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Muscle Activity and Power Output Between Stationary and Outdoor Cycling

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MUSCLE ACTIVITY AND POWER OUTPUT BETWEEN STATIONARY AND OUTDOOR CYCLING

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ABSTRACT

Muscle activity and power output between stationary and outdoor cycling

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The purpose of this study is to compare lower extremity muscle activity and power output during cycling outdoors overground and cycling on a stationary bike trainer at different self-perceived intensity levels. Recreational and competitive cyclists and triathletes, eight male (48.6±8.7 years, 178.9±7.8 cm, 87.1±8.3kg) and three female (40.3±6.8 years, 158±1 cm, 59.6±9.3 kg), signed institutionally approved informed consents and participated in this study. Power data were collected using power instrumented bicycle pedals (PowerTap, Madison, WI) attached to the cyclist's bicycle. Muscle activity was recorded using wireless electromyography (Delsys, Inc., Natick, MA) sampling at 1926Hz. Participants were tested for maximum voluntary isometric contraction (MVIC) for all muscles tested: the rectus femoris, biceps femoris, vastus lateralis, gluteus maximus, and gastrocnemius. MVIC data were used to normalize electromyography (EMG) from each cycling condition. Participants were instructed to complete four-minute cycling trials at different self-perceived intensity levels (RPE 11, RPE 13, RPE 15) during overground and stationary cycling. For overground cycling, participants rode around a pre-marked, 400-m loop. For stationary cycling, participant's bicycles were fixed to a stationary

bike trainer. During each condition, participants continuously pedaled for two minutes, then were instructed to coast for two seconds. They then resumed cycling for another two minutes.

EMG data were processed by correcting for any zero offset, full-wave rectifying the data, and normalizing to MVIC. The two second pause was visually identified, then a twenty second average for each muscle was calculated following the pause. Power data were also visually inspected, and the two second pause was identified. A twenty second average was calculated for power output following the pause. A 2 (stationary versus overground) x 3 (RPE) repeated measures ANOVA was run for each dependent variable ($\alpha=0.05$). The statistical analysis was completed using SPSS statistical software (v24).

Power output did not differ between overground and stationary, regardless of intensity ($p>0.05$). However, power output increased as intensity increased, regardless of mode ($p<0.05$). There was no significant difference between overground and stationary cycling for the rectus femoris, regardless of intensity ($p>0.05$). Muscle activity significantly increased as RPE level increased, regardless of mode ($p<0.05$). Biceps femoris muscle activity was influenced by the interaction of mode and intensity. Using post hoc testing, it was determined that muscle activity increased as intensity increased during stationary cycling ($p<0.05$). However, there was no significant difference in muscle activity between modes of cycling and no change in activity as RPE level increased ($p>0.05$). There was no significant difference between overground and stationary cycling for vastus lateralis muscle activity ($p>0.05$). Muscle activity increased as RPE level increased, regardless of mode ($p<0.05$). Gluteus maximus activity was significantly greater during overground cycling than stationary cycling, regardless of intensity ($p<0.05$). Muscle activity also increased as self-selected intensity increased, regardless of mode ($p<0.05$). There was no significant difference between mode of cycling for gastrocnemius ($p>0.05$). Muscle

activity increased as RPE level increased ($p<0.05$). The results of this study show that hip extensor and knee flexor muscles have unique responses between submaximal overground and stationary cycling.

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CHAPTER 1

Introduction

Bicycling, also commonly known as cycling, is a popular mode of exercise and competition around the world. USA Triathlon (2015) and USA Cycling (2013) revealed a continuous growth in these endurance sports over the last decade. In fact, general participation in cycling in the United States alone has grown from 39.7 to 46.6 million from 2006 to 2013 (Statista, 2015). The prevalence of this sport has generated research interest over the last few decades. Research has investigated different physiological and biomechanical responses during cycling through different populations (e.g., Baum & Li, 2003; Bertucci et al., 2012; Kenny, 1995). Much of the current cycling literature has been performed in controlled, laboratory based settings using a cycle ergometer or stationary bicycle trainer (Coyle et al., 1991; Martin & Spirduso, 2001). Laboratory based testing makes it relatively easy to study cycling.

Two key measures studied in cycling research are muscle activity and power output. Theoretically, a cyclist's ability to maximize power output and optimize muscle activity can lead to improved performance. For this reason, both muscle activity and power have been studied under different circumstances, such as changes in cadence and the amount of force applied to the pedal (Coast & Welch, 1985; Sanderson, 1991). However, it is not clear how well results from laboratory based research apply to cycling outdoors. While research has begun to look at differences between stationary and outdoor cycling (Bertucci et al., 2007; Bertucci et al., 2012; Kenny et al., 1995), there are still many questions to answer on the similarities and differences between these modes of cycling.

Purpose

The purpose of this study is to compare lower extremity muscle activity and power output during cycling outdoors overground and cycling on a stationary bicycle trainer at different self-perceived intensity levels.

Research Questions

1. How does muscle activity compare during riding on a stationary cycle trainer and cycling overground while outdoors at similar perceived intensity levels?
2. How does power output compare during riding on a stationary cycling trainer and cycling overground while outdoors at similar perceived intensity levels?

Hypotheses

1. Muscle activity for all muscles measured will be greater when cycling on a stationary trainer than when cycling outdoors at similar perceived intensity levels.
    a. Muscle activity will also increase as RPE level increases.
2. Power output will be greater when cycling on a stationary trainer than when cycling outdoors at similar perceived intensity levels.
    a. Power output will also increase as RPE level increases.

CHAPTER 2

Literature Review

Overview

Cycling is a popular sport throughout the world, encompassing participation of more than 46 million people in the United States alone (Statista, 2015). On a bicycle, people assume the role of an engine, driving themselves forward as a while system (Martin et al., 1998). Different internal and external components influence the nature of the movement. Accordingly, this literature review will cover two of the driving factors to motion during cycling, power output and muscle activity. The overall goal of this chapter is to outline gaps in the literature pertaining to the relationship between stationary and overground cycling. Specifically, it will provide background literature on power output and muscle activity, literature on stationary and outdoor cycling, and the studies examining the differences between the two. Finally, it will address the use of a rate of perceived exertion scale as a tool to determine a self-perceived exertion level.

Power Output during Cycling

For a cyclist to propel themselves forward, they must overcome numerous external factors that impede normal motion. Work by Martin et al. (1998) explains this based on engineering and physical principles. It is important to identify these factors to understand what the cyclist needs to overcome to produce movement. In a simple definition, the power a cyclist must produce can be seen in the equation $P_{NET} = P_{AT} + P_{RR} + P_{WB} + P_{PE} + P_{KE}$, where P_{NET} is the power produced by the cyclist, P_{AT} is the power needed to overcome aerodynamic drag, P_{RR} is the power needed to overcome rolling resistance, P_{WB} is the power loss to the bearings of a wheel, and P_{PE} and P_{KE} is the power related to changes in potential and kinetic energy.

One of the biggest factors to overcome during cycling in aerodynamic drag. Aerodynamic drag (P_{AT}) is related to the frontal area and shape of the cyclist and bike, the air density, and air velocity (dependent on direction of the velocity and direction of the wind). Larger cyclists will have a larger frontal area, causing an increase in drag. The overground velocity of the rider and bicycle also causes a change in the air velocity to work against the rider. The power a cyclist needs to produce to overcome the drag and the air velocity over the rider is $P_{AD} = F_D \times V_G$, where F_D is the drag force and V_G is the velocity of the air moving over the cyclist. Another factor counteracting the forward movement of the cyclist/bicycle system is rolling resistance (P_{RR}). Simply put, the rolling resistance on the cyclist is based on the interaction between the tires of the bike and the surface it is rolling on. Differences in tire pressure, the weight of the cyclist and the bike, the tread pattern on the tire, and the texture and gradient (i.e., the slope) of the surface being ridden on. While it may not be large, the friction in the bearings of the bicycle wheels also has to be overcome by the cyclist. The power a cyclist needs to produce to overcome friction (P_{WB}) is dependent on the overall velocity of the cyclist. When riding outdoors, two other factors that need to be accounted for are potential and kinetic energy. Potential energy is seen when gravity acts on a cyclist riding up or down hall. The work on the rider from potential energy is related to the mass of the cyclist/bike system and the change in elevation over the course of the ride. Accordingly, the power associated with the potential energy (P_{PE}) of a rider is related to the mass of the system and the vertical component of velocity. Kinetic energy is stored in a moving system and is related to the mass and velocity of the system. When the velocity of the rider changes, work must be done to, or by, the system, depending on the change in velocity. Power (P_{KE}) is related to kinetic energy by the rate of change in kinetic energy. However, there is also a portion of kinetic energy stored in the rotating wheels of the bike. Therefore, total P_{KE} is related to the rate of change of work done based on changes in velocity and based on energy stored in the bicycle wheels. If the parameters from the power equation provided can be determined, then power a cyclist needs to produce can be determined (Martin et al., 1998).

Laboratory Based Power Measurement

Power is defined as the amount of work done per unit of time. However, power can also be seen as a combination of force and velocity (Hamill & Knutzen, 2009). During cycling, power is determined by the amount of force applied to the pedal during each pedal stroke combined with the pedaling velocity of the cyclist, measure in revolutions per minute. As a one measure of performance during cycling, power has been an area of interest in laboratory based literature. Bishop (1997) explored power output, among other variables, during cycling on a stationary cycle ergometer to determine the reliability of a laboratory based endurance performance test. He found that repeatability in performance measures such as HR and power output provided evidence for the use of a laboratory based test for endurance performance in trained female cyclists. Accordingly, performance during time trials on a cycle ergometer has been shown to be correlated with average absolute work rate, or power ($r = -0.88$, $p < 0.001$), in competitive male cyclists (Coyle et al., 1991). Other research has found that both power and cadence manipulation can have an effect on gross efficiency (a ratio measure of mechanical energy to energy expenditure), oxygen consumption, and heart rate. In experienced, but not elite, cycling populations, optimizing these physiological variables occurs at specific interactions between pedal rate and power output (Coast & Welch, 1985; Pierre et al., 2006).

Researchers have also used power to find optimal setups for a cyclist's bicycle. Changes in certain settings, such as seat height or crank length, can alter how much power a cyclist can produce. Martin and Spirduso (2001) found that trained cyclists maximized power output at 20% of total leg length, or 41% of tibia length, corresponding to a crank length of 170-mm. Similarly, anaerobic power output can be optimized when seat height is set around 109% of inseam height and the relative angle of the knee is between 25 and 35 degrees (Peveler et al., 2007). Even the seat tube angle (STA), or the position of the seat relative to the crank axis of the bicycle, can play a role in cycling performance. Average and peak power output is highest when the STA is lowest, meaning when a cyclist is sitting further behind the crank of the bike they produce a higher amount of power (Umberger et al., 1998).

