CHANGES IN MOVEMENT MECHANICS AND TRIAL TIME BETWEEN A PRE-PLANNED CHANGE OF DIRECTION SPEED TASK AND A REACTIVE AGILITY TASK

by

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DEDICATION

I would like to dedicate this dissertation to the memory of my beloved Grandma Joan and to my Granddad Harold. I love you both and miss you every day.

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I would like to thank my wife Michelle and both of our families for their unwavering love and support throughout this long process. Without Michelle's great sacrifices I would not have been able to fulfill this dream of mine. I would also like to thank Dr. Jennifer Caputo, Dr. Richard Farley, and Dr. Dana Fuller for persevering with me and pushing me to finish when it looked like I might not. Finally, I would like to thank Dr. Marcus Elliot and his staff at the Peak Performance Project and all of the UC Santa Barbara men's soccer players and coaches who helped to make this possible.

ABSTRACT

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The purpose of this study was to investigate whether the introduction of a cognitive component to a change of direction task would have an effect on the application of medio-lateral and vertical forces, the angle of the lower limb at push-off, and movement time in elite college soccer players (N =18). Participants were tested in either pre-planned change of direction speed (CODS) then reactive agility, or reactive agility then pre-planned CODS. Measures of total trial time, lower limb angle, medio-lateral ground reaction forces (GRF), and vertical GRF were carried out. A one-way repeated measures multivariate analysis of variance (MANOVA) documented a relationship among medio-lateral ground reaction force, vertical ground reaction force, lower limb angle, and total trial time with type of activity F (4, 14) = 4.21, p = .02, lambda = .45. A one-way repeated measures ANOVA indicated that total trial time was longer in the reactive agility task than in the pre-planned CODS task F (1, 17) = 4.32, p = .001, Eta^2 = .46. An additional one-way repeated measures ANOVA indicated response time was longer in the reactive agility task than in the pre-planned CODS task, F (1,1 7) = 12.14, p = .003, Eta^2 = .42. There was no difference in movement time between pre-planned CODS and reactive agility tasks. No changes were observed in any other variables between pre-planned CODS and reactive agility tasks. These findings have important implications for the training and testing of athletes. It is important to include a cognitive component in agility training due to the fact that improvement in the physical aspects of

agility may not be enough for athletes to achieve the highest level of performance. Inclusion of these components is likely to have a direct impact on an athlete's performance in his or her chosen sport.

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CHAPTER I

INTRODUCTION

There are discrepancies in the literature as to how agility should be defined. The majority of studies investigating agility tend to focus on the physical aspects alone. Sheppard and Young (2006) highlighted the importance of including cognitive and perceptual considerations in any definition. For the purposes of this paper, agility is defined as an unplanned, rapid, whole-body change of velocity or direction in response to a stimulus. In this definition, both the physical and cognitive components of agility performance are taken into consideration.

There are many physical factors that appear to have an effect on agility performance including straight sprinting speed, leg strength and power, anthropometric measurements, and technique. There is little support in the literature for the contention that straight sprinting speed and change of direction speed (CODS) are related. Young, McDowell, and Scarlett (2001) indicated that the more complex the change of direction (COD) task, the weaker the relationship between the two variables. In contrast, there does appear to be a relationship between leg strength and CODS performance. Peterson, Alvar, and Rhey (2006) and Jullien et al. (2008) demonstrated that leg strength is highly correlated with CODS, with strength explaining 60% of the variance in CODS. When strength was adjusted to body weight it explained 66% of the variation in CODS. This indicates that when an athlete is able to produce more force per unit of body mass, he or she will be better able to overcome the inertia of the body in order to produce faster CODS movements.

Interestingly, Barnes et al. (2007) indicated that there was a low correlation between leg power and CODS. In this study, performance on a counter movement jump explained 34% of the variation in CODS indicating that they are independent qualities (Thomas & Nelson, 2001). Miller, Herniman, Ricard, Cheatham, and Michael (2006) and Thomas, French, and Hayes (2009) showed that a period of plyometric training improved CODS performance indicating that there might be a relationship between CODS and reactive power. While there appears to be relationships between several physical performance parameters and CODS, it is unclear from the literature whether there are relationships between anthropometric measures and CODS.

It seems reasonable to conclude that anthropometric characteristics such as body composition would affect CODS performance. However, there is little evidence in the literature to support this. There is no direct relationship between body composition and CODS although there is a pattern in the results of research into the anthropometric and performance characteristics of athletes that suggests leaner athletes generally perform better in CODS tests and play at a higher level in their respective sports (Gabbett, 2007; Gabbett & Georgeiff, 2007; Gabbett, Georgeiff, & Domrow, 2007; Gabbett, 2005a; Gabbett, 2005b; Reilly, Williams, & Nevill, 2000).

