

STRATEGIES TO DECREASE MOVEMENT VARIABILITY
IN THE ANKLE JOINT IN CYCLISTS

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ABSTRACT

Coordination variability is thought to be indicative of a cyclist's skill level as novices have higher levels of variability than experts (Sides & Wilson, 2012). It was hypothesized that the externally focused instructions with visual feedback group would decrease coordination variability in the ankle joint to a greater extent than those in the internally focused instructions with visual feedback group. Six cyclists (30-40 years) completed a four day acquisition period and a retention test. During this time, participants cycled for 10-15 minutes at a power output equal to 2.0-2.5W/kg of body mass. Participants were provided with internally or externally focused instructions and visual feedback relating to those instructions. Two separate 6 (Trial Block) X 2 (Group) Mixed Model Repeated Measures ANOVAs were used to determine if the groups' coordination variability (via MARP and DP values) changed as a result of the intervention. Both groups responded in a similar manner with DP values increasing above pretest values because participants were asked to perform a new task. DP values tended to decrease during the intervention and at retention, DP values continued to decrease. It is believed that the intervention was not long enough to cause a lasting change in how cyclists performed.

Keywords: Attentional Focused Instructions and Feedback; Coordination Variability

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LIST OF ABBREVIATIONS

BDC	Bottom Dead Center
CRP	Coordinative Relative Phase
DP	Deviation Phase
EXT	Externally Focused Instructions
INT	Internally Focused Instructions
MARP	Mean Absolute Relative Phase
ROM	Range of Motion
TDC	Top Dead Center

CHAPTER ONE: INTRODUCTION

In order to gain competence in a skill, learners must engage in a considerable amount of practice (Ericsson, Krampe, & Tesch-Romer, 1993). Practice length is not the only factor influencing skill acquisition, thus researchers have conducted experiments to determine how to enhance the learning of a variety of skills. Motor learning researchers have focused on finding methods that enhance performance (Wulf, Shea, & Lewthwaite, 2010), while biomechanics researchers have focused on the differences that exist between athletes of different skill levels (Wilson, Simpson, van Emmerik, & Hamill, 2008). One area in which these fields intersect is cycling. The present study is an attempt to merge the information obtained by biomechanics researchers about the coordination variability that exists among novice cyclists and that obtained by researchers in motor learning about how attentional focused instructions and feedback have been utilized to enhance learning in healthy subjects.

Coordination Variability

The amount of variability present within the neuromuscular system changes as individuals learn the movement patterns necessary to perform a skill (Shumway-Cook & Woollacott, 2007). During the initial stages of learning a skill, there is a tendency to produce very stiff and seemingly unnatural movements (Shumway-Cook & Woollacott, 2007). As individuals become more comfortable with the newly learned movement, they begin to appear more fluid. Once individuals know how to perform a skill, the amount of

variability present in one's performance may remain stable or may change across multiple repetitions of a given task (Bartlett, Wheat, & Robins, 2007). Although some variability is required in order to be effective, too much or too little may lead to a decrease in performance (Sides & Wilson, 2012; Wilson et al., 2008), and increase one's susceptibility to injury (Hamill, Palmer, & Van Emmerik, 2012).

Intra-limb coordination variability provides a means to analyze how a participant's neuromuscular system adapts while learning a given task (Glazier, Wheat, Pease, & Bartlett, 2006). Intra-limb coordination variability (from this point forward is referred to as only coordination variability) is a measure of the amount of variability present within a single limb while performing a specific task. The amount of coordination variability present within the neuromuscular system should reach a level of stability as individuals learn a given task (Wilson et al., 2008).

Novices and skilled individuals have different levels of coordination variability across different skills. Novices have shown greater variability than skilled performers when bouncing a basketball (Broderick & Newell, 1999) and playing handball (Wagner, Pfusterschmied, Klous, Serge, & Müller, 2012). In other studies, novices and highly skilled performers have shown more coordination variability than those with intermediate skill level in the triple jump (Wilson et al., 2008). According to Wilson et al., as participants learn a skill, the amount of coordination variability present within the neuromuscular system undergoes a U-shaped pattern. While novices have high coordination variability due to the neuromuscular system being highly unstable, experts have high coordination variability due to their ability to adapt to change (Wilson et al., 2008). Athletes of intermediate skill level have a smaller amount of coordination

variability than novices and experts (Wilson et al., 2008). This will be discussed in greater detail in the literature review section.

In the sport of cycling, elite cyclists utilize different movement patterns than novices and are more effective than novices in terms of overall mechanical efficiency and muscle activation (Chapman, Vicenzino, Blanch, & Hodges, 2008; Chapman, Vicenzino, Blanch, & Hodges, 2009). It is believed that these differences can be accounted for at the ankle joint since novices show a decreased range of motion at the ankle and increased coordination variability of the knee and ankle in the sagittal plane when compared to elite cyclists (Chapman et al., 2009; Sides & Wilson, 2012). Novices also show greater individual variance than experts in terms of the duration of the activation of ankle plantar-flexors and dorsi-flexors (Chapman et al., 2008). These differences are important because high levels of coordination variability are thought to be detrimental to cycling performance (Sides & Wilson, 2012). This indicates that muscular coordination is one of the key components of effective cycling and changes in the level of coordination variability could result in a decrease in performance.

Physiological and biomechanical researchers have found that the movement patterns of cyclists are affected by their experience (Sides & Wilson, 2012), their chosen cadence (Bini et al., 2010), the workload (Blake, Champoux, & Wakeling, 2012), and the influence of fatigue (Bini, Diefenthaler, & Mota, 2010). However, the most effective way to enhance the learning of proper pedaling mechanics has not been determined. Perhaps this can be answered from a motor learning perspective. Cycling requires practice and training in order for a person to adopt an efficient coordination pattern (Wilson et al., 2008) and practice provides the perfect venue for integrating attentional

focused instructions, cues, and visual feedback. These tools may prove to be beneficial for individuals learning to cycle as well as those who are training to enhance their performance. The way these tools have been used in the past to enhance performance will be discussed in the following sections.

Attentional Focused Instructions

The effect of attentional focused instructions has been studied extensively in motor learning (Chiviawosky, Wulf, & Wally, 2010; Shea & Wulf, 1999; Wulf, McConnel, Gärtner, & Schwarz, 2002; Wulf, McNevin, & Shea, 2001; Wulf & Su, 2007; Zachry, Wulf, Mercer, & Bezodis, 2005). There are two forms of instructions that are provided to learners, internally focused instructions, which direct a learner's attention to their body, or externally focused instructions, which direct their attention to the effect of their movement (Wulf, 2007). With discrete and continuous skills, researchers have found that internally focused instructions cause an interruption to the movement control process, which leads to a decrease in performance (during acquisition) and learning (as measured by a retention test; Chiviawosky et al., 2010; Wulf et al., 2002; Wulf et al., 2001; Zachry et al., 2005). In contrast, externally focused instructions are thought to allow a "more automatic control process" to occur, which is needed in order to develop an effective movement pattern (Wulf et al., 2002, p. 180).

Many studies have been conducted to examine the effects of attentional focused instructions as related to movement effectiveness. These include but are not limited to: dynamic balancing tasks (Chiviawosky et al., 2010; Wulf, 2008; Wulf et al., 2001); accuracy in sports skills like the golf swing (Wulf & Su, 2007); basketball free throw (Zachry et al., 2005); lofted soccer pass (Wulf et al., 2002); soccer throw (Wulf,

Chiviacowsky, Schiller, & Avila, 2010); and the volleyball tennis serve (Wulf et al., 2002). Movement effectiveness is thought of in terms of accuracy, consistency, and reliability where the goal of the movement is to produce a desired result, i.e. to hit a bull's eye on a dart board (Wulf, 2013). Most studies conducted on movement effectiveness have found that externally focused instructions improve performance to a greater extent than internally focused instructions (Wulf, 2013).

Little research exists on the effects of attentional focused instructions on endurance activities (Freudenheim, Wulf, Madureira, Pasetto, & Corrêa, 2010; Schücker, Hagemann, Strauss, & Völker, 2009; Stoate & Wulf, 2011). An external focus of attention has been shown to increase the speed of intermediate swimmers performing the front crawl (Freudenheim et al., 2010; Stoate & Wulf, 2011), to lower the oxygen consumption of trained endurance runners (Schücker et al., 2009), and to improve the efficiency and effectiveness of oar placement for rowers (Parr & Button, 2009). Movement efficiency is thought of in terms of movement that is economically performed and easily executed (Wulf, 2013). While an external focus of attention has been found to enhance one's ability to perform some endurance tasks (Freudenheim et al., 2010; Schücker et al., 2009; Stoate & Wulf, 2011) more research is needed to determine if learning is also enhanced. The following section will discuss how researchers have provided participants with visual feedback directing their attention to a specific aspect of a skill in addition to providing them with attentional focused instructions.

Attentional Focused Feedback

Feedback given to learners allows them to detect errors in their performance by allowing them to compare the movement they produced with the expected movement

(Schmidt & Lee, 2011). Feedback is used to direct a learner's attention to an aspect of the skill that needs to be refined and has been found to allow them to learn a skill quicker than if they are not provided with feedback (Schmidt & Lee, 2011). Two types of feedback are available for learners, intrinsic and extrinsic. Intrinsic feedback refers to information learners obtain about their movement via proprioceptors, while extrinsic (augmented) feedback is information that is provided by an outside source regarding the movement characteristics (knowledge of performance, KP) or the movement outcomes (knowledge of results, KR; Schmidt & Lee, 2011). Extrinsic feedback is intended to enhance the effects of intrinsic feedback by providing information the learner may not be aware of.

Augmented feedback is typically delivered in a verbal format and can have either an internal or external focus of attention. Similar to the attentional focused instruction literature, externally focused visual feedback has been shown to be more beneficial than internally focused visual feedback for both novices and experts in terms of improving the movement pattern and learning for both discrete and continuous tasks (Wulf, 2007, 2013; Wulf et al., 2010; Wulf et al., 2002). Shea and Wulf (1999) examined dynamic balancing utilizing a stabilometer. Concurrent visual feedback regarding the location of the stabilometer in relation to the horizontal axis was provided. Participants who were told the feedback they received referred to the movement of the stabilometer (externally focused) were able to balance longer than those who were told the feedback provided referred to the movement of their feet relative to the floor (internally focused). The study by Shea and Wulf supports the use of concurrent visual feedback to learners in order to help them adjust their movement to a set reference point.

Biomechanics researchers have found that providing learners with externally focused visual feedback has a positive effect on cycling (Lin, Lo, Lin, & Chen, 2012; Mornieux, Gollhofer, & Stapelfeldt, 2010; Sanderson, 1986). Sanderson found that when participants were able to see the amount of force they were exerting on the pedal, they were able to minimize the amount of force they applied to the pedal during the recovery phase even when visual feedback was removed. The application of force during the recovery phase has been shown to reduce pedaling effectiveness, thus the participant's ability to reduce their force application during this point of the pedal cycle improved their effectiveness (Sanderson, 1986). Mornieux et al. (2010) found that cyclists were able to keep the tangential pedal force positive when provided concurrent visual feedback about the force applied to the pedal, which resulted in improved pedaling effectiveness. Lin et al. (2012) found that stroke patients generated greater power and a smoother cycling movement pattern when provided concurrent visual feedback about their cadence. Neither Mornieux et al. (2010) nor Lin et al. (2012) determined whether the results observed during the intervention were permanent using a retention test. However, these studies indicate that individuals are able to utilize concurrent externally focused visual feedback to adjust their movement patterns to a set reference point.

Need for the Current Study

Variables such as cadence (Bini, Rossato, et al., 2010), workload (Blake et al., 2012), fatigue (Bini, Diefenthaler, & Mota, 2010), and experience (Sides & Wilson, 2012) have been studied to determine the impact on cycling performance. In addition, researchers have found that elite cyclists exhibit different levels of coordination variability than novices (Sides & Wilson, 2012). To date, the effects of providing

participants with attentional focused instructions concurrently with visual feedback and the impact they have on the cycling pattern specifically with regards to coordination variability among cyclists has not been studied. Attentional training programs are inexpensive and can easily be incorporated into a training program; therefore, the results from this study could have implications on how cyclists train. This study will merge the research that has been conducted by motor learning and biomechanics researchers on attentional focused manipulations with the aim of increasing knowledge on the effect of attentional focus manipulations on endurance tasks in terms of both performance and learning. This study will utilize the information obtained about cyclists of different skill levels and attentional focus manipulations to determine if this kind of manipulation is effective at changing an individual's level of coordination variability.

Purpose of the Study

The purpose of this study was to determine if different types of instructions provided concurrently with visual feedback lead to decreased coordination variability in the ankle joint of cyclists. Three expected outcomes were identified: 1) cyclists who received externally focused instructions would decrease the coordination variability in the ankle joint to a greater extent than those who received internally focused instructions, 2) those who were provided with concurrent visual feedback would perform better than those who did not receive feedback (control), and 3) those who received externally focused instructions would show less coordination variability than those who received no instructions or visual feedback (control group). This will be determined by a decrease in the coordination variability of the ankle joint.

Limitations and Delimitations

A limitation of the study is that we did not control whether participants engaged in physical activity outside of the study; this could have changed as a result of their personal motivation, their time commitments, or a major change in lifestyle, and thus impact the results seen in this study. A delimitation of the study is that since this study is limited to cyclists within a specific age range who do not have recent injuries the results from the current study cannot be generalized to the entire cycling community. In addition, the cyclists varied widely in their experience level. This study also focused on the ankle joint at the exclusion of other joints in the lower body that are utilized when cycling.

Significance of the Study

Results from the present study may provide information about the type of instructions that should be given to cyclists. Coaches may be able to influence an athlete's focus of attention during practice. Research conducted in the athletic environment indicates that coaches provide feedback and instructions in such a manner as to induce an internal focus of attention during practice, leading athletes to focus internally during competition (Porter, Wu, & Partridge, 2010). Coaches and instructors believe that it is necessary for athletes to focus on their movements, i.e. to adopt an internal focus, whether through instructions or feedback, in order for their performance to improve (Wulf, 2007; Wulf, 2013). Contrary to what many believe, researchers have found that an internal focus of attention has a detrimental effect on performance throughout a wide variety of skills (Wulf, 2013). More research is needed to determine if an internal focus of attention is beneficial or detrimental for cycling performance. The results from this

study could have implications about how to enhance the acquisition of a less variable movement pattern among cyclists.

Operational Definitions

For the purposes of this study, coordination variability was assessed as the variability observed within the ankle joint throughout each practice period.