Power Measured Outdoors

While studying cycling in laboratory settings can prove to be advantageous, it can be difficult to apply such research when cycling moves outdoors, especially during competition. Over the last decade, researchers have begun to explore the impact of measuring power in high level competition. During high level racing at the Tour De France and Giro d'Italia, power profiles revealed higher average power output during mountain and climbing stages than during flat stages (Vogt et al., 2007a; Vogt et al., 2007b). In professional tour races, such as these, it was reported that average cadence for flat land stages were around 90 rpms and cadence for climbing stages dropped to between 70 and 80 rpms (Lucia et al., 2001; Vogt et al., 2007a). Interestingly, even though average power output was higher during climbing stages, cyclists spent more time at power levels above 500 W during flat stages (Vogt et al., 2007a). Similar power trends were seen in women's World Cup racing. Women from the Australian National cycling team spent more time in power zones above 500 W during flat land cycling over climbing stages (Ebert et al., 2005). An ability to sustain power over the course of a race is important to overall performance. Power profiles recorded during a multiple triathlons showed that average power output significantly decreased from the beginning of the cycling stage to the end of the cycling stage of the triathlon (Abbiss et al., 2006; Bernard et al., 2009). Profiles such as these give insight to performance during cycling competitions, especially for elite and professional cyclists. Interestingly, stationary time trials that have found different results, where power output to increase over the course of a 40-km time trial (Bini et al., 2008). It raises a question to why there are differences in these power profiles.

Changes in environmental conditions, such as wind and temperature, can play a role in cycling performance. Magnitude and direction of wind, and even the velocity of the cyclist, can contribute to the aerodynamic drag force a rider must overcome (Martin et al., 1998). Abbiss et al. (2006) found that during the cycling leg of an Ironman Triathlon, speed of the athlete and the torque applied during each pedal stroke varied more when riding into a headwind than with a tailwind. They also found that power output, cadence, and speed significantly declined ($p<0.05$) over the course of the cycling stage in headwind and tailwind sections of the ride. Variations in ambient temperature and humidity, 21-25˚C and 52-84% relative humidity respectively, have also been reported during outdoor cycling events (Abbiss et al. 2006). Research has shown cyclists alter specific pacing strategies, including power and cadence, during 100-km time trials in hot and cold temperatures. Specifically, performance time and power output was worse during hot (33.7±0.5˚C, 44±9% relative humidity) versus cold (10.5±0.3˚C, 65±4% relative humidity) temperatures (Abbiss et al., 2010). Changes in temperature also affected total activity of lower extremity muscles during cycling; several authors have reported the relationship between muscle activity and power output (Abbiss et al., 2010; Blake & Wakeling, 2012) because lower extremity muscles generate power during cycling.

Basics of Electromyography

"Electromyography is the study of muscle function through the inquiry of the electrical signal the muscles emanate" (Basmajian & de Luca, 1985). Simply put, electromyography, or EMG, measures the electrical activity, also known as the action potential, of the active motor units of a muscle (Basmajian & de Luca, 1985; Winter, 2005). The magnitude of this electrical signal gives an idea to the activity of the muscle for a specific movement. These signals are measured using either a surface or indwelling electrode. Basmajian and de Luca (1985) detail the uses, advantages, and disadvantages of each kind of electrode. Surface electrodes are simply electrodes that are applied on top of the skin over a muscle. Once applied, these electrodes can detect the signal of a muscle through the skin and subcutaneous tissues. They also have many advantages, including convenience and simplicity of use and the ability to detect gross EMG signals from multiple motor units. However, these electrodes are limited to measuring only superficial muscles and cannot be used to measure small muscles because of the possibility of detecting signals from adjacent muscles. Indwelling electrodes, the most common of which is a needle, are used to measure these anatomically deeper and smaller muscles. A wire ran through the center of the needle detects a signal by having the bare tip of the needle inserted directly into the muscle. This process allows researchers to measure individual motor units and to easily reposition the needle when necessarily. Another well used electrode is a fine wire electrode. As with a needle, wire electrodes can measure deep and small muscles. An added benefit is the small size of the wire allows for only minimal pain and can be removed easily. Unfortunately, once inserted these electrodes cannot be repositioned unless removed and they have a tendency to migrate after insertion. During functional movement, such as walking, the use of surface and fine wire electrodes have shown a strong relationship in the repeated measurement of muscle activity for larger, upper leg muscles (Jacobson et al., 1995). When measuring adjacent muscles in the lower leg, Perry et al. (1981) used fine wire and surface electrodes to determine surface electrodes can pick up signals from adjacent muscles, also known as ‘cross-talk’. These findings are in agreement with recommendations from Basmajian and de Luca (1985). It is important to keep these principles in mind when evaluating muscle activity information.

Characteristic of Muscle Activity during Cycling

The detection of electrical signals generated by muscles when activated has become a common tool in human movement research, including cycling. A review by Hug and Dorel (2009) discusses that while multiple methods of measuring muscle activity exist, such as fine wire indwelling needles, using surface EMG techniques give a better overall representation of the total muscle. While indwelling wire techniques can show activity of individual muscles, especially deep muscles, they only record a signal from a relatively small area; thus, using surface EMG will provide information from a larger mass of the muscle. Chapman et al. (2006) found consistent patterns of muscle recruitment in the tibialis anterior between indwelling and surface EMG. Surface EMG measurements during cycling can give information on multiple aspects of a muscle’s activity, such as timing of muscle activation (Baum & Li, 2003; Duc et al., 2008; Hug & Dorel, 2009), magnitude of muscle activity (Bini et al., 2008; Blake & Wakeling, 2012; Marsh & Martin, 1995), and muscular coordination/co-contraction (Candotti et al., 2009; Winter, 2005).

Early work characterizes the contribution of different lower extremity muscles to the different parts of the crank cycle; a point in the crank cycle refers to the location of the pedal around a 360° axis of rotation on the crank of the bicycle. According to Jorge and Hull (1986), specific sections of muscles are active during the power stroke, or the down phase of a pedal stroke, and others are active during the recovery period, or up phase, of a pedal stroke. Muscles of the quadriceps, the rectus femoris, vastus medialis, and vastus lateralis, as well as hamstring muscles, are important during the power stroke phase (Candotti et al., 2009; Jorge & Hull, 1986). The activation of all three quadriceps muscles begin at different points during the recovery phase of the crank cycle; the rectus femoris, a bi-articular muscle, activates earlier in the recovery phase than either the vastii muscles, both of which are mono-articular muscles (Jorge & Hull, 1986). However, the activation of all three muscles ends towards the end of the power stroke phase. The gluteus maximus is another primary mover muscle during the power stroke; however, unlike the muscles of the quadriceps or hamstring groups, the activation of the glutes starts immediately before the start of the power stroke and ends 130° into the down stroke. Muscles of the hamstring muscle group, the biceps femoris and semimembranosus, activate at the beginning of the power stroke and continue well into the recovery phase of the crank cycle. The large contributions of muscles in both the quadriceps and hamstrings through the crank cycle lead to overlap of muscle activation of muscles from both upper leg compartments. Muscles of the lower leg, the tibialis anterior and gastrocnemius, do not show the same patterns of overlap as the upper leg. The gastrocnemius muscle is active from the start of the power stroke, through the down stroke, and turns off half way through the upstroke. The tibialis anterior, on the other hand, acts in opposition to the gastrocnemius and is only active during the latter half of the upstroke (Jorge & Hull, 1986). While these patterns of muscle activation can vary based on population differences, it is important to keep in mind the general pattern of motion and contribution of different muscle groups to motion during cycling. Understanding these patterns have allowed researchers to explore changes in muscle activity when adopting different strategies during cycling.

Laboratory Measures of Muscle Activity during Cycling

With power and cadence as popular measures for performance and research during cycling, muscle activity testing has looked extensively into how changes in cadence and power output affect muscle activity. Early literature shows increases in EMG for upper and lower leg muscles as power output is increased when cycling on a stationary trainer (Jorge & Hull, 1986). Research by Baum and Li (2003) found that the load placed on muscle during cycling, as well as changes in cadence, elicits changes in peak EMG magnitude, muscle onset and offset, and timing of peak EMG values within the crank cycle. As cadence increases, it changes the duration of muscular firing of biceps femoris and tibialis anterior, peak activity magnitudes in upper and lower leg muscles, and timing of peak EMG in upper and lower leg muscles. Increases in cadence, at constant power outputs, has also been shown to increase average and peak EMG in rectus femoris, vastus lateralis, and gastrocnemius muscles (Marsh & Martin, 1995). Candotti et al. (2009) found changes in muscular agonist-antagonist co-contraction levels between cyclists and triathletes as cadences were increased.

Co-contraction levels of agonist-antagonist muscles have been studied as a means of muscular efficiency. Winter (2005) discusses that increased amounts of co-contractions is inefficient because muscles are fighting against each other without producing a net movement. Co-contraction relationships between rectus femoris-biceps femoris pairs and vastus lateralis-biceps femoris pairs change as cadence is increased, where the VL-BF pair demonstrates a constantly higher percentage of co-contraction when compared with RF-BF pairs (Candotti et al., 2009). However, as stated previously, it must be kept in mind that alternations in muscle activity patterns does not necessarily mean muscles are working against each other. In the case of lower leg muscles, such as the tibialis anterior and gastrocnemius, while co-activity may occur, these muscles may not necessarily act as direct antagonists (Chapman et al., 2006).

Muscle Activity for Outdoor Cycling

Hilly or mountainous terrain has been shown to elicit changes in power output during outdoor competition cycling (Ebert et al., 2005; Vogt et al., 2007a). Likewise, changes in the grade of a road can affect muscle activity. When comparing cycling on a stationary trainer while horizontal to cycling at an 8% incline, in both a sitting and standing position, both gluteus maximus and tibialis anterior peak EMG activity increased when cycling from a standing position over either seated position; likewise, average rectus femoris and gluteus maximus activity increase when standing (Li & Caldwell, 1998). Duc et al. (2008) explored incline cycling further, testing experienced cyclists when sitting and when standing at 4, 7, and 10% inclines while cycling on a specialized motorized treadmill. When standing, peak muscle activity of the gluteus maximus occurred earlier in the crank cycle on the 7% slope. However, no other lower extremity muscles were affected by the incline. Instead, a seated versus standing position had a more profound change in magnitude and timing of the glutes, hamstrings, and quadriceps muscle groups (Duc et al., 2008). It would seem that the posture during cycling has more of an effect on muscle activity than the slope of the road.