Limb segment length may also affect CODS performance (Cronin, McNair, & Marshall, 2003). Athletes with longer lower limb segments may be at a disadvantage in CODS tasks due to their higher center of mass. This means that it will take longer for them to lower their center of mass in order to decelerate and change direction. The technique required to perform a CODS movement may be a limiting factor regardless of height or limb segment length. Both limb segment length and technique will directly affect the ground reaction forces of a CODS movement. For athletes with a higher center of mass, either through being taller or through sub-optimal technique, it will be more difficult to apply forces in the medio-lateral plane into the ground, thus reducing the efficiency of their movements. The cognitive factors involved in agility movements may also affect an athlete's technique.

The cognitive factors that have been shown to impact sports performance are visual scanning strategy and knowledge of situations. These two factors have been shown to affect an athlete's anticipation in sporting situations (Jackson, Warren, & Abernathy, 2006; Laurent, Ward, Williams, & Ripoll, 2006; Mann, Williams, Ward, & Janelle, 2007; Savelsberg, Van Der Kamp, Williams, & Ward, 2005; Vaeyens, Lenoir, Williams & Philippaerts, 2007; Williams, Davids, Burwitz, & Williams, 1993; Williams & Davids, 1998; Williams, Ward, Knowles, & Smeeton, 2002). Skilled athletes use various visual scanning strategies combined with their knowledge of situations to pick up and extract relevant information from the environment in order to anticipate the actions of their opponents or a ball. It is apparent that skilled players employ a different visual search strategy than lesser skilled players making it possible to filter relevant information from the environment (Williams et al., 1993). A large part of skilled athletes' ability to anticipate opponent's actions comes not only from their visual scanning strategy but also from their knowledge of situations.

Knowledge of situations plays a role in the process of extracting important information from the environment and anticipating the upcoming actions of opponents or the ball. Over years of training and competition, athletes are able to build up complex knowledge structures based on past experiences (Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007). It has been suggested that situational probabilities are used by racket sport athletes' to anticipate the shots of opponents in order to maximize the efficiency of their subsequent behavior (Alain & Proteau, 1980). This knowledge combined with a better ability to pick up relevant information gives the skilled performer a distinct advantage in anticipating an opponent's actions and formulating an anticipatory response. Gabbett, Kelly, and Sheppard (2008) demonstrated that a test of reactive agility discriminated between elite and sub-elite athletes whereas a pre-planned CODS test did not, despite identical physical demands, providing evidence that these two cognitive factors directly affect agility performance. It is unclear whether movement technique was altered by the addition of a cognitive component to this test or whether cognitive processing alone was responsible for the decreased performance in the lower performance group.

It appears that there are many factors that affect agility performance including physical, technique, and cognitive factors. Physical attributes are clearly important to sports performance; however, there is a lack of evidence suggesting that physical attributes alone can discriminate between elite and sub-elite performers. Cognitive factors have been shown to discriminate between elite and sub-elite performers in both sport specific situations and in reactive agility tests. Besier, Lloyd, Ackland, and Cochrane

(2001a) and Besier, Lloyd, Ackland, and Cochrane (2001b) suggested that there is increased loading on the knee when a cognitive component is added to an agility movement suggesting that this cognitive component affects the technique applied in agility movements. There is presently no research in the literature investigating the effects of the addition of cognitive components to agility testing and their effects on technique and an athlete's ability to apply medio-lateral forces into the ground.

In order to change direction or accelerate, athletes must overcome inertia by applying force in the opposite direction to which they intend to move. In the case of lateral COD movements, athletes must be able to apply force in the medio-lateral plane in order to move to the left or right. In order to have optimum efficiency when changing direction, the center of mass must be lowered to create better angles in the lower limbs to generate medio-lateral force. When time pressure is applied to this movement by adding a cognitive component there will be less time to decelerate and lower the center of mass. In this case, the athlete may be in a more upright stance when performing the actual direction change and thus may be limited in the ability to apply medio-lateral forces into the ground. If this were the case, it would reduce the athlete's efficiency of movement and could potentially impact performance. Therefore, it is important to better understand the factors that may impact an athlete's ability to apply medio-lateral forces into the ground during lateral agility movements.

Purpose of the Study

The purpose of this study was to investigate whether the introduction of a cognitive component to a change of direction task would have an effect on the application of medio-lateral and vertical ground reaction forces, the angle of the lower limb at push-off, and total time in elite college soccer players.

Hypotheses

1. It was hypothesized that there would be a reduction in force applied in the medio-lateral plane by the push-off leg during the reactive agility test compared with the pre-planned CODS test.
2. It was hypothesized that there would be an increase in force applied in the vertical plane by the push-off leg during the reactive agility test compared with the pre-planned CODS test.
3. It was hypothesized that there would be an increased angle at the lower limb on the push-off leg in the reactive agility test as compared to the pre-planned lateral movement.
4. It was hypothesized that total time would be slower in the reactive agility test as compared to the pre-planned CODS test

Operational Definitions

Agility: An unplanned, rapid, whole-body movement with change of velocity or direction in response to a stimulus.

Change of direction speed (CODS): The physical attributes that contribute to overall agility performance.

Ground reaction forces: The reaction forces provided by the support surface on which the movement is performed.

Movement speed: The time taken, from the initiation of movement, to the cover 3 m during both the CODS test and the reactive agility test.

Pre-planned CODS test: A test that involves only the physical aspects of agility performance with no cognitive component.

Reactive agility test: A tests that involves both physical and cognitive components of agility performance.

Assumptions

1. It was assumed that all participants put forth their maximum effort during all tests.
2. It was assumed that participants did not have any undisclosed injuries that impacted their performance.

Delimitations

1. The sample was limited to elite collegiate soccer players. All athletes were playing at the National Collegiate Athletics Association division I level.
2. The results were limited to lateral movements starting from a static position.

Significance of the Study

The results of this study have important implications for the training and testing of athletes. While the addition of a decision making component to a CODS task had no effect on the physical components of agility, there was a significant change in response time. This indicated that coaches should be emphasizing the cognitive aspects of agility as part of their year round physical preparation program. Coaches should still instruct their athletes on proper technique when approaching a situation in which they are likely to have to change direction. Breaking down agility movements during evaluation allows for agility training programs to be designed specific to the needs of each individual athlete, rather than simply applying a CODS protocol to an entire group of athletes.

CHAPTER II

LITERATURE REVIEW

This chapter begins with the formulation of a comprehensive definition of agility based on the current literature. This is followed by an outline of the relationships between physical and biomechanical characteristics and CODS, including straight sprinting speed, muscle strength and power, anthropometry, and technique. The cognitive and perceptual qualities of agility are then reviewed. These include visual scanning and knowledge of situations as they relate to anticipation in sporting contexts. This is followed by a section on the testing of agility performance as opposed to testing CODS. The chapter ends with an overall summary and a review of the purpose of this investigation.

Defining Agility

The selection of a single, clear definition of agility has important implications for the testing of agility performance in research and in practical team settings. Tasks ranging from lunges (Cronin et al., 2003) to change of direction in response to a stimulus (Gabbett et al., 2008) have been described as agility in the literature. The varied nature of these two activities creates confusion as to how to measure agility and determining what factors are involved in agility performance (Sheppard & Young, 2006). The acceptance of a comprehensive definition of agility by coaches and the sports science community will help to reduce confusion in the training and testing of agility among athletes.

Agility is a multifaceted concept that involves CODS, acceleration, deceleration, and stopping and starting, as well as perceptual qualities such as visual scanning and decision making. Sheppard and Young (2006) suggested that a comprehensive definition of agility should recognize the perspectives of numerous fields within sport sciences namely, strength and conditioning, motor learning, and biomechanics. Within these three fields the physical components, cognitive processes, and the technical skills involved with agility performance are addressed, respectively. However, there is presently no consensus in the literature pertaining to a single definition of agility. The following section contains an outline of the various components of agility and provides a comprehensive definition based upon the relevant information presented.

Physical components of agility. Agility is often described using physical components alone. There have been many definitions in the literature pertaining to the physical components of agility. These definitions have included the ability to change direction, accelerate and decelerate, start and stop, and to maintain balance and control while performing the above (Baker & Newton, 2008; Barnes et al., 2007; Bloomfield, Polman, O'Donoghue, & McNaughton, 2007; Little & Williams, 2005; Pauole, Madole, Garhammer, Lacourse, & Rozenek, 2000; Young et al., 2001). Young, James, and Montgomery (2002) suggested that the physical attributes outlined above could best be described as CODS, which is affected by a number of different physical qualities. The research outlined above does not address the cognitive aspects of agility, which have been demonstrated to limit agility performance (Gabbett et al., 2008).

Cognitive aspects of agility. According to Abernathy, Woods, and Parks (1999), successful team sport performance depends upon well-developed physical qualities and superior anticipation and decision making skills. Therefore, it is important to acknowledge the influence of these cognitive factors involved in sports performance, as well as the physical attributes required, when defining agility. Young et al. (2002) proposed a model in which the universal components of agility were outlined. In this model, the major physical quality of agility was described as CODS and it was suggested that this was made up of numerous physical attributes. These were technique, straight sprinting speed, anthropometry, and leg muscle qualities (reactive strength, concentric strength and power, and left/right muscle imbalance). Also outlined in this model are the cognitive factors that influence agility performance, which include perceptual and decision making ability. Again, it is proposed that these cognitive factors are influenced by a number of other factors such as visual scanning, knowledge of situations, pattern recognition, and anticipation.

Additionally, Chelladurai (1976) suggested that there were four classifications of agility movements. These were simple, spatial, temporal, and universal. Simple agility skills are those in which there is no spatial or temporal uncertainty. These skills, such as a gymnastics routine, are initiated by the athlete and pre- planned movements are performed within a known area. As such, simple agility drills address only the physical components of agility. Activities that fall under the spatial agility definition are those in which there is spatial uncertainty, but there is no temporal uncertainty. A volleyball service receive is an example of spatial agility as the receiver knows when the ball is going to be served, but does not know where the ball is going to be directed and so must react to this stimulus. A temporal agility activity is one where there is temporal uncertainty, but the movement is pre-planned. A sprinter's start is an example. The sprinter does not know when the starter's pistol will sound, but they must respond with a pre-planned acceleration out of the blocks. The most complex agility movements in Chelladurai's classifications are universal agility movements. During a universal agility movement there is both temporal and spatial uncertainty. An example of universal agility is offensive or defensive plays in any open team sport. During these plays, opposition players can have no certainty as to when or where their opponent will move. As such, they have to react to these two stimuli and cannot have fixed pre-planned strategies to achieve their goals. The latter classification of agility movements is the most "sports specific" as it directly applies to game situations.

These classifications of agility outline the importance of cognitive factors in agility movements in order that they are more representative of the demands placed on an athlete during competition. In a recent study by Gabbett et al. (2008), the influence of cognitive factors on agility was explored as a means of discriminating between higher skilled and lesser skilled players.

Gabbett et al. (2008) studied first and second grade rugby league players. The researchers investigated speed, CODS, and reactive agility in these athletes in order to determine which, if any, tests discriminated between the two skill levels. The two separate tests of CODS did not discriminate between the higher and lesser skilled rugby league players. In contrast, the reactive agility test discriminated between the two classes of players in the study. The first grade players demonstrated faster movement and decision times during the reactive agility test suggesting that they were able to recognize movement cues earlier and respond to the opponent's movement faster than the second grade players. This study again highlights the important role cognitive factors play in agility performance on the sports field. The fact that there was no difference between first and second grade players on the CODS tests indicates that these can only be useful in assessing the physical aspects of an athlete's agility.

Sheppard and Young (2006) suggested that in order to simplify the definition of agility, exclusion criteria rather than the inclusion criteria proposed by Chelladurai (1976) should be used. This would mean that there is no need to have classifications within agility as tasks could be identified by describing the skill itself using its biomechanical or physiological perspectives (Sheppard & Young). In defining activities in this manner, skills such as sprint starts that have previously been described as agility tasks due to the fact that they incorporate reaction to a stimulus (Chelladurai), would no longer be considered as agility tasks as they involve pre-planned movement.

Sheppard and Young (2006) proposed the following definition of agility: A rapid whole-body movement with change of velocity or direction in response to a stimulus. This definition is inclusive of the cognitive aspect of agility as well as the physical characteristic of acceleration, deceleration, and CODS (Sheppard & Young). However, missing from this definition is the fact that a movement must not be pre-planned. It seems more appropriate that the definition should read: An unplanned, rapid, whole-body movement with change of velocity or direction in response to a stimulus. Under this definition, a task must be an open skill with no pre-planned response in order to qualify as an agility movement, which has implications for the testing and training of agility. This comprehensive definition of agility will be accepted for the purposes of this study.

This clear definition helps to outline the importance of agility to the athlete. In all field and court sports there is a need for athletes to perform rapid bouts of highly intense activity that involve acceleration, deceleration, CODS, and maximal speed in response to a stimulus, whether that be a ball, opponent, or a team mate. This means that there is little opportunity for pre-planned movements in field or court sports. As such, it is crucial that athletes are specifically trained to perform these movements as part of their periodized physical preparation programs.

There is presently no comprehensive definition of agility used across the literature. The vast majority of studies define agility using only the physical attributes that make up a movement. These include the ability to change direction, accelerate, decelerate, start and stop, and to maintain balance and control whilst performing these actions. These attributes have been described as CODS (Young et al., 2002), a term that will be used in this review to describe the physical attributes associated with agility performance. Sheppard and Young (2006) suggested that not only the physical attributes should be included in a definition of agility but also the perceptual and cognitive qualities that are key to high level sports performance. Two perceptual factors that affect sports performance are visual scanning and knowledge of situations; these have a major impact on an athlete's ability to anticipate the actions of an opponent in order to produce a rapid and successful response. In order to fully understand agility performance, its component parts must be examined. In the following section the physical attributes associated with agility performance will be outlined.

Physical Attributes and their Relationships with CODS

Having established a clear and comprehensive definition of agility, it is important to identify the physical and cognitive attributes that can be limiting factors in the performance of agility tasks. Establishing the relationships between these attributes and agility will help to identify specific factors that should be trained in order to improve agility performance.

Much of the research that has attempted to establish relationships between physical attributes and agility has focused on CODS (Sheppard & Young, 2006). This section begins with an outline of the relationships between physical performance attributes and CODS and then is followed by a section on the cognitive factors that affect agility.

Relationship between straight sprint speed and CODS. There is little research in the literature to suggest that there is a strong relationship between straight sprint speed and CODS. Young et al. (2001) studied whether straight speed training transfers to CODS tests of varying complexity in adults with at least one season of experience in activities that required sprinting and CODS maneuvers. Participants were placed into a straight sprint speed training group, an agility group, or a control group for a 6-week training period and were tested on seven speed tests of increasing complexity. The researchers found that the straight sprint training group showed significant improvement only on tests one (straight sprint) and two (least complex CODS test). The agility group showed significant improvement on tests two through seven (CODS tests), but not on test one. Overall, the straight speed group showed fewer gains between pre- and post-testing as the complexity of the task increased, while the opposite was true of the agility group. The agility group demonstrated fewer gains as the complexity of the test decreased and became more representative of a straight speed test. These findings indicate that straight sprint speed and COD are independent qualities that should be trained separately. The findings of this study were supported by those of Little and Williams (2005).

In studying the relationship between acceleration, maximum sprint speed, and CODS, Little and Williams (2005) assessed professional soccer players in a 10-meter (m) sprint, a 20 m flying sprint, and a zigzag course consisting of four 5 m sections at 100° angles. While there was a statistically significant relationship between the three performance parameters, there was only 12% common variance between acceleration and CODS and only 21% common variance between flying 10m sprint speed and CODS. Thomas and Nelson (2001) suggested that a common variance of less than 50% indicates that two variables are independent. As such, the researchers concluded that acceleration, maximum speed, and CODS are independent qualities. While Little and Williams found that acceleration, maximum speed, and CODS were independent qualities, Gabbett et al. (2008) found speed, CODS, and reactive agility to be independent.

Gabbett et al. (2008) tested speed, CODS, and reactive agility in Rugby League players. This study demonstrated that although there was a significant relationship between 5 m, 10 m, and 20 m sprint speed and all measures of CODS, the common variance between these tests was below 50% and as such should be seen as independent qualities. These findings were similar to those of Vescovi and McGuigan (2008), who studied the relationship between sprinting, jumping, and agility in female athletes. This study also demonstrated a significant relationship between the physical attributes, although the weak to moderate relationship suggests that they are independent qualities, according to Thomas and Nelson (2001).

It is clear from the literature outlined here that although there appears to be some relationship between speed and CODS, it cannot explain all of the variation in CODS performance. Speed and CODS should be viewed as separate qualities for the purposes of training and assessment. Other factors that may impact CODS are leg strength and power.

Relationship between leg strength/power and CODS. Having discussed the relationship between straight sprint speed and agility in the previous section, it is clear that the two are independent qualities and should be approached differently for training and testing purposes. Examining the relationship between lower extremity strength and power has important implications for the design and implementation of strength and conditioning programs with court and field athletes who are required to change direction at speed.

Peterson et al. (2006) examined the contributions of maximal force production to measures of explosive movement in young college athletes, finding that strength was highly correlated with CODS performance ($r = -.78$). Interestingly, after further investigation, the researchers found that strength relative to body mass was a better predictor of CODS performance than absolute strength ($r = -.81$). This indicates that amongst these participants, strength accounted for 60% and 66% of the variance in CODS. This indicates that these two variables are related (Thomas & Nelson, 2001).

Similarly, Jullien et al. (2008) studied the effects of strength training on running speed and CODS in young professional soccer players. A 3-week period of strength training significantly increased performance on an agility drill designed to replicate the demands of soccer. Further, there was no significant difference between the group who undertook strength training and the group who undertook sport specific and coordination training, indicating that the two training modalities could be applied in a complimentary strength and conditioning program in order to further boost CODS performance.

These studies highlight the importance of strength as an underlying factor in power performance. Peterson et al. (2006) particularly highlighted the importance of strength in young, inexperienced athletes. At this point, strength is a major limiting factor in power performance and thus should be a focal point in the strength and conditioning program. With more experienced athletes, it is likely that strength would no longer be a limiting factor and the focus of the program can shift to be velocity specific. Several researchers have examined the relationship between explosive power and agility performance.

Barnes et al. (2007) examined the relationship between jumping and CODS performance in female volleyball athletes. Jumping ability was significantly correlated with agility performance. However, center of mass displacement explained only 34% of the variation in CODS performance. Again, as this relationship is less than 50%, the two performance variables should be viewed as separate qualities (Thomas & Nelson, 2001).

In contrast, Miller et al. (2006) found that a 6-week plyometric training program elicited significant improvements in the T-test agility measure, the Illinois agility test, and in ground contact time as compared to a control group. The shorter ground contact time brought about by a plyometric training program is likely due to increased muscle power and neural adaptations. These findings support the suggestion by Young et al. (2002) that reactive strength was correlated to CODS due to the similar nature of the push-off action in a drop jump and CODS movements.

Thomas et al. (2009) also demonstrated that a 6-week plyometric training program had a significant positive effect on agility performance. Counter movement jumps and depth jumps were used as part of separate training programs, with each training modality eliciting similar significant results, with no significant difference between the programs. This suggests that either method can be effectively employed in a strength and conditioning program to improve agility performance.

There is limited literature available on the relationship between strength and power and CODS. The available literature shows equivocal data pertaining to the correlation between these two important facets of athletic performance. One reason for the lack of support for a relationship between power and CODS could be that many of the studies used vertical jump performance as an indicator of power. During a vertical jump, forces applied into the ground are predominantly in the vertical plane. This varies from CODS performance where a significant amount of force applied into the ground should be in the horizontal plane. Other factors that may affect agility performance are anthropometric measures. Characteristics such as body composition and limb segment length have an effect on the force production per unit of lean body mass and biomechanical advantage, respectively. Both will affect the ability of an athlete to perform rapid changes of direction.

Anthropometric characteristics and CODS. There is limited research available that directly correlates anthropometric measures with CODS. Sheppard and Young (2006) suggested that factors such as body fat and limb segment length could contribute to CODS performance. When comparing two athletes with the same body mass, the athlete with a greater percentage of body fat will have greater inertia, which will require them to produce more force per unit of lean tissue to produce a change in direction or velocity.

While results from several studies into the physiological and anthropometric qualities of athletes have suggested that leaner athletes generally perform better in CODS tests and also play at a higher level in their chosen sport (Gabbett, 2007; Gabbett & Georgeiff, 2007; Gabbett et al., 2007; Gabbett, 2005a; Gabbett, 2005b; Reilly, Bangsbo, Franks, 2000) these studies did not directly correlate the two variables. Therefore, further research that directly correlates these two variables is required before any conclusions can be drawn. Another factor that could affect CODS performance is limb segment length.

Limb segment length and its relationship to CODS performance has received little attention in the literature. Cronin et al. (2003) studied the determinants of lunge performance, as it is a typical movement used in racket sports to change direction. Cronin et al. suggested that leg length has an influence in CODS performance as measured by a lunge, common in sports such as tennis, squash, and racketball. It can be postulated that an individual with a lower center of gravity would perform better on CODS tests due to the need to lower the center of mass in order to change direction, accelerate, and decelerate. This would allow the shorter athlete to apply more horizontal force into the ground during lateral CODS actions than the taller athlete. However, currently there are no comprehensive investigations into the relationship between anthropometric measurements and CODS performance. In spite of an athlete's height or limb segment length, the athlete's ability to lower his or her center of mass requires a great deal of technical skill. Theoretically, technique could be a limiting factor in agility performance.

Technique and CODS. Technical aspects of CODS movements can have a large effect on the biomechanics and, therefore, the ground reaction forces involved. In most running sports, athletes try to reach maximal speed in a minimum amount of time (Sheppard & Young, 2006). This varies from track and field sprinters who accelerate under more control and over a greater distance in order to reach peak velocity at the correct portion of the race (Francis, 1997). Another difference between field or court sport sprints and track and field sprints is that track and field sprints are carefully thought out and strategized, whereas sprints in field or court sports are not pre-planned. The lack of pre-planning in straight sprints and CODS alters the mechanics of the movements, which has implications for training speed for sports outside of track and field.

Besier et al. (2001a; 2001b) studied the external loads placed on the knee during planned and unplanned changes of direction. They found that when healthy male adults had to react to a light stimulus to change direction whilst running, greater loading was placed on the knee joint. This was thought to be due to sub-optimal posture during the approach. As CODS tasks require athletes to decelerate and lower the center of mass, a more upright posture would mean that it would require more time to prepare for the CODS. When a time-stress is placed on the movement by adding a decision making component, the need for the alterations in posture is highlighted. Sayers (2000) suggested that team sport athletes vary from track and field athletes in their running style in that they must run with a lower center of mass and increased forward lean in order to optimize acceleration and deceleration, and to increase stability. The lower center of mass and increased stability allow for more rapid changes of direction. It would appear that there are different running techniques required for sports that do not allow for pre-planned sprints of changes of direction as compared to track and field sprints. It is suggested that running with a lower center of mass improves performance in CODS maneuvers through improved stability and a decrease in time taken to decelerate and lower the center of mass in order change direction. The technique used and the height of the center of mass during a CODS movement is likely to affect the ground reaction forces.

Ground reaction forces. Ground reaction forces describe the reaction forces provided by the support surface on which a movement is performed (Enoka, 2008). These forces are used to represent Newton's law of action-reaction. They represent the reaction of the ground to the acceleration of all body segments. Ground reaction forces are measured by a force plate and can be measured in three dimensions with a high degree of temporal resolution. The three dimensions in which ground reaction forces are measured can be functionally defined as vertical (up and down), medio-lateral (horizontal), and anterio-posterior (front to back). These definitions represent the reactions of the ground to actions that are transmitted through the feet into the ground and that correspond to the acceleration of the body in these respective directions (Enoka).

Ground reaction forces are crucial to CODS movements. As described above, the ground reaction forces reflect the acceleration of the body in the opposite direction of the applied force. The ability of athletes to apply the necessary force in the opposite direction in which they are to travel is important to the efficiency of the CODS movements. If athletes are unable to lower their center of mass, and are therefore too upright when performing a COD then they are likely to apply too much force in the vertical plane and less in the medio-lateral plane. This means that the athlete would be propelled upwards instead of laterally, slowing down the direction change.

In summary, much of the research into agility has focused solely on CODS, while neglecting the cognitive factors that affect agility performance. There are many factors that may affect CODS performance including, straight sprinting speed, leg strength and power, anthropometric measurements, and technique. The research indicates that there is no relationship between straight running speed and CODS. When testing this relationship it is clear that the more complex the CODS test, the lower the relationship between CODS and straight sprinting speed. Leg strength was highly correlated with CODS (Peterson et al., 2006; Jullien et al., 2008), while there was less of a relationship between leg power and CODS (Barnes et al., 2007). Plyometric training was found to improve CODS performance indicating that there may be some relationship between reactive power and CODS (Miller et al., 2006; Thomas et al., 2009). Plyometric type movements may be more related to CODS due to the similar nature of these activities. The goal of plyometric training is to decrease ground contact time, meaning that more force is applied in less time. This is the same action required of CODS and so improvements in plyometric actions will transfer to CODS tasks.

There is little direct evidence that anthropometric measures are related to CODS. Theoretically, measurements like body composition and limb length could affect CODS performance. Evidence suggests that athletes with higher body fat are generally slower on CODS tasks than leaner athletes although these attributes have never been directly compared (Gabbett, 2007; Gabbett & Georgeiff, 2007; Gabbett et al., 2007; Gabbett, 2005a; Gabbett, 2005b; Reilly et al., 2000). Also, it appears that limb segment length is related to CODS (Cronin et al., 2003). Athletes with longer limb segments may be at a disadvantage in CODS tasks as they will be slower in lowering their center of mass to a height at which they can apply optimum horizontal force into the ground. Technique may also be a factor affecting CODS regardless of an athlete's height or limb segment length (Besier at al., 2001a; 2001b). If sub-optimal technique is used during COD tasks then the ability to apply medio-lateral force into the ground will be limited and the overall efficiency of movement will be reduced. Ground reaction forces are used to represent Newton's law of action-reaction, meaning that they are a direct reaction from the ground to propel the body in the direction in which the force is applied. This gives an indication as to why it is so important to be able to apply the greatest possible force in the direction in which we wish to travel. Any factor that affects the ability to do this will reduce the efficiency, and therefore, speed of movement. Overall, the evidence suggests that the physical attributes outlined do have an effect on CODS and therefore should be considered when designing strength and conditioning programs. However, when defining agility, the importance of cognitive factors was highlighted and therefore should also be taken into consideration.

Cognitive Factors that Affect Agility Performance

Among the many cognitive factors that could affect an athlete's ability to execute the physical changes of direction that occur during sports are visual scanning and knowledge of situations, as they relate to anticipation and performance in sports specific scenarios. As outlined by Besier et al. (2001a; 2001b) the time pressure of reacting to a stimulus changes the kinematics of CODS movements. Theoretically, the more proficient an athlete is in these cognitive requirements, the faster the athlete is able to initiate his or her physical response to the stimulus. Both of these cognitive factors will be outlined in this section.

Visual scanning. `Visual search strategy' refers to the way in which performers continually move their eyes to focus on important features, thereby enabling them to base their decisions on relevant information only (Williams et al., 1993). Visual scanning and the ability to anticipate an opponent's movements or to anticipate the flight of a ball are important in the ability to execute a rapid and accurate response. As indicated in the previous section, before an athlete can change direction when in motion, he or she must first decelerate and lower his or her center of mass. If a CODS is pre-planned then the athlete has no pressure to make a decision and is likely to perform the direction change faster than if a decision is required. When a decision is required it is likely that the athlete who can read the visual cues of an opponent or ball earlier will be able to initiate his or her response sooner and will therefore be more proficient in changing direction than an athlete who does not pick up the visual cues as quickly.

According to Williams (2000), skilled soccer players controlled eye movement patterns that were necessary for seeking and picking up important sources of information. They also saw that skilled players used different visual search strategies depending on the game situation. When viewing the entire field as in an 11 vs. 11 situation (Williams et al. 1993), skilled players used a different visual search strategy than when viewing micro-states of the game, i.e., 1vs. 1 or 3 vs. 3 situations (Williams & Davids, 1998). It was also found that defensive players used different visual search strategies than offensive players. These different search strategies would allow the more skilled players to better read each situation and formulate the appropriate response. Williams et al. (2002) found this to be the case with tennis players.

Williams et al. (2002) found that skilled tennis players were faster than less skilled players in anticipating the direction of an opponent's tennis strokes. The researchers concluded that these results were in part due to more effective visual search behaviors. Interestingly, the researchers also found that participants who underwent a period of perceptual training showed improvement in their performance on both laboratory and field based tests of anticipation.

Savelsbergh et al. (2005) studied the anticipation and visual search behavior in expert soccer goalkeepers, all of whom played in one of the top three leagues in the Netherlands (premier, first division, and semi-professional division). Successful experts were better able to predict the height and direction of a penalty kick, waited longer before initiating a response, and appeared to spend longer fixating on the non-kicking leg when compared with non-successful experts. These results indicate that expert goal keepers were more selective when seeking their sources of information from the penalty taker. In viewing the non-kicking leg, the expert goalkeepers were better able to judge the direction of the penalty shot. Also, waiting longer to initiate their response may have given them more time to judge the swing of the kicking leg in order to predict the height of the ball. Having more confidence as to the height and direction of the ball would have given the goalkeepers an advantage in that they would be able to gear their stance as if it were a pre-planned action.

Similarly, Jackson et al. (2006) studied the anticipation skill and susceptibility to deceptive movement in novice and expert rugby players. The researchers found that expert players were better able to predict the direction of movement of a simulated opponent than were novice players. Experts were able to detect cues in the opposition player's movement earlier than novice players in a visual occlusion task. Expert players were also found to be less susceptible to deceptive movement than their novice counterparts.

Laurent et al. (2006) confirmed these results, finding that expert basketball players, who had more than 10 years of experience and played at national level in France, were better able to discriminate behaviors and had different visual behaviors than novices, who were students with no competitive basketball experience and little recreational playing experience. This different visual behavior and better ability to discriminate may begin to explain the results found by Jackson et al. (2006). Mann et al.

(2007) found similar results across a wide range of research in their meta-analysis quantifying the differences in cognitive abilities between novice and expert performers. Their findings also indicated that experts were better than non-experts in detecting perceptual cues as evidence by superior response accuracy and response time.

According to Vaeyens, Lenoir, Williams, and Philippaerts (2007), successful decision makers used more goal- oriented search strategies that resulted in superior performance in anticipation tasks, which was again indicated by better response time and accuracy. The researchers observed that successful decision makers spent more time fixating on the player with the ball and more time alternating their gaze to other parts of the display than less successful decision makers. These results are typical of expert players in other research studies across various sports.

In summary, it is clear from the research into visual scanning that there is a distinct difference between expert and novice performers with the expert players being able to pick up and filter important visual cues to formulate more rapid responses that are also more accurate. It appears that among the mechanisms for this improved anticipation ability is the type of visual scanning strategy employed. Expert performers seem more able to search for the relevant sources of information and extract cues that indicate the opponent's course of action. This increased ability to recognize cues, including reduced response time and increased response accuracy, could directly impact reactive agility performance. Besier (2001a; 2001b) observed that time pressures placed on CODS tasks by the introduction of decision making component altered the kinematics of the movement, likely altering the speed at which the movement occurred. If an athlete is able to reduce the time taken to make a decision then he or she will have more time to initiate his or her response, i.e., decelerate and lower his or her center of mass in order to change direction.

Evidence for this exists in research performed by Gabbett et al. (2008). These researchers found that a test of reactive agility discriminated between first and second class rugby league players. In this study, pre-planned CODS and straight line speed did not discriminate between these groups. This study highlights the importance of the perceptual aspect of agility movements outlined above. The first class players were able to read and respond to visual cues earlier than second grade players allowing them to execute the physical aspects of agility faster. This has important implications for the training and testing of athletes, as does the specificity of tasks included in perceptual training and testing. Another factor that could influence an athlete's ability to perform CODS tasks through improved anticipation is the performer's knowledge of the situation.

Knowledge of situations. In his review of the literature pertinent to perceptual abilities in soccer, Williams (2000) suggested that expert performers use their knowledge of situational probabilities to anticipate future events. Skilled performers are able to use their experience to assign subjective probability to those events likely to occur within any given situation (Williams). Alain and Proteau (1980) investigated whether defensive players in racket sports were able to use situational probabilities to anticipate the shots available to their opponents. Players evaluated the probabilities of the possible events that could occur and then used this evaluation to maximize the efficiency of their subsequent behavior. The researchers proposed that skilled racket sport players typically made an anticipatory response whenever the probability of success was greater than 70%. It was suggested that a player's initial anticipatory movement was guided by expectations and then corrective or confirmatory movements were made based on actual outcomes (Alain & Proteau).

More recently, Ward and Williams (2003) studied the contributions of visual, perceptual, and cognitive skills to the development of expertise in soccer. Measures of anticipatory performance and use of situational probabilities were found to be the greatest predictors of skill level amongst 9-17 year old soccer players. These results were confirmed by Vaeyens, Lenoir, Williams, and Mazyn, et al., (2007) who found that youth soccer players had faster response times to game like situations than non players. The researchers suggested that this was a result of their extensive exposure to the domain over many years of practice and that skilled performers had developed elaborate task-specific knowledge structures, coupled with efficient encoding and retrieval processes. This provided the skilled performