KINEMATICS AND MUSCLE ACTIVATION PATTERNS DURING SIMULATED UPHILL PEDALING ON AN INDOOR CYCLE ERGOMETER

By

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ABSTRACT

Kinematic and Muscle Activation Patterns During Simulated Uphill Pedaling on an Indoor Cycle Ergometer

Benjamin Thomas Stein

INTRODUCTION: An indoor cycle ergometer allows for competitive and recreational mountain bike cyclists to simulate uphill conditions with precisely controlled and monitored pedaling. While simulating an uphill condition indoors, with or without a climbing block, the cyclist body may not be in the same position as while pedaling outdoors. This possible difference in body position may have training implications. **PURPOSE**: The purpose of this study was to determine if there are differences in kinematics and/or muscle activation patterns while pedaling on a level surface compared to an inclined surface while pedaling on a mountain bike on an indoor cycle ergometer. **METHODS:** A total of 12 healthy (8 male and 4 female) participants (age 36 ± 2 yrs; height 1.72 ± 0.06 m; mass 71 ± 10 kg [mean ± SD]) volunteered to take part in this study. Two conditions were assessed. In the first, the participants pedaled 10 MPH during a flat simulated 10% incline and in the second participants pedaled an actual 10% incline at an average of 360WATTS. Kinematic and electromyography (EMG) data were collected from two trials in each condition, with the mean of ten pedal revolutions analyzed. The following sagittal plane angles were calculated: absolute trunk, relative trunk, pelvis, hip, knee, and ankle. The EMG variables calculated included the duration of EMG activity and the magnitude and timing of the peak activation. The kinematic data were collected using reflective markers placed on the lower limbs and captured with an eight camera MX 20 Vicon motion analysis system. In addition, a total of 5 wireless, BTSFree EMG sensors for surface EMG applications were placed on the right lower limb in order to collect the EMG data. EMG data were collected from the gluteus maximus (GLMA), vastus lateralis (VAL), biceps femoris (long head) (BCFL), gastrocnemius (GAS), and tibialis anterior (TA). **STATISTICAL ANALYSIS:** In order to test for significant differences across the two cycling conditions, two Repeated Measures MANOVAs were used, one for the kinematic variables and one for the EMG variables. Significance was set at $p \leq 0.05$. **RESULTS & CONCLUSION:** Overall, the results of the current study indicate that there is no significant difference regarding kinematics and muscle activity patterns between the two indoor cycle ergometer conditions. Compared with previous research, data suggests there is no training implications between simulated uphill level pedaling and actual inclined pedaling while using an indoor cycle ergometer. Data from the current study also suggests that the use of a climbing block to raise the front wheel 10 degrees does not significantly alter cycling posture.

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CHAPTER I: INTRODUCTION OF STUDY

Introduction

An indoor cycle ergometer allows for competitive and recreational cyclists to train with precisely controlled and monitored pedaling. With the wide availability of increasingly economical and sophisticated devices, indoor cycle ergometers are becoming a more popular training method for cyclists at all levels. Both road cyclists and mountain bike cyclists can use the indoor cycle ergometer as a training method when environmental conditions are not optimal for outdoor training or when a controlled training environment is warranted. The indoor cycle ergometer allows cyclists to ride and compete with friends and is becoming popular in cycling endurance training centers. In some instances, the cycle ergometer can enable cyclists to record their speed, power output, and pedaling efficiency while relaying the information to a computer. In addition, the cycle ergometer's software can simulate a virtual course through which a cyclist can pedal or simulate a cycling event. Cyclists can also choose to use a climbing block to raise the front wheel up to match certain inclines. As an example, if a cyclist pedals uphill in the virtual world, the cycle ergometer applies a load to the roller and the effect of pedaling uphill is simulated. However, while pedaling indoors, a cyclist's body position while pedaling indoors is not the same as the cyclist's position while pedaling outdoors. This difference can be attributed to outdoor conditions involving roots, rocks, and more importantly steep gradients. This difference in body position may have training implications.

The position of a cyclist on a bicycle can determine how well the body performs during a cycling task (Ashe et al., 2003; Dorel, Couturier, & Hug, 2009). There is considerable evidence that road bike cycling kinetics and kinematics change during simulated uphill pedaling. The vast majority of research on the mechanics of uphill pedaling focuses on road cyclists' body posture, kinematic, and muscle activity effects of seated simulated uphill versus standing simulated uphill cycling (Caldwell, Hagberg, McCole, & Li, 1999; Duc, Bertucei, Pernin, & Grappe, 2008; Li & Caldwell, 1998; Neptune & Hull, 1996). It is unclear if the results from road cycling research translate to mountain biking because there are several key differences between road cycling and mountain biking.

The mountain bike cyclist typically encounters terrain that includes a significant amount of steep gradients with various conditions and yet little research exists on how inclination can affect mechanical demands of the mountain bike cyclist. For example, mountain bike cyclists are sometimes faced with steep inclines and are unable to stand to assist while ascending due to loose dirt or lack of traction on the rear tire. Standing while ascending on a mountain bike, in contrast to road cycling, may cause a mountain bike cyclist to slip or lose grip resulting in inefficient pedaling and loss of power. Mountain bike cyclists are unable to change hand grip placement like a road cyclist can. Thus, it is likely that the mountain bike cyclist must be able to adjust power output, body posture, and muscle activation patterns to ensure mechanical efficiency and the ability to effectively apply force to the pedals while ascending steep gradients (Gregor & Rugg, 1986). Therefore, it is important for the mountain bike cyclist to utilize training practices that are specific to the demands of ascending steep grades. Despite the differences in mountain bikers' and road cyclists' body positions, both will often utilize the indoor cycle ergometer for training practices by increasing the resistance or using a climbing block to raise the front wheel in order to simulate steep gradients. Yet, there is minimal research that supports or disputes simulation of uphill cycling with the use of an indoor cycle ergometer as a training practice for mountain bikers (Faria, 2009; Faria, Parker, & Faria, 2005a).

A cyclist's posture while on a bike when ascending will determine how well the body generates force during an uphill cycling task (Millet, Tronche, Fuster, & Candau, 2002). Changes in the cyclist's body posture due to increased grade or gravitational demands secondary to ascending may have an influence on the cyclist's performance. When confronted with inclination, the cyclist should be in the most effective seat position to maximize muscle power generation. The power applied at the pedals will vary as the muscles' length in the lower limb changes. The muscle length tension relationship states that a muscle can produce its largest force near its resting length. And at resting length, an optimal overlap occurs between the muscle contractile elements (actin and myosin filaments), resulting in a greater number of cross bridges that can be formed for muscle contraction (Too & Landwer, 2003). The length/tension relationship of the muscles will depend on the efficiency of cross bridge formation at a given joint angle. For example, if the hip flexion angle changes while ascending due to a change in trunk angle, then the force produced by hip flexors and extensors may also change (Too & Landwer, 2003). To be more specific, changes in the hip angle will change the length of the rectus femoris and gluteus maximus altering their maximum force generation capabilities at the knee while decreasing the ability to transfer power through the pedal cranks of the bicycle

(Too & Landwer, 2003; Yoshihuku & Herzog, 1996). All of the aforementioned factors are important in the context of training specificity for uphill training practices.

A change in body posture while cycling uphill may also influence muscle activation patterns. For example, Brown and colleagues found that a change in trunk angle during a simulated uphill cycling task alters muscle activity patterns during the pedal rotation for road cyclists (Brown, Kautz, & Dairaghi, 1996). There is also a 50% increase in gluteus maximus muscle activity in road cyclists when standing compared to seated uphill pedaling (Li & Caldwell, 1998). When the trunk angle is altered due to inclination, changes will occur in the power output during the propulsive phase of the pedal rotation (Dorel et al., 2009). These changes in muscle activity can be contributed to the change in trunk angle which affects the muscle length tension relationship (Savelberg, Van de Port, & Willems, 2003). Thus, when the cyclist leans forward over the front end of the bike in a more aero-dynamic position, there will be changes on both the mechanical aspects of pedal force production and lower limb muscle activity (Dorel et al., 2009).

While there is evidence that cycling mechanics are influenced by inclination, it is a common training practice for mountain bikers to use a cycle ergometer for indoor and off-season training purposes. The use of the cycle ergometer can have the benefits of increased safety, efficiency, convenience, and the ability to monitor and record workout data. An example of a cycle ergometer is the Computrainer™. The Computrainer™ allows the cyclists to simulate ascents up to 15% gradient using electromagnetic resistance to mimic cycling up an incline. However, it is unclear what changes may occur when pedaling flat with resistance compared to pedaling at an actual incline (e.g., using a climbing block under the front wheel) with matching simulated resistance. It is important for training specificity purposes to determine whether similar kinematics are seen in resistance simulated uphill pedaling while flat in contrast to resistance simulated uphill pedaling at an actual incline. Currently there is no evidence that supports or disputes the use of a computerized cycle ergometer as a training tool to simulate uphill gradients. Therefore, with this study, investigation of the changes in kinematics and muscle activity patterns involving a simulated uphill gradient can contribute to current mountain biking training knowledge and understanding.

Purpose of the Study

The purpose of this study is to determine if there are differences in kinematics and/or muscle activation patterns while pedaling on a level surface compared to an inclined surface on a mountain bike. To address this question, data will be collected while riders cycle on a Computrainer™ cycle ergometer simulating a 10% gradient.

Expected Results

1. There will be a change in trunk angle in the anterior, horizontal, and downward direction from flat to inclined when the body shifts forward due to gravitational demands in order to compensate for the actual change of incline (Duc et al., 2008).
2. There will be a difference in hip angle due to the difference in trunk angle compensating in the anterior, horizontal direction from flat to incline when the body shifts due to gravitational demands in order to compensate for the actual change of incline. This change in hip angle will be seen during flexion of the hip phase and in the pedal revolution seen from 0-90 degrees.
3. There will be a difference in ankle angle in the form of a change in ankle dorsi flexion from flat to incline seen in the pedal revolution from 90-180 degrees.

4. Overall, mean joint angles involving the trunk, hip, and ankle will be altered when in the inclined pedaling condition in contrast to the flat pedaling position.
5. There will be a difference in EMG activity, including EMG $_{\text{duration,}}$ EMG $_{\text{peak-timing}}$, and EMG $_{\text{peak,}}$ in the gluteus maximus and lower limb muscles vastus lateralis and biceps femoris when compared to flat and inclined.
6. There will be an increase in EMG activity, including EMG $_{\text{duration,}}$ EMG $_{\text{peak-timing}}$, and EMG $_{\text{peak}}$ in the shank muscles including the gastrocnemius and anterior tibialis when compared to flat to incline to compensate for a change in trunk angle (Duc et al., 2008; Li & Caldwell, 1998).

Significance of the Study

Cyclists typically use the cycle ergometer, or bicycle trainer, set at a simulated uphill resistance while pedaling on a level surface or with a climbing block see Figure 1 front wheel**.** Moving the cyclist's front wheel up to an actual gradient matching the simulated uphill resistance of the incline might cause changes in joint angles, which may alter body posture and/or muscle activation.

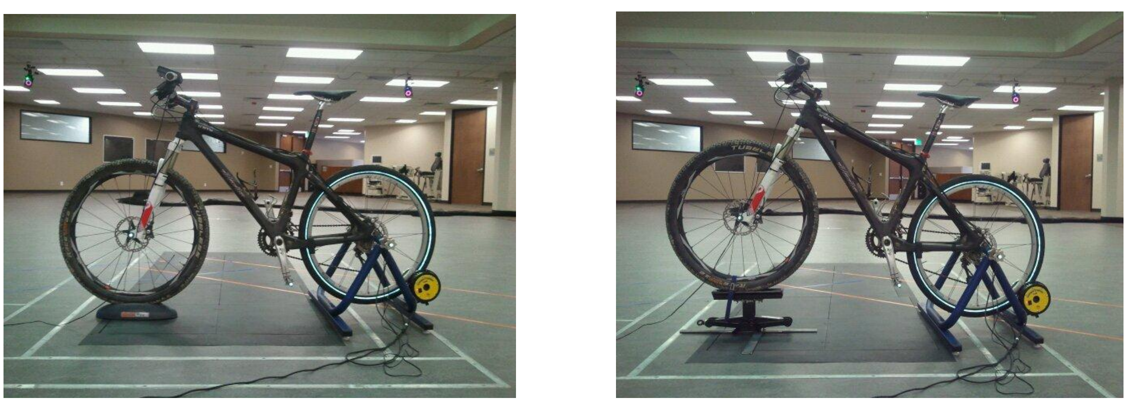

Figure 1 Bicycle attached to Computrainer™ (rear tire)

Hence, it is important to determine if there are differences in body posture or muscle activity in order to expand the knowledge of variables that affect the uphill mountain bike cycling training methods. Currently, there is no evidence that supports or refutes that kinematic or muscular activity changes might occur if the mountain bike cyclists' position is altered due to inclination. Furthermore, bicycle trainers are widely used by professionals to amateur cyclists, yet little research has been done on bicycle trainers as a training practice. It is important to understand any changes that may occur while pedaling with a simulated uphill resistance in order to educate users of the cycle ergometer.

Limitations/Delimitations

Field tests investigating kinematic changes involving mountain bikers are difficult to accomplish because of the high cost of equipment, or difficulty setting up motion capturing equipment in outdoor environments. Therefore, laboratory research has been the method of choice. A plausible limitation that may occur is that the Computrainer™ eliminates the lateral sway that is common in mountain biking outdoors, especially while climbing. Lateral sway is the change in center of mass from side to side in contrast to posterior and anterior. Duc et al, (2008) tested riders at a 4% slope to test the hand grip position and the influence of lateral sway. The study found that with lateral sways EMG activity is more affected by the change of pedaling posture. In this present study, lateral sway will not be a factor due to the control of the study involving the stationary position the cyclists will be placed in. Furthermore, when using the Computrainer™, the principle investigator will set the simulated gradient to 10%, even though in most mountain biking events, it is not uncommon to see a slope of 10% or more. Participants will additionally not be able to simulate their race pace in the laboratory environment, due to the lack of environmental factors that contribute to mountain bike racing events. These can include the psychology factor of racing, heat/humidity, rocks, and roots.

Other plausible limitations of this study are that the above conditions ensured that: (1) air resistance due to forward movement of the cyclist was eliminated, (2) frictional resistance due to wheel rotation was constant and determined by the Computrainer™, which is unlikely during outdoor cycling caused by the variation in mountain bike terrain and tire tread, (3) pedal cadence was constant, which is nearly impossible in mountain bike cycling due to continuous changes in steep terrain, and (4) the mechanical power output requirement for each subject was constant, which is also difficult to achieve during mountain bike cycling due to variations in incline.

One assumption of the Computrainer™ is the application of “press-on force” that the Computrainer™ mimics. Press-on force is the amount of contact pressure between the tire and the friction roller of the load generator of the cycle ergometer. “The Computrainer™ system uses the bike rear wheel to drive a copper flywheel, spinning in the field of an electromagnet” (Computrainer™ manual). In this study, press-on force was set at 4.0 lbs on the Computrainer™ fly wheel to mimic a 10% slope. The press-on force is meant to replicate rolling resistance, which is proportional to the weight of the bicycle and rider due to gravity, and to the normal force of the road on the bicycle. There is no way to determine if the Computrainer™ is determining the optimal press-on force without knowing the equation that RacerMate uses to determine press-on force. However, with the use of a simplified equation (Equation 2) found in the methods portion of this study, the power output will be determined for each participant. Each participant will be weighed with bicycle and the appropriate wattage to climb a 10% slope will be determined from the equation.

CHAPTER II: LITERATURE REVIEW

Introduction

Mountain biking is a sport gaining popularity among recreational athletes with nearly 25.5 million participants annually (*Outdoor Recreation Participation Topline Report 2012*, 2012) . Many mountain bikers use indoor training practices, which can have the benefits of increased safety, efficiency, convenience, measurable performance gains, and the ability to monitor and record workout data. Cyclists' can use the indoor ergometer as a training method in order to simulate uphill climbing resistance or effort. The training practices of a mountain bike cyclist are not exactly similar to the road cyclist due to on-the-bike pedaling demands, such as reduced traction while on dirt. Furthermore, the use of the indoor cycle ergometer for mountain bikers is not well researched, leaving a void of information on the practicality of its use. The purpose of this study is to quantify the changes for mountain bike cyclists' kinematics and muscle activation while pedaling a mountain bike while simulating an uphill gradient.

Cross-country cycling is the most popular of the three mountain bike disciplines, including downhill and dual slalom (Burke, 2003). The cyclist's primary purpose when pedaling in a cycling event is to use mechanical power output to perform the task to win the race (Faria, Parker, & Faria, 2005b). Previous studies investigating mountain bikers have been done on exercise intensity responses during a mountain bike event (Cross-Country or XC) in order to assess the time spent at certain heart rate (HR) intensity

(Impellizzeri & Marcora, 2007). It has been found that mountain bikers, both male and female, have an average race time of more than 2 hours with their average HR maintained at 90% of the riders' HR maximum. It was also found that more than 80% of the race is spent above lactate threshold, a physiological measure of intensity (Impellizzeri & Marcora, 2007). Physiological demands of mountain biking include four determinants: cardiovascular power, energetic power, resistance to fatigue, and muscle power (Burke, 2003). With the vast amount of research done on metabolic and physiological responses to the intensity of mountain bike cycling, there is a need to better understand the variables that influence an important aspect of mountain bike performance: inclination. In order for the mountain bike cyclist to perform at such high physiological demands and resist muscle fatigue while confronting inclination, training practices become an important requirement for mountain biking performance enhancement in order to prepare for intensities expected during competition.

The mountain bike cyclist's training methods are important for performance enhancement in order to attempt to gain a competitive advantage while ascending steep inclines. Training methods appear to be the strongest indicator toward achievement of the best possible competitive cycling performance (Faria, 2009). To be successful, a mountain bike cyclist requires optimal conditioning, an increased level of technical skill not required of road cyclists, and the ability to incorporate these requirements during training and competition (Burke, 2003). To date, cyclists' training practices have primarily focused on intensity of training, pedaling technique, pedaling efficiency, and the metabolic effects of pedaling (Faria, 2009). Although pedaling dynamics are very important to cycling-specific training, there are other variables that go into performance enhancement, including uphill-specific training methods. The cyclists' uphill training method involving the bicycle trainer can provide an opportunity to examine how the muscular system adapts to changes in the environment due to gravitational forces that change while ascending (Li & Caldwell, 1998). Furthermore, examining the mountain bike cyclists' training methods can also contribute to the cyclists' mechanical efficiency- the ability of the cyclist to effectively apply forces to the pedals while outdoors (Gregor & Rugg, 1986).

Mountain Biking

To better understand mountain bike cycling mechanics, it is important to understand that the intensity and terrain of mountain biking events differ from road cycling intensity and terrain. Mountain bike terrain can include forest roads, single tracks, gravel paths, and should include a significant amount of climbing and descending. Typically, a mountain bike competition course will be between 30km and 35km in distance, with an average total altitude climb of about 1500m (Impellizzeri & Marcora, 2007). Due to changes in terrain, mountain bike cyclists' may often have different body postures or cycling mechanics than road cyclists' while riding and ascending steep grades, and thus previous research done on road cyclists' may not be as applicable to mountain bike cycling. With the lack of research on mountain biking, there is a need to better understand the cycling mechanics of mountain bike cyclists, especially while ascending. Furthermore, there is a need to better understand training methods that mountain bike cyclists' utilize and the alterations in mechanics that may occur.

A mountain bike cyclist's mechanical efficiency can be attributed to pedaling technique, body posture, and muscle force/tension-length relationships (Millet Tronche, fuster, & Candau, 2002). In order to attain mechanical efficiency, the lower limbs of the cyclist must be positioned on the bicycle for optimal pedaling efficiency (Too & Landwer, 2003). During a mountain biking cycling task, body posture must change to account for increased grade or gravitational demands secondary to ascending. This change in body posture can be seen when a cyclist leans their body forward, horizontally, to account for change in inclination. This change in body posture causes a change in the muscle force/tension-length relationship during an uphill cycling task, altering muscle lengths and muscle power production contributing to cycling mechanics (Too & Landwer, 2003).

Cycling Mechanics

Too and Landwer (2003) examined, from a biomechanical perspective, how muscle force is produced and modified, and how the muscle force produced interacts with external mechanical factors contributing to power production for “human powered vehicles” or recumbent bicycles. Too and Landwer concluded that a change in body orientation or trunk angle will have an effect on muscle force/tension-length relationships and force production at the pedals if the hip angle does not change (Too & Landwer, 2003). Changes in the cyclist’s posture without changes in the hip angle may contribute to a decrease or increase in body weight force on the pedals. It was also found that changing the body posture with respect to the horizontal does affect peak power production and power output while pedaling (Too & Landwer, 2003). However, their research involved recumbent cycling and, as such, it is still unknown whether kinematic changes translate to mountain bike cyclists while pedaling.

In order to better understand cycling mechanics, Yoshihuku and Herzog (1996) examined, by way of a modeling approach, the optimal design parameters for a "bicycle-rider system" involving four design parameters: crank length, pelvic inclination, seat height, and rate of crank rotation (Yoshihuku & Herzog, 1996). In their study, the authors sought to maximize the power output from muscles of the lower limbs during cycling. Yoshihuku and Herzog suggest that the maximum instantaneous power output of the muscles examined is determined by its contracting velocity at each position of the crank rotation or pedaling revolution (Yoshihuku & Herzog, 1996). Yoshihuku and Herzog (1996) found that there is an optimal position for lower limb muscles that can be affected by each of the four design parameters examined. As an example, crank length was found to have an optimal length of 0.17m with a knee angle of 30 degrees (Yoshihuku & Herzog, 1996). Furthermore, the optimal rate of crank rotation was also found to be directly influenced by muscle length during the pedal rotation (Yoshihuku & Herzog, 1996). To date, the influence of a change in posture on mountain bike cyclists' have yet to be examined, as does the effect of a change in posture on muscle activity for mountain bike cyclists.