Aside from the grade of a ride, the length of a ride and environmental effect on muscle activity are also passed over. Increases in ambient temperature and humidity have been shown to decrease EMG activity of biceps femoris and soleus muscles, and accordingly impairment finish times, during a stationary 100-km self-paced time trial (Abbiss et al., 2010). A stationary 30-minute simulated time trial found no significant changes in muscle activity of knee flexor or extensor muscles (Duc et al., 2005). However, a longer simulated 40-km time trial found activity of the vastus lateralis increased during measures in the 38th km when compared to early in the trial, while biceps femoris and soleus activity was not affected (Bini et al., 2008). It may be that the length of time of an event can cause different changes in EMG activity. Though most literature measures muscle activity while simulating outdoor obstacles, actual outdoor EMG studies are scarce. Blake and Wakeling (2012) measured muscle activity of 10 lower extremity muscles during a four lap maximum effort test on a 4.7-km outdoor loop. From the first to the last lap, average muscle activity decreased for quadriceps and hamstring muscles, while soleus and gluteus maximus activity increased. The mode of testing (i.e., stationary versus outdoor cycling) may also be the cause of differences in muscle activity over the course of a cycling event. Nevertheless, there are no published manuscripts on muscle activity while riding outdoors versus indoors at submaximal intensities.

Overground Differences

Comparing biomechanics between modes of locomotion is not a new interest in the research world. Early running literature started to explore differences in overground and treadmill movement in the 1970s. Nelson et al. (1972) examined differences in basic running stride parameters between overground and treadmill uphill, flat ground, and downhill running.

They found that stride length, stride rate, support (the time a foot is in contact with the ground) and non-support (time where there is no foot-ground contact) times were different for the mode of running at faster speeds. Changes in stride parameters were also observed when running on a track and on a treadmill. At self-selected running speeds, Elliott and Blanksby (1976) determined that stride length decreased and stride rate increased when running on a treadmill versus overground. When studying leg biomechanics, Nigg et al. (1995) found differences in ankle joint inversion, rear foot eversion, and initial leg angle between overground and treadmill running on different size treadmills.

Stationary versus Overground Cycling

Some question has arisen from contradiction in current cycling literature, one of the largest being how does literature performed in laboratory settings compare to cycling outdoors? While earlier research has tried to recreate outdoor cycling conditions in a laboratory, it still does not shed enough light into these differences. More recently, researchers have begun to answer this question. Bertucci et al. (2005) found that when comparing sprint cycling on a stationary ergo-trainer with cycling in a gym that the maximum force applied to the bike pedal, and peak power output while in a standing position, were greater when cycling in the gym. However, peak power output was greater on the stationary ergo-trainer when subjects remained seated on the bicycle. A 10 second sprint test in adolescent cyclists found that average power, maximum power, and average cadence were all higher on a stationary ergometer than cycling on a track (Nimmerichter & Williams, 2015).

Laboratory based testing has recreated overground cycling using simulated time trials (Bini et al., 2008; Duc et al., 2005). By measuring power output and heart rate, repeated time trials performed on a cycle ergometer and outdoors on a 40-km course found no significant differences between indoor and outdoor cycling. However, the average time for the outdoor time trial was significantly slower than on the indoor cycle ergometer (Smith et al., 2001). Different modes of indoor cycle testing (cycle ergometer, stationary trainer, bicycle treadmill) can also cause differences in results. Kenny et al. (1995) had trained cyclists perform submaximal rides on a cycle ergometer, on a cycling treadmill, and out in the field at different work intensities. At intensities relating to sub-lactate threshold and lactate threshold, oxygen consumption was significantly lower in the field than in the laboratory conditions. Similarly, peak and average force applied to the crank of the bicycle was higher for field cycling than treadmill and ergometer cycling, respectively, at sub-lactate threshold intensities. Adolescent cyclists showed different outcomes, where average power output was higher on a stationary ergometer than on a track. However, they did have a significantly higher cadence when riding outdoors than on the stationary ergometer (Nimmerichter & Williams, 2015).

Outdoor research has re-investigated the effect of an incline during cycling. When pedaling at different cadences at their maximal aerobic power, cyclists rode on a stationary ergometer, outdoors on a flat course and up a 9.25% grade. Cyclists exhibited higher peak torque values and a lower crank angle during uphill cycling at 60 rpms than on ergometer cycling. The minimum torque values measured were larger for level ground cycling than ergometer cycling with a 100 rpm cadence (Bertucci et al., 2007). When comparing flat and uphill cycling directly between ergometer and outdoor cycling at high power outputs, preferred cadence was higher for uphill ergometer cycling than overground uphill cycling. However, gross efficiency (the ratio of power output to total energy expenditure), oxygen consumption, and cycling economy (ratio of power output to oxygen consumption) were significantly higher in field cycling than ergometer cycling (Bertucci et al., 2012).

Rate of Perceived Exertion

In much of the literature already discussed, performance variables such as power output and cadence have been used as a control rather than a measured variable (Li & Caldwell, 1998; Baum & Li, 2002; Sanderson, 1991) as a possible means of matching intensity. However, measured power output and cadence between stationary and overground cycling has been shown to differ based on the mode of exercise (Nimmerichter & Williams, 2015; Bertucci et al., 2005). Another measure of intensity used is a rate of perceived exertion, or RPE, scale. Borg (1982) developed a subjective scale to measure an individual's self-perceived exertion during different exercise tasks. This scale was numbered from 6 to 20, corresponding to extremely light and maximal effort intensity. When trying to match work level with controlled cadences and power output, cyclists have reported significant differences in RPE values between laboratory and outdoor cycling (Bertucci et al., 2007). One attribute for this difference may be the mode of exercise. If an individual views one task as distasteful in respect to another, such as laboratory versus outdoor cycling, then reports of their perceived exertion may differ (Bertucci et al., 2007; Rejeski, 1981). This RPE bias may disappear if used as a control to match work intensities, and rather measure power and cadence as performance variables.

The reliability of a perceived exertion scale is still debated. However, validity and reliability of this RPE scale has been tested for during cycling exercise. Skinner et al., (1973) tested fit and obese university students while performing progressive and randomly assigned workloads. Using physiological variables, heart rate and oxygen consumption, a perceived exertion scale during cycling was deemed valid and reliable. Other locomotion research has used an RPE scale to set intensity levels. For instance, when comparing deep water running and treadmill running at different RPE levels, EMG activity of lower extremity muscles were affected by both exercise intensity level (RPE) and mode of exercise (Masumoto et al., 2009). This also shows that a perceived exertion scale may also be advantageous to compare between different modes of exercise.

Conclusion

Current cycling literature has studied several performance measures, such as power output and muscle activity, by trying to simulate outdoor conditions in a laboratory setting. Even with the measurement of power during professional racing, there is still a lack of strong research measuring important cycling elements outside. In fact, measurement of muscle activity outdoors in nearly non-existent. While laboratory testing is beneficial by controlling environmental factors such has wind and the grade of a road, there is contradictory evidence on the translation of laboratory to outdoor cycling. More recently, researchers have started to bridge the gap between laboratory and outdoor cycling, finding differences in physiological and biomechanical variables. With the importance of muscle activity to development power output already demonstrated, research needs to start looking into this relationship when outside. There is also a problem with the control of intensities in the literature. While power and cadence have been used as a way of setting the level of work during cycling, difference between stationary and overground cycling have shown power and cadence can change depending on the mode of exercise. Using a rating of perceived exertion scale as a control may be a way to correct for this problem. Moving forward, research needs to start examining not only similarities and differences between laboratory and outdoor cycling, but more thoroughly exploring power output and muscle activity when riding overground.

CHAPTER 3

Methods

The purpose of this study is to compare lower extremity muscle activity and power output during cycling outdoors overground and cycling on a stationary bicycle trainer at different self-perceived intensity levels. To accomplish this aim, subjects performed a one-day test while cycling overground on a pre-marked 400-meter course and with their bike fixed to a stationary cycle trainer. Power output and muscle activity were recorded while the subjects rode at three different intensity levels on both the stationary trainer and overground course. Each intensity level was determined from Borg's 6-20 RPE scale – light (RPE 11), somewhat hard (RPE 13), and hard (RPE 15).

Participant Characteristics

Recreational and competitive cyclists and triathletes, eight male (48.6±8.7 years, 178.9±7.8 cm, 87.1±8.3kg) and three female (40.3±6.8 years, 158±1 cm, 59.6±9.3 kg), were recruited from the Las Vegas valley by word-of-mouth and social media. Inclusion criteria included healthy cyclists, either road or triathlete, they were free of injury that would interfere with the ability to cycle, and they owned a road specific bicycle that was compatible with the instrumentation used in the study. Participants have been cycling for 11.1±13.3 years and ride 133.2±60.6 miles per week. All participants signed a university approved informed consent prior to volunteering in the study.

Instrumentation

Bicycle Equipment

All participants had power meter instrumented pedals (PowerTap P1 Power Pedals, PowerTap, Madison, WI) attached to the crank of their bicycle. The corresponding clips were attached to the bottom road-specific bicycle shoes. To collect power data, the instrumented pedals were connected wirelessly to a Garmin Edge 500 GPS unit (1 Hz). After the pedals were installed and synced to the GPS unit on each bicycle, the pedals were calibrated. For stationary cycling conditions, participant's bicycles were secured onto a Wahoo Kickr smart stationary trainer (Wahoo Fitness).

Figure 1. PowerTap instrumented pedals.

EMG Unit

A Delsys Trigno Personal Monitor and Trigno Snap-Lead Sensors (Delsys, Inc., Natick, MA) sampling at 1926Hz were used to collect muscle activity data of five lower extremity muscles. Each snap-lead sensor contained a tri-axial accelerometer sampling at 148Hz used to identify events for post-processing. Data was collected and stored in the TPM, then downloaded for processing using Delsys analysis software.

EMG Placement

Duel EMG electrodes (Ambu Blue Sensor N, Noraxon USA Inc.) were placed over the surface of the skin, in line with the muscle fibers, of five lower extremity muscles – biceps femoris, rectus femoris, vastus lateralis, gluteus maximus, and medial gastrocnemius – using SENIAM electrode placement guidelines. Trigno sensors were attached to the EMG electrodes and secured to the skin adjacent to the electrodes.

