Kwon, DP, **Swafford, AP**, Fukuda, DH, Stout, JR, Stock MS. No Acute Effects of Placebo or Open-Label Placebo Supplementation on Strength and Neuromuscular Fatigue. American College of Sports Medicine 66th Annual Meeting, 2019, Orlando, FL.

7. Swafford, AP, Stock, MS, Kwon, DP, MacLennan, RJ, Fukuda, DH, Stout, JR. Effects of placebo versus open-label placebo on fatigue resistance during repeated maximal strength testing: Preliminary results. National Strength and Conditioning Association 41st Annual Conference and Exhibition, 2018, Indianapolis, IN.

Presentations at Regional Meeting

1. Swafford, AP, Roche, CD, Mercer, JA. Peak Forces on Professional Acrobatic Performance. Poster presentation at the Southwest Regional Chapter of the American College of Sports Medicine 38th Annual Conference, 2018, Costa Mesa, CA.

Published Research Abstracts at Regional Meetings

1. MacLennan, R, **Swafford, A**, Kwon, D, DeFreitas, J, Stock, M. Do Decrease in Voluntary Activation Account for Fatigability Differently in Males and Females? Central States Regional Chapter of American College of Sports Medicine Annual Conference, 2019, Broken Arrow, OK.

2. Swafford, AP, Roche, CD, Mercer, JA. Peak Forces on Professional Acrobatic Performance. Southwest Regional Chapter of the American College of Sports Medicine 38th Annual Conference, 2018, Costa Mesa, CA.

Other Presentations

1. Swafford, AP, Roche, CD, Mercer, JA. Descriptive Kinetics on Unique Skills Performed by a Professional Acrobatic Artist. Graduate Research Forum, 2020, University of Nevada, Las Vegas.

STUDENT TEACHING

University of Nevada, Las Vegas, Department of Kinesiology and Nutrition Sciences

- KIN 456/656 Biomechanics of Endurance Performance [Lecture] (undergraduate/graduate hybrid)
- KIN 346 Biomechanics [Lecture] (undergraduate level]
- KIN 346 Biomechanics [Lab] (undergraduate level]
- KIN 224 Anatomy and Physiology II [Lab] (undergraduate level)

ADDITIONAL INFORMATION

Mentorships

Graduate Rebel Advantage Program 2019-2021

- Mentorship that assists undergraduate students with the graduate school application process.

Student Memberships and Credentials

- Student Member of American College of Sports Medicine
    - Southwest Regional Chapter
- Student Member of National Strength and Conditioning Association
- American Red Cross AED, CPR, and First Aid Certification
- American Red Cross Lifeguard Certification 2020-2021

Volunteer Services during Doctoral Studies

Graduate & Professional Student Association 2021-2022

- *Member-at-large*

Graduate & Professional Student Association 2020-2021

- *Department Representative*

Graduate & Professional Student Association Election Board Committee 2020-2021

Events:

Vegas Golden Knights Preseason Camps 2018 & 2019

- Assisted with physical assessment stations.

National Biomechanics Day Spring 2019

- Demonstrated and taught high school students biomechanics concepts in the Sports Injury Research Center Laboratory.

Dawson Day Spring 2019

- Demonstrated and taught biomechanics concepts to elementary students for a STEM appreciate event in the Sports Injury Research Center Laboratory.

S.T.E.A.M Day Summer 2019

- Demonstrated and taught biomechanics concepts to elementary students for a science, technology, engineering, arts, and mathematics appreciate event at a local community center.

EMPLOYMENT PRIOR TO DOCTORAL STUDIES

Research Assistant, University of Central Florida August 2017-May 2018

- Interpreted data and performed data analysis in the UCF Applied Physiology Laboratory.
- Performed research study using instruments and equipment provided in the laboratory.