A phase angle is a measurement of a segment's velocity and angle during a given time frame. Continuous Relative Phase (CRP) is a measure of the coordination that exists between two segments throughout a particular time period (Stergiou, Jensen, Bates, Scholten, & Tzetzis, 2001). Mean Absolute Relative Phase (MARP) is a measure of the coupling that exists between two segments throughout a trial (Stergiou et al., 2001). Deviation Phase (DP) is a measure of the coordination variability that exists between two segments (Stergiou et al., 2001). These terms will be explained in greater detail within the methods section and pictures showing how these calculates were made will be presented.

Top dead center (TDC) is defined as the point at which the right pedal arm is perpendicular to the floor along the top of the crank; this position corresponds to 0° (see Figure 1). Bottom dead center (BDC) is defined as the point at which the right pedal arm is perpendicular to the floor along the bottom of the crank; this position corresponds to 180° (see Figure 1). The pedal cycle were divided into two portions, the downstroke and the upstroke. The downstroke portion of the pedal cycle corresponded to 0° - 180° while the upstroke portion corresponded to $>180^\circ$ - 360° . One revolution was defined as the time between TDC (360° ; see Figure 1) on two consecutive points (vertical axis).

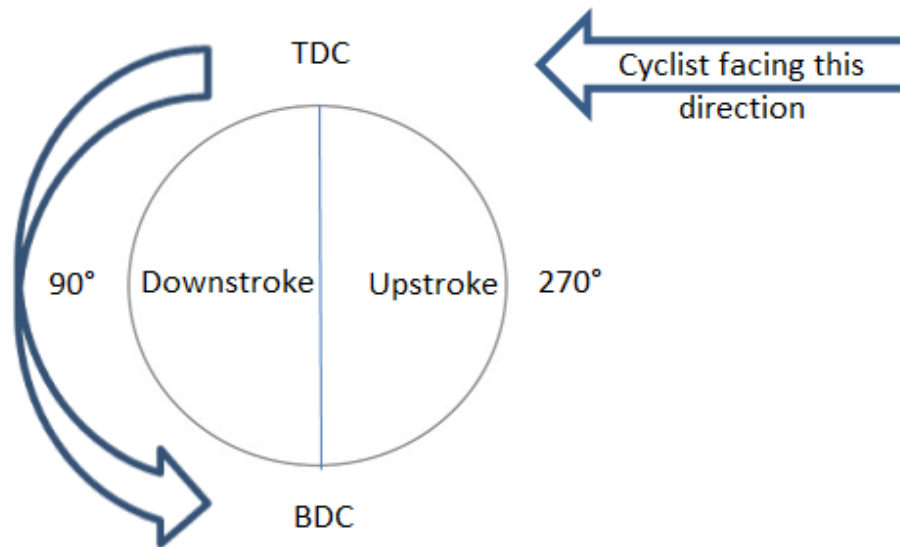


Figure 1 Crank Arm Location

The following section will discuss the information that was utilized to create the current research question. This section will highlight key studies in each area of research (motor learning and biomechanics) that were merged in the current study. In addition, it will provide the rationale for the way the study was designed.

CHAPTER TWO: LITERATURE REVIEW

Cycling has been utilized as a form of transportation, recreation, and competition for years. Biomechanics researchers have examined the factors that contribute to cycling effectiveness, including the differences that exist between cyclists with different levels of expertise (Chapman et al., 2009; Sides & Wilson, 2012; Takaishi, Yamamoto, Ono, Ito, & Moritani, 1998). It has been determined that novice cyclists exhibit high coordination variability at the ankle joint and it is speculated that this variability may have a negative impact on performance (Chapman et al., 2009; Sides & Wilson, 2012). This literature review will examine the factors that have been found to impact pedaling effectiveness (specifically focusing on the differences among novice and elite performers with respect to the coordination variability of the ankle joint). In addition, information will be presented about how motor learning researchers have used attentional focused instructions and visual feedback to enhance the learning of a wide range of skills (Wulf, 2013) and how biomechanics researchers have observed the effect of feedback on cycling performance (Mornieux et al., 2010; Sanderson, 1986).

Cycling

Muscle activation patterns, overall mechanical efficiency, and intra-limb coordination have been studied to determine the most efficient movement patterns among cyclists (Blake et al., 2012). The coordination of the ankle joint during cycling seems to be impacted by many factors including changes to cadence (Bini, Rossato, et al., 2010), workload (Blake et al., 2012), and the onset of fatigue (Bini, Diefenthaler, & Mota,

2010). Blake et al. (2012) found that when overall mechanical efficiency is high, there is greater activation of the ankle plantar-flexors and more plantar flexion through the top and downstroke of the pedal cycle, while there is more dorsiflexion during the upstroke of the pedal cycle. Power output is positively correlated to intra-limb coordination and that overall mechanical efficiency is dependent on the coordination of multiple muscles (Blake et al., 2012). These findings indicate that pedaling effectiveness is associated with intra-limb coordination. Bini, Diefenthaeler, and Mota (2010) found that cyclists adapt their pedaling technique to overcome increases in workload and fatigue. During cycling, adaptations to increasing cadence are characterized by decreased range of motion at the knee and ankle joints (Bini, Rossato, et al., 2010). The ankle joint becomes more plantar flexed with increasing cadence (Sanderson, Martin, Honeyman, & Keefer, 2006) and higher cadences produce more stable and economic movement patterns (Wilson & Sides, 2010). These findings indicate that cyclists are able to change pedaling techniques while cycling, which is a key component in the current research study.

According to Sides and Wilson (2012), coordination variability may be indicative of a cyclist's skill level and as such may not be beneficial to cycling performance as novices exhibit high levels of coordination variability when compared to experts. As mentioned earlier, coordination variability is a measure of the amount of variability present within a single limb while performing a specific task. Expert cyclists are more efficient (i.e., expend less energy) than novices and show greater stability in their movement patterns (Chapman et al., 2008; Chapman et al., 2009), greater coordination among joints (Chapman et al., 2009; Sides & Wilson, 2012), and shorter durations of muscle activity (Chapman et al., 2008). Even though biomechanical differences exist

between novice and expert cyclists, it is important to remember that even elite athletes exhibit coordination variability when performing the same skill including cycling (Bartlett et al., 2007; Sides & Wilson, 2012). Because of their experience with a sport, elite athletes are able to change the amount of coordination variability present in their movement pattern as the task constraints change. Novices on the other hand lack experience and thus are unable to adapt to changing task constraints, which results in the production of variability that is not functional for the task (Davids, Glazier, Araújo, & Bartlett, 2003). Functional movement variability allows the neuromuscular system to adapt to changing task constraints easily while non-functional movement variability constrains the neuromuscular system and is the result of ineffective movement patterns.

Dynamic Systems Theory

Movement variability, of which coordination variability is a subcomponent, was thought to be a problem in the motor system that needed to be minimized or eliminated (Glazier et al., 2006). Movement variability is the amount of variability present within the entire neuromuscular system while performing a specific task and is now thought to be essential to human movement in that it provides an individual with the capability of adapting to a variety of contexts (Glazier et al., 2006). The neuromuscular system is effective because it is able to adapt to changes in the biological system, the environment, and the task constraints in order to produce a more consistent pattern when performing the same movement (Stergiou & Decker, 2011).

The problem learners are faced with when performing a task are the excessive number of degrees of freedom required to complete the task (Davids et al., 2003). Degrees of freedom are the independent movements a joint is capable of, for example,

your ankle is capable of two degrees of freedom (plantarflexion/dorsiflexion and inversion/eversion). According to Dynamic Systems Theory, these redundancies (i.e., allowing the ankle and knee to invert/evert when only flexion/extension is needed) are reduced through the temporary coupling of multiple degrees of freedom, thus creating coordinative structures composed of a single 'virtual' degrees of freedom complex (Davids et al., 2003). The neuromuscular system creates coordinative structures by linking limbs and joints together. For example, when kicking a ball, one's entire body works in sequence. First, a person leans back in preparation to kick the ball and winds up the leg (by swinging the leg back from the hip while the knee and ankle are flexing). The ball is then kicked by flexing from the hip (by swinging the leg forward) followed by knee extension and ankle dorsiflexion as the foot comes in contact with the ball. It should be noted that there is overlap in the coordinative structures that exist in the neuromuscular system with each limb and joint belonging to more than one coordinative structure. This overlap allows the neuromuscular system to function effectively in a variety of tasks.

Dynamic Systems Theory suggests that when the neuromuscular system is unable to respond to the constraints associated with a given task resulting in the production of a highly unstable movement pattern, the neuromuscular system switches to a different, more consistent movement pattern (Stergiou & Decker, 2011). Skilled performers are adept at manipulating the number of degrees of freedom available to perform a specific task as the constraints associated with the execution of the task change (Davids et al., 2003). Less skilled performers exhibit greater non-functional movement variability as a result of rigidly fixing the number of degrees of freedom in an attempt to simplify the

task (Davids et al., 2003; Shumway-Cook & Woollacott, 2007), whereas skilled performers show functional movement variability that allows them to perform a given task when conditions change (Wilson et al., 2008).

Kinematic measurements (i.e., displacement, velocity, and coordinative relative phase) can be used to quantify the amount of variability that exists within the motor system (Glazier et al., 2006). Researchers look for the changes that occur as the motor system develops attractor patterns, these attractor patterns produce stability within the neuromuscular system when a specific task is performed (Glazier et al., 2006). Attractor patterns are the neuromuscular system's preferred movement patterns (i.e., the preferred kinematic measurements while performing a specific task; Shumway-Cook & Woollacott, 2007). Buttfield, Ball, and MacMahon (2009) state that more work is needed to determine how coordination changes with learning, because these changes could indicate an increase in the learning of a skill. The adoption of an attractor pattern is characterized by stability within the neuromuscular system, which should lead to a decrease in kinematic variables (Glazier et al., 2006). In the sections that follow, information will be presented about how an external focus of attention and augmented feedback have been found to enhance the learning of a skill.

Attentional Focused Instructions

Attentional focused instructions are intended to direct a learner's attention to some aspect of the skill they are being asked to perform. Learners may be given internally focused instructions, which direct their attention to their body, or externally focused instructions, which direct their attention to the effect of their movement (Wulf et al., 2002). For over 15 years, researchers have looked at the effect of attentional focused

instructions and the majority of those have found that an external focus of attention enhances both motor learning and performance to a greater extent than an internal focus of attention (Wulf, 2013). Wulf (2013) has questioned if the actual words used in previous research that found an internal focus of attention more beneficial for learning acted like or directed the learner in a similar manner as an external focus.

While a lot of research exists on the benefits of an external focus of attention for discrete skills, few studies have been conducted on their effect on continuous tasks. Researchers examining continuous tasks have found that an external focus of attention decreases swim time (Stoate & Wulf, 2011), improves technique in rowing (Parr & Button, 2009), increases balance time on a stabilometer (Chiviawosky et al., 2010; Shea & Wulf, 1999), and increases the speed of participants on a Pedalo™ (Holz, Hoerz, Munsingen, Germany; Totsika & Wulf, 2003) to a greater extent than an internal focus of attention. These studies indicate that attentional focused instructions may prove to be as effective for one's performance in continuous tasks as they are for performing and learning discrete skills. More research is needed to determine if this is the case for continuous tasks including cycling.

According to the Constrained Action Hypothesis an internal focus of attention constrains the motor system (Wulf et al., 2001). As the learner attempts to consciously control his/her own movements, they interfere with the automatic control processing that would normally occur (Wulf et al., 2001), causing motor performance to suffer. However, asking participants to focus on the effect of the movement (external focus) allows the motor system to operate without interference, thus resulting in enhanced performance (during acquisition) and greater learning (as measured during a retention

test; Wulf et al., 2001). While performing a continuous task like running, it has been found that internally focused instructions lead to less economical movement compared to externally focused instructions (Schücker et al., 2009). This information is critical in that the goal of the present study is to reduce the amount of coordination variability present within the neuromuscular system, which could make movement more economical since expert cyclists show low levels of coordination variability relative to novices (Sides & Wilson, 2012).

Externally focused instructions have been found to enhance performance (Freudenheim et al., 2010; Schücker et al., 2009; Stoate & Wulf, 2011; Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Wulf & Dufek, 2009; Zachry et al., 2005) and learning (Chiviawosky et al., 2010; Parr & Button, 2009; Shea & Wulf 1999; Wulf et al., 2001; Wulf & Su, 2007) more than internally focused instructions for a variety of discrete skills and some continuous tasks like dynamic balancing, moving a Pedalo™, swimming, running, and rowing. When participants are asked to concentrate on the implement that is being used in the study (external focus of attention) instead of what their body is doing (internal focus of attention), they are more effective at completing the desired task. For example, participants move a Pedalo™ (see Figure 2) faster when they are given instructions to push the platforms forward (external focus) rather than instructions to push their feet forward, thus showing enhanced performance (internal focus; Totsika & Wulf, 2003). In other experiments, participants increased the amount of time they could balance on a stabilometer with the use of externally focused instructions to keep the lines/markers in front of their feet horizontal instead of internally focused instructions to keep their feet horizontal (Chiviawosky et al., 2010; Shea & Wulf, 1999;

Wulf et al., 2001). Wulf (2013) has found that externally focused instructions that vary from internally focused instructions in only the term that is used as to where participant's should focus their attention but describe the same objective, i.e. cycling while focusing on either one's feet (internal) or on the pedal (external), are more effective for learning a given task (Wulf, 2013). These findings are important because they led to the rationale of where to direct participant's attention in the present study ('pedal' for the external group, and 'ankle' for the internal group). In the following paragraph, information will be presented about how attentional focused instructions provide support for both Dynamic Systems Theory and the Constrained Action Hypothesis.



Figure 2 eibe play: Double Pedalo

Directing a learner's attention to one part of their body can impact the entire neuromuscular system. Freudenheim et al. (2010) found that swimmers were able to swim faster when provided with externally focused instructions regardless of whether they focused their attention on their arms or legs. These results indicate that focusing on one aspect of a movement may impact the entire movement and not just the area of interest. Further, an interpretation of these results is that the neuromuscular system has created attractor patterns for a specific task and that focusing on only one aspect of that task can cause changes to the entire movement pattern, which provides support for

Dynamic Systems Theory. Wulf and Dufek (2009) found that when participants adopted an external focus of attention, they displayed an increased release of bodily constraints (i.e., they freed up the degrees of freedom) as compared to those that adopted an internal focus of attention. These results indicate that an internal focus of attention interrupts the normal processing that should occur, thus movement patterns are proceduralized appearing frozen and rigid. These results provide support for the Constrained Action Hypothesis, as adopting an external focus of attention allows for a more automatic form of control than an internal focus of attention. Even though increasing degrees of freedom through an external focus of attention may be perceived as being a negative, one should keep in mind that the body has multiple attractor patterns that it can utilize. The goal of the neuromuscular system, as explained by Dynamic Systems Theory, is to produce the most economical movement pattern and thus the neuromuscular system is charged with finding the most efficient attractor pattern. By releasing bodily constraints (i.e., freeing up degrees of freedom), the neuromuscular system is increasing movement economy. In the following section, information will be presented about how individuals are provided with attentional focused augmented visual feedback to enhance the learning of a skill.