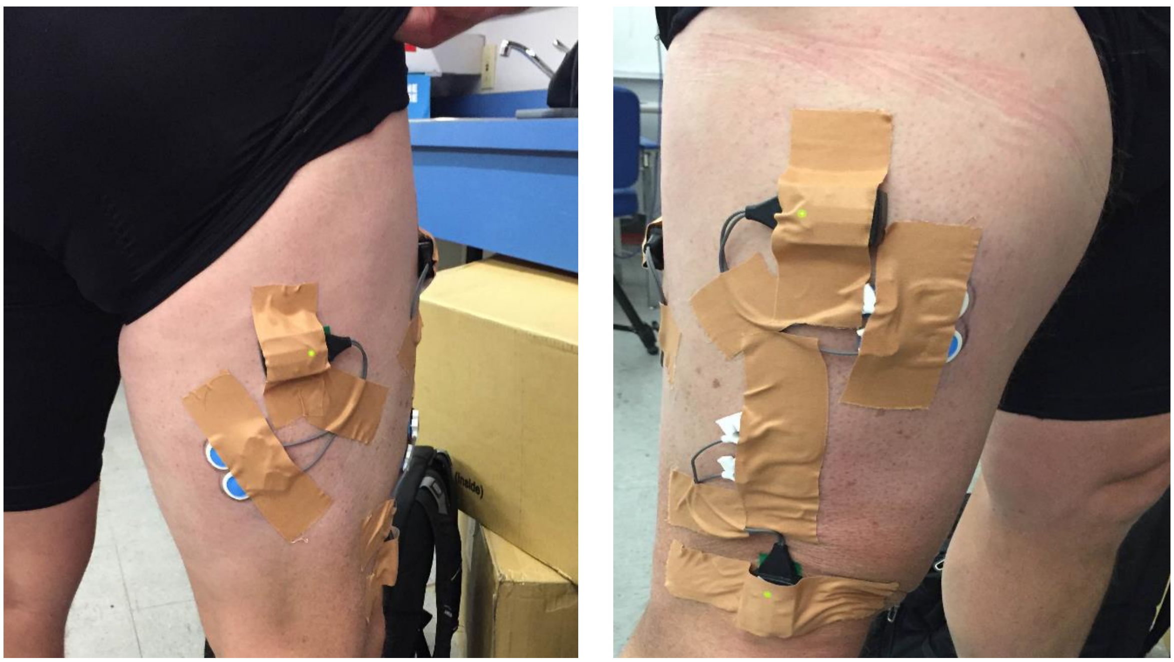

Figure 2. EMG electrode placement according to SENIAM recommendations.

Test Protocol

Participants arrived at the UNLV Sports Injury Research Center main lab and were given a university approved informed consent form to read and sign. After signing the informed consent form and answering any questions, participant gender, age, mass, height, and cycling history. Participants were then given time to perform a self-selected warm-up. Following the warm-up, the skin of the participant's right leg was prepared for EMG electrodes by shaving off any hair in the area (if necessary), abrading the skin, and cleaning the electrode site with alcohol swabs. Maximum voluntary isometric contractions (MVICs) trials were conducted for each muscle tested. After the MVIC trials were performed, the instrumented pedals were installed on the participant's bicycle, synced to the GPS unit, and calibrated. The GPS unit was also attached to the handle bar of the participant's bike.

The participants and research team then traveled out to the designated testing area. The testing area was a 400-meter section of the Thomas and Mack parking lot north of the UNLV Campus Services Building. This area was blocked off from the rest of the parking lot with cones and caution tape. Participants were given time to familiarize themselves with the overground course. After familiarizing themselves with the course, data collection began. The participants cycled at three self-perceived intensity levels, starting with a light intensity (RPE 11) and ascending to moderately hard (RPE 13) and hard (RPE 15), on both a stationary bike trainer and cycling around the course. Participants cycled for four minutes during each condition. The order of the mode of cycling (overground versus stationary) was counterbalanced, but all RPE conditions were performed from light to moderately hard to hard intensities. For the overground conditions, the EMG mobile and GPS units were started, then the participants began cycling continuously around the course. After two minutes, the participant was instructed to stop pedaling, or coast, for two seconds, after which they resumed pedaling for another two minutes. For stationary cycling, the EMG mobile and GPS units were started, then the participants began cycling for two minutes. After the two-minute window, the participant was instructed to stop pedaling for two seconds, then resumed pedaling for two more minutes. Participants were allowed ample rest time between conditions as needed. For each condition, both overground and stationary cycling, participants were required to pedal continuously while remaining in a seated position. They were allowed to freely alter gear ratios and pedaling strategies in order to maintain the same RPE level for the duration of each condition. Following the final condition, participants were given time for a self-driven cool down. The participant and research team then returned to the lab, and all EMG and power equipment were removed from the participant and their bicycle.

Data Reduction

Electromyography

EMG data were collected using the Delsys TPM unit and downloaded using Delsys EMGWorks software. Raw EMG and acceleration data were then read into MATLAB (The MathWorks, Inc.). Using a custom code, EMG data were corrected for zero offset and full-wave rectified. For MVIC trials, the maximum one second average EMG value for each muscle was identified. The MVIC values were used to normalize the EMG data for each cycling condition. Then, for each regular cycling condition, EMG data were corrected for zero offset and full-wave rectified. vertical acceleration peaks from the gastrocnemius EMG unit were graphed and the two second pause from each data collection trial were visually identified. After identifying the pause in the data, the next ten seconds of data were skipped, then a 20 EMG window was visually identified to ensure the quality of the EMG signal. EMG data for each muscle were averaged for the 20 second window.

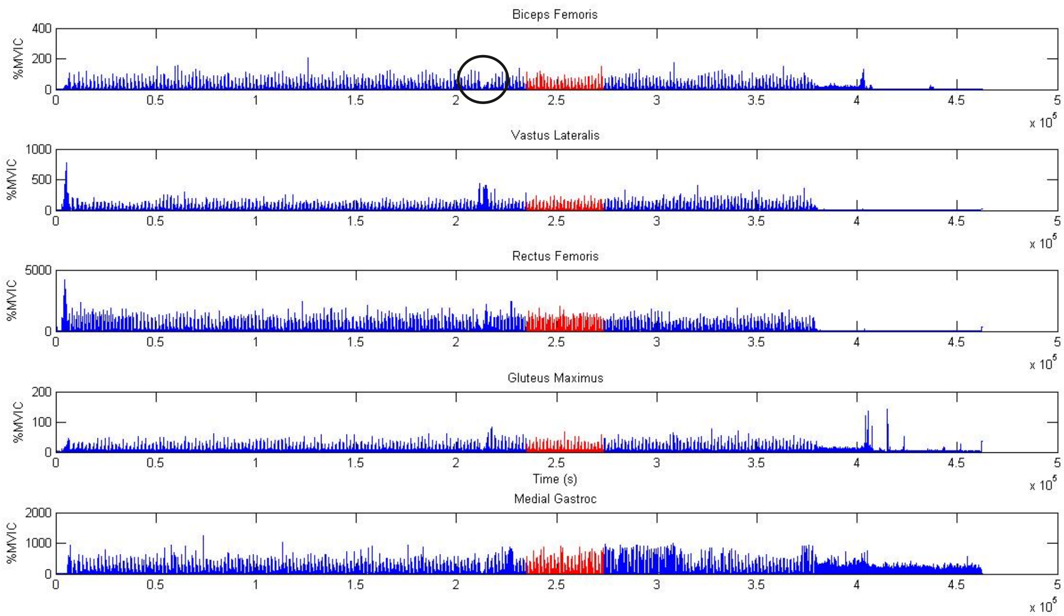

Figure 3. A plot of processed EMG data for each muscle. The black circle shows the pause from data collection. The red EMG data is the 20 seconds that were averaged for the analysis.

Power Output

Power data from the GPS unit was downloaded and opened in Excel. Individual columns of data were visually inspected and the two second pause from the data collection was identified. Following the paused time frame, ten seconds of data were skipped, then an average of the next 20 seconds of power data were calculated.

Statistical Analysis

Descriptive statistics for power output and all five muscles are reported as the mean ± standard deviation for each condition. Multiple 2 (stationary versus overground) x 3 (RPE) repeated measures ANOVAs were conducted for each muscle, and power output, using SPSS Statistics 24 software with a significance level set to $\alpha = 0.05$. If an interaction occurred, paired samples t-tests or a one-way repeated measures ANOVA with Bonferroni post-hoc tests were run to identify differences between intensity levels.

CHAPTER 4

Results

Group means and standard deviations of power output and muscle activity for overground and stationary cycling conditions are presented in Table 1.

Condition	Power Output (W)	Biceps Femoris (%MVIC)	Rectus Femoris (%MVIC)	Vastus Lateralis (%MVIC)	Gluteus Maximus (%MVIC)	Medial Gastrocnemius (%MVIC)
Stationary RPE 11	117.00±33.75	25.99±21.77	134.57±25.82	50.57±52.27	2.99±1.22	27.64±15.36
Stationary RPE 13	192.89±49.27	37.11±31.83	194.46±100.44	73.11±71.59	5.24±2.86	34.60±23.81
Stationary RPE 15	245.50±61.04	50.15±42.22	235.59±179.32	89.07±95.04	9.57±6.61	36.38±22.72
Overground RPE 11	138.47±47.73	43.13±51.67	148.74±63.03	59.52±72.36	5.31±1.93	24.57±10.44
Overground RPE 13	201.17±42.89	49.77±56.13	163.78±79.35	64.18±75.58	8.22±4.31	26.09±8.99
Overground RPE 15	235.37±46.36	53.81±64.45	178.40±78.33	73.34±74.43	11.36±5.08	28.06±12.10

Table 1. Means and standard deviations for power output and lower extremity muscle activity.

Power Output

Average power output was not influenced by the interaction of cycling mode and RPE ($p>0.05$). There was no significant difference for power output between mode of cycling, regardless of RPE level ($p=0.547$). Power was significantly different between RPE levels, regardless of mode ($p<0.001$).

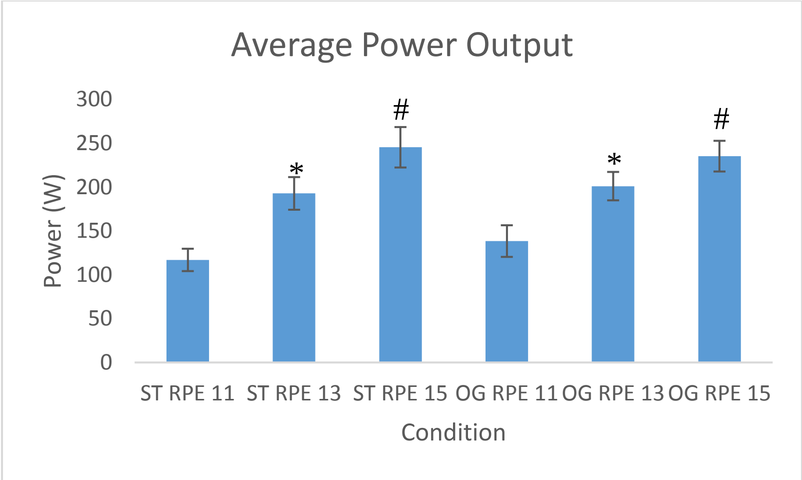

Figure 4. Mean and standard errors for average power output. There was no significant difference between mode of cycling (p>0.05). There was a significant difference between cycling intensity, regardless of mode. *Significantly greater than RPE 11 at same cycling mode. #Significantly greater than RPE 11 and RPE 13 at same cycling mode.