Muscle Activity

Different body postures have contributed to altered muscle activity patterns during pedaling for road cyclists (Brown et al., 1996). A study by Brown et al, (1996) examined the contributing force of gravity on the control of lower limb movements. They believed that the contributing force of gravity strongly influenced the control of lower limb movements by affecting sensory input and task mechanics, and they hypothesized that altering the contribution of gravitational force to the total forces used in control of pedaling at different body orientation, would cause a modification in joint torque and muscle activation patterns. These modifications were found to generate steady–state pedaling, at altered body orientations. In the study, eleven subjects pedaled a modified ergometer at nine different body orientations, with a cadence of 60 rpm against an applied load of 15 N at each orientation. Brown and colleagues (1996) found that with different body orientations, there was a systematic alteration of all net joint torques, including the hip, knee, and ankle, which was also found to reflect systematic changes in muscle activity.

Inclination or pedaling uphill can contribute to muscle activity changes (Duc et al., 2008; Li & Caldwell, 1998). Li and Caldwell (1998) examined the neuromuscular modifications of road cyclists during changes in incline, and the effects of these modifications on body posture. In the study, eight subjects were tested on a computerized ergometer under three conditions with similar workloads of 250 watts. The subjects pedaled on a level surface while seated, 8% uphill while seated, and 8% uphill while standing, and were able to use a cadence of their choice with their chosen gear ratio. Li and Caldwell found that the change in cycling gradient from 0 to 8% did not produce a significant change in lower limb muscle activity, but that from seated to standing at an 8% uphill gradient caused an increase in muscle activity in some hip and knee extensor muscles. Additionally, EMG patterns of monoarticular extensor muscles were more affected by the change from seated to standing pedaling than the biarticular flexor muscles. The results can be contributed to the change in pedaling kinetics and kinematics due to the removal of saddle support and forward horizontal shift in center of mass (Duc et al., 2008).

In a similar study examining muscular activity, Duc et al, (2008) investigated the effects of slope, posture, hand grip placement, and the effect of lateral sway (Duc et al., 2008). Duc and colleagues examined ten trained, healthy, male competitive road cyclists, whom performed two test sessions in a laboratory setting. The first session examined maximal aerobic power, while the second session consisted of four pedaling sessions of eight randomized conditions with different uphill cycling gradients on an indoor ergometer. During the study's first session, each subject used their own racing road bike while pedaling on a large motorized treadmill of 3.8 m length and 1.8 m width (Duc et al., 2008). The second testing condition involved uphill conditions on a computerized ergometer, including 4% seated, 7% seated, 10% seated, 4% standing, 7% standing, and 10% standing, plus two more conditions at 4% to examine lateral sway. Duc and colleges found that, unlike the slope, the effect of changing pedaling posture from seated to standing resulted in a change of both the intensity and the timing of the EMG activity of all the muscles, except those crossing the ankle's joint (Duc et al., 2008).

The research investigating uphill cycling conditions examined body posture and slope affecting muscle force/tension-length relationship and muscle activation while pedaling. To date, there are no investigations into whether simulation of an uphill cycling condition is beneficial to the cyclist. With a majority of terrain for a mountain bike event being in an ever-changing environment of inclination, there is a need to better understand some aspects of training modalities for mountain bike cyclists, including uphill pedaling.

Training Modalities

When the weather is cold and there is too much snow outdoors, some cyclists will choose to ride indoors on what is known as a bicycle trainer for convenience. So far, research has examined the effects of road cyclists' posture while simulating an uphill cycling condition (Duc et al., 2008; Li & Caldwell, 1998; Savelberg, Van de Port, & Willems, 2003). There remains a need to better understand the training modalities that are used by road and mountain bike cyclists, including the use of an indoor cycle ergometer to simulate uphill cycling conditions. When using an indoor ergometer, a cyclist can set the resistance to simulate uphill pedaling by way of applying resistance to the ergometer flywheel. Cyclists typically use the ergometer on a level surface or with a climbing block. Uphill cycling performance during cycling competitions is rather important, but there is paucity of research investigating uphill cycling variables (Duc et al., 2008; Faria et al., 2005a; Li & Caldwell, 1998). The variables of inclination can include fatigue involving muscle force/tension-length relationships that can contribute to the performance of cyclist. In addition, power generation at the pedals may be altered due to a change in posture caused by gravitational demands.

Recent investigations into cyclists' training methods include monitoring the training statuses of competitive cyclists in order to evaluate the methods and their efficacy while training and competing (Faria et al., 2005b). Most of the research has investigated heart rate (HR) intensity or VO_{2max} and workload values for cyclists in order to enhance performance. An example of a cyclist's training method is interval training, which typically involve an increase in training volume to induce an overload in the training stimulus (Faria et al., 2005b). When the cyclist needs to intensify his or her training, intervals are used. With a vast amount of investigation into training intensity and physiological adaptations, there has been paucity into the investigating of hill climbing specificity and what variables may be used in order to enhance performance.

The most convenient method for tackling inclination is to train on a hill or do hill repeats outdoors; however, environmental variables such as temperature, precipitation, and trail conditions can provide barriers to this type of training. The advancement in indoor cycle ergometers provides an alternate way to simulate uphill ascending. A lack of research exists for mountain bikers and what the changes might occur when pedaling on a level or flat surface with simulated uphill resistance in contrast to being in an actual uphill gradient. It is important to determine whether similar kinematics are seen in resistance simulated uphill cycling while pedaling flat in contrast to resistance simulated uphill. This is important in order to expand the knowledge of variables that affect uphill cycling performance, particularly for mountain bikers. Currently, there is no evidence that supports or disputes the use of a computerized cycle ergometer as a tool to simulate uphill gradients. Therefore, with this study, investigation of the changes in kinematics and muscle activity involving a simulated uphill gradient can contribute to current mountain biking knowledge and understanding.

CHAPTER III: METHODS

Introduction

This chapter provides a description of the methods used to assess the differences in kinematics and muscle activity patterns seen while pedaling on a level surface with a simulated loaded incline, in contrast to an actual loaded incline with the use of an indoor cycling ergometer. The indoor cycling ergometer that was used for testing is the Computrainer™, an instrument made by RacerMate® (Seattle, WA) used to test power, pedaling efficiency, and aerobic fitness to measure improvement for cyclists. The participants in this study performed two cycling conditions, riding their own hard-tail mountain bikes while attached to the Computrainer™. Each condition consisted of a simulated resistance determined by the mass of the rider plus bicycle. The participants then generated the necessary power output to propel the mass of the rider and bicycle up a 10% gradient, one condition without a climbing block and one with a climbing block. Kinematic and muscular activity variables during each cycling condition were collected. This chapter outlines the participant inclusion and exclusion criteria, recruitment policies, testing procedures, measurement instruments, data collection, and statistical analysis used.

Participants

A total of 12 healthy (8 male and 4 female) mountain bike cycling participants (age 36 ± 2 yrs; height 1.72 ± 0.06 m; mass 71 ± 10 kg [mean ± SD]) volunteered to take part in this study. The participants are defined as Professional (n=1), Category 1 (Expert) (n=5) and Category 2 (Sport) (n= 6). Category placement for cyclists is determined by USA Cycling and the levels the cyclists compete at currently. Competitive cyclists for this study are defined as those cyclists competitively racing in categories 1, 2, 3, and Professional/Elite and possessing an annual license from USA Cycling™. USA Cycling™ defined categories were used in order to recruit active cyclists with roughly 5+ years of cycling experience. In consideration of cost, time, and subject burden, participants were asked to use their own hard-tail mountain bikes for data collection. Participants who had received treatment from a physician or doctor concerning a musculoskeletal injury in the past six months were excluded from the study.

Participants were recruited at local mountain bike races and via email with the use of the South West Idaho Cycling Association (SWICA) list serve. Participants were also recruited though local fitness clubs and cycling shops by word of mouth. Participation was strictly voluntary and a signed written consent approved by the Boise State University Institutional Review Board was obtained from each participant. All responses were treated with complete confidentiality. Only the principal investigator and thesis advisor were able to access the participants' documents, which are stored in a private, secure location. In addition, all participants' information stored in computers was assigned confidential ID numbers. No monetary incentive was awarded for participation in this study.

Exclusion criteria for participation were as follows: The participants were required to use a 26-inch (wheel diameter), hard-tail mountain bike. Mountain bikes with rear suspension are referred to as soft-tail. Soft-tail mountain bikes were not allowed for use during this study due to sag or "bobbing" from the rear suspension while climbing. All participants' bicycles were mounted with the same wheel fitted with a rear WTB® SLICK 1.5 City/Hybrid mountain bike tire (wtb.com) for road use. The WTB slick mountain bike tire was used to keep rear tire resistance constant, and to decrease the sound that is typically generated from the Computrainer™ when used with treaded tires.

Procedure

The study consisted of one testing session. Participants brought their hard tail mountain bikes to the Center for Orthopedic & Biomechanics Research at the Ron and Linda Yanke Family Research Park located at 220 Park Center Blvd in Boise, Idaho. Participants were given an overview of the study including the purpose, requirements, and procedures that will take place during the testing. The principal investigator answered any questions participants had about the study. All participants were asked to wear cycling gear without reflective material. The participants were shown to a changing room for privacy. All anthropometric measurements, reflective marker placements, and EMG sensor placement performed on the participants were performed by the principal investigator and additional personnel approved by the IRB.

Motion Capture, Collection, and Processing

Three-dimensional coordinates of the markers were captured at 240Hz with an eight camera MX 20 Vicon motion analysis system (Vicon, Lake Forest, CA). A 6Hz lowpass Butterworth filter was used to process the coordinate data prior to the calculation of the sagittal plane trunk, pelvis, hip, knee, and ankle angles. In addition, interpolation of the data was done in order to fill missing marker gaps. A total of 32 reflective markers were applied to the participants in preparation for motion capture. The marker set was fixed securely onto the lateral side of the right and left lower extremity limbs. Markers were placed on the right and left lateral side of the thigh, shank, foot, heel, and lateral, medial epicondyle of the knee. One marker was placed on each of the right and left anterior superior iliac spine and posterior superior iliac spine. Upper body markers were placed on the left and right medial and lateral wrist, lateral forearm, lateral left and right upper arm, lateral left and right shoulder, clavicle, xiphiod process, right scapula, C7, T10, and right and left side of the anterior head and right and left side of the posterior head (see Figure 2). For the study, kinematics were measured for the right lower limb only, which included analysis of the mean joint angles of the right hip (RHIP), right knee (RKNEE), right ankle (RANKLE), pelvis (PELVIS), trunk angle (TA), and trunk segment (TS) (in relation to lab floor). Mean joint angles were calculated from the ten average joint angles from each pedal revolution. Joint Range of Motion (ROM) was calculated by subtracting the minimum angle from the maximum angle within each pedal revolution. Kinematic joint ROM and mean joint angle were calculated in Visual 3D (C-Motion, Germantown, MD) in the sagittal plane.