Attentional Focused Feedback

Feedback is utilized in an attempt to increase performance and to enhance learning. Individuals obtain feedback about how they are performing a task in one of two ways, as intrinsic or extrinsic feedback. Intrinsic feedback is information that is obtained about an individual's movement through the use of one's proprioceptors while extrinsic (augmented) feedback is information that is obtained from an outside source (Schmidt & Lee, 2011). An example of intrinsic feedback is one's perception of where their foot is

located relative to space, whereas an example of extrinsic feedback is telling the cyclist the actual position of their foot relative to space. Augmented feedback can come in one of two forms, as information related to the characteristics of the movement, i.e. knowledge of performance (KP), or as information related to the outcome of the movement, i.e. knowledge of results (KR; Schmidt & Lee, 2011). Augmented feedback has been found to enhance learning in that participants that receive feedback perform better than participants that do not receive feedback (Shea & Wulf, 1999).

Augmented feedback is given in either a verbal or a visual format and can have either an internal or an external focus. The effect of augmented feedback on learning a new skill is similar to the results found on the effect of attentional focused instructions in that augmented feedback provided with an external focus results in greater accuracy, balance, and an enhanced movement form as opposed to feedback provided with an internal focus (Shea & Wulf, 1999; Wulf et al., 2010; Wulf et al., 2002). Participants are able to utilize visual feedback about the location of an implement being used, such as a stabilometer, to increase the amount of time they can balance (Shea & Wulf, 1999). In addition, participants are able to utilize information about the forces they are applying to an implement, such as a pedal, to adjust their movements to a set reference point (Mornieux et al., 2010; Sanderson, 1986). These results indicate that visual feedback provided with an external focus of attention can be utilized to help participant's achieve a specific skill faster than that achieved without visual feedback. More detail about the use of visual feedback with these implements will be given in the following paragraphs.

Shea and Wulf (1999) conducted an experiment where they had participants balance on a stabilometer to determine if visual feedback enhanced the effects of

attentional focused instructions with externally focused instructions being more beneficial to participants. While balancing on the stabilometer, participants in the internally focused groups were asked to keep their feet at the same height; those in the externally focused groups were asked to keep the yellow lines located in front of their feet (located on the stabilometer itself) at the same height. Those participants that received feedback were shown four lines on a computer screen while those that did not receive feedback were only given attentional focused instructions. Participants in the feedback groups were told that the lines located on the outermost region of the screen represented the horizontal axis and were told either that the lines located on the inside of the screen represented their feet (internally focused) or the yellow lines (externally focused). In reality, the lines located on the inside of the screen represented the same thing for both groups, their deviation from the horizontal plane. Shea and Wulf (1999) found both groups that were provided with concurrent visual feedback performed better than the groups that received only attentional focused instructions and that the externally focused groups performed better than the internally focused groups. This information is important because it shows that visual feedback seems to enhance the effects of attentional focused instructions, an external focus of attention provided with concurrent visual feedback is even more effective than externally focused instructions provided without visual feedback. The frequency with which feedback is given to participants has been studied extensively and will be discussed in the following paragraph.

The Guidance Hypothesis states that providing learners with feedback after every trial improves performance during practice but causes a detriment to learning as measured during retention tests (Salmoni, Schmidt, & Walter, 1984). This is due to the

learner becoming dependent on the feedback and thus not learning the proper technique. Contrary to this view, Wulf et al. (2010) found that feedback provided with an external focus after every trial is more beneficial than reduced frequency externally focused feedback in terms of enhancing the acquisition of the correct movement form. Wulf et al. (2010) claim these results don't support the Guidance Hypothesis because externally focused feedback directs learners to the effect of their movement (external focus of attention) when performing a task. It should be noted support for the Guidance Hypothesis has been obtained by researchers who have utilized feedback that induced an internal focus (Wulf et al., 2010). More research is needed to determine if externally focused feedback provided frequently is indeed beneficial for learning a skill.

Biomechanics researchers have provided cyclists instructions and visual feedback to determine the impact of these instructions and feedback on proper cycling techniques. These researchers utilized instructions and feedback that were external in nature since they asked participants to focus on the amount of force they applied to the pedal (Mornieux et al., 2010; Sanderson, 1986). Sanderson (1986) asked participants to reduce the amount of force applied to the pedal (externally focused) during the upstroke while cycling on a stationary bike. He found that providing participants with visual feedback about the force they were applying to the pedal (externally focused) in the form of a bar graph resulted in improved pedaling techniques. However, Sanderson found that some participants were unable to apply the instructions they were provided and thus showed no change to their pedaling technique. In another study, participants were "asked to keep the tangential force positive during the upstroke" (externally focused). Participants had to pull up on the pedal in order to keep the tangential force positive, causing the ankle joint

to stiffen, thus improving the pedaling effectiveness by changing muscle coordination patterns (Mornieux et al., 2010). This information indicates that participants are able to utilize externally focused instructions provided concurrently with visual feedback to improve pedaling techniques. It should be noted that Mornieux et al. (2010) indicate that in order to properly assess the benefits of the pull up action during the upstroke, cyclists must be allowed to practice. This is important because one of the goals in the current study is to see how practice changes coordination variability during the pedal stroke.

The Integration of Motor Learning and Biomechanics

The use of biomechanical measurements to evaluate the influence of motor learning on the learning of a skill is gaining popularity among researchers. Biomechanical measurements may be used to provide individuals with KP and KR (e.g., forces, angles, velocity, etc.; Buttifield et al., 2009). Biomechanics can be used to determine if an individual's performance changes due to alterations in their technique or to constraints on overall range of motion such as injury (Buttifield et al., 2009). Biomechanics has been used to enhance the learning of a new skill through the use of visual feedback (Mornieux et al., 2010; Sanderson, 1986).

In addition, biomechanical and physiological variables have been shown to improve through the use of an external focus of attention (Schücker et al., 2009; Vance et al., 2004; Wulf et al., 2010; Wulf et al., 2002). Instructions with an external focus of attention have been found to promote maximal and accurate force production, and to positively impact the movement form (Vance et al., 2004; Wulf et al., 2010; Wulf et al., 2002). These findings imply that the movement with which a skill is executed may be manipulated via the use of attentional focused instructions and that individuals may be

trained to apply force at the right time and to an extent that will result in an increased ability to execute a given skill.

Summary

Biomechanics provides a useful tool to evaluate the effectiveness of an attentional focused intervention. Previous studies indicate that externally focused instructions are beneficial to learning and that they produce a greater effect than internally focused instructions for a variety of discrete and continuous tasks (Chiviawosky et al., 2010; Wulf, 2013; Wulf et al., 2002; Wulf et al., 2001; Zachry et al., 2005). Studies also indicate that visual feedback provided with an external focus of attention is beneficial for cyclists (Mornieux et al., 2010; Sanderson, 1986). Biomechanical measurements will be utilized in the present study to investigate the effect attentional focus instructions and visual feedback have on the coordination of the ankle joint during cycling. The following section will discuss in detail how this study was designed. It will also provide rationale for why certain parameters were chosen as well as describe what these parameters were.

CHAPTER THREE: METHODS

This study was conducted to determine if feedback provided concurrently with attentional focused instructions enhanced a cyclist's performance as measured by a decrease in coordination variability. This section will discuss the recruitment protocol, the procedures that were utilized in the study, and how data were analyzed. In addition, this section will provide a brief rationale about the decisions that were made regarding participant recruitment and the procedures that were utilized in the study.

Participants

This study was designed for 50 recreational cyclists (i.e., cycle primarily as a means of transportation or cycle for fitness) between the ages of 18 and 40. A Lifestyle Questionnaire (see Appendix A) was administered to interested participants to exclude those who had an injury limiting their ability to complete the testing protocol as well as those who did not own a bike or clipless pedals. In order to determine participant's level of cycling experience, the Lifestyle Questionnaire inquired about the type of cyclist participants considered themselves to be (road, mountain, or tri-athlete), what their primary reason for cycling was (transportation, competition, or recreation), how many cycling competitions they participated in per year, average distance traveled per week, and whether or not they had a USA cycling license and what category license they possessed.

Participants were recruited from a community in the northwest. Flyers were posted around a northwest university campus, at public meeting places, local gyms, the YMCA, and local bike shops. In addition, information about the study was emailed to cycling groups within the community.

Participants were informed about the potential benefits and risks associated with their participation, the need for them to wear minimal and/or skin tight clothing, and the protocol they would follow during the study. Potential risks included minor discomfort and/or skin irritation from the adhesive used to hold the reflective markers in place. Participants were not informed of the expected outcome so as to minimize the effects the information might have on the data collected. The University's Institutional Review Board approved all recruitment methodologies and the informed consent form (see Appendix B). The following section will discuss the procedures that were followed throughout the study.

Procedures

An equal number of participants would be assigned to five experimental groups, including: (1) an internally focused with visual feedback, (2) an externally focused with visual feedback, (3) an internally focused with no visual feedback, (4) an externally focused with no visual feedback, and (5) a control. The primary investigator met with each participant for an introductory session prior to the start of the study to review the informed consent and to administer the Lifestyle Questionnaire.

All participants underwent a four day acquisition period, which consisted of four 10-minute Trial Blocks conducted one day apart. Participants returned for a 10-minute retention test, following a 72-96 hour retention interval of no training. Each 10-minute

acquisition Trial Block and the retention test Trial Block consisted of five two-minute trials (see Appendix C for a description of each Trial Block). Data were collected during the second minute of each trial.

On day one of the acquisition period, participants had the reflective markers applied for the first time. Once the markers were in place, participants were asked to sit on their bicycle and complete a 5-minute warm-up at a mild intensity of 2.0W/kg of their body mass at their chosen speed. The lowest mean power output for competitive cyclists during the flat stages of a multistage race has been found to be 2.0W/kg of body mass (Vogt, Schumacher, Blum, et al., 2007). The reason for utilizing this power output was to allow for comparison between novice and competitive cyclists. In addition, the flat stages of a multistage race are associated with a low to moderate mean exercise intensity (Lucía, Hoyos, & Chicharro, 2001) and thus mean power outputs during these stages were chosen for the required load. Any negative effects of utilizing this power output would be negated by allowing cyclists to choose their own cadence.

Following the warm-up period, participants were asked to cycle for two minutes at a moderate intensity of 2.5W/kg of their body mass at their chosen speed; pretest data were collected during the last minute. A power output equal to 2.5W/kg of body mass has been found to be the lowest power output associated with the highest mean of 3.1W/kg of body mass for competitive cyclists during the flat stages of a multistage race (Vogt, Schumacher, Roecker, et al., 2007). The rationale for choosing this power output is the same as that for choosing the power output during warm-up. The pretest was followed by a one minute familiarization period for those in Groups 1 and 2 (the feedback groups) only, during which time participants were informed that the graph they were seeing on

the television (see Figure 3) represented the angle of their foot (internal focus) or of the pedal (external focus). Following the familiarization period, the first acquisition Trial Block began.

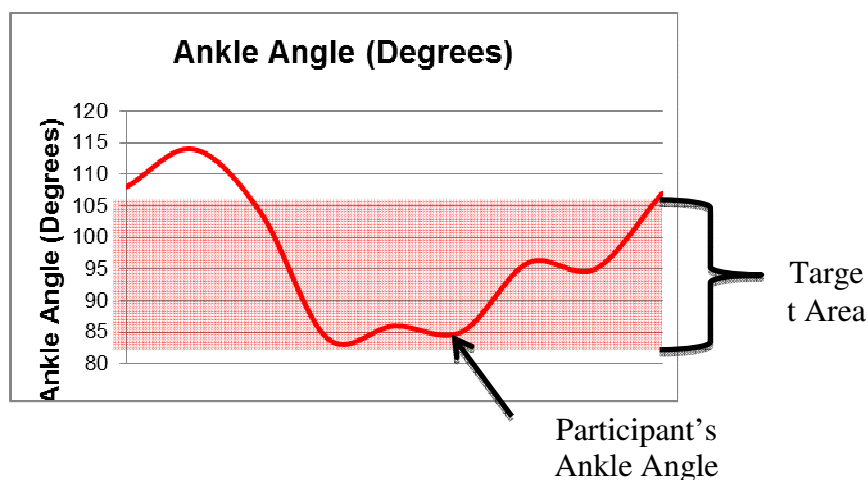


Figure 3 Ankle Angle Graph¹

Before each acquisition Trial Block, participants were given either internally focused instructions or externally focused instructions. Internally focused instructions consisted of the following: “I want you to focus on pushing down with your **foot** during the downstroke and pulling up with your **foot** during the upstroke while keeping the red line within the red box.” Externally focused instructions consisted of the following: “I want you to focus on pushing down on the **pedal** during the downstroke and pulling up on the **pedal** during the upstroke while keeping the red line within the red box.” It should be noted that the only difference in instructions provided to the internally focused and externally focused groups was the word “foot” and “pedal.” Every minute

¹ This figure represents the feedback participants were given during the intervention.

during each 10-minute acquisition Trial Block, participants were reminded of instructions via cues like: “remember to push down on the **pedal** during the down stroke” or “remember to push down with your **foot** during the down stroke.”

On days 2-4, participants completed the same 5-minute warm up and 10-minute moderate intensity cycling protocol as described above. All participants returned 72-96 hours after the acquisition period for a 5-minute warm-up and a 10-minute retention test. During the retention test, all participants cycled at a moderate intensity of 2.5W/kg of their body mass at their chosen speed without attentional focused instructions, cuing, or visual feedback.

Instruments

A Computrainer™ (cycle ergometer, Racermate Inc., Seattle, WA) was used to provide resistance as well as to provide the participants with information about their cadence. The rear wheel was replaced with a standard slick road wheel to facilitate calibration and to minimize wear or damage to either the bicycle or the Computrainer™.

An eight camera Vicon Nexus motion capture system (Vicon Motion Systems, Oxford, UK) collected 3D kinematic data at a sample rate of 120Hz was utilized to collect data of each participant’s lower body. Sixteen markers were placed on the participants in a pattern corresponding to the Plug-In Gait marker set (“Tutorial”; see Table 1 for a detailed description of each marker placement and Figure 4). Measurement of each participant’s leg length (medial malleolus to ASIS) was obtained via a tape measure for both legs. Inter-ASIS (Left ASIS to Right ASIS), ankle (medio-lateral distance across the malleoli), and knee width (medio-lateral distance across the line of the

knee axis), was obtained via a caliper. Each participant's bicycle was fitted with three reflective markers on the left pedal to allow for analysis of the location of the pedal.

Table 1 Marker Location

Marker	Location
LASI	Placed directly over the left anterior superior iliac spine
RASI	Placed directly over the right anterior superior iliac spine
LPSI	Placed directly over the left posterior superior iliac spine
RPSI	Placed directly over the right posterior superior iliac spine
LKNE	Placed on the lateral epicondyle of the left knee
RKNE	Placed on the lateral epicondyle of the right knee
LTHI	Placed on the left thigh in line with the plane that contains the hip and knee joint centers
RTHI	Placed on the right thigh in line with the plane that contains the hip and knee joint centers
LANK	Placed on the lateral malleolus of the left leg
RANK	Placed on the lateral malleolus of the right leg
LTIB	Placed on the left shank in line with the plane that contains the knee and ankle joint centers
RTIB	Placed on the right shank in line with the plane that contains the knee and ankle joint centers
LTOE	Placed at the base of the second metatarsal head of the left foot
RTOE	Placed at the base of the second metatarsal head of the right foot
LHEE	Placed on the left calcaneous at the same height as the left toe marker
RHEE	Placed on the right calcaneous at the same height as the right toe marker

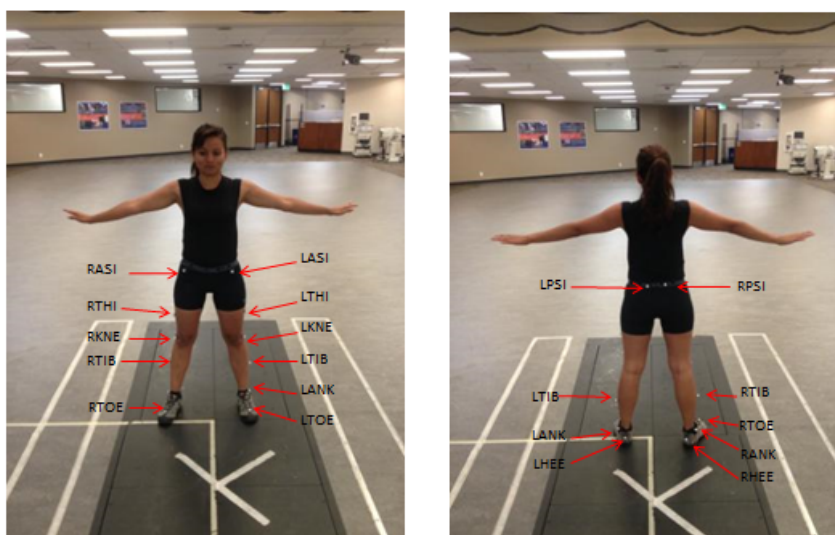


Figure 4 Marker Placement²

Real-time data were presented to each participant in the form of a line graph showing them the flexion and extension of their left ankle or the left pedal angle in relation to the horizontal axis (see Figure 3). Participant's bicycles were set-up so participants faced a television mounted on the wall of the lab, which displayed the line graph. Participants were asked to keep either their ankle flexion/extension or the left pedal angle in the target zone, a range indicated via a red box running the length of the line graph (see Figure 3).

Data Collection and Processing

Data collection consisted of 3D kinematic data of the lower limb during the second minute of every two minute trial. The first minute of each trial was intended to

² The picture on the left represents marker placement in the front; the figure on the right represents marker placement in the back.

allow participants to achieve a degree of comfort with the instructions and cues before data were recorded.

All kinematic data were filtered using a low pass Butterworth filter with a cut-off frequency of 6Hz with Visual 3D motion analysis software (C-Motion, Germantown, MD). From the data collected during each trial, 10 consecutive revolutions were analyzed further. There is no consistency in the number of revolutions that are analyzed in cycling studies with a range of 3-30 revolutions, therefore 10 revolutions were chosen to be analyzed in the current study (Mornieux et al., 2010; Sanderson et al., 2006; Sides & Wilson, 2012). One revolution is defined as the time between two consecutive points as determined by the pedal segment reaching its maximal value along the z-axis (vertical axis); Top Dead Center (TDC) to TDC (see Figure 1).

Filtered data were then used to calculate 3D foot and shank segment angles (see Figure 7A left; dorsiflexion represented by positive slope; plantarflexion is represented by negative slope; 2 cycles/revolutions are shown in each graph). The derivatives of these segments were then calculated to determine the segment's angular velocities. Only ankle dorsiflexion and plantarflexion were analyzed as the instructions and feedback that were provided to participants targeted this motion. A custom program written in MatLAB (MathWorks, Natick, MA) were utilized to calculate all of the measurements discussed in the following paragraphs.

Due to the differences in time it took participants to complete one revolution, segment angle and angular velocities were assessed on a revolution by revolution basis and interpolated to 100% of one revolution. Segment angles were then normalized to the maximum and minimum of each data set so that zero represented the midpoint of the

movement (see Figure 5A left) while angular velocities were normalized to the greatest absolute value to maintain zero velocity at the origin (see Figure 5A right; Kurz & Stergiou, 2002; Sides & Wilson, 2012).

Angular position and velocity phase plots were created for the entire normalized pedal cycle (revolution) based on the segment's angle and angular velocity (see Figure 5B; Seay, Haddad, van Emmerik, & Hamill, 2006). Phase angles were then calculated for the left foot and shank segments. A phase angle is a measurement of a segment's velocity and angle during a given time frame. Phase angles were calculated as the arctan of the segment's normalized angular velocity with respect to the segment's normalized angular displacement (see Figure 5C; Seay et al., 2006).

Continuous Relative Phase (CRP) values were calculated for the left ankle (see Figure 5D). CRP is a measure of the coordination that exists between two segments throughout a particular time period (Stergiou et al., 2001). CRP is calculated by subtracting the phase angles of the corresponding segments: $\phi_{\text{Sagittal Rel. Ankle Phase}} = \phi_{\text{Foot}} - \phi_{\text{Shank}}$ (Stergiou et al., 2001). CRP values close to 0° indicate that the segments are coupled together, while values closer to 180° indicate that the segments are not coupled together (Stergiou et al., 2001).

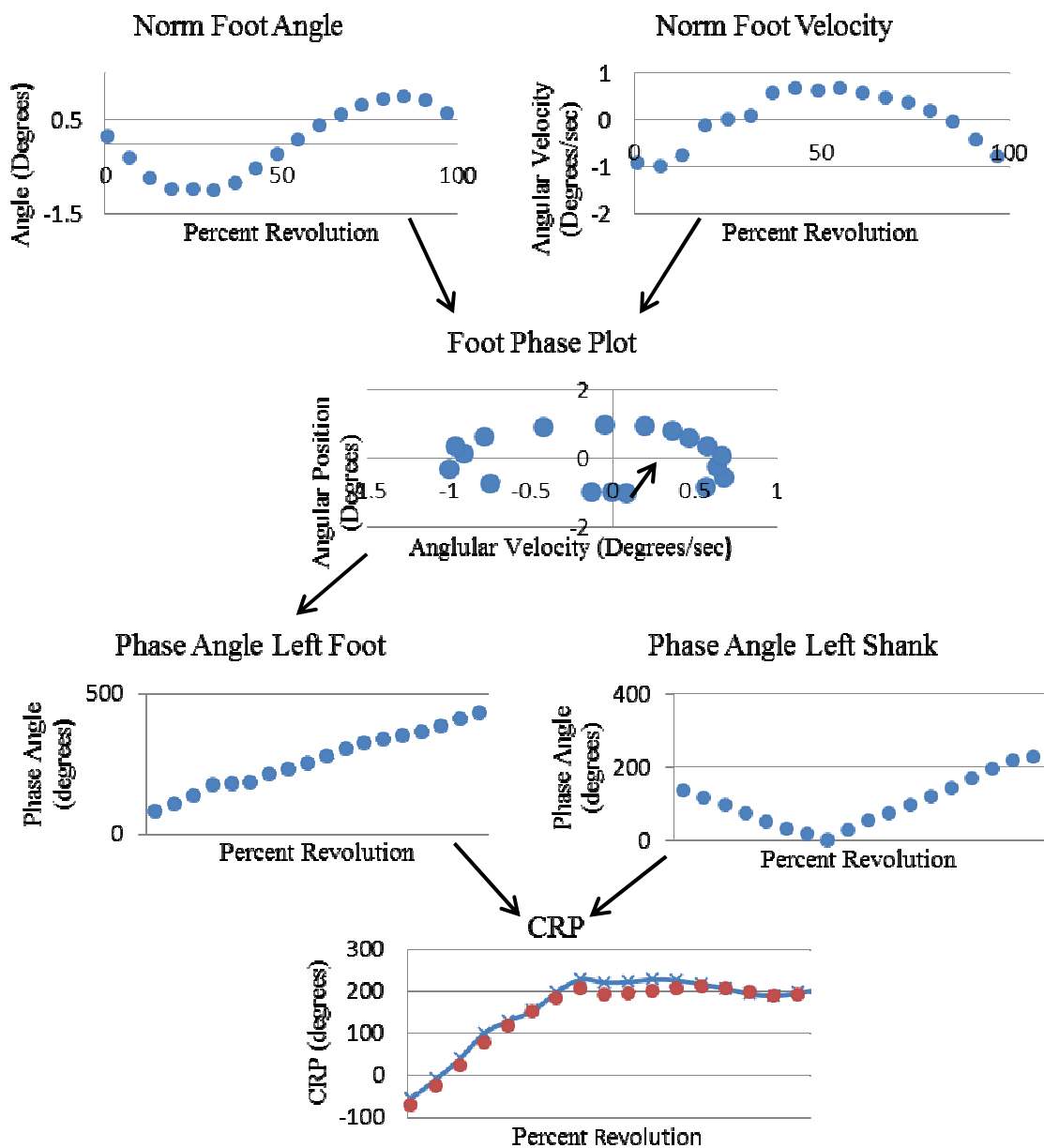


Figure 5 Data Analysis Explained³

3 Figure 5A left represents the normalized angular position of the left foot throughout one revolution. Figure 5A right represents the normalized angular velocity of the left foot throughout one revolution; dorsiflexion is indicated by increasing negative values while plantarflexion is represented by increasing positive values. Figure 5B represents the phase plot for the left foot. Figure 5C left represents the phase angle for the left foot and is obtained as the deviation from the horizontal of the phase plot. Figure 5C right represents the phase angle for the left shank. The same measurements (A & B) were conducted for the left shank to obtain the phase angle. Figure 5D represents two CRP curves.

The CRP values were averaged to produce Mean Absolute Relative Phase (MARP) values. MARP values were calculated as follows: $MARP = (\sum_{i=1}^p |\phi_{\text{Sagittal Rel. Ankle Phase } |_i}) / p$, where p represents the number of CRP values (Stergiou et al., 2001). A low MARP value is indicative of greater coupling between the segments (Stergiou et al., 2001). In addition to MARP, the standard deviations of the ensemble CRP curve points were averaged to calculate the Deviation Phase (DP) values (Stergiou et al., 2001). A low DP value is indicative of less variability (i.e., greater stability) between segments (Stergiou et al., 2001).

Data Analysis

Average MARP and DP values from the pretest, each acquisition Trial Block, and the retention test were compared to determine if movement patterns and coordination variability changed as a result of the intervention. Two separate 6 (Trial Block) x 2 (Group) Mixed Model Repeated Measures ANOVAs with a significance level of $p=0.05$ were run for MARP and DP values. A Tukey LSD Post Hoc test was run if any significant difference was found between conditions. The following section will discuss the results of this study.

CHAPTER FOUR: RESULTS

Introduction

Recreational (i.e., cycle primarily as a means of transportation or cycle for fitness) and competitive cyclists were recruited for this study when further research revealed that even competitive athletes had different levels of coordination variability. This study was designed for 50 participants, however significant difficulties in participant recruitment resulted in a small number of participants involved in the study. Seven healthy male and female cyclists between 30-40 years of age participated in this study. Since the main intent of this study was to determine if cyclists could benefit from the combination of visual feedback and attentional focused instructions, the seven participants that were successfully recruited for this study were divided into two groups: (1) an internally focused with visual feedback group, and (2) an externally focused with visual feedback group. By reducing the number of groups studied, only the first expected outcome in this study remained, that providing participants with externally focused instructions and visual feedback would reduce the coordination variability in the ankle joint to a greater extent than internally focused instructions provided with visual feedback.

Participants

Descriptive statistics are provided for the participants, how often participants competed in cycling competitions per year, the distance traveled (miles per week), and the mean and standard deviations of their ages (see Table 2). Four participants were

provided internally focused instructions with concurrent visual feedback (INT) while two participants were provided externally focused instructions with concurrent visual feedback (EXT). One participant did not complete acquisition Trial Block 4; this data was not included in the final analysis.

Table 2 Subject Demographics

Group	Gender	Age	Height (Inches)	Weight (lbs)	Competitions/Year	Miles/Week	Experience
INT	Male	39	72.25	233	2	150	High
INT	Male	35	68.5	181.5	0	40-50	Med.
INT	Female	32	66.25	175.5	0	30-40	Med.
INT	Female	35	64	139.5			Low
EXT	Male	38	66.5	155	3	200	High
EXT	Male	31	69.33	148	0	30	Low

Mean Absolute Relative Phase (MARP)

MARP describes the coordination pattern that existed between the left foot and shank segments for each Trial Block (see Table 3 for descriptive statistics for each group).

Table 3 MARP Values for each Trial Block

Trial Block	Externally Focused		Internally Focused	
	Mean	SD	Mean	SD
Pretest	156.79	8.18	159.12	3.40
Acquisition Trial Block 1	160.27	4.29	157.29	3.08
Acquisition Trial Block 2	156.80	0.15	156.19	3.07
Acquisition Trial Block 3	158.50	1.31	156.73	3.58
Acquisition Trial Block 4	161.80	0.56	157.75	2.12
Retention	155.14	2.53	156.92	1.88

Deviation Phase (DP) Values

DP describes the coordination variability that existed between the left foot and shank segments for each Trial Block (see Table 4 for descriptive statistics for each group).

Table 4 DP Values for each Trial Block

Trial Block	Externally Focused		Internally Focused	
	Mean	SD	Mean	SD
Pretest	4.05	2.16	5.08	2.14
Acquisition Trial Block 1	8.21	5.50	8.99	4.29
Acquisition Trial Block 2	10.73	1.95	6.34	2.13
Acquisition Trial Block 3	6.11	2.05	6.73	2.97
Acquisition Trial Block 4	7.86	3.35	6.19	1.77
Retention	6.38	0.51	5.54	1.44

Statistical Analysis of Mean Absolute Relative Phase (MARP)

A 6 (Trial Blocks) X 2 (Groups) Mixed Model Repeated Measures ANOVA found that the Trial Blocks (pretest, acquisition Trial Blocks, and retention test) were not significantly different, $F(5,20) = 2.263, p = .087 (\eta^2 = .361)$. No interaction was found between the Trial Blocks and the Groups, $F(5,20) = 1.902, p = .139 (\eta^2 = .322)$, indicating that the two groups responded in a similar manner to the intervention. In addition, no significant effect by Group was found, $F(1,4) = 0.161, p = .709 (\eta^2 = .039)$. Figure 6 shows the changes that occurred between Trial Blocks.

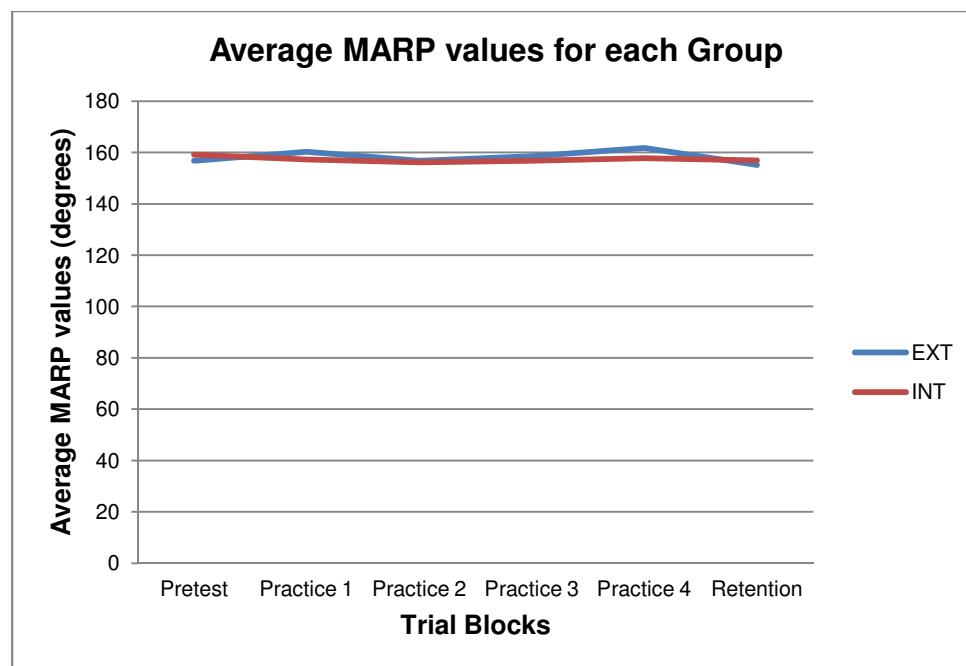


Figure 6 Average MARP values across each Trial Block for each Group⁴

Statistical Analysis of Deviation Phase (DP)

A 6 (Trial Blocks) X 2 (Groups) Mixed Model Repeated Measures ANOVA found that the Trial Blocks (pretest, acquisition Trial Blocks, and retention test) were Trial Blocks and Groups, $F(5,20) = 1.85$, $p = .148$ ($\eta^2 = .316$), indicating that the two groups responded in a similar manner to the intervention. In addition, no significant effect by Group was found, $F(1,4) = 0.152$, $p = .717$ ($\eta^2 = .037$). Figure 7 indicates that the pretest DP values were lower than every other Trial Block, thus indicating that the intervention caused an increase to the DP values in both groups.

⁴ Externally focused (EXT) and Internally focused (INT)

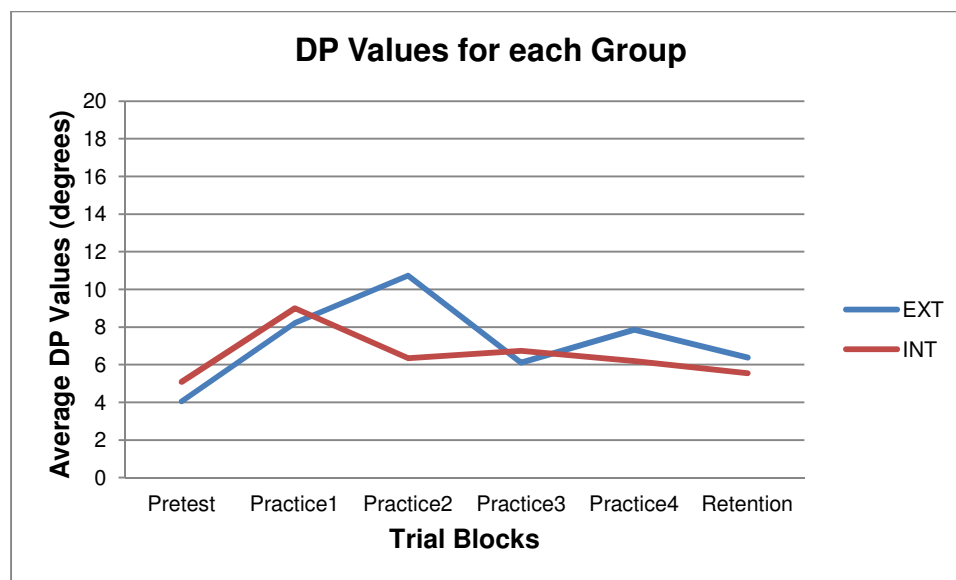


Figure 7 Average DP values across each Trial Block for each Group⁵

A Tukey LSD Post Hoc test was conducted to determine between which Trial Blocks significant differences existed. The pretest was found to be significantly different than all Trial Blocks except acquisition Trial Block 3, $p < .05$. The pretest was found to approach significant difference from acquisition Trial Block 3, $p = .058$. Acquisition Trial Block 2 was found to be significantly different than the retention test, $p = .019$.

⁵ Externally focused (EXT) and Internally focused (INT)

REFERENCES

- Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics*, *6*(2), 224-243.
- Bini, R. R., Diefenthaler, F., & Mota, C. B. (2010). Fatigue effects on the coordinative pattern during cycling: Kinetics and kinematics evaluation. *Journal of Electromyography & Kinesiology*, *20*, 102-107.
- Bini, R. R., Rossato, M., Diefenthaler, F., Carpes, F. P., Cunha dos Reis, D., & Moro, A. R. P. (2010). Pedaling cadence effects on joint mechanical work during cycling. *Isokinetics & Exercise Science*, *18*, 7-13.
- Blake, O. M., Champoux, Y., & Wakeling, J. M. (2012). Muscle coordination patterns for efficient cycling. *Medicine & Science in Sports & Exercise*, *44*(5), 926-938.
- Broderick, M. P., & Newell, K. M. (1999). Coordination patterns in ball bouncing as a function of skill. *Journal of Motor Behavior*, *31*(2), 165-188.
- Buttfield, A., Ball, K., & MacMahon, C. (2009). The use of motor learning in Biomechanics: A call for more collaboration. *International Journal of Sport Psychology*, *40*(4), 603-615.
- Chapman, A. R., Vicenzino, B., Blanch, P., & Hodges, P. W. (2008). Patterns of leg muscle recruitment vary between novice and highly trained cyclists. *Journal of Electromyography & Kinesiology*, *18*, 359-371.

- Chapman, A., Vicenzino, B., Blanch, P., & Hodges, P. (2009). Do differences in muscle recruitment between novice & elite cyclists reflect different movement patterns or less skilled muscle recruitment? *Journal of Science & Medicine in Sport, 12*, 31-34.
- Chiviacowsky, S., Wulf, G., & Wally, R. (2010). An external focus of attention enhances balance learning in older adults. *Gait & Posture, 32*, 572-575.
- Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: The functional role of variability and its implications for sports medicine. *Sports Medicine, 33*(4), 245-260.
- eibe play. (n.d.) [Image of a pedalo]. *Double pedalo*. Retrieved from:
<http://www.eibe.co.uk/shop/item/507089/507120/0/638775/double-pedalo.html>
- Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363-406.
- Freudenheim, A. M., Wulf, G., Madureira, F., Pasetto, S. C., & Corrêa, U. C. (2010). An external focus of attention results in greater swimming speed. *International Journal of Sports Science & Coaching, 5*(4), 533-542.
- Glazier, P. S., Wheat, J. S., Pease, D. L., & Bartlett, R. M. (2006). The interface of biomechanics and motor control: Dynamic systems theory and the functional role of movement variability. In K. Davids, S. J. Bennett, & K. M. Newell (Eds.), *Movement system variability* (pp. 49-69). Champaign (IL): Human Kinetics.

- Hamill, J., Palmer, C. & Van Emmerik, R. E. A., (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy, & Technology*, 4(45), 2-9.
- Kurz, M. J., & Stergiou, N. (2002). Effect of normalization and phase angle calculations on continuous relative phase. *Journal of Biomechanics*, 35, 369-374.
- Lin, S.-I., Lo, C.-C., Lin, P.-Y., & Chen, J.-J. J. (2012). Biomechanical assessments of the effect of visual feedback on cycling for patients with stroke. *Journal of Electromyography & Kinesiology*, 22, 582-588.
- Lucía, A., Hoyos, J., & Chicharro, J. L. (2001). Physiology of professional road cycling. *Sports Medicine*, 31(5), 325-337.
- Mornieux, G., Gollhofer, A., & Stapelfeldt, B. (2010). Muscle coordination while pulling up during cycling. *International Journal of Sports Medicine*, 31, 843-846.
- Parr, R., & Button, C. (2009). End-point focus of attention: Learning the 'catch' in rowing. *International Journal of Sport Psychology*, 40(4), 616-635.
- Porter, J. M., Wu, W. F. W., & Partridge, J. A. (2010). Focus of attention and verbal instructions: Strategies of elite track and field coaches and athletes. *Sports Science Review*, 19, 77-89.
- Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin*, 95(3), 355-386.
- Sanderson, D. J. (1986). *The use of augmented feedback for the modification of riding mechanics of inexperienced cyclists*. (Unpublished doctoral dissertation). The Pennsylvania State University, University Park, Pennsylvania.

- Sanderson, D. J., Martin, P. E., Honeyman, G., & Keefer, J. (2006). Gastrocnemius and soleus muscle length, velocity, and EMG responses to changes in pedalling cadence. *Journal of Electromyography & Kinesiology*, *16*, 642-649.
- Schmidt, R. A., & Lee, T. D. (2011). Augmented feedback. In M. Schrag (Ed.), *Motor control and learning: A behavioral emphasis* (pp. 393-428). Champaign, IL: Human Kinetics.
- Schücker, L., Hagemann, N., Strauss, B., & Völker, K. (2009). The effect of attentional focus on running economy. *Journal of Sports Sciences*, *27*(12), 1241-1248.
- Seay, J. F., Haddad, J. M., van Emmerik, R. E. A., & Hamill, J. (2006). Coordination variability around the walk to run transition during human locomotion. *Motor Control*, *10*, 178-196.
- Shea, C. H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Studies*, *18*, 553-571.
- Shumway-Cook, A., & Woollacott, M. H. (2007). Motor learning and recovery of function (p.21-46) In: *Motor control: Translating research into clinical practice*. Lippincott Williams & Wilkin: Baltimore, MD.
- Sides, D., & Wilson, C. (2012). Intra-limb coordinative adaptations in cycling. *Sports Biomechanics*, *11*(1), 1-9.
- Stergiou, N., & Decker, L. M. (2011). Human movement variability, nonlinear dynamics, and pathology: Is there a connection? *Human Movement Science*, *30*, 869-888.
- Stergiou, N., Jensen, J. L., Bates, B. T., Scholten, S. D., & Tzetzis, G. (2001). A dynamical systems investigation of lower extremity coordination during running over obstacles. *Clinical Biomechanics*, *16*, 213-221.

- Stoate, I., & Wulf, G. (2011). Does the attentional focus adopted by swimmers affect their performance? *International Journal of Sports Science & Coaching*, 6(1), 99-108.
- Takaishi, T., Yamamoto, T., Ono, T., Ito, T., & Moritani, T. (1998). Neuromuscular, metabolic, and kinetic adaptations for skilled pedaling performance in cyclists. *Medicine & Science in Sports & Exercise*, 30(3), 442-449.
- Totsika, V., & Wulf, G. (2003). The influence of external & internal foci of attention on transfer to novel situations & skills. *Research Quarterly for Exercise & Sport*, 74(2), 220-225.
- Tutorial: Plug-In Gait Lower-Limb. Retrieved from: [http://www.c-motion.com/v3dwiki/index.php?title=Tutorial: Plug-In Gait Lower-Limb](http://www.c-motion.com/v3dwiki/index.php?title=Tutorial:_Plug-In_Gait_Lower-Limb)
- Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior*, 36(4), 450-459.
- Vogt, S., Schumacher, Y. O., Blum, A., Roecker, K., Dickhuth, H.-H., Schmid, A., & Heinrich, L. (2007). Cycling power output produced during flat and mountain stages in the Giro d'Italia: A case study. *Journal of Sports Sciences*, 25(12), 1299-1305.
- Vogt, S., Schumacher, Y. O., Roecker, K., Dickhuth, H.-H., Schoberer, U., Schmid, A., & Heinrich, L. (2007). Power output during the Tour de France. *International Journal of Sports Medicine*, 28, 756-761.

- Wagner, H., Pfusterschmied, J., Klous, M., Serge P. v. D., & Müller, E. (2012). Movement variability and skill level of various throwing techniques. *Human Movement Science, 31*, 78-90.
- Wilson, C., & Sides, D. (2010, July). The influence of work rate and cadence on movement coordination in cycling. Paper presented at the annual meeting of International Symposium on Biomechanics in Sports, Marquette, Michigan, USA.
- Wilson, C., Simpson, S. E., van Emmerik, R. E. A., & Hamill, J. (2008). Coordinative variability and skill development in expert triple jumpers. *Sports Biomechanics, 7*(1), 2-9.
- Wulf, G. (2007). *Attention and motor skill learning*. Champaign, IL: Human Kinetics.
- Wulf, G. (2008). Attentional focus effects in balance acrobats. *Research Quarterly for Exercise & Sport, 79*(3), 319-325.
- Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport & Exercise Psychology, 6*, 77-104.
- Wulf, G., Chiviawosky, S., Schiller, E., & Avila, L. T. G. (2010). Frequent external-focus feedback enhances motor learning. *Frontiers in Psychology, 1*, 1-7.
- Wulf, G., & Dufek, J. S. (2009). Increased jump height with an external focus due to enhanced lower extremity joint kinetics. *Journal of Motor Behavior, 41*(5), 401-409.
- Wulf, G., McConnel, N., Gärtner, M., & Schwarz, A. (2002). Enhancing the learning of sports skills through external-focus feedback. *Journal of Motor Behavior, 34*(2), 171-182.

- Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology, 54A*(4), 1143-1154.
- Wulf, G., Shea, C., Lewthwaite, R. (2010). Motor skill learning and performance: A review of influential factors. *Medical Education, 44*, 75-84.
- Wulf, G., & Su, J. (2007). An external focus of attention enhances golf shot accuracy in beginners and experts. *Research Quarterly for Exercise and Sport, 78*(4), 384-389.
- Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67*, 304-309.

APPENDIX A

Lifestyle Questionnaire

Lifestyle Questionnaire

Name: _____

Date: _____

DOB: _____

Gender: _____

Cycling Habits:

- How often do you compete in cycling competitions?
 - Never
 - 1 – 2 a year
 - >2 a year
- If you have competed in a cycling competition, was it a licensed event?
 - Yes
 - No
- If yes, do you have a cycling license?
 - Yes
 - No
- If yes, what kind?
 - Competitive
 - Non-competitive
- When was your last cycling competition if any?
 - <6 months ago
 - 0-6 months ago
- Are you currently training for a cycling competition (check one)?
 - Yes
 - No
- Do you cycle primarily as a means of transportation or recreation (check one)?
 - Transportation
 - Recreation
- At what intensity do you cycle (check all that apply)?
 - Mild (perceived exertion low)
 - Moderate (perceived exertion moderate)
 - High (perceived exertion high)
- Do you own a bike (check one)?
 - Yes
 - No
 - If yes, what kind (check one)?
 - Road
 - Mountain
- If you own a Mountain Bike, what kind of tires do you have?
 - Slick
 - Treaded
- Do you have pedals that allow you to clip in (check one)?
 - Yes

No

Miscellaneous Information:

- Do you have any medical condition that will impede your ability to finish the training protocol?
 - Yes
 - No

APPENDIX B

Informed Consent Form

Informed Consent Form

Principal Investigator: Claudia Chavez

Co-Investigator: Eric Dugan, PhD

Study Title: Strategies to Decrease Movement Variability in the Ankle Joint in Cyclists

This informed consent is intended to provide you with information to help you understand the nature of this research study. It will describe what you will be asked to do as a participant and the possible risks/discomfort involved. You may ask for clarification at any time. If after reviewing this form and asking questions, you decide to participate you will be asked to sign this form thereby indicating your consent to participate. A copy of the signed form will be kept on record separately from the data collected. You will be given a copy of this form to keep for your personal records.

Purpose and Background

You are being asked to participate in a research study to determine the effect different types of instructions and visual feedback have on cyclists when provided during a practice period. The information obtained from this study will be used to determine what type of instructions and visual feedback are beneficial for cyclists and will be used in part of a master's thesis. You are being asked to participate because you are a cyclist. This study is restricted to those 18-40 years of age.

Procedures

Prior to the start of the study, you will be asked to complete an Inclusion/Exclusion Questionnaire related to your cycling experience in order to

determine your eligibility to participate in the study. In order to complete the Inclusion/Exclusion Questionnaire you will be asked to come to the Boise State University Center for Orthopaedic and Biomechanical Research (COBR) located 1.0 mile off campus on Parkcenter Blvd. Once your eligibility is confirmed, the following measurements will be obtained: height, weight, leg length, hip, ankle, and knee width. These measurements will be obtained using a scale, tape measure and calipers. The administration of the Informed Consent form, the Inclusion/Exclusion Questionnaire, and obtaining your measurements should take no more than an hour.

If you are eligible for this study, you will be asked to return to COBR for five days (Tuesday-Friday and the following Monday). All sessions will take place in under an hour.

Data will be collected via video recording and you will be asked to wear either skin-tight or minimal clothing without any reflective surfaces in order for proper placement of the reflective markers. The reflective markers are 5cm wide and are attached with double-sided tape to either your skin or clothing. The cameras are designed to identify only reflective surfaces; the use of the reflective markers allows the cameras to find and track your body.

The practice period will occur over four consecutive days (Tuesday-Friday) and will be followed by a retention test on the Monday after the last practice session. During the practice sessions, you will be asked to cycle at a speed of your choice for approximately 15 minutes. The first five minutes will be used as a warm-up period, while the remaining 10 minutes will be used to gather information regarding your pedaling patterns while cycling. You will be provided with instructions, some of which may tell

you what you should focus on while pedaling. All instructions will be provided prior to the start of the practice session and if you are given instructions about what to focus on, key phrases will be repeated every minute. In addition, you may be provided with visual feedback allowing you to see what you are being asked to focus on. If you are provided with visual feedback, you will only see the visual feedback during the 10 minute data collection during the practice sessions and you will be informed how to interpret the information presented. During the retention test you will not receive instructions about what to focus on or any visual feedback.

You must bring your own bike with you to COBR during the practice period and the retention test. Your bike will be placed on a Computrainer™ and your rear wheel will be replaced with a slick road wheel in order to minimize differences in the calibration of the Computrainer™.

Risks/Discomfort

The need to wear skin-tight or minimal clothing may cause you some anxiety, however, all doors will be locked to prevent the entry of unauthorized personal and only essential personal will remain in the lab during the practice sessions and post-test.

The adhesive tape attaching the reflective markers to your skin may cause an allergic reaction and removing the markers may cause some discomfort. Every effort will be made to reduce the amount of discomfort associated with you having the option of removing the markers yourself. If you experience an allergic reaction please notify the primary investigator as well as your personal physician.

Benefit from the study

Results from this study may enhance the knowledge about what information cyclists should be given in order to improve performance.

Confidentiality

Data for all subjects will be identified via a unique number (the key will be stored separately from the data). The number key and the inclusion/exclusion questionnaires will be kept in a locked file cabinet at COBR that only the principal investigator and co-investigator have access to. Your name will not be associated with the video recordings nor will it be used in any reports or publications which result from this research. Your participation in this study will be kept strictly confidential.

Compensation

You will not be paid for your participation in this study.

Freedom of Consent

You do not have to participate in this study if you do not want to. Your participation in this research study is completely voluntary and you may withdraw your consent at any time. If you withdraw your consent, your participation in the study ends at that point. You may refuse to answer any questions you do not want to answer.

Questions

If you have any questions or concerns about your participation in this study, you should first talk with the principal investigator, Claudia Chavez, at 208-391-2964. You may also contact the co-investigator, Eric L. Dugan, PhD, at 208-426-3512.

If you have questions about your rights as a research participant, you may contact the Boise State University Institutional Review Board (IRB), which is concerned with the protection of volunteers in research projects. You may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-5401 or by writing: Institutional Review Board, Office of Research Compliance, Boise State University, 1910 University Dr., Boise, ID 83725-1138.

Documentation of Consent

I have read this form carefully and I fully understand the test procedures that I will perform and the risks and discomforts associated with my involvement. Knowing these risks and having had the opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this research study

Printed Name of Study
 Participant

Signature of Study Participant

 Date

 Signature of Person Obtaining Consent

 Date

APPENDIX C

Intervention/Retention Set-Up

Intervention/Retention Set-Up

- Day 1
 - Warm-Up (5 minutes at 2.0W/kg of body mass)
 - Pretest (2 minutes at 2.5W/kg of body mass)
 - Data Collected during last minute
 - Familiarization (1 minute; groups 1 & 2 only)
 - Shown the ankle/pedal angle in the graph
 - Acquisition Trial Block 1 (10 minutes at 2.5W/kg of body mass)
 - Trial 1 (2 minutes)
 - Data Collected during minute two
 - Trial 2 (2 minutes)
 - Data Collected during minute two
 - Trial 3 (2 minutes)
 - Data Collected during minute two
 - Acquisition Trial 4 (2 minutes)
 - Data Collected during minute two
 - Trial 5 (2 minutes)
 - Data Collected during minute two
- Day 2
 - Warm-up (same as Day 1)
 - Acquisition Trial Block 2 (procedure the same as Trial Block 1)
- Day 3
 - Warm-up (same as Day 1)
 - Acquisition Trial Block 3 (procedure the same as Trial Block 1)
- Day 4
 - Warm-up (same as Day 1)
 - Acquisition Trial Block 4 (procedure the same as Trial Block 1)
- Day 5 & 6
 - No training
- Day 7
 - Warm-up (same as Day 1)
 - Retention Trial Block 5 (procedure the same as Trial Block 1)

APPENDIX D

Journal Article

STRATEGIES TO DECREASE MOVEMENT VARIABILITY
IN THE ANKLE JOINT IN CYCLISTS

Claudia Guadalupe Chavez

ABSTRACT

Coordination variability is thought to be indicative of a cyclist's skill level as novices have higher levels of variability than experts (Sides & Wilson, 2012). It was hypothesized that the externally focused instructions with visual feedback group would decrease coordination variability in the ankle joint to a greater extent than those in the internally focused instructions with visual feedback group. Six cyclists (30-40 years) completed a four day acquisition period and a retention test. During this time, participants cycled for 10-15 minutes at a power output equal to 2.0-2.5W/kg of body mass. Participants were provided with internally or externally focused instructions and visual feedback relating to those instructions. Two separate 6 (Trial Block) X 2 (Group) Mixed Model Repeated Measures ANOVAs were used to determine if the groups' coordination variability (via MARP and DP values) changed as a result of the intervention. Both groups responded in a similar manner with DP values increasing above pretest values because participants were asked to perform a new task. DP values tended to decrease during the intervention and at retention, DP values continued to decrease. It is believed that the intervention was not long enough to cause a lasting change in how cyclists performed.

Keywords: Attentional Focused Instructions and Feedback; Coordination Variability

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Introduction

Researchers have determined that novice cyclists exhibit high levels of coordination variability at the ankle joint which could contribute to a decrease in their performance when compared to elite cyclists (Chapman, Vicenzino, Blanch, & Hodges, 2009; Sides & Wilson, 2012). Methods to enhance a cyclist's performance are being investigated by biomechanics researchers with some integrating attentional focused instructions and feedback into their practice sessions (Mornieux, Gollhofer, & Stapelfeldt, 2010; Sanderson, 1986). The manipulation of attentional focused instructions and feedback is a popular method used by motor learning researchers to enhance a learner's performance with discrete skills (i.e. throwing, and kicking; Wulf, McConnel, Gärtner, & Schwarz, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005) and is being utilized with increasing frequency with continuous tasks (Freudenheim, Wulf, Madureira, Pasetto, & Corrêa 2010; Schücker, Hagemann, Strauss, & Völker, 2009; Stoate & Wulf, 2011). The present study is an attempt to merge the information obtained by biomechanics researchers about the coordination variability that exists among novice cyclists and that obtained by researchers in motor learning about how attentional focused instructions and feedback have been utilized to enhance learning in healthy subjects.

In the sport of cycling, elite cyclists utilize different movement patterns and are more effective than novices in terms of overall mechanical efficiency and muscle activation (Chapman, Vicenzino, Blanch, & Hodges, 2008; Chapman et al., 2009). It is believed that elite cyclists are more effective than novices because of differences in movement seen at the ankle joint (Chapman et al., 2009). In cycling, novices show a decreased range of motion at the ankle joint and increased coordination variability of the

ankle in the sagittal plane when compared to elite cyclists (Chapman et al., 2009; Sides & Wilson, 2012). According to Sides and Wilson, coordination variability may be indicative of a cyclist's skill level, and may not be beneficial to cycling performance. According to Dynamic Systems Theory, although some variability is required in order to be effective, too much or too little variability may lead to a decrease in performance (Sides & Wilson, 2012), and increase one's susceptibility to injury (Hamill, Palmer, & Van Emmerik, 2012). Cycling requires practice and training in order for a person to adopt an efficient coordination pattern (Wilson, Simpson, van Emmerik, & Hamill, 2008) and practice provides the perfect venue for integrating attentional focused instructions, cues, and visual feedback.

Attentional focused instructions are intended to direct a learner's attention to some aspect of the skill they are being asked to perform. Learners may be given internally focused instructions which direct their attention to their body, or externally focused instructions which direct their attention to the effect of their movement (Wulf, 2013). For over 15 years researchers have looked at the effect of attentional focused instructions on discrete skills and the majority of those have found that an external focus of attention is more effective than an internal focus of attention in terms of enhancing both motor performance and learning (Wulf, 2013). The effect of providing learners with augmented attentional focused feedback when learning a discrete skill correlates with the results found on the effect of attentional focused instructions. Augmented feedback provided with an external focus of attention results in greater enhancement to performance than feedback provided with an internal focus of attention (Wulf, Chiviacowsky, Schiller, & Avila, 2010). With continuous tasks, researchers have found

that participants are able to utilize visual feedback about the implement being used to increase their performance as compared to not having visual feedback (Mornieux et al., 2010; Sanderson, 1986; Shea & Wulf, 1999). These findings led to the rationale of where to direct participant's attention in the present study (pedal for the external group, and ankle for the internal group). No research has been conducted on the effect of showing participants internally focused visual feedback for an endurance task.

In an attempt to explain why externally focused instructions are more beneficial for performance researchers proposed the Constrained Action Hypothesis. This hypothesis states that an internal focus of attention causes the learner to consciously control his/her own movements which interferes with the automatic control processing that would normally occur (Wulf, McNevin, & Shea, 2001) causing motor performance to suffer. However, asking participants to focus on the effect of the movement (external focus) allows the motor system to operate without interference thus resulting in enhanced performance and greater learning (Wulf et al., 2001).

The effects of providing cyclists with attentional focused instructions concurrently with visual feedback have not been studied with regards to coordination variability. The purpose of this study was to determine if attentional focused instructions provided with concurrent visual feedback lead to decreased coordination variability in the ankle joint of cyclists. It was hypothesized that cyclists who received externally focused instructions with concurrent visual feedback would decrease the coordination variability in the ankle joint to a greater extent than those who received internally focused instructions with concurrent visual feedback.

Methods

Participants

Five male and two female cyclists (N=7) between 30-40 years of age participated (see Table 1). One participant did not complete the fourth day of the acquisition period; therefore, only six participants' data were analyzed. Participants were excluded from the study if they had a condition limiting their ability to exercise. Participants were required to own a bicycle with clipless pedals and a quick release on the rear wheel. Recreational and competitive cyclists from a community in the Northwest were recruited for this study. Participants signed an informed consent that was approved by the University's Institutional Review Board to ensure that participant's rights were protected throughout the study. Participants were not informed of the expected outcome so as to minimize the effects the information might have on the data collected.

Procedures

Participants were divided into two groups: (1) an internally focused instructions with visual feedback (INT), and (2) an externally focused instructions with visual feedback (EXT). All participants underwent a four day acquisition period which consisted of four 10-minute Trial Blocks conducted one day apart. Participants returned 72 hours later for a 10-minute retention test. Each 10-minute Trial Block, including the retention test, consisted of five 2-minute trials. Data were collected during the second minute of each trial.

On day one of the acquisition period, participants had the reflective markers applied for the first time. Once the markers were in place, participants were asked to sit on their bicycle and complete a 5-minute warm-up at a mild intensity of 2.0W/kg of their

body mass at their chosen speed. Following the warm-up period, participants were asked to cycle for two minutes at a moderate intensity of 2.5W/kg of their body mass at their chosen speed, pretest data were collected during the last minute of this 2-minute trial. The pretest was followed by a one minute familiarization period during which participants were informed that the graph they were seeing on the television (see Figure 1) represented the angle of their foot (internally focused) or of the pedal (externally focused). Following the familiarization period, the first acquisition Trial Block began.

Before each acquisition Trial Block, participants were provided either internally focused instructions or externally focused instructions. Internally focused instructions consisted of the following: “I want you to focus on pushing down with your *foot* during the down stroke and pulling up with your *foot* during the upstroke while keeping the red line within the red box”. Externally focused instructions consisted of the following: “I want you to focus on pushing down on the *pedal* during the down stroke and pulling up on the *pedal* during the upstroke while keeping the red line within the red box”. It should be noted that the only difference in instructions provided to the internally focused and externally focused groups was the word “foot” and “pedal”. It has been suggested that externally focused instructions that vary from internally focused instructions in only the term that is used to direct a learner’s attention are more effective for learning a given task (Wulf, 2013). Every minute during each 10-minute acquisition Trial Block, participants were reminded of instructions with the following statements: “remember to push down on the *pedal* during the down stroke” or “remember to push down with your *foot* during the down stroke”.

During acquisition Trial Blocks 2-4, following the application of the reflective markers, participants completed the same 5-minute warm up and 10-minute moderate intensity cycling protocols described above. All participants returned 72 hours after the final acquisition Trial Block for a 5-minute warm-up and a 10-minute retention test. During the retention test, participants cycled at a moderate intensity of 2.5W/kg of their body mass at their chosen speed for one 10-minute Trial Block without attentional focused instructions, visual feedback, or cuing.

Instruments

Personal bicycles were utilized to minimize change in each participant's coordination pattern. A Computrainer™ (cycle ergometer, Racermate Inc., Seattle, WA) was used to provide resistance and to provide information regarding the participant's cadence. Participants were asked to cycle at their preferred cadence at a power output equal to 2.0W/kg of body mass during the warm up and 2.5W/kg of body mass during intervention part of the practice sessions (2.0-2.5W/kg of body mass corresponds to low to moderate intensity; Lucía, Hoyos, & Chicharro, 2001). The rear wheel was replaced with a standard slick road wheel to facilitate calibration and to minimize wear or damage to either the bicycle or the Computrainer™.

An eight camera Vicon Nexus motion capture system (Vicon Motion Systems, Oxford, UK) collecting 3D kinematic data at a sampling rate of 120Hz was utilized to collect data of each participant's lower body. Sixteen markers were placed on the participants in a pattern corresponding to the Plug-In Gait marker set ("Tutorial"). Each participant's bicycle was fitted with three reflective markers on the left pedal to allow for analysis of the location of the pedal.

Real-time data were presented to each participant in the form of a line graph showing them the flexion and extension of their left ankle or the left pedal angle in relation to the vertical axis (see Figure 1). Participant's bicycles were set-up facing a television monitor that displayed the line graph. Participants were asked to keep either their ankle flexion/extension (internally focused) or the left pedal angle (externally focused) in the target zone, a range indicated via a red box running the length of the line graph (see Figure 1).

All 3D kinematic data of the lower limb were filtered using a low pass Butterworth filter with a cut-off of 6Hz with Visual 3D motion analysis software (C-Motion, Germantown, MD). From the data collected during each trial, 10 consecutive revolutions were analyzed further. One revolution was defined as the time between Top Dead Center (TDC) on two consecutive points as determined by the pedal segment reaching its maximal value along the z-axis.

Calculations for CRP and MARP

Filtered data were then used to calculate 3D foot and shank segment angles and velocities. Only ankle dorsiflexion and plantarflexion were analyzed as the instructions and feedback that were provided to participants targeted this motion. A custom program written in MatLAB (MathWorks, Natick, MA) was utilized to calculate the CRP, MARP, and DP measurements described in the following paragraphs. Figure 2 demonstrates the process by which these measurements were calculated.

Because of differences in the time it took participants to complete one revolution (TDC to TDC), segment angle and angular velocities were assessed on a revolution by revolution basis and interpolated to 100% of one revolution. Segment angles were then

normalized to the maximum and minimum of each data set so that zero represented the midpoint of the movement while angular velocities were normalized to the greatest absolute value to maintain zero velocity at the origin (Sides & Wilson, 2012). Figure 2A shows the normalized foot angle and velocity for one revolution. For the normalized foot angle (Figure 2A), dorsiflexion is indicated by increasing negative values while plantarflexion is represented by increasing positive values. Angular position and velocity phase plots were created for the entire normalized revolution based on the segment's angle and angular velocity (see Figure 2B; Seay, Haddad, van Emmerik, & Hamill, 2006). Phase angles were then calculated for the left foot and shank segments. A phase angle is a measurement of a segment's velocity and absolute angle during a given time frame. Phase angles were calculated as the arctan of the segment's normalized angular velocity with respect to the segment's normalized angular displacement (see Figure 2C; Seay et al., 2006).

Continuous Relative Phase (CRP) values were calculated for the left ankle. CRP is a measure of the coordination that exists between two segments throughout a particular time period (Stergiou, Jensen, Bates, Scholten, & Tzetzis, 2001). CRP is calculated by subtracting the phase angle of the distal segment from the phase angle of the proximal segment (see Figure 2D):

$$\phi_{\text{Sagittal Rel. Ankle Phase}} = \phi_{\text{Foot}} - \phi_{\text{Shank}} \text{ (Stergiou et al., 2001)}$$

CRP values close to 0° indicate that the segments are moving in-phase, while values closer to 180° indicate that the segments are moving out of phase (Stergiou et al., 2001).

The CRP values were averaged to produce Mean Absolute Relative Phase (MARP) values. MARP values were calculated as follows:

$$\text{MARP} = (\sum_{i=1}^p |\varphi_{\text{Sagittal Rel. Ankle Phase}}|_i) / p$$

where p represents the number of CRP values (Stergiou et al., 2001). A low MARP value is indicative of greater coupling between the segments (Stergiou et al., 2001). In addition to MARP, the standard deviations of the ensemble CRP curve points were averaged to calculate the Deviation Phase (DP) values (Stergiou et al., 2001). A low DP value is indicative of less variability, greater stability, between segments (Stergiou et al., 2001).

Data Analysis

Average MARP and DP values from the pretest, each acquisition Trial Block, and the retention test were compared to determine if movement patterns and coordination variability changed as a result of the intervention. Two separate 6 (Trial Block) x 2 (Group) Mixed Model Repeated Measures ANOVAs with a significance level of $p=0.05$ were run for MARP and DP values. A Tukey LSD Post Hoc test was run if any significant difference was found between conditions.

Results

Participants

Descriptive statistics for each of the participants (i.e., how often participants competed in cycling competitions per year, the distance traveled (miles per week), and the mean and standard deviations of their ages) can be found in Table 1. Four participants were provided internally focused instructions with concurrent visual feedback (INT) while two participants were provided externally focused instructions with concurrent visual feedback (EXT).

Mean Absolute Relative Phase (MARP)

MARP is a value that was used in the present study to describe the coordination pattern that existed between the left foot and shank segments for each Trial Block (see Table 2 for descriptive statistics for each group). A 6 (Trial Block) X 2 (Group) Mixed Model Repeated Measures ANOVA found that the Trial Blocks (pretest, acquisition Trial Blocks, retention test) were not significantly different, $F(5,20) = 2.263, p = .087$ ($\eta^2 = .361$). No interaction was found between the Trial Blocks and the Groups, $F(5,20) = 1.902, p = .139$ ($\eta^2 = .322$), indicating that the two groups responded in a similar manner to the intervention. In addition, no significant effect by Group was found, $F(1,4) = 0.161, p = .709$ ($\eta^2 = .039$).

Deviation Phase (DP)

DP is a value that was used in the present study to describe the coordination variability that existed between the left foot and shank segments for each Trial Block (see Table 3 for descriptive statistics for each group). A 6 (Trial Blocks) X 2 (Groups) Mixed Model Repeated Measures ANOVA found that the Trial Blocks (pretest, acquisition Trial Blocks, and retention test) were significantly different, $F(5,20) = 4.17, p = .009$ ($\eta^2 = .510$). No interaction was found between Trial Blocks and Groups, $F(5,20) = 1.85, p = .148$ ($\eta^2 = .316$), indicating that the two groups responded in a similar manner to the intervention. In addition, no significant effect by Group was found, $F(1,4) = 0.152, p = .717$ ($\eta^2 = .037$).

A Tukey LSD Post Hoc test was conducted to determine between which Trial Blocks significant differences in coordination variability existed. The pretest was found to be significantly different than all Trial Blocks except acquisition Trial Block 3, p

<0.05. The pretest was found to approach significant difference from acquisition Trial Block 3, $p = .058$. Acquisition Trial Block 2 was found to be significantly different than the retention test, $p = .019$.

The changes to MARP and DP values that were observed between Trial Blocks were small (max difference in MARP 6.66 degrees; max difference in DP 4.62 degrees).

Discussion

This study was designed to determine if attentional focused instructions provided with concurrent visual feedback would change the amount of coordination variability present within the ankle joint in cyclists. It was expected that participants that received externally focused instructions would decrease the amount of coordination variability present at the ankle joint to a greater extent than those that received internally focused instructions.

The results from this intervention showed that there were no significant differences found between groups (externally or internally focused) across the Trial Blocks indicating that both groups responded to the intervention in a similar manner. The cyclists in this study appear to have developed a coordination pattern that remains relatively stable to attentional focused manipulations as the instructions and feedback caused no significant differences between the MARP values of the pretest, the acquisition Trial Blocks, and the retention test. In addition, the DP values increased above pretest values because participants were asked to perform a new task.

The increase in the DP values from the pretest to the first acquisition Trial Block may indicate that the participants were attempting to do what they were asked to do (i.e., focusing on the 'foot' or the 'pedal'). When a learner is asked to focus on a new task,

they tend to exhibit high coordination variability due to the motor system rigidly fixing the number of degrees of freedom in an attempt to simplify the task (Davids, Glazier, Araújo, & Bartlett, 2003; Shumway-Cook & Woollacott, 2007). It appears that as the intervention progressed, the amount of coordination variability present within the neuromuscular system decreased (from Acquisition Trial Block 1 to 4). In addition, the DP values continued to decrease from the end of the acquisition period to the retention test. The duration of the acquisition period may not have been long enough to see a decrease greater than the pretest values. Most of the research conducted on attentional focused instructions occurs over a short time span of either a few trials in one day (Chiviakowsky, Wulf, & Wally, 2010) or a few trials conducted a few days apart (Wulf et al., 2002). Very little research exists on the effect of attentional focused manipulations on endurance tasks but one of the longest and more effective was in rowing (Parr & Button, 2009). The acquisition period in that study occurred over six weeks and consisted of 24 training sessions. It is possible that a longer training period is necessary to cause a change to the movement pattern of a repetitive task like rowing and cycling. More research is needed to determine how long an intervention needs to be to cause a significant decrease to the amount of coordination variability that exists in a cyclist's movement pattern.

It is also possible that participants were asked to focus on too many instructions when asked to focus on both the down stroke and the upstroke during the same trial. If participants are asked to focus on too much information at any given time the motor control system may experience overload where information processing cannot occur without interruptions and thus performance suffers (Schmidt, 2008). An intervention

focusing on either the upstroke or downstroke of the pedal cycle may prove to be more beneficial than one focused on both actions as in the current study.

Conclusion

This study was conducted to determine if the effects found on attentional focused manipulation would also be found among cyclists as measured by a decrease to the coordination variability of the ankle joint. This study added to the literature by using biomechanical tools to analyze the effectiveness of an attentional focused intervention. While the results from this study indicated an increase in the coordination variability in the ankle joint of cyclists (pretest DP value is lower than all other Trial Blocks), these results indicate that this kind of intervention does cause an effect to this variable. It is acknowledged that with such few participants included in this particular study, the results should be taken with caution. Future studies should not only increase the number of participants but should also increase the length of the acquisition period to determine if DP values continue to decrease as a result of the intervention or if the neuromuscular system reaches stability at pretest values.

In conclusion, these results indicate that an attentional focused intervention can cause a change to the coordination variability present in the ankle joint in cyclists. More research is needed to determine if this kind of intervention can improve the level of coordination variability present within the motor system of cyclists as the current study indicates that the initial increase in DP values decreases throughout the intervention. In addition, focus should be on either the down stroke or the upstroke in order to prevent information overload.

References

- Chapman, A. R., Vicenzino, B., Blanch, P., & Hodges, P. W. (2008). Patterns of leg muscle recruitment vary between novice and highly trained cyclists. *Journal of Electromyography & Kinesiology*, *18*, 359-371.
- Chapman, A., Vicenzino, B., Blanch, P., & Hodges, P. (2009). Do differences in muscle recruitment between novice & elite cyclists reflect different movement patterns or less skilled muscle recruitment? *Journal of Science & Medicine in Sport*, *12*, 31-34.
- Chiviacowsky, S., Wulf, G., & Wally, R. (2010). An external focus of attention enhances balance learning in older adults. *Gait & Posture*, *32*, 572-575.
- Dauids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: The functional role of variability and its implications for sports medicine. *Sports Medicine*, *33*(4), 245-260.
- Freudenheim, A. M., Wulf, G., Madureira, F., Pasetto, S. C., & Corrêa, U. C. (2010). An external focus of attention results in greater swimming speed. *International Journal of Sports Science & Coaching*, *5*(4), 533-542.
- Hamill, J., Palmer, C. & Van Emmerik, R. E. A., (2012). Coordinative variability and overuse injury. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy, & Technology*, *4*(45), 2-9.
- Lucía, A., Hoyos, J., & Chicharro, J. L. (2001). Physiology of professional road cycling. *Sports Medicine*, *31*(5), 325-337.

- Mornieux, G., Gollhofer, A., & Stapelfeldt, B. (2010). Muscle coordination while pulling up during cycling. *International Journal of Sports Medicine*, *31*, 843-846.
- Parr, R., & Button, C. (2009). End-point focus of attention: Learning the 'catch' in rowing. *International Journal of Sport Psychology*, *40*(4), 616-635.
- Sanderson, D. J. (1986). The use of augmented feedback for the modification of riding mechanics of inexperienced cyclists. (Unpublished doctoral dissertation). The Pennsylvania State University, University Park, Pennsylvania.
- Schmidt, R. A. (2008). *Motor learning and performance: A situation-based learning approach* (4th ed.). Champaign, IL: Human Kinetics.
- Schücker, L., Hagemann, N., Strauss, B., & Völker, K. (2009). The effect of attentional focus on running economy. *Journal of Sports Sciences*, *27*(12), 1241-1248.
- Seay, J. F., Haddad, J. M., van Emmerik, R. E. A., & Hamill, J. (2006). Coordination variability around the walk to run transition during human locomotion. *Motor Control*, *10*, 178-196.
- Shea, C. H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Studies*, *18*, 553-571.
- Shumway-Cook, A., & Woollacott, M. H. (2007). Motor learning and recovery of function (p.21-46) In: *Motor control: Translating research into clinical practice*. Lippincott Williams & Wilkin: Baltimore, MD.
- Sides, D., & Wilson, C. (2012). Intra-limb coordinative adaptations in cycling. *Sports Biomechanics*, *11*(1), 1-9.

- Stergiou, N., Jensen, J. L., Bates, B. T., Scholten, S. D., & Tzetzis, G. (2001). A dynamical systems investigation of lower extremity coordination during running over obstacles. *Clinical Biomechanics*, *16*, 213-221.
- Stoate, I., & Wulf, G. (2011). Does the attentional focus adopted by swimmers affect their performance? *International Journal of Sports Science & Coaching*, *6*(1), 99-108.
- Tutorial: Plug-In Gait Lower-Limb. Retrieved from: [http://www.c-motion.com/v3dwiki/index.php?title=Tutorial: Plug-In Gait Lower-Limb](http://www.c-motion.com/v3dwiki/index.php?title=Tutorial:_Plug-In_Gait_Lower-Limb)
- Wilson, C., Simpson, S. E., van Emmerik, R. E. A., & Hamill, J. (2008). Coordinative variability and skill development in expert triple jumpers. *Sports Biomechanics*, *7*(1), 2-9.
- Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport & Exercise Psychology*, *6*, 77-104.
- Wulf, G., Chiviawosky, S., Schiller, E., & Avila, L. T. G. (2010). Frequent external-focus feedback enhances motor learning. *Frontiers in Psychology*, *1*, 1-7.
- Wulf, G., McConnel, N., Gärtner, M., & Schwarz, A. (2002). Enhancing the learning of sports skills through external-focus feedback. *Journal of Motor Behavior*, *34*(2), 171-182.
- Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology*, *54A*(4), 1143-1154.

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin*, 67, 304-309.

Captions

Figure 1: Ankle/Pedal Angle: The red box indicates the target zone while the line represents each participant's ankle or pedal angle

Figure 2: Data Analysis Explained. Figure 2A left represents the normalized angular position of the left foot throughout one revolution. Figure 2A right represents the normalized angular velocity of the left foot throughout one revolution; dorsiflexion is indicated by increasing negative values while plantarflexion is represented by increasing positive values. Figure 2B represents the phase plot for the left foot. Figure 2C left represents the phase angle for the left foot and is obtained as the deviation from the horizontal of the phase plot. Figure 2C right represents the phase angle for the left shank. The same measurements (A & B) were conducted for the left shank to obtain the phase angle. Figure 2D represents two CRP curves. This figure was adapted from Seay et al., 2006.

Figure 3: Mean Absolute Relative Phase (MARP) Values across Trial Blocks for each Group

Figure 4: Deviation Phase (DP) Values across Trial Blocks for each Group

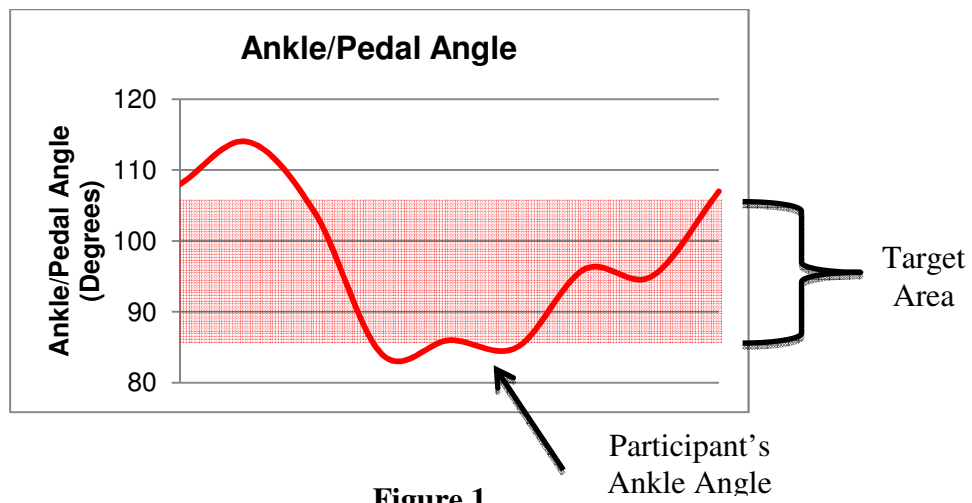


Figure 1

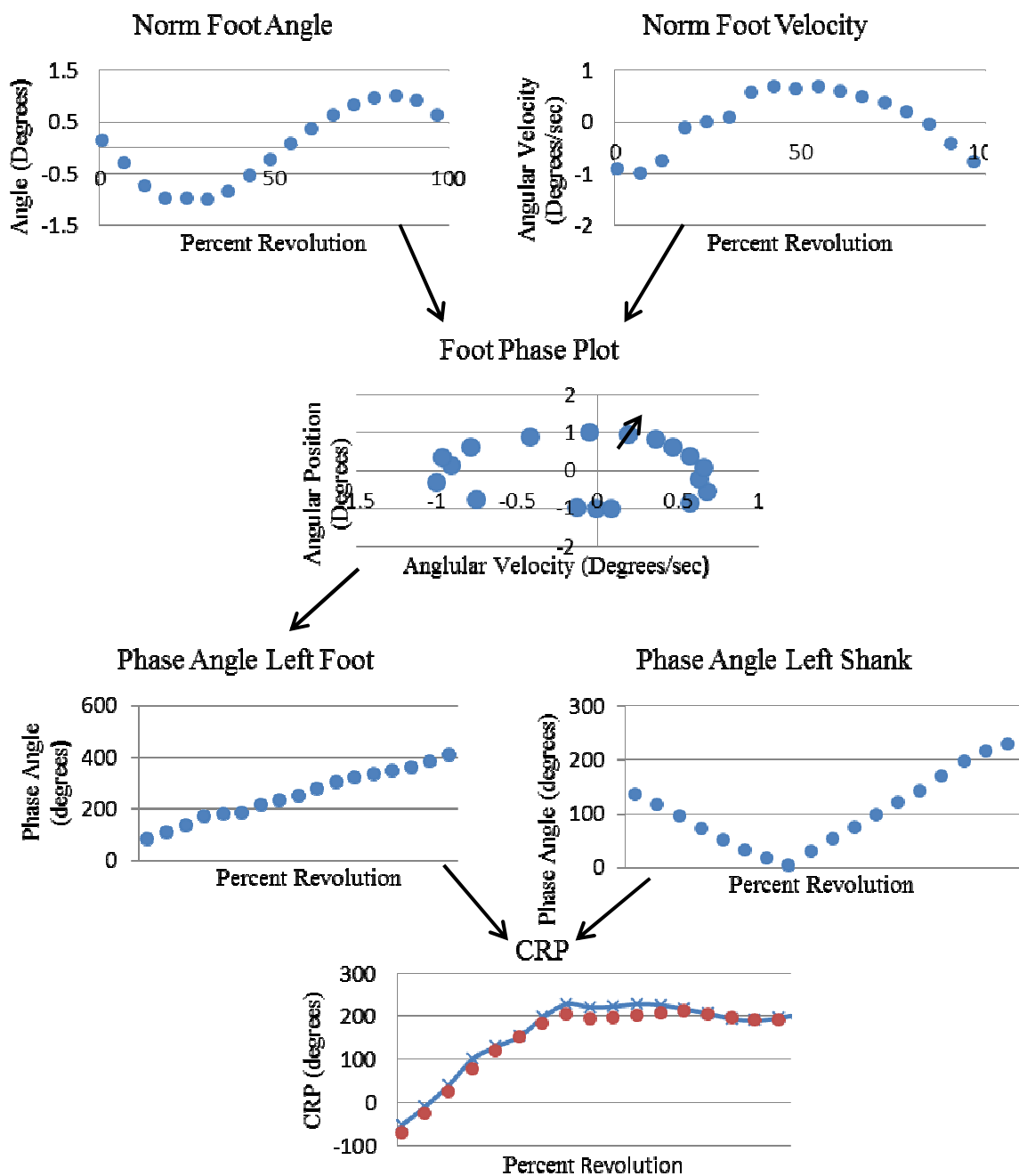


Figure 2

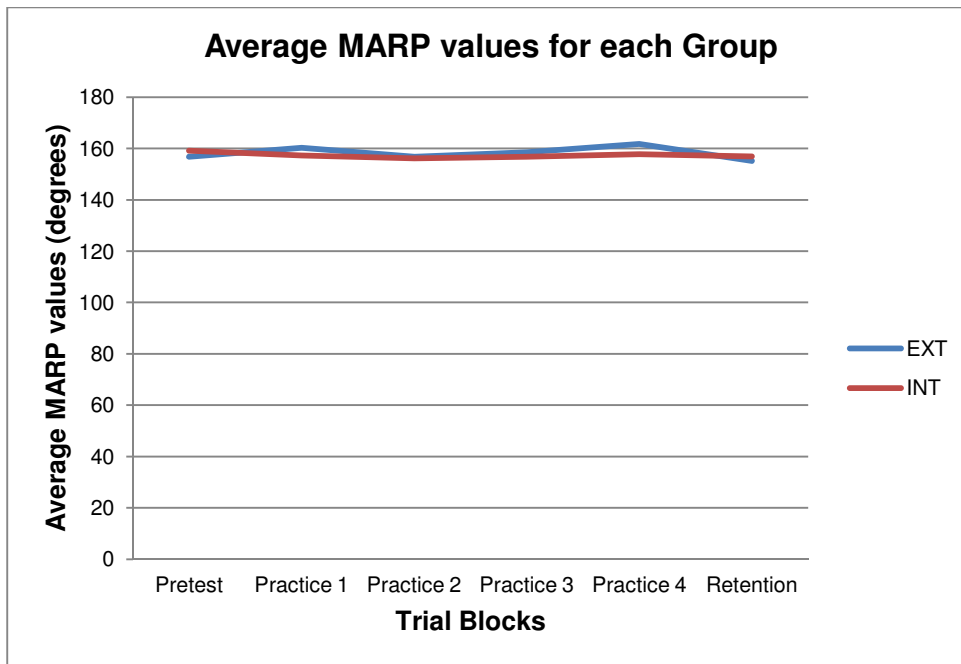


Figure 3

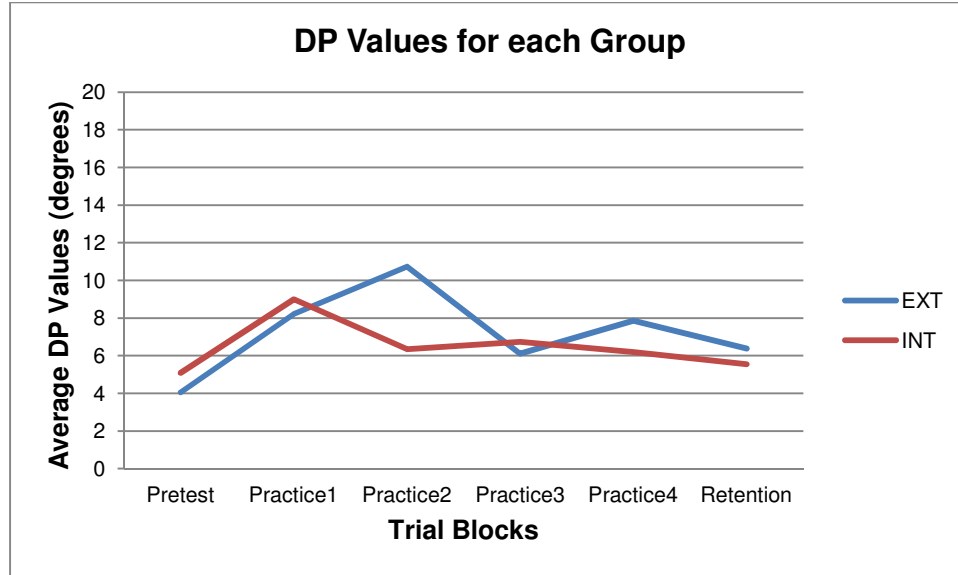


Figure 4

Table 2. Descriptive Statistics

Group	Gender	Age	Height (Inches)	Weight (lbs)	Competitions/ Year	Miles/ Week	Experience
INT	Male	39	72.25	233	2	150	High
INT	Male	35	68.5	181.5	0	40-50	Med.
INT	Female	32	66.25	175.5	0	30-40	Med.
INT	Female	35	64	139.5			Low
EXT	Male	38	66.5	155	3	200	High
EXT	Male	31	69.33	148	0	30	Low

Table 3. MARP Values for each Group

Trial Block	Externally Focused		Internally Focused	
	Mean	SD	Mean	SD
Pretest	156.79	8.18	159.12	3.40
Acquisition Trial Block 1	160.27	4.29	157.29	3.08
Acquisition Trial Block 2	156.80	0.15	156.19	3.07
Acquisition Trial Block 3	158.50	1.31	156.73	3.58
Acquisition Trial Block 4	161.80	0.56	157.75	2.12
Retention	155.14	2.53	156.92	1.88

Note: Mean Absolute Relative Phase (MARP)

Table 4. DP Values for each Group

Trial Block	Externally Focused		Internally Focused	
	Mean	SD	Mean	SD
Pretest	4.05	2.16	5.08	2.14
Acquisition Trial Block 1	8.21	5.50	8.99	4.29
Acquisition Trial Block 2	10.73	1.95	6.34	2.13
Acquisition Trial Block 3	6.11	2.05	6.73	2.97
Acquisition Trial Block 4	7.86	3.35	6.19	1.77
Retention	6.38	0.51	5.54	1.44

Note: Deviation Phase (DP)