Muscle Activity

Biceps femoris muscle activity was influenced by the interaction of mode and RPE (p=0.002). For stationary cycling, BF was significantly difference between RPE 11 and RPE 13 (p=0.043) and between RPE 11 and RPE 15 (p=0.021), but not between RPE 13 and RPE 15 (p=0.165). There was no significant difference between RPE levels for overground cycling (p=0.235).

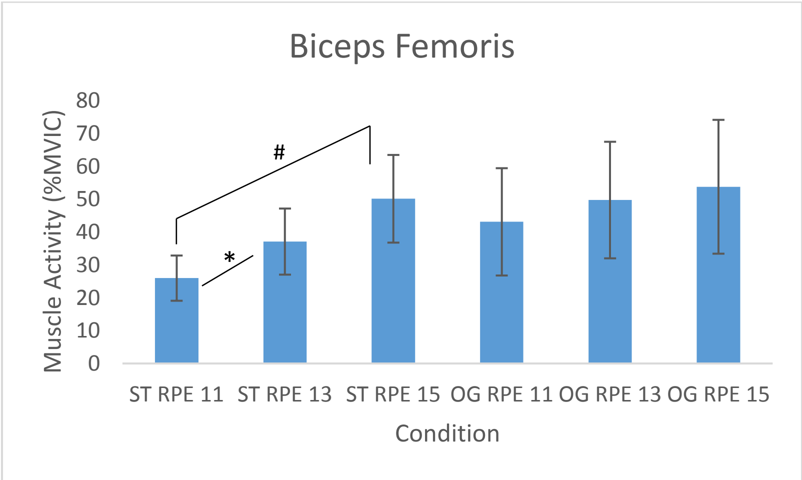

Figure 5. Mean and standard errors for biceps femoris muscle activity (% MVIC) for overground and stationary cycling at each RPE level. *Significant difference between stationary cycling RPE 11 and RPE 13 (p=0.043). #Significant difference between stationary cycling RPE 11 and RPE 15 (p=0.021).

Rectus femoris muscle activity was not influenced by the interaction of cycling mode and RPE (p=0.106). There was no significant difference for RF activity between mode of cycling, regardless of RPE level (p=0.285). Rectus femoris muscle activity was significantly different between RPE levels, regardless of mode of cycling (p=0.004).

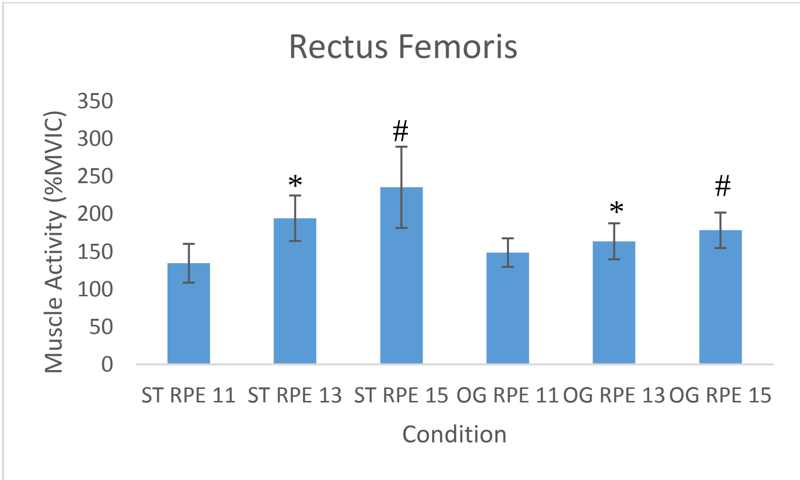

Figure 6. Means and standard errors for rectus femoris average muscle activity (% MVIC) for overground and stationary cycling at each RPE level. There is a significant difference between RPE levels, regardless of mode of cycling (p=0.004).
*Significantly greater than RPE 11 at same cycling mode. #Significantly greater than RPE 11 and RPE 13 at same cycling mode.

Vastus lateralis muscle activity was not influenced by the interaction of cycling mode and RPE (p=0.187). There was no significant difference for VL muscle activity between mode of cycling, regardless of RPE level (p=0.207). Muscle activity was significantly different between RPE levels, regardless of mode of cycling (p=0.001).

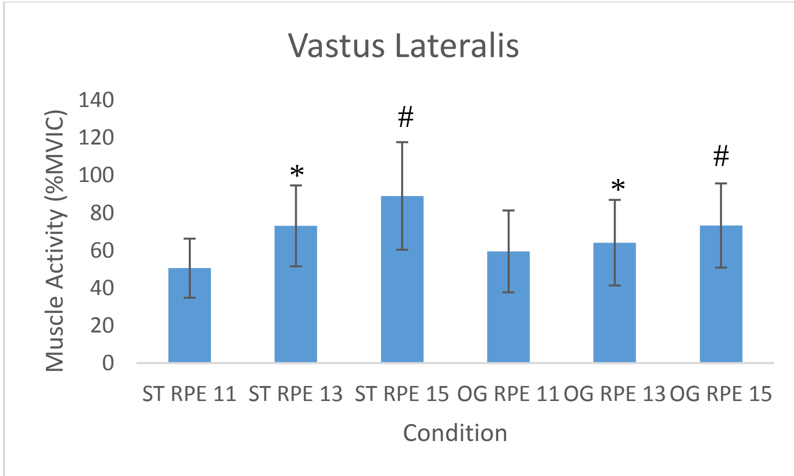

Figure 7. Means and standard errors for vastus lateralis average muscle activity (% MVIC) for overground and stationary cycling at each RPE level. There is a significant difference between RPE levels, regardless of mode of cycling (p=0.001).
*Significantly greater than RPE 11 at same cycling mode. #Significantly greater than RPE 11 and RPE 13 at same cycling mode.

Gluteus maximus muscle activity was not influenced by the interaction of cycling mode and RPE (p=0.639). GM muscle activity was significantly different between overground and stationary cycling, regardless of RPE level (p=0.008). GM activity was significantly different between RPE levels, regardless of mode of cycling (p<0.001).

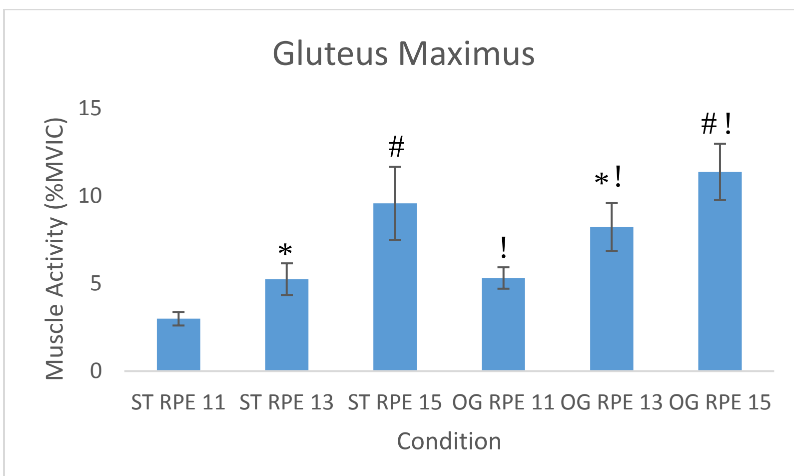

Figure 8. Means and standard errors for gluteus maximus average muscle activity (% MVIC) for overground and stationary cycling at each RPE level. Muscle activity was significantly different between mode of cycling, regardless of intensity (p=0.008). There is a significant difference between RPE levels, regardless of mode of cycling (p<0.001).
*Significantly greater than RPE 11 at same cycling mode. #Significantly greater than RPE 11 and RPE 13 at same cycling mode. ! Significantly greater than stationary cycling at same RPE level.

Medial gastrocnemius activity was not influenced by the interaction between cycling mode and RPE (p=0.089). GA muscle activity was not significantly different between modes of cycling, regardless of RPE level (p=0.246). Gastrocnemius activity was significantly different between RPE levels, regardless of mode of cycling (p=0.014).

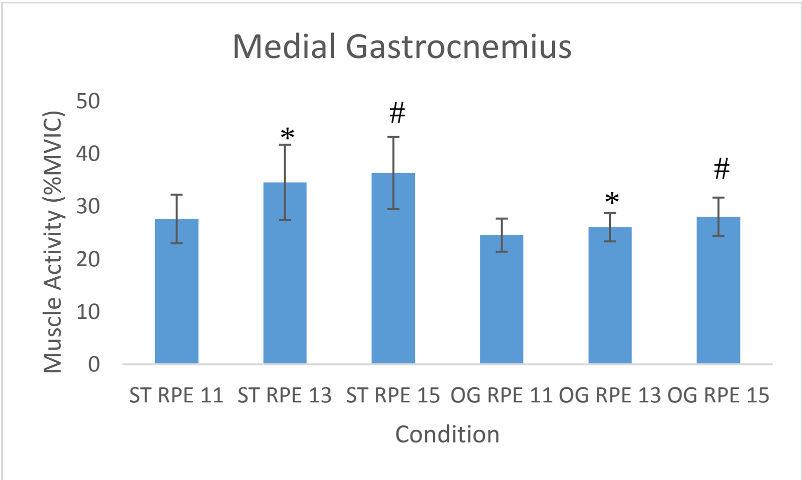

Figure 9. Means and standard errors for medial gastrocnemius average muscle activity (% MVIC) for overground and stationary cycling at each RPE level. There is a significant difference between RPE levels, regardless of mode of cycling (p=0.014).
*Significantly greater than RPE 11 at same cycling mode. #Significantly greater than RPE 11 and RPE 13 at same cycling mode.

CHAPTER 5

Discussion

The most important observation of this experiment was there was no significant difference in power output between stationary and overground cycling. However, a significant increase in power output was observed as self-perceived intensity increased. The hypothesis that power output would be greater during stationary cycling was refuted; however, the hypothesis that power would increase as RPE level increased was supported. Similarly, muscle activity for the rectus femoris, vastus lateralis, and gastrocnemius increased as RPE level increased. However, there was no significant difference in muscle activity between modes of cycling for these muscles. The biceps femoris muscle had a unique response in that there was an interaction between mode and intensity. Specifically, there was no significant difference in muscle activity between overground and stationary cycling. Similarly, during overground cycling, there was no significant difference in biceps femoris muscle activity between effort levels. However, muscle activity increased as RPE level increased during stationary cycling. The gluteus maximus was the only muscle to show any significant difference between modes of cycling. Muscle activity was significantly greater during overground cycling, regardless of intensity levels. Gluteus maximus activity also increased as RPE levels increased, regardless of the mode of cycling.

Power Output

The magnitude of power observed in the present study was similar to other studies. Bertucci et al. (2012) had subjects perform submaximal cycling at power outputs relating to 90% of the cyclists' ventilatory threshold (VT). The power values observed in this study during level ground, preferred cadence cycling are 239±18 W versus 245.1±61.1 W in the current study for stationary cycling and 240±19 W versus 235.4±46.4 W during overground cycling (Bertucci et al., 2012). Likewise, previous research has reported a relationship between power output and cycling performance (Coyle et al., 1991). Accordingly, power has been used and studied in multiple areas of cycling as a method to monitor and/or quantify intensity of effort (Bernard et al., 2009; Martin and Spirduso, 2001; Martin et al., 1998).

Bertucci et al. (2005) and Nimmerichter and Williams (2015) reported differences in maximum power output between stationary and overground cycling. However, unlike the current study, these authors looked at maximum effort and sprint cycling rather than submaximal cycling. Accordingly, the power values from these studies were much greater than what was observed in the current study. It may be that while differences in power output may occur between overground and stationary while cycling at a maximum effort, this may not be the case in submaximal cycling.

Muscle Activity

While previous research has explored lower extremity muscle activity during cycling, this was the first study to compare muscle activity between stationary and overground cycling. In the current study, muscle activity increased as effort level increased for both overground and stationary cycling. Similarly, Baum and Li (2003) observed that an increase in load during cycling caused changes in muscle activity and muscle coordination. For instance, the peak magnitude of biceps femoris muscle activity increased as load increased (Baum and Li, 2003). However, in the current study, the biceps femoris muscle activity increased during stationary cycling as RPE increased, but not during overground cycling.

The gluteus maximus was the only muscle to display a difference between modes of cycling, having greater muscle activity during overground cycling than stationary cycling regardless of intensity. While previous research has not explored muscle activity between different modes of cycling, Bertucci et al. (2012) reported physiological differences between cycling modes, where gross efficiency and cycling economy were greater when cycling overground rather than on a stationary trainer. Interestingly, the only muscles to exhibit different results between modes of cycling were hip extensors and knee flexors, while there was no difference for hip flexors and knee extensors. One possible reason for these differences were the contributions of each muscle through the pedal stroke. Observations by Jorge and Hull (1986) illustrate the different contributions of each lower extremity muscle to the crank cycle. Based on this work, the gluteus maximus and biceps femoris activity begins around the top dead center (TDC). However, rectus femoris and vastus lateralis muscle activity begins earlier in the crank cycle. Interestingly, it was also reported that the biceps femoris contributes to the knee extension phase of the crank cycle (Jorge and Hull, 1986). The differences in the onset and offset of these muscles may be a factor contributing to the differences seen in the current study.

There were several confounding factors that were considered while interpreting the results. It was considered that participants may have become fatigued during the data collection process. However, the order of cycling mode was counterbalanced and participants were given time to rest between conditions before resuming. It is not clear how wind and temperature influenced the outcome of this study. The temperature during data collections was 34.1±6.0 °C and the wind was 1.2±0.6 m/s. While it has been reported that differences in ambient temperature can affect power output and muscle activity during cycling (Abbiss et al., 2010), all overground and stationary cycling conditions were performed outdoors to minimize the effect on changes in temperature in the current study. Previous research on outdoor cycling has deemed wind velocities under a 3.0 m/s threshold as acceptable for outdoor data collection conditions (Bertucci et al., 2012). The wind velocities in the current study were below that threshold.

Nevertheless, participants were instructed to maintain a given RPE (versus a specific speed). Previous literature has observed that alterations in cadence can lead to changes in muscle activity patterns (Baum and Li, 2003; Candotti et al., 2009; Marsh and Martin, 1995). While the current study allowed participants to cycle at their preferred cadence, it is not known if controlling the cadence at each RPE level would have had an effect on muscle activity. It is not clear if the size of the overground testing area influenced the data collection. Previous literature has used a larger course for outdoor data collection (Blake and Wakeling, 2012). However, all participants in the current study were able to maintain each RPE level for overground cycling.

Conducting data collection in the field presented several logistical challenges. First, there were difficulties finding a suitable location for the outdoor data collection that would provide enough room for participants to perform the overground cycling conditions and an area that would have electrical connections for the stationary cycling conditions. Extra time was also needed to set up cones and caution tape to provide safety for the participants. Additional time was also needed to transport water, shade cover, and testing materials to the data collection area.

While no significant difference was observed in power output between modes of cycling, there was a large range of individual responses between modes of cycling (Figure 10). Figure 10 presents individual responses on differences between overground and stationary cycling at each RPE level. It is not known why there was a large range of individual responses. It is conjectured that this is related to the range of participants' cycling experience (recreational versus competitive endurance athlete, different training levels on a stationary trainer, etc.).

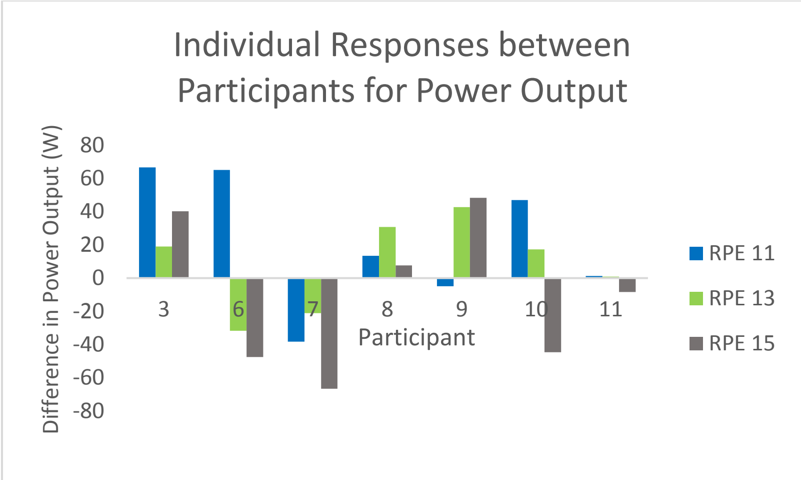

Figure 10. Individual responses between participants for power output. Positive power values represent greater power output during overground cycling for the given RPE level. Negative power values represent greater power output during stationary cycling for the given RPE level.

Future studies should focus on the influence cycling experience has on the relationship between RPE, power, and indoor vs. overground cycling. It is suspected that power output may be different between overground and stationary cycling for trained, competitive cyclists. However, the present study does not have a sufficient number of subjects in that category to make a conclusive statement.

The difference in gluteus maximus muscle activity between overground and stationary cycling, as well as the different bicep femoris responses seen in stationary cycling but not for overground cycling, is evidence that these muscles are being used differently during stationary and overground cycling. It is conjectured that lower extremity muscle activity patterns are different between overground and stationary cycling. Future research is needed to expand upon the present analysis which was focused on average muscle activity.

A limitation of the present study were the parameters that were measured. While muscle activity and power data were able to be collected, the nature of the outdoor study design did not allow for the collection of synchronized kinematic data. This limitation of focusing on EMG and power over a large period of time does not allow for a more detailed analysis on muscle activity, such as identifying muscle activity through different phases of the crank cycle. However, the analysis performed in this study still gave a representation of the muscle activity and power output for each cycling condition. It is also unknown if calculating normalized power would have had an effect on the outcome of this study. Normalized power is calculated by taking individual power data points to the 4^{th} power, taking an average of these values, then taking a 4^{th} root of the average. This process corrects for any zeros or outliers that may be present in the data set. However, since the participants were instructed to ride continuously with a constant effort, it is not conjectured that the normalized power calculation would have changed the results of the study. Another limitation is generalizing the results based upon the intensities that were used. RPE levels of 11, 13, and 15 were used for the present study. However, it is not known if using other self-perceived intensities would have had an effect on muscle activity or power output. Participants were allowed to use either a triathlon specific or a road specific bicycle. This limits how the results may be generalized based on possible mechanical differences between these kinds of bicycles and other types of bikes that are available on the market.

Conclusion

The unique aspect of this study is researching muscle activity during stationary and overground cycling concurrent with measuring cycling power. It is concluded that while working at similar self-perceived exertion levels, power output did not differ between overground and stationary cycling for the group. Similarly, muscle activity for the rectus femoris, biceps femoris, vastus lateralis, and gastrocnemius were not different between the modes of cycling. However, gluteus maximus muscle activity was significantly greater during overground cycling, showing that muscle activity can differ between modes of cycling. It is important to recognize that there was a range of individual responses and future research is needed to discern why subjects responded differently between conditions. While there was no difference observed in cycling power and muscle activity of the quadriceps muscles, the unique responses of the biceps femoris and gluteus maximus muscles suggest that there is a difference between submaximal overground and stationary cycling. Future research is needed to explore any biomechanical differences between these modes of cycling.

APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

Department of Kinesiology and Nutrition Sciences

TITLE OF STUDY: Muscle activity and power output during overground and stationary cycling

INVESTIGATOR(S): John Mercer, Ph.D., Jared Joerger

For questions or concerns about the study, you may contact John Mercer at **702-895-4672.**

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, toll free at 877-895-2794 or via email at IRB@unlv.edu.**

Purpose of the Study

You are invited to participate in a research study. The purpose of this study is to compare lower extremity muscle activity and power during cycling outdoors overground and on a stationary cycle.

Participants

You are being asked to participate in the study because you fit this criteria: 18 years old or older, free of injury that would interfere with the ability to bicycle, experienced cyclist (road, triathlete), are experienced in using an stationary cycling trainer, ride a minimum of 60 miles a week between overground and stationary cycling, you have a bike that we can install power-pedals on and is compatible with our stationary trainer (Wahoo Kickr).

Procedures

If you volunteer to participate in this study, you will be asked to do the following:

- Complete two cycling conditions:
    1. Cycling using a stationary trainer that your bike will be secured on

2. Cycle outdoors on a pre-marked route.

- Prior to completing any conditions, we will put sensors on your body to measure how active muscles are (i.e., Electromyography EMG). To do this, we will place several stickers on your skin above certain muscles on your quadriceps (front of thighs), hamstrings (back of thighs), and on your lower leg.
  - Each place where we put the stickers, we will need to clean the skin with alcohol rubbing pads, shave any hair, and have you perform maximum voluntary contractions (MVCs), for that muscle.
  - You will need to wear a transmitting unit during all cycling conditions (like a big cell phone).
- We will also install a set of power pedals on your bike that measures power. You can see these pedals before deciding to participate to make sure your bike is compatible with the pedals as well as the stationary trainer that we'll use (Wahoo Kickr).
- For each condition, we will ask that you complete a ride at a specific rating of perceived exertion (RPE). We will measure muscle activity and cycling power each time.
- You will be given a pair of cycling shoes to wear – you will be allowed to adjust the cleat so it is comfortable.
  - You will be required to wear socks (your own).
  - All shoes will be sprayed with disinfectant after each use.
- You will be asked to perform a total of six cycling condition:
  - Overground cycling at RPE levels of 11 (light), 13 (somewhat hard), and 15 (hard).
  - Stationary cycling at RPE levels of 11 (light), 13 (somewhat hard), and 15 (hard).
- We will give you explanations of RPE before any testing procedures begin.
- You will cycle under each condition continuously for four minutes. You will be given adequate time between each condition to rest before you signal you are ready to resume testing procedures.
- After fitting your bike with the pedals and attaching the EMG to your leg, we will perform the MVICs for each muscle we are measuring.
- Afterwards, we will travel to our marked-off testing area in the White parking lot by the Thomas and Mack center in front of the Campus Services Building.
  - Before testing, you will be given time to ride around the testing area to get comfortable.
  - You will perform all six conditions in this area.

After each of the six conditions are performed, we will return to the biomechanics lab and all of the equipment will be carefully removed from your skin and bicycle. You will be given time for a self-selected cool down (if you want one), and you will be allowed to leave at your choosing.

Benefits of Participation

There may not be direct benefits to you as a participant in this study. However, we hope to learn if there are differences in muscle activity or power output between cycling outdoors and cycling on a stationary trainer.

Risks of Participation

There are risks involved in all research studies. This study may include only minimal risks. You may become uncomfortable cycling with EMG electrodes on your leg, and you may be uncomfortable being observed while cycling. There is also the risk of cycling accident while riding outdoors. There is the risk of damage to your bike when changing out cycling gear (i.e., pedals, wheel). With a cycling study, there is a risk of muscle soreness.

To minimize this risk, the outdoor cycling condition will be on the campus of UNLV (parking lot) and the area will be marked. Before starting any condition, you will be given time to cycle after you are set up with the instruments. To minimize risk of muscle soreness, you will be given adequate time to rest between testing trials.

While you are testing, there might be other people in the laboratory or outdoors 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 for any indoor activities by allowing access to the lab by people who have a specific need (e.g., data collection for another project, instruction, etc.). We cannot restrict outdoor access, however.

Cost /Compensation

There may not be financial cost to you to participate in this study. The study will take about 2 hours of your time. You will not be compensated for your time.

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 properly disposed of. However, we will retain de-identified data (i.e., no name or other material that could link you to the data) until we have published the results of the study.

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. Participation in this study will not influence any aspect of our class (if you are a student). 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

Data Collection Sheet

Date: _____________ Subject #: _____________

Anthros:
-Height: _________ cm
-Mass: __________ kg
-Age: ___________ years
-Years of cycling: ________ years
-Miles ridden per week: __________ miles
-# of competitions/competitive rides participated in: _________
-Explanation of RPE: _Y/N_

PowerTap Pedals:
-Clips Installed on shoes: Yes / No
-Pedals Installed: Yes / No
-Pedals synced and calibrated: Yes / No
-Subject fitted with shoes: Yes / No
-Prefer of stationary/outdoor cycling: _________

EMG sensor attachment:
-Biceps Femoris (Sensor 4): ____
-Vastus Lateralis (Sensor 5): ____
-Rectus Femoris (Sensor 6): ____
-Gluteus Maximus (Sensor 7): ____
-Gastrocnemius (Sensor 8): ____

MVCs (Trial #, check mark if completed)
-Rectus Femoris: ______________
-Vastus Lateralis: ______________
-Biceps Femoris: ______________
-Gluteus Maximus: ______________
-Gastrocnemius: ______________

-Order conditions are performed in (make sure ST and OG are grouped together; go in order ascending of RPE)

Order:		Time Started On Garmin:		
____	C1 (ST RPE 11):	_______________	Stopped____	Reset Garmin ____
____	C2 (ST RPE 13):	_______________	Stopped____	Reset Garmin ____
____	C3 (ST RPE 15):	_______________	Stopped____	Reset Garmin ____
____	C4 (OG RPE 11):	_______________	Stopped____	Reset Garmin ____
____	C5 (OG RPE 13):	_______________	Stopped____	Reset Garmin ____
____	C6 (OG RPE 15):	_______________	Stopped____	Reset Garmin ____

Notes:
____
____
____
____

APPENDIX C

EMG MVIC Data Reduction and Processing – MATLAB Code

```
%-----------------------------------------------------------------
%            Set loop parameters
%-----------------------------------------------------------------

%define number of subjects, conditions, trials to process
numberofsubjects    = 1;
numberofconditions  = 4;
numberoftrials      = 1;

%indicate what subject, condition, trial to start with
startwithsubject    = 1;
startwithcondition  = 1;
startwithtrial      = 1;

%-----------------------------------------------------------------
%            Enter information regarding where
%            data files are located
%-----------------------------------------------------------------

%directory information
inputdirectory      = ['C:\Users\yager_000\Documents\Biomech_Lab_Data\input_directory\Thesis\mvcs'];
%directory where data are located
numberofcols        = 40;           %number of columns in data file
headers             = 145;          %number of headers in data file
fileextension       = ['.txt'];     %put in whatever the extension is
emgwindow           = 50;           %search window in number of points
fs                  = 1926;         %sample rate, or fs
outputdirectory     = ['C:\Users\yager_000\Documents\Biomech_Lab_Data\output_directory\Thesis\mvcs'];
%directory where output data is located
%-----------------------------------------------------------------

%create main counter
main_counter = 1;

%create loop counter within mvc loop
counter = 1;

%time for discrete events, 1 second interval
discrete_event1 = [1 : 9914];
discrete_event2 = [1915 : 11840];

%-----------------------------------------------------------------
%            MAIN LOOP STRUCTURE
%-----------------------------------------------------------------

%start of subject loop
for subjects = startwithsubject:startwithsubject+numberofsubjects-1

  %start of condition loop
```

```
for conditions = startwithcondition:startwithcondition+numberofconditions-1

  %start of trial loop
  for trials = startwithtrial:startwithtrial+numberoftrials-1

    %-----------------------------------------------------
    %         Create filename
    %-----------------------------------------------------

    %temporary variables
    ss = int2str(subjects);
    cc = int2str(conditions);
    tt = int2str(trials);

    %here is the code to create the filename
    %this is a character string
    filename = ['s' ss 'c' cc 't' tt fileextension];

    %-----------------------------------------------------
    %         Open the date file
    %-----------------------------------------------------

    data = my_fopen(inputdirectory, filename, numberofcols, inf, headers);

    %assign variables
       time = data(: , 1);
       bf = data(: , 2);     %biceps femoris muscle
       vl = data(: , 10);    %vastus lateralis muscle
       rf = data(: , 18);    %rectus femoris muscle
       gm = data(: , 26);    %gluteus maximus muscle
       ga = data(: , 34);    %gastrocnemius muscle

    % Remove DC bias
       bf = bf - mean(bf);
       vl = vl - mean(vl);
       rf = rf - mean(rf);
       gm = gm - mean(gm);
       ga = ga - mean(ga);

    % Rectify data
       bf = abs(bf);
       vl = abs(vl);
       rf = abs(rf);
       gm = abs(gm);
       ga = abs(ga);


    %create loop to move forward 1 data point
    for mvc = 1:9914

    % identify discrete events
       event_1(counter) = round(discrete_event1(mvc));
       event_2(counter) = round(discrete_event2(mvc));
```

```
        % Average emg phase 1
            average_bf(counter) = mean(bf(event_1(counter) : event_2(counter)));
            average_vl(counter) = mean(vl(event_1(counter) : event_2(counter)));
            average_rf(counter) = mean(rf(event_1(counter) : event_2(counter)));
            average_gm(counter) = mean(gm(event_1(counter) : event_2(counter)));
            average_ga(counter) = mean(ga(event_1(counter) : event_2(counter)));

            %closing open figures
            %close(gcf)

            %update counter
            counter = counter + 1;

        end %end mvc loop

      end %end trials loop
      %make sure only the muscle tested for each trial receives a
      %value other than zero using if statement
        if conditions == 1
          bf_mvc = max(average_bf);
        else
          bf_mvc = 0;
        end
        if conditions == 2 %for both quad muscles
          vl_mvc = max(average_vl);
          rf_mvc = max(average_rf);
        else
          vl_mvc = 0;
          rf_mvc = 0;
        end
        if conditions == 3
          gm_mvc = max(average_gm);
        else
          gm_mvc = 0;
        end
        if conditions == 4
          ga_mvc = max(average_ga);
        else
          ga_mvc = 0;
        end

        %compile mvc emg data
        outputdata(main_counter , :) = [subjects conditions trials bf_mvc vl_mvc rf_mvc gm_mvc ga_mvc];

        %updata main loop counter
        main_counter = main_counter+1;

    end %end conditions loop

end %end subjects loop

%create output file name, corresponds to the subject being processed
outputfile = ['s' ss fileextension];
```

```
%save and export data; make sure prescision is set to 10, that way enough
%decimal points are exported to get the appropriate data to use in the
%other .m file
my_save(outputdirectory , outputfile , outputdata , 10);
```

APPENDIX D

EMG Data Reduction and Processing – Cycling Conditions MATLAB Code

```
%clear workspace and screen
clear
clc

%close any open figures
close(gcf)

%begin main loop, set parameters

%defining number of subjects, conditions, and trials to process
numberofsubjects    = 1;
numberofconditions  = 6;
numberoftrials      = 1;

%define what subject, condition, trial to start with
startwithsubject    = 11;
startwithcondition  = 1;
startwithtrial      = 1;

%============================================
%Define directory information
%============================================

inputdirectory      = ['C:\Users\yager_000\Documents\Biomech_Lab_Data\input_directory\Thesis'];      %for main
EMG conditions
inputdirectory2     = ['C:\Users\yager_000\Documents\Biomech_Lab_Data\output_directory\Thesis\mvcs']; %input
directory for MVC files
numbofcols          = 40;       %number of columns in the data file
headers             = 145;      %number of headers in the data file
fileextension       = ['.txt']; %the extension for the data file
accwindow           = 50;       %search window for this number of data points
fs_emg              = 1926;     %sampling rate for emg
fs_acc              = 148;      %sampling rate for accelerometer
outputdirectory     = ['C:\Users\yager_000\Documents\Biomech_Lab_Data\output_directory\Thesis']; %output
directory for main EMG conditions

%--------------------------------------------

%create counter for loop structure
counter = 1;

%--------------------------------------------
%Create structure for MVC file
%--------------------------------------------

%create filename
%assign temporary variable
sub = int2str(startwithsubject);
```

```
filename2 = ['s' sub fileextension];

data1 = my_fopen(inputdirectory2, filename2, 8, inf, 0);

%assign variables for MVCs in this .m file
bf_mvc = data1(: , 4); %biceps femoris MVC
vl_mvc = data1(: , 5); %vastus lateralis MVC
rf_mvc = data1(: , 6); %rectus femoris MVC
gm_mvc = data1(: , 7); %glute maximus MVC
ga_mvc = data1(: , 8); %gastroc MVC

%find max MVC values and assign variables to them them
bf_mvc_max = max(bf_mvc);
vl_mvc_max = max(vl_mvc);
rf_mvc_max = max(rf_mvc);
gm_mvc_max = max(gm_mvc);
ga_mvc_max = max(ga_mvc);

%----------------------------------------------
%Create Main Loop Structure for data collection
%----------------------------------------------

%start subject loop
for subjects = startwithsubject:startwithsubject+numberofsubjects-1

    %start condition loop
    for conditions = startwithcondition:startwithcondition+numberofconditions-1

        %start trial loop
        for trials = startwithtrial:startwithtrial+numberoftrials-1

            %--------------------------
            %create filename
            %--------------------------

            %assign temporary variables
            ss = int2str(subjects);
            cc = int2str(conditions);
            tt = int2str(trials);

            %create character string for filename
            filename = ['s' ss 'c' cc 't' tt fileextension];

            %------------------------------------
            %        open data file
            %------------------------------------

            data = my_fopen(inputdirectory, filename, numbofcols, inf, headers);

            %use dlmread function to make sure all data is read in
            data = dlmread(filename, '\t', headers, 0);

            %assign variables; only need 2 antagonist muscles
```

```
time_emg = data(: , 1);  %time variable for emg
bf = data(: , 2);        %biceps femoris muscle
vl = data(: , 10);       %vastus lateralis muscle
rf = data(: , 18);       %rectus femoris muscle
gm = data(: , 26);       %gluteus maximus muscle
ga = data(: , 34);       %gastrocnemius muscle
time_acc = data(: , 37); %time variable for accelerometer data
acc_z = data(: , 38);    %accelerometer data from ga emg unit
                         %use acc data to identify discrete
                         %events; use y plane for analysis



%remove DC bias
bf = bf - mean(bf);
vl = vl - mean(vl);
rf = rf - mean(rf);
gm = gm - mean(gm);
ga = ga - mean(ga);

%rectify EMG data
bf = abs(bf);
vl = abs(vl);
rf = abs(rf);
gm = abs(gm);
ga = abs(ga);

%use max MVC values to turn values into percentages
bf_perc = ((bf/bf_mvc_max)*100);
vl_perc = ((vl/vl_mvc_max)*100);
rf_perc = ((rf/rf_mvc_max)*100);
gm_perc = ((gm/gm_mvc_max)*100);
ga_perc = ((ga/ga_mvc_max)*100);

%plot data to use findpeak function on
plot(time_acc, acc_z);
xlabel('time (s)')
ylabel('accelerations')

%use ginput function to identify the first peak after the
%pause; use this peak as a starting point, the move forward 10
%seconds. Then take a 40 second average of each muscle
fprintf('\nclick on first accel peak after the pause in the data\n')
fprintf('\npress enter after selecting the peak\n')
[peakpos, ypos] = ginput(1);

pause
%clear command window after selecting the peak
clc
%create position variable to use with EMG data
tnew = round(peakpos/fs_acc);
tstart = tnew*fs_emg;

%use this new EMG position variable to find the two time points
%that will be used to define the 20 second EMG window being
```

```
%analyzed

%identify new start position (10 seconds after 'tstart'
%variable
newstart = tstart+(10*fs_emg);
%identify end position (20 seconds after new start position)
newend = newstart+(20*fs_emg);

%create new EMG variables defining the section of the signal
%being analyzed
bf_new = bf_perc(newstart:newend, 1);
vl_new = vl_perc(newstart:newend, 1);
rf_new = rf_perc(newstart:newend, 1);
gm_new = gm_perc(newstart:newend, 1);
ga_new = ga_perc(newstart:newend, 1);

%plot data with these new events
subplot(5 , 1 , 1)
plot(time_emg, bf_perc)
hold on
plot(time_emg(newstart : newend), bf_new, 'r')
ylabel('%MVIC')
title('Biceps Femoris')
hold off

subplot(5 , 1 , 2)
plot(time_emg, vl_perc)
hold on
plot(time_emg(newstart : newend), vl_new, 'r')
ylabel('%MVIC')
title('Vastus Lateralis')
hold off

subplot(5 , 1 , 3)
plot(time_emg, rf_perc)
hold on
plot(time_emg(newstart : newend), rf_new, 'r')
ylabel('%MVIC')
title('Rectus Femoris')
hold off

subplot(5 , 1 , 4)
plot(time_emg, gm_perc)
hold on
plot(time_emg(newstart : newend), gm_new, 'r')
ylabel('%MVIC')
title('Gluteus Maximus')
xlabel('Time (s)')
hold off

subplot(5 , 1 , 5)
plot(time_emg, ga_perc)
hold on
plot(time_emg(newstart : newend), ga_new, 'r')
```

```
        ylabel('%MVIC')
        title('Medial Gastroc')
        hold off

        fprintf('\n press enter after looking at the graph\n')
        pause

        close(gcf)

        %calculate average muscle activity for each muscle for 15
        %second analysis

        bf_aver = mean(bf_new);
        rf_aver = mean(rf_new);
        vl_aver = mean(vl_new);
        gm_aver = mean(gm_new);
        ga_aver = mean(ga_new);

        %compile data into 1 file
        %outputdata(counter , :) = [subjects conditions trials bf_RMS rf_RMS vl_RMS gm_RMS ga_RMS];
        outputdata(counter , 1) = [subjects];
        outputdata(counter , 2) = [conditions];
        outputdata(counter , 3) = [bf_aver];
        outputdata(counter , 4) = [rf_aver];
        outputdata(counter , 5) = [vl_aver];
        outputdata(counter , 6) = [gm_aver];
        outputdata(counter , 7) = [ga_aver];
        %close any open figures
        close(gcf)

        %update counter
        counter = counter + 1;

      end
    end
end

%create output file name
outputfile = ['s' ss 'thesis_emg_output_new.txt'];

%save and export data (use precision number as # of data points to export)
my_save(outputdirectory , outputfile , outputdata , 4);
```

APPENDIX E

Power Output Data Reduction and Processing

ns1:Time	ns1:Cadence3	ns2:Watts	ns2:Ma
2016-06-05T20:31:07.000Z	61	155	
2016-06-05T20:31:08.000Z	61	155	
2016-06-05T20:31:09.000Z	63	196	
2016-06-05T20:31:10.000Z	63	196	
2016-06-05T20:31:11.000Z	63	150	
2016-06-05T20:31:12.000Z	65	115	
2016-06-05T20:31:13.000Z	66	105	
2016-06-05T20:31:14.000Z	66	105	
2016-06-05T20:31:15.000Z	66	105	
2016-06-05T20:31:16.000Z	67	81	
2016-06-05T20:31:17.000Z	67	73	
2016-06-05T20:31:18.000Z	66	94	
2016-06-05T20:31:19.000Z	66	94	
2016-06-05T20:31:20.000Z	66	134	
2016-06-05T20:31:21.000Z	66	157	
2016-06-05T20:31:22.000Z	67	157	
2016-06-05T20:31:23.000Z	0	0	
2016-06-05T20:31:24.000Z	0	0	
2016-06-05T20:31:25.000Z	0	0	
2016-06-05T20:31:26.000Z	16	158	
2016-06-05T20:31:27.000Z	67	209	
2016-06-05T20:31:28.000Z	67	294	
2016-06-05T20:31:29.000Z	65	294	
2016-06-05T20:31:30.000Z	65	294	
2016-06-05T20:31:31.000Z	67	157	
2016-06-05T20:31:32.000Z	68	153	
2016-06-05T20:31:33.000Z	67	143	
2016-06-05T20:31:34.000Z	66	137	
2016-06-05T20:31:35.000Z	66	146	
2016-06-05T20:31:36.000Z	66	147	
2016-06-05T20:31:37.000Z	64	169	
2016-06-05T20:31:38.000Z	64	169	
2016-06-05T20:31:39.000Z	62	225	
2016-06-05T20:31:40.000Z	63	225	
2016-06-05T20:31:41.000Z	63	179	
2016-06-05T20:31:42.000Z	63	155	
2016-06-05T20:31:43.000Z	63	116	
2016-06-05T20:31:44.000Z	63	116	
2016-06-05T20:31:45.000Z	63	179	
2016-06-05T20:31:46.000Z	64	172	
2016-06-05T20:31:47.000Z	64	141	

The two second pause was visually identified from the columns of power data, then a twenty second average was calculated following the pause. The cells highlighted in yellow signal the two second pause from the data collection.

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CURRICULUM VITAE

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Education:

M.S.	University of Nevada Las Vegas, Las Vegas, NV Kinesiology (Biomechanics concentration)	2016 (proposed)
B.S.	University of Nevada Las Vegas, Las Vegas, NV Comprehensive Kinesiology	2014

Certifications:

C.S.C.S.	National Strength and Conditioning Association Certified Strength and Conditioning Certification	2016

Academic Experience:

Graduate Research Assistant — 2015-2016

-Equipment Testing
-Data Collection and Analysis
-Undergraduate Mentorship

Grants:

Joerger, J. (2015). Upper extremity muscle activity during the lacrosse shot: exploring the influence of shaft stiffness. UNLV Graduate and Professional Student Association Travel Award. $375.

Conference Presentations:

Joerger, J., Coupe, A., & Mercer, J.A. FACSM (2015). Upper extremity muscle activity during the lacrosse shot: Exploring the influence of shaft stiffness. Medicine and Science in Sports and Exercise, 47(5), s201.

Joerger, J., & Mercer, J.A. FACSM (2015). Muscle activity of an athlete during wheelchair propulsion and hand cycling: A case study. Southwest Regional American College of Sports Medicine Annual Meeting, Orange County, CA, October.

Galor, K., Bailey, J., **Joerger, J.**, & Mercer, J.A. FACSM (2015). Is variability of stride frequency a factor that determines preferred stride frequency during running? Southwest Regional American College of Sports Medicine Annual Meeting, Orange County, CA, October.

Joerger, J., & Mercer, J.A. FACSM (2016). Muscle activity of an athlete during wheelchair propulsion and hand cycling: a case study. 9th Annual Interdisciplinary Research Scholarship Day, University of Nevada Las Vegas, April.