Figure 2 Placements of Reflective Markers and EMG Electrodes

Two additional markers were placed on both sides of the pedals to determine pedaling revolution. Three additional markers were placed on the Computrainer™ in order to replicate the center of the rear hub. One marker was placed on the outer part of front wheel hub. Collected data, including EMG and kinematic variables, were expressed as a function of the crank arm angle (ϴ) as it rotates from the highest pedal position [0° or top dead center (TDC)] to the lowest (180° or bottom dead center) and back to TDC to complete a 360° crank cycle (Li & Caldwell, 1998).

EMG Collection and Processing

A total of 5 wirelesses BTSFree EMG (BTS Bioengineering, Garbagnate Milanese, MI), sensors, self-adhesive, disposable, Ag/AgCL snap, dual electrodes (space 2.0 cm between) for surface EMG applications were securely placed on the right lower limb of each participant. EMG were collected from the gluteus maximus (GLMA), vastus lateralis (VAL), biceps femoris (long head) (BCFL), gastrocnemius (GAS), and tibialis anterior (TA) (Duc et al., 2008; Li & Caldwell, 1998). Pre-amplified electrode pairs were placed on each muscle belly along the longitudinal line of muscle fibers as described by Li and Caldwell (1998). Shaving hair on the lower limbs and the use of rubbing alcohol was used in order to increase adhesiveness of the EMG electrodes.

EMG data were collected at 1000Hz. All EMG data collected were with MyoLab (BTS Bioengineering, Garbagnate Milanese, MI) software then imported into Visual 3D software program. Raw EMG data were filtered with a low-pass Butterworth filter (cut off frequency 22 Hz) to produce a linear envelope for each muscle activity pattern. To quantify the muscle activity pattern, a series of normalized (normalization to the highest peak activity during the torque velocity test) EMG variables were calculated from the linear envelope data collected from each trial. The linear envelope was then divided into ten pedal cycles and a mean linear envelope was computed for each muscle. Finally, the linear envelopes of each muscle were scaled to a percentage of the maximum value found for each individual muscle for each participant (Duc et al., 2008; Li & Caldwell, 1998).

The following values were extracted from the mean linear envelope: EMG burst duration ($EMG_{duration}$), peak timing ($EMG_{peak\text{-}timing}$), and maximum EMG burst magnitude (EMG_{peak}). The $EMG_{duration}$ is defined as the duration in degrees of the crank angle between the onset and the offset value. EMG_{peak} is the maximum value from the linear envelope during each trial. $EMG_{peak\text{-}timing}$ is the crank angle in degrees where the EMG maximum activity occurred (Duc et al., 2008; Li & Caldwell, 1998). An estimated threshold value of 25% of the maximum value was used to determine the onset and offset of EMG burst in order to determine all three variables, as seen in Li and Caldwell (1988) and Duc et al. (2008). Visual inspection was used in order to determine if the 25% threshold was enough to identify a sizable muscle burst for each muscle during each trial.

Appropriate thresholds were deemed adequate if they easily reflected the onset and offset points, and were without minimal discrepancies in a meaningful burst (Duc et al., 2008; Li & Caldwell, 1998). In the case that 25% is considered too low, the threshold was raised to 30% or more of the maximum values determined by the mean linear envelope, as seen in Duc et al. (2008). Once reaching the necessary threshold, the muscle was considered active.

Computrainer™ Calibration

Before the testing sequence began, participants were instructed to pedal their bikes while on the Computrainer™ for calibration purposes. One requirement of the Computrainer™ usage is the application of "press-on force" that the Computrainer™ mimics. Press-on force is the amount of contact pressure between the tire and the friction roller of the load generator. "The Computrainer™ system uses the bicycle rear wheel to drive a copper flywheel, spinning in the field of an electromagnet" to simulate cycling conditions (Computrainer™ manual). Therefore, Computrainer™ calibration will require the press-on force to be set at 4.0 lbs in order to mimic a 10% slope.

In order to simulate the 10% slope, the use of a Computrainer™ software ergometer test was created by the principal investigator. Computrainer™ ergometer tests (erg file) are time/watt-based tests, and the load felt by the cyclist is controlled during the test regardless of speed or RPM. With the use of the equation in Figure 4, the principal investigator determined the power output in watts for each participant required to ascend a 10% incline at 10 mph. Each erg file created was different for each cyclist due to the mass of the rider and bicycle. The erg files for the current study included a protocol that was 11 min in duration, with two 1 min pedaling power output needed to ascend a 10%

slope, followed by 3 min rest interval. As an example, a 68 kg rider with 11 kg bike weight will need to generate 354 W in order to ascend a 10% gradient at 10mph. The erg file ramping will be as follows: 3 min at 100-200 W, 1 min at 354 W, 3 min at 100-200 W, and 1 min at 354 W, followed by 3 min cool down at 100 W.

The pedaling power output used in the erg file for each participant was calculated with a simplified functional equation of motion (Equation 1) (Burke, 2003).

$$P_{cyc} = P_{dt} + mVA_{cyc} + WV_{sin}(ArctanG) + WVC_{rr_1}\cos(ArctanG) + NCrr_2V^2 + 1/2pC_dAV(V + V_w)^2$$

Equation 1 Functional Equation of Motion for Cycling

The elements in the equation above include the following: *Pcyc* is the net instantaneous mechanical power produced by the rider, P_{dt} is power to overcome drive train friction, *m* is the mass of the rider and bicycle, *V* is bicycle velocity, *Acyc* is instantaneous acceleration or deceleration of the bicycle/rider system, *W* is the weight of the bicycle and rider, *G* is the grade, Crr_1 is the coefficient of static rolling resistance, *N* is the number of wheels, Crr_2 is the coefficient of dynamic rolling resistance, *Cd* is the coefficient of aerodynamic drag, *A* is the frontal surface area of the rider and bicycle, *p* is the air density, and *Vw* is the velocity of the headwind or tail wind. The equation can be simplified even more (Equation 2) because the laboratory setting did not have a velocity of wind, air density, and any other variables that are controlled in a laboratory environment. Therefore, the load that was used for each participant was determined by the following simplified equation:

$$P_{cyc} = WVsin\,(ArctanG)$$

Equation 2 Simplified Functional Equations for Cycling

Where *Pcyc* is the power output of the cyclist, *W* is weight of bicycle and rider system, and *G* is the grade. With this equation, the principal investigator determined the power of the cyclist needed to ascend 10% grade. Power to ascend 10% gradient is equal to the weight of the bicycle and rider multiplied by the sine of 10% grade multiplied by the velocity. The velocity that will be chosen in order to ascend an actual 10% incline will be 10 mph.

Participant Testing Sequence

Following reflective marker and EMG sensor placement, participants were asked to perform a series of calibration trials in order to calculate hip and knee joint centers of the right and left knee and the right and left hip. After the calibration trials, ankle, toe, heel, and knee reflective markers were removed. After removal of a few lower limb markers (knees, ankles, toes, and heel), and after the Computrainer™ calibration, participants provided a maximal voluntary contraction (MVC) for each muscle being collected. In order to get the MVC, the all-out torque-velocity test (T-V test) was performed (Rouffet & Hautier, 2008). The T-V test was selected to measure reference EMG data values within a very short time period, and in a standardized condition that replicates the identical type of contraction and muscle length changes during pedaling (Rouffet & Hautier, 2008). Participants performed two maximal pedaling sprints on their bicycle while attached to the Computrainer™. Before the MVC were collected participants were given a 10 minute warm-up with a self-selected load. The MVC was done by applying the same load (as determined by Equation 2) to the Computrainer™. After the 10 minute warm-up, participants then gave two, back-to-back, 5 second maximal sprint efforts, separated by a 5 second rest period. Muscle activity was recorded and then normalized for EMG data collection processing previously described. Data collection began after a brief cool down to recover from MVC efforts.

The motion capture procedure was as follows: warm up, flat surface with resistance and actual incline with resistance. The order of testing was randomized between actual incline and flat surface for each participant. The order of testing was determined by the principal investigator. The first condition (level simulated 10% slope) was done with the previously discussed erg file. Speed was closely monitored for both conditions in order to keep a 10 mph or 16.1 kph for the duration of the 1 minute collection time. After the first condition, participants dismounted their bikes and were given a 3 minute rest period. The participant's bike was then placed on a proto-type lift/jack (15.5 cm in height) used to raise the front wheel of the bike to an estimated 10% incline, which can be affected by front tire tread size. In order to control for accurate incline, the use of an inclinometer made in the USA by Empire Level MFG Corp (Mukwonago, WI) Magnetic Polycast Protractor was used to check for accurate incline. During the second condition, the power output from each participant remained at the determined watts from the simplified Equation 2 in order to ascend a 10% incline. The participant proceeded through the same erg file created by the principal investigator. During the second condition, the participant was at an estimated 10% incline, and loaded 10% simulated grade. Finally, after the two conditions were completed and two sets of data collected, with a total of 2 minutes from each condition, the participant was asked to dismount his or her bike and their reflective markers, and the EMG sensors were removed.

Statistical Analysis

Analyses were performed with the statistical package IBM SPSS 19.0. In order to test for significant differences across the two conditions of level and incline, a repeated measures Multivariate Analysis of Variance (MANOVA) was used with significance set at $p \leq 0.05$. If the MANOVA indicated that significant differences existed between the two conditions, a discriminate analysis was used as a post-hoc test to determine how the individual variables contributed to the difference. The MANOVA is used to assess the statistical significance of the effect of one or more independent variables; in this case, conditions incline and level on a set of two or more dependent variables.

CHAPTER IV: RESULTS

Introduction

In the current study, sagittal plane kinematics and muscle activity patterns were assessed to determine whether there was a difference while pedaling on a level surface compared to pedaling at an incline. Participants pedaled their own hard-tail mountain bike attached to an indoor cycle ergometer. The two conditions (level vs. incline) were assessed where the participants pedaled 10 MPH during a flat simulated 10% incline and an actual 10% incline. Basic kinematic and EMG data were collected from the two conditions with the mean of ten pedal revolutions analyzed while pedaling on an indoor cycle ergometer. This chapter contains the descriptive statistics and the results of the Repeated Measures MANOVA for the variables of interest.

Descriptive Statistics

Tables 1 and 2 include the means and standard deviations for all variables collected.

Table 1 Means and Standard Deviations of Kinematics (Joint ROM and Mean Joint Angle).

Joint ROM	*Level Mean (SD)*	*Incline Mean (SD)*
RHIP	54° (4.8)	53° (4.6)
RKNEE	84° (6.5)	82° (5.5)
RANKLE	30° (8.6)	29° (8.9)
PELVIS	6° (1.9)	5° (1.1)
TA	8° (2.6)	6° (2.2)
TS	6° (2.9)	5° (2.4)

Mean Joint Angle	*Level Mean (SD)*	*Incline Mean (SD)*
RHIP	64° (10)	63° (9.8)
RKNEE	68° (6.4)	68° (6.5)
RANKLE	80° (7.2)	80° (7.5)
PELVIS	20° (6.6)	14° (5.9)
TA	29° (8.2)	28° (8.2)
TS	48° (5.7)	42° (6.7)

Participants' kinematic means and SD for the level and incline conditions. The mean of each joint angle for the level compared to incline. Kinematic variables were calculated from 10 pedal cycles.

Table 2 Means and Standard Deviations of Muscle Activity Patterns ($EMG_{Duration}$, $EMG_{Peak\text{-}Timing}$, and EMG_{Peak})

$EMG_{Duration}$	*Level Mean (SD)*	*Incline Mean (SD)*
GLMA	172° (42.6)	154° (46.1)
BCFL	154° (46.8)	151°(44.3)
VAL	162° (34.5)	164° (41.2)
TA	155° (44.5)	167° (43.4)
GAS	179° (82.8)	153° (63.7)
$EMG_{Peak\text{-}Timing}$	*Level Mean (SD)*	*Incline Mean (SD)*
GLMA	164° (114)	156° (89)
BCFL	151° (83.4)	179° (80.1)
VAL	157° (117.8)	181° (115.2)
TA	170° (84.2)	197° (75.2)
GAS	191° (126.7)	187° (125.9)
EMG_{Peak}	*Level Mean (SD)*	*Incline Mean (SD)*
GLMA	53% (24)	50% (27)
BCFL	69% (17)	68% (18)
VAL	65% (12)	68% (16)
TA	66% (17)	60% (20)
GAM	61% (20)	59% (19)

$EMG_{Duration}$ and $EMG_{Peak\text{-}Timing}$ are expressed as a function of the crank arm angle (θ) as it rotates from the highest pedal position [0° or top dead center (TDC)] to the lowest (180° or bottom dead center) and back to TDC to complete a 360° crank cycle. EMG_{Peak} is expressed as a percentage of peak value normalized from T-V test.

Repeated Measures MANOVA

A non-significant multivariate main effect between conditions level and incline was found for all kinematic dependant variables, including joint ROM and mean joint angle (Wilks' $\lambda = .354$, $F(12, 11) = 1.674$, $p = 0.201$). Therefore, a discriminate analysis was not performed due to the non-significant difference between the level and incline conditions for all kinematic variables.

A non-significant multivariate main effect between conditions level and incline was found for all muscle activity dependant variables, including $EMG_{Duration}$, EMG_{Peak_Timing}, and $EMG_{Peak,}$ (Wilks' $\lambda = .104$, $F(20,3) = 1.289$, $p = 0.479$). Therefore, a discriminate analysis was not performed due to the non-significant difference between the level and incline conditions for all EMG variables.

When visually inspecting the means of the variables, there was no significant difference in kinematic joint angle mean and range of motion between the two conditions. While individual variable changes were not tested, it appears that the means for most participants were very similar. These results do not lead to the conclusion that there is a significant difference between conditions in regard to kinematics. In addition, for the five muscles tested, when visually inspecting the descriptive means of the $EMG_{Duration}$, $EMG_{Peak\text{-}Timing}$, and EMG_{Peak}, there were no significant differences in muscle activity patterns between the two conditions. The large SD indicates that there is a high degree of variability between participants. Given the high variability in the data, a meaningful comparison of data from this study with previous studies was difficult to accomplish.

CHAPTER V: DISCUSSION AND CONCLUSION

Introduction

The purpose of this study was to quantify changes in sagittal plane kinematics and muscle activation patterns of pedaling on a level surface compared to pedaling at an incline while utilizing an indoor cycle ergometer. The results of this study indicate that there is no significant difference in kinematics and muscle activity patterns between the two indoor cycle ergometer conditions.

Overall, most of the participants' kinematics and muscle activity patterns for the right leg were consistent with those reported in similar cycling studies examining seated pedaling and inclination (Duc et al., 2008; Li and Caldwell, 1998). The kinematic angle changes including the trunk, pelvis, and ankle seen in previous studies seemed to mirror results from the current study (Dingwell, Joubert, Diefenthaeler, & Trinity, 2008). In the study by Li and Caldwell (1998), EMG data showed no significant change in muscle activity while seated at an incline in contrast to sitting level (Caldwell et al., 1998; Duc et al., 2008). However, in the current study, muscle activity patterns were quite variable and the standard deviation of the EMG activation on and off times was much larger than seen in previous studies (Duc et al., 2008; Li & Caldwell, 1998).

One reason for the large standard deviation between conditions level and incline could be the variability between participants' cycling mechanics. The disparity in results may be an indicator of the potential differences in pedaling style, which could have been influenced by participants' expertise or bicycle setup. The disparity in results could also be due to the type of cyclists recruited for this study (mountain bike vs. road cyclist), which may have also played a role in pedaling style. The disparities in pedaling style that may have affected kinematics and muscle activity patterns can be attributed to seat height, crank length, cleat pedal interface, and bicycle frame geometry (Burke, 2003; Burke,1994; Yoshihuku & Herzog, 1996). Kinematic and muscle activity patterns including pedaling technique have been reported to vary across crank length, pelvic inclination, seat height, and rate of crank rotation (Burke, 1994; Yoshihuku & Herzog, 1996).

There was a high level of variability in the cyclists' data, which may be attributed to the differences in cycling style and category level. In the current study, participants did not exhibit pedaling techniques, expected of the high level of cyclists recruited. An example of the cyclists' variability can be found in the ankle and knee angles. As an example, participant 4 had a dorsi flexion angle of 25° during the level condition and 23° of ankle dorsi flexion during the incline. Participant 11 was at the opposite spectrum, during the level condition the ankle never went into dorsi flexion and instead remained in plantar flexion at 4° and for the incline 1° of ankle dorsi flexion. Overall, the mean ankle dorsi flexion for all participants was 24° for both conditions. During pedal loading, a cyclist would want to avoid unintentional dorsi-flexion during the power phase of the pedal cycle to limit loss of power delivery in the fore/aft direction of the pedal (see Figure 3) (Burke, 2003). Dr. Edmund Burke suggests that the normal pedal force should act perpendicular to the pedal surface and the tangential force component acting along the surface of the pedal in the fore/aft direction (Burke, 2003). Figure 3 represents the recommended direction and an example of the magnitude of pedal loading and pedal orientation (Burke, 2003).

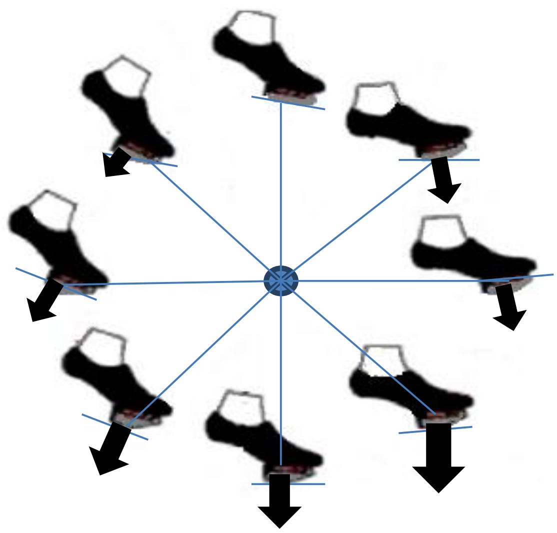

Figure 3 Pedal loading and pedal orientation. Solid black arrows are a representation of the direction and the magnitude of pedal loading and pedal orientation. Black arrows are normal forces. (Adopted from High Tech Cycling, by Dr. Edmund Burke.)

In this study, the muscle activity with the highest burst, $EMG_{peak,}$ was used for data analysis. It was not until EMG data were further analyzed that we detected there might be a potential connection to ankle dorsi flexion and TA muscle activity during the power phase of the pedal cycle. In this study, the TA fired more than once above the 25% threshold, during the power phase and the recovery phase of the pedal cycle in 6 of the participants (four during the incline, two during the level). This finding is important because while utilizing the indoor cycle ergometer, cyclists will train with power (wattage) to increase performance (Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Burke, 2003), and may un-unknowingly be losing power while pedaling. Figure 4 shows an example of the double firing of the TA by participant 14. It is important to note that in the current study the power output required differed from previous studies (Duc et al., 2008; Li & Caldwell, 1998). Power output was roughly 100 watts higher than any previous studies (Duc et al., 2008; Li & Caldwell, 1998). The participants pedaled their own hard-tail mountain bike at a power output based on body weight. In Figure 4 participant 12 exhibits an example of TA firing in the recover or pull though phase of the pedal revolution, around 300 (Duc et al., 2008; Li & Caldwell, 1998). During the power phase (See Figure 4), Participant 12's TA functions to stabilize the ankle as the foot stabilizes during the power phase of pedaling (eccentric contraction) and acts later to pull the foot through the recovery phase of pedaling (concentric contraction) (Dingwell et al., 2008). Four participants in this study were seen to start muscle activation for the TA around 50° and then again around 270°.

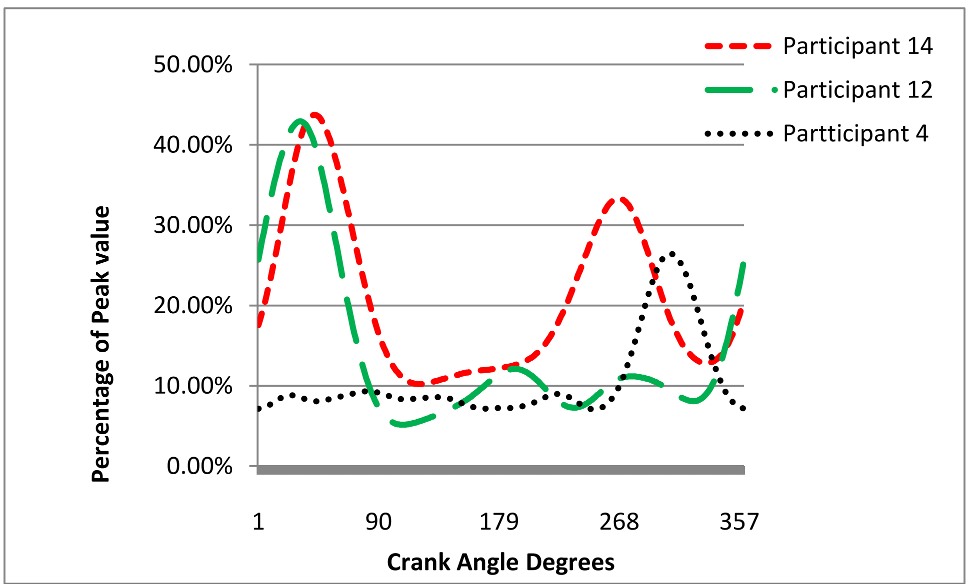

Figure 4 Comparison of Level TA muscle activity. Graph illustrating variances between participants TA activity for the level condition. Percentage is based on normalized muscle activity from T-V test.

It is also plausible that the cyclists' position on the bicycle could have played a part in participants' variability seen in ankle and knee measurements. Recent investigations recommend that the correct saddle height for an individual with no knee pain allows for an estimated range of 25 to 30 degrees of flexion of the extended leg when the pedal is at bottom dead center or BDC (Burke, 2003). BIKEFIT™ (Kirkland, WA) recommends a knee flexion of 27° to 37° at BDC. During kinematic data analysis of this study, results revealed that an average of eight participants' knee angles was not within the recommended knee flexion at BDC. As an example (see Figure 5), participant 8 had a minimum knee angle during the level condition of 8° of knee flexion with a 10° knee flexion during the incline. Participant 3 was at the opposite spectrum, where during the level the minimum knee flexion was 36° and for the incline 29° knee flexion. Participant 10 was nearly equal during both conditions with 31° of knee flexion.

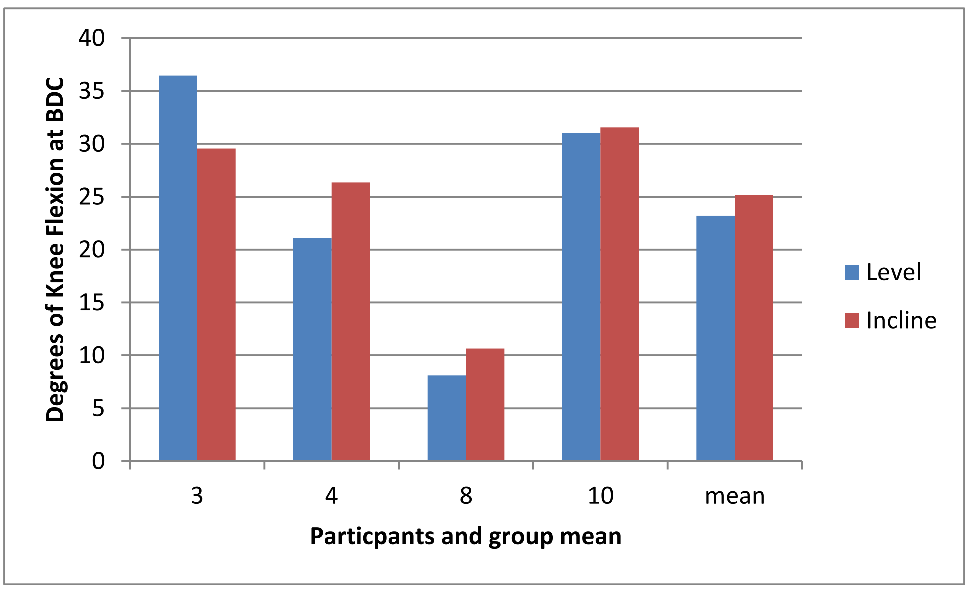

Figure 5 A comparison of the Participants mean knee flexion at BDC. Graph illustrating the variability of knee angles across conditions for 4 participants.

This variability of knee angle between participants could be contributed to saddle placement being placed too high or too low (Burke, 2003). In addition, according to BIKEFIT™ recommendations, four participants had a satisfactory knee angle flexion

(BDC) during the level and three participants for the incline. The group means minimum knee flexion for the level condition was 24° and for the incline 25° (Figure 5). There was no significance with this observation; however, it is worth considering proper body placement on a bicycle for future studies. The variance across participants was high and it seems that most of the participants did something different than expected. In fact, with the exception of a few participants, most did not exhibit expected cycling mechanics.

Limitations of Study

The current study has limitations with regards to data collection and analysis. Twelve participants participated in the study, and each participant had 5+ years of cycling experience. Participants used their own hard-tail mountain bike, which meant that there was no attention given to seat height, seat fore/aft, and cleat pedal interface by the principal investigator. In addition, during the current study, technical difficulties led to the EMG collection frequency changing twice. This frequency switch happened to six of the twelve participants; six participants collected at1000Hz (original frequency) and the other six collected at 2000Hz. EMG changes did not occur within participants, but only between participants. Also, three different frequencies were used for MOCAP collection: 100Hz (n=2), 120Hz (n=3), and 240Hz (n=7). The different MOCAP frequencies occurred because of the principal investigator's lack of experience involving quantitative research.

In addition, within the data collections, every effort was made to minimize marker and EMG sensor movement. Even though the markers were placed on each participant consistently, error of marker placement could have affected the kinematic values obtained. In regards to EMG electrode placement, every effort was made to minimize any interference that may have occurred from participant movements.

Future Studies

Even with limitations, including body placement while pedaling and research inexperience, the current study mirrors that of similar investigations by Li and Caldwell (1996) and Duc and colleagues (2003). Similarly, this study found no change in muscle activation while simulating an uphill terrain indoors. However, after looking at the data, something to consider for future training practices is the cyclists' joint range of motion in the lower extremities. Using the indoor cycle ergometer as a research tool can allow for investigators to work on biomechanical pedaling efficiency, including investigating ankle kinematics further.

A direction for future kinematic and muscle activity patterns studies should include testing with physiological parameters. Kinematic and muscle activity changes should be investigated during a test to exhaustion while simulating inclination. Variables would include inclined power demands and the magnitude of change involving kinematics and muscle activity patterns throughout the test. This can also allow for investigators to have a better idea of what a cyclist does with an increase in power demand at the pedals. Furthermore, investigations should include increased inclines of more than 15% since it is not uncommon to find mountain biking terrain of 20% or more.

Conclusion

In conclusion, the current study found no significant statistical difference between the two conditions (level vs. incline) with respect to kinematics and muscle activity patterns. The findings of the current study are important to better understand the significance of using a cycle ergometer for simulated incline training practices. Results of the current study suggest that there are no training implications of using a block or setting the bike at an actual incline when simulating uphill pedaling while using an indoor cycle ergometer for outdoor training practices. The reason for the lack of differences between conditions with respect to kinematic and muscle activity patterns is hard to pinpoint due to inconsistent pedaling techniques among the participants, data collection, and errors throughout the research process. Results from the current study do not support the hypothesis that the use of a climbing block to raise the front wheel results in significant changes in cycling posture or muscle activation.

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APPENDIX

Journal Article

KINEMATICS AND MUSCLE ACTIVATION PATTERNS DURING SIMULATED UPHILL PEDALING ON AN INDOOR CYCLE ERGOMETER

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Abstract

Background: While there is some evidence that joint kinematics and muscle activity patterns change during uphill cycling, there is little known about if there are differences while using an indoor cycle ergometer to simulate inclination. The purpose of this study is to quantify changes in kinematics and muscle activation patterns while pedaling on a level surface compared to pedaling at an incline on a mountain bike while attached to an indoor cycle ergometer.

Methods: Three dimensional joint kinematics and muscle activity patterns were collected during two simulated uphill conditions while utilizing an indoor cycle ergometer. The two conditions (level vs. incline) were assessed where the participants pedaled 10 MPH during a flat simulated 10% incline and an actual 10% incline. Joint kinematic variables were joint range of motion (ROM) and mean joint angle. Variables included right hip (RHIP), right knee (RKNEE), and right ankle (RANKLE), PELVIS, Trunk Angle (TA) and Trunk Segment (TS). Muscle activity variables included the gluteus maximus (GLMA), biceps femoris (long head) (BCFL), vastus lateralis (VAL), gastrocnemius (GAS) and tibialis anterior (TA). Joint kinematics and EMG data were collected from the two conditions with the mean of ten pedal revolutions analyzed while pedaling on an indoor cycle ergometer

Findings: A non-significant multivariate main effect between the two conditions was found for joint kinematics and muscle activity patterns ($p > 0.05$).

Interpretation: While there were no significant differences between the level and incline condition, these differences did support our expected results. In fact, these results suggest that there are interesting changes that occur while pedaling at a high power output. These findings are similar to previous evidence suggesting pedaling on a

level simulated uphill versus an actual uphill on a cycle ergometer does not significantly change (Duc et al., 2008; Li & Caldwell, 1998)

1. Introduction

The indoor cycle ergometer allows for competitive and recreational cyclists to train with precisely controlled and monitored pedaling. With the wide availability of increasingly economical and sophisticated devices, indoor cycle ergometers are becoming a more popular training method for cyclists at all levels. In some instances the cycle ergometer can enable the cyclist to record their speed, power output, and spinning efficiency while relaying the information to a computer. In addition, the computer can simulate a virtual course through which the cyclist can pedal or simulate an event. As an example, if the cyclist pedals uphill in the virtual world the cycle ergometer applies a load to the roller and the effect of pedaling uphill is simulated. However, while pedaling indoors the cyclist body position is not the same as while pedaling outdoors. This can be contributed to outdoor conditions involving roots, rocks, and more importantly inclination. This difference in body position may have training implications

The position of a cyclist on a bicycle can determine how well the body performs during a cycling task (Ashe et al., 2003; Dorel et al., 2009). There is considerable evidence that road bike cycling kinetics and kinematics change during a simulated uphill. The vast majority of research on the mechanics of uphill pedaling focuses on road cyclist's body posture, muscle activity and kinematic effects of seated simulated uphill versus standing simulated uphill cycling (Caldwell et al., 1999; Duc et al., 2008; Li & Caldwell, 1998; Neptune & Hull, 1996). It is unclear if the results from road cycling paradigms translates to mountain biking because there are several key differences between road cycling and mountain biking

Mountain bikers, for example, are sometimes faced with steep inclines and are unable to stand while ascending the steep grade due to loose dirt or lack of traction on the rear tire. Standing while ascending on a mountain bike may cause a mountain biker to slip or lose grip resulting in inefficient pedaling. It is likely that the mountain biker must be able to adjust power output, body posture and muscle activation patterns to ensure mechanical efficiency and the ability to effectively apply force to the pedals while ascending steep gradients (Gregor & Rugg, 1986). Therefore, it is important for the mountain bike cyclist to utilize training practices that are specific to the demands of ascending steep grades. However different mountain bikers and road cyclists' body positions are both will often utilize the indoor cycle ergometer for training practices by increasing the resistance to simulate steep gradients. Yet, there is minimal research that supports or disputes simulation of uphill cycling with the use of an indoor cycle ergometer as a training practice (Faria, 2009; Faria et al., 2005a).

It is important for training specificity purposes to determine whether similar kinematics are seen in resistance simulated uphill pedaling while flat in contrast to resistance simulated uphill pedaling at an actual incline. Currently there is no evidence that supports or disputes the use of a computerized cycle ergometer as a training tool to simulate uphill gradients. Therefore, with this study, investigation of the changes in kinematics and muscle activity patterns involving a simulated uphill gradient can contribute to current mountain biking training knowledge and understanding. Therefore, the purpose of this study is to quantify changes in kinematics and muscle activation patterns while pedaling on a level surface compared to pedaling at an incline on a mountain bike. To address this question, data changes will be collected while using an indoor computerized cycle ergometer simulating a 10% gradient.

2. Methods

2.1 Particpants

A total of twelve healthy (8 male and 4 female) mountain bike cycling participants ages 18 to 55 participants (n=12), volunteered to take part in this study. The participants are defined as Professional (n=1), category 1 (n=5) and category 2 (n= 6). Cyclist category placement was determined by USA Cycling and the level of experience that the participants compete at. Competitive cyclists for this study are defined as competitively racing in categories 1, 2, 3 and Professional/Elite and possess an annual license from USA Cycling. USA Cycling defined categories were used in order to recruit active cyclists with roughly 5 years of cycling experience. Participants who have received treatment from a physician or doctor concerning a musculoskeletal injury in the past six months were excluded from the study

The participants were required to use a hard-tail mountain bike. Mountain bikes with rear suspension are referred to as soft-tail. Soft-tail mountain bikes were not allowed for use during this study due to sag or “bobbing” from the rear suspension while climbing. All participants’ bicycles were mounted with the same rear wheel fitted with a rear WTB® SLICK 1.5 City/Hybrid mountain bike tire (wtb.com) for road use. The WTB slick mountain bike tire was used to keep rear tire resistance constant, and to decrease the sound that is typically generated from the Computrainer™ when used with treaded tires.

2.2 Procedures

The study consisted of one testing session. Participants brought their own hard tail mountain bikes to the research laboratory. A standard full body marker set was applied to each of the participants' in preparation for motion capture protocol. The marker set was fixed securely onto the lateral side of the right and left lower extremity limbs. Markers were placed on the right and left lateral side of the thigh, shank, foot, heel and lateral, medial epicondyle of the knee. One marker each was placed on the right and left anterior superior iliac spine, posterior superior iliac spine. Upper body markers were placed on the left and right medial and lateral wrist, lateral forearm, lateral left and right upper arm, lateral left and right shoulder, clavicle, xiphiod process, right scapula, C7, T10, and right and left side of the anterior head and right and left side of the posterior head. Joint kinematics was measured for the right lower limb only.

Two additional markers were placed on both sides of the pedals to determine pedaling revolution. Three additional markers were placed on the cycle ergometer in order to replicate the center of rear hub. One marker was placed on the outer part of front wheel hub. Collected data, including kinematic and EMG variables, is expressed as a function of the crank arm angle (ɵ) as it rotates from the highest pedal position [0° or top dead center (TDC)] to the lowest (180° or bottom dead center) and back to TDC to complete a 360° crank cycle (Li & Caldwell, 1998).

A total of 5 wirelesses BTSFree EMG (BTS Bioengineering, Garbagnate Milanese, MI), sensors, self-adhesive, disposable, Ag/AgCL snap, dual electrodes (space 2.0 cm between) for surface EMG applications were securely placed on the right lower limb of each participant. EMG data was collected from the gluteus maximus (GLMA), vastus lateralis (VAL), biceps femoris (BCFL), gastrocnemius (GAS), tibialis anterior (TA) (Duc et al., 2008; Li & Caldwell, 1998). Pre-amplified electrode pairs were placed on each muscle belly along the longitudinal line of muscle fibers as described by Li and Caldwell (1998).

In order to simulate the 10% slope the use of a Computrainer™ software ergometer (erg) test was created by the principle investigator. Computrainer™ ergometer tests are time/watt based tests, and the load felt by the cyclist is controlled during the test regardless of speed or RPM. With the use of the equation in Equation 1, the principle investigator determined the power output in watts for each participant required to ascend a 10% incline at 10 mph. Each erg file created was different for each cyclist due to the mass of the rider and bicycle. Each erg file was 11 minutes in duration, with two 1 minute pedaling power output needed to ascend a 10% slope, followed by 3 minute rest intervals. As an example, a 68 kg rider with 11 kg bike weight will need to generate 354 W in order to ascend a 10% gradient at 10mph. The erg file ramping will be as follows: 3 min. at 100-200 W, 1 min. at 354 W, 3 min. at 100-200 W, and 1 min. at 354 W, followed by 3 min. cool down at 100 W.

$$P_{cyc} = WVsin\ (ArctanG)$$

Equation 1 Simplified Functional Equation for Cycling

2.3 Data Analysis

Three-dimensional coordinates of the labeled 3D trajectory markers was captured at 240Hz with an eight camera MX 20 Vicon motion analysis system (Vicon, Lake Forest, CA). A 6Hz lowpass Butterworth filter was used to process the coordinate data prior to the calculation of the sagittal plane trunk, hip, knee and ankle angles. Joint kinematics was measured for the right lower limb only. This included analysis of the mean joint angles of the right hip (RHIP), right knee (RKNEE), right ankle (RANKLE), pelvis (PELVIS), trunk angle (TA), and trunk segment (TS) (in relation to lab floor). Mean joint angles were calculated from the average joint angle during each pedal revolution. In addition, joint angle range of motion (ROM) of the RHIP, RKNEE, RANKEL, PELVIS, TA and TS. Joint ROM was calculated by subtracting the minimum angle from the maximum angle within each pedal revolution. Joint kinematics was calculated in Visual 3D (C-Motion, Germantown, MD) in the sagittal plane

EMG data was collected at 1000Hz. All EMG data collected was with MyoLab (BTS Bioengineering, Garbagnate Milanese, MI) software then imported into Visual 3D software program. . The following values were extracted from the mean linear envelope: EMG burst duration ($EMG_{duration}$), peak timing, ($EMG_{peak\text{-}timing}$), and maximum EMG burst magnitude (EMG_{peak}). The $EMG_{duration}$ is defined as the duration in degrees of the crank angle between the onset and the offset value. EMG_{peak} is the maximum value from the linear envelope during each trial. $EMG_{peak\text{-}timing}$ is the crank angle in degrees where the EMG maximum activity occurred (Duc et al., 2008; Li & Caldwell, 1998). An estimated threshold value of 25% of the maximum value was used to determine the onset and offset of EMG burst in order to determine all three variables, as seen in Li and Caldwell (1988) and Duc et al (2008). Visual inspection was used in order to determine if the 25% threshold was enough to identify a sizable muscle burst for each muscle during each trial. Appropriate thresholds were deemed adequate if they easily reflected the onset and offset points, and were without minimal discrepancies in a meaningful burst (Duc et al., 2008; Li & Caldwell, 1998). In the case that 25% is considered too low, the threshold was raised to 30% or more of the maximum values determined by the mean linear envelope. Once reaching the necessary threshold, the muscle was considered active.

2.4 Statistical Analysis

In order to test for significant differences across the two conditions (level vs. incline) a Repeated Measures MANOVA was used with significance set at $p \leq 0.05$. A discriminate analysis was used as a post-hoc test to determine how the individual variables contributed to the difference between conditions.

3. Results

A non-significant multivariate main effect between conditions level and incline was found for all joint kinematic dependant variables, including joint ROM and mean joint angle, (Wilks' $\lambda = .354$, $F(12, 11) = 1.674$, $p = 0.201$). Therefore, a discriminate analysis was not performed due to the non-significant difference between the level and incline conditions for all joint kinematic variables.

A non-significant multivariate main effect between conditions level and incline was found for all muscle activity dependant variables, including $EMG_{Duration}$, $EMG_{Peak\_Timming}$, and EMG_{Peak}, (Wilks' $\lambda = .104$, $F(20,3) = 1.289$, $p = 0.479$). Therefore, a discriminate analysis was not performed due to the non-significant difference between the level and incline conditions for all EMG variables.

Table 1 the Means and Standard Deviations of Joint Kinematics (Joint ROM) the Means and Standard Deviations for Joint Kinematics (Mean Joint Angle)

Joint ROM	***Level Mean (SD)***	***Incline Mean (SD)***
RHIP	54° (4.8)	53° (4.6)
RKNEE	84° (6.5)	82° (5.5)
RANKLE	30° (8.6)	29° (8.9)
PELVIS	6° (1.9)	5° (1.1)
TA	8° (2.6)	6° (2.2)
TS	6° (2.9)	5° (2.4)
Mean Joint Angle	***Level Mean (SD)***	***Incline Mean (SD)***
RHIP	64° (10)	63° (9.8)
RKNEE	68° (6.4)	68° (6.5)
RANKLE	80° (7.2)	80° (7.5)
PELVIS	20° (6.6)	14° (5.9)
TA	29° (8.2)	28° (8.2)
TS	48° (5.7)	42° (6.7)

Table 2 the Means and Standard Deviations of Muscle Activity Patterns

$EMG_{Duration}$, EMG_{Peak_Timing}, and EMGPeak

$EMG_{Duration}$	***Level Mean (SD)***	***Incline Mean (SD)***
GLMA	172° (42.6)	154° (46.1)
BCFL	154° (46.8)	151°(44.3)
VAL	162° (34.5)	164° (41.2)
TA	155° (44.5)	167° (43.4)
GAM	179° (82.8)	153° (63.7)
$EMG_{Peak-Timing}$	***Level Mean (SD)***	***Incline Mean (SD)***
GLMA	164° (114)	156° (89)
BCFL	151° (83.4)	179° (80.1)
VAL	157° (117.8)	181° (115.2)
TA	170° (84.2)	197° (75.2)
GAM	191° (126.7)	187° (125.9)
EMG_{Peak}	***Level Mean (SD)***	***Incline Mean (SD)***
GLMA	53% (24)	50% (27)
BCFL	69% (17)	68% (18)
VAL	65% (12)	68% (16)
TA	66% (17)	60% (20)
GAM	61% (20)	59% (19)

4. Discussion

The purpose of this study was to quantify changes in sagittal plane kinematics and muscle activation patterns of pedaling on a level surface compared to pedaling at an incline while utilizing an indoor cycle ergometer. The results of this study indicate that there is no significant difference in kinematics and muscle activity patterns between the two indoor cycle ergometer conditions.

Overall, most of the participants' kinematics and muscle activity patterns for the right leg chosen in this study were consistent with those reported in similar cycling studies examining seated pedaling and inclination (Duc et al. 2008; Li and Caldwell, 1988). In previous studies, kinematic angle changes including the trunk, pelvis, and ankle mirrored results from current study (Dingwell et al., 2008). In the study by Li and Caldwell (1998) EMG data had no significant change in muscle activity while seated at an incline in contrast to level seated (Caldwell et al., 1999; Duc et al., 2008). However, in the current study, muscle activity patterns were quite variable and the standard deviation of the EMG activation on and off times was much larger than seen in previous studies (Duc et al., 2008; Li & Caldwell, 1998).

One reason for the large standard deviation between conditions level and incline could be the variability between participants' cycling mechanics. The disparity in results may be an indicator of the potential differences in pedaling style, which could have been influenced by participant expertise or bicycle setup. The disparity of results could also be due to the type of cyclist recruited for this study (mountain bike vs. road cyclist) which may have also played a role in pedaling style. The disparities in pedaling style for kinematics and muscle activity patterns can be attributed to seat height, crank length, cleat pedal interface, and bicycle frame geometry (Burke, 2003; Burke, 1994; Yoshihuku & Herzog, 1996). Kinematic and muscle activity patterns including pedaling technique have been reported to vary across crank length, pelvic inclination, seat height, and rate of crank rotation (Burke, 1994; Yoshihuku & Herzog, 1996).

There was a high level of variability in the cyclists' data which may be attributed to the differences in cycling style and category level. In the current study, participants did not exhibit pedaling techniques, expected of the high level of cyclists recruited. An example of the cyclists' variability can be found in the ankle and knee angles. As an example, participant 4 had a dorsi flexion angle of 25° during the level condition and 23° of ankle dorsi flexion during the incline. Participant 11 was at the opposite spectrum, during the level the ankle never went into dorsi flexion and instead remained in plantar flexion at 4° and for the incline 1° of ankle dorsi flexion. Overall, the mean ankle dorsi flexion for all participants was 24° for both conditions. During pedal loading a cyclist would want to avoid unintentional dorsi-flexion during the power phase of the pedal cycle to limit loss of power delivery in the fore/aft direction of the pedal (See Figure 3) (Burke, 2003). Dr. Edmund Burke suggests that the normal pedal force should act perpendicular to the pedal surface and the tangential force component acting along the surface of the pedal in the fore/aft direction (Burke, 2003). Figure 3 represents the recommended direction and an example of the magnitude of pedal loading and pedal orientation (Burke, 2003).

Figure 3 Diagram adopted from High Tech Cycling, by Dr. Edmund Burke

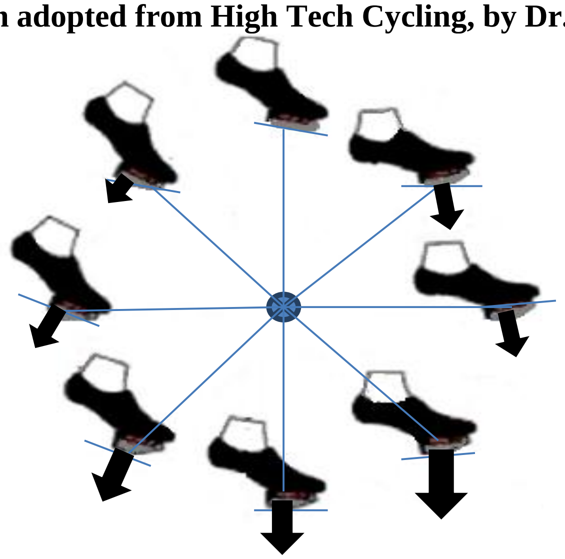
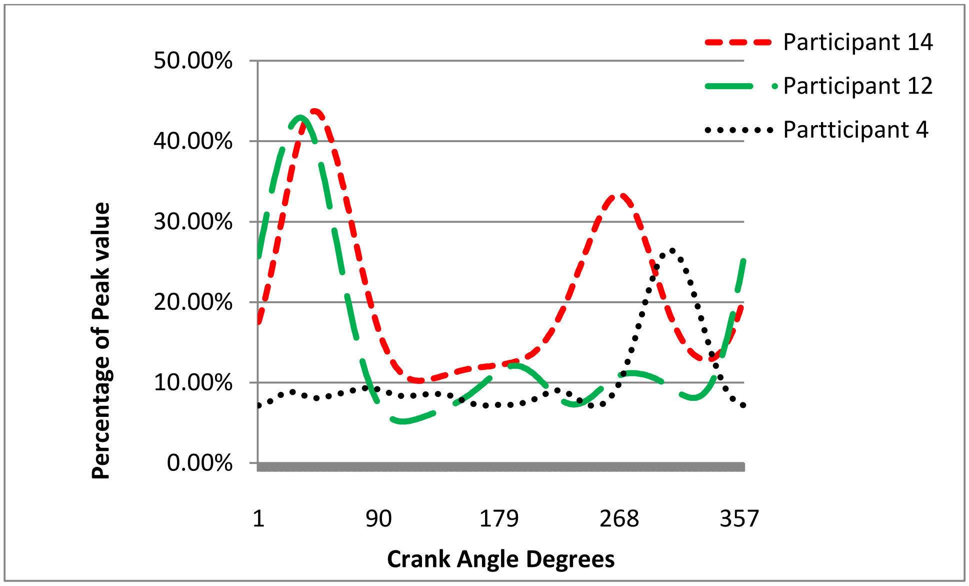


Figure 3 Pedal loading and pedal orientation. Solid black arrows are a representation of the direction and the magnitude of pedal loading and pedal orientation. Black arrows are normal forces.

In this study, the muscle activity with the highest burst, EMG_{peak}, was used for data analysis. It was not until EMG data were further analyzed that we detected there might be a potential connection to ankle dorsi flexion and TA muscle activity during the power phase of the pedal cycle. In this study, the TA fired more than once above the 25% threshold, during the power phase and the recovery phase of the pedal cycle in 6 of the participants (four during the incline, two during the level). This finding is important because while utilizing the indoor cycle ergometer, cyclists will train with power (wattage) to increase performance (Burgomaster et al., 2005; Burke, 2003), and may un-unknowingly be losing power while pedaling. Figure 4 shows an example of the double firing of the TA by participant 14. It is important to note, that in the current study the power output required differed from previous studies (Duc et al., 2008; Li & Caldwell, 1998). Power output was roughly 100 watts higher than any previous studies (Duc et al., 2008; Li & Caldwell, 1998). The participants pedaled their own hard-tail mountain bike at a power output based on body weight. In Figure 4,participant 12 exhibits an example of TA firing in the recover or pull though phase of the pedal revolution, around 300 (Duc et al., 2008; Li & Caldwell, 1998). During the power phase (See Figure 4), Participant 12's TA functions to stabilize the ankle as the foot stabilizes during the power phase of pedaling (eccentric contraction) and acts later to pull the foot through the recovery phase of pedaling (concentric contraction) (Dingwell et al., 2008) Four participants in this study were seen to start muscle activation for the TA around 50° and then again around 270°.

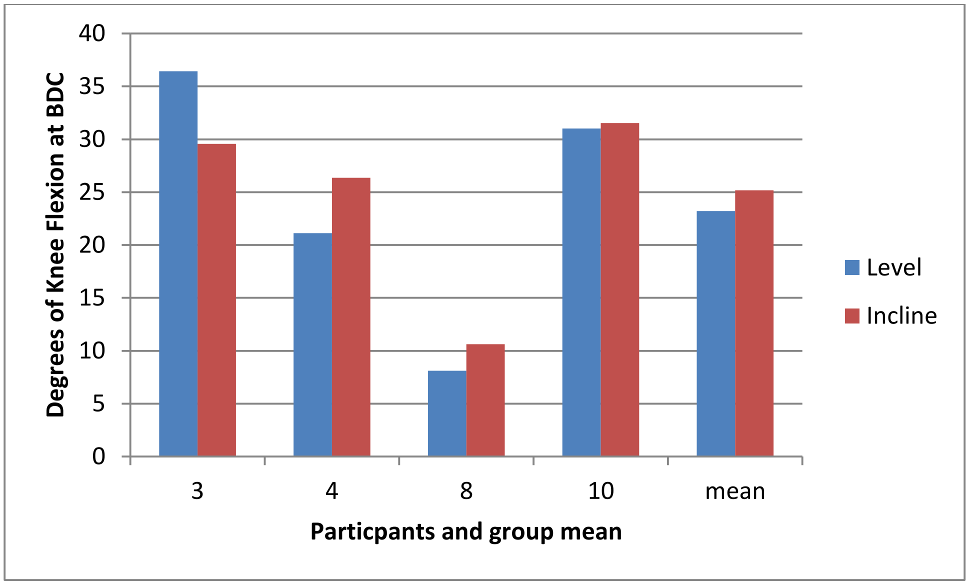
Figure 4 Comparison of Level TA muscle activity



Graph illustrating variances between participants TA activity for the level condition. Percentage is based on normalized muscle activity from T-V test.

It is also plausible that the cyclists' position on the bicycle could have played a part in participants' variability seen in ankle and knee measurements. Recent investigations recommend that the correct saddle height for an individual with no knee pain allows for an estimated range of 25 to 30 degrees of flexion of the extended leg when the pedal is at bottom dead center or BDC (Burke, 2003). BIKEFIT™ (Kirkland, WA) recommends a knee flexion of 27° to 37° at BDC. During kinematic data analysis of this study, results revealed that an average of eight participants' knee angles was not within the recommended knee flexion at BDC. As an example (see Figure 5), participant 8 had a minimum knee angle during the level condition of 8° of knee flexion with a 10° knee flexion during the incline. Participant 3 was at the opposite spectrum, where during the level the minimum knee flexion was 36° and for the incline 29° knee flexion. Participant 10 was nearly equal during both conditions with 31° of knee flexion.

Figure 5: A comparison of the Participants mean knee flexion at BDC



Graph illustrating the variability of knee angles across conditions for 4 participants.

This variability of knee angle between participants could be contributed to saddle placement being placed too high or too low (Burke, 2003). In addition, according to BIKEFIT™ recommendations, four participants had a satisfactory knee angle flexion (BDC) during the level and three participants for the incline. The group means minimum knee flexion for the level condition was 24° and for the incline 25° (Figure 5). There was no significance with this observation; however, it is worth considering proper body placement on a bicycle for future studies. The variance across participants was high and it seems that most of the participants did something different than expected. In fact, with the exception of a few participants, most did not exhibit expected cycling mechanics.

Limitations of Study

The current study has limitations with regards to data collection and analysis. Twelve participants participated in the study, and each participant had 5+ years of cycling experience. Participants used their own hard-tail mountain bike which meant that there was no attention given to seat height, seat fore/aft and cleat pedal interface by the principal investigator. In addition, during the current study, technical difficulties led to the EMG collection frequency changing twice. This frequency switch happened to six of the twelve participants; six participants collected at1000Hz (original frequency) and the other six collected at 2000Hz. EMG changes did not occur within participants, but only between participants. Also, three different frequencies were used for MOCAP collection: 100Hz (n=2) 120Hz (n=3) and 240Hz (n=7). The different MOCAP frequencies occurred because of the principal investigators lack of experience involving quantitative research.

In addition, within the data collections, every effort was made to minimize marker and EMG sensor movement. Even though the markers were placed on each participant consistently, error of marker placement could have affected the kinematic values obtained. In regards to EMG electrode placement every effort was made to minimize any interference that may have occurred from participant movements.

Future Studies

Even with limitations including body placement while pedaling, and research inexperience, the current study mirrors that of similar investigations by Li and Caldwell (1996), Duc and colleagues (2003). Similarly this study found no change in muscle activation while simulating an uphill indoors. However, after looking at the data, something to consider for future training practices is the cyclists' joint range of motion in the lower extremities. Using the indoor cycle ergometer as a research tool can allow for investigators to work on biomechanical pedaling efficiency, including investigating ankle kinematics further.

A direction for future kinematic and muscle activity patterns studies should include testing with physiological parameters. Kinematic and muscle activity changes should be investigated during a test to exhaustion while simulating inclination. Variables would include inclined power demands and the magnitude of change involving kinematics and muscle activity patterns throughout the test. This can also allow for investigators to have a better idea of what a cyclist does with an increase in power demand at the pedals. Furthermore, investigations should include increased inclines of more than 15% since it is not uncommon to find mountain biking terrain of 20% or more.

5. *Summary*

The current study found no significant statistical difference between the two conditions (level vs. incline) with respect to kinematics and muscle activity patterns. The findings of the current study are important to better understand the significance of using a cycle ergometer for simulated incline training practices. Results of the current study suggest that there are no training implications of using a block or setting the bike at an actual incline when simulating uphill pedaling while using an indoor cycle ergometer for outdoor training practices. The reason for the lack of differences between conditions with respect to kinematic and muscle activity patterns is hard to pinpoint due to inconsistent pedaling techniques among the participants, data collection, and errors throughout the research process. Results from the current study do not support the hypothesis that the use of a climbing block to raise the front wheel results in significant changes in cycling posture or muscle activation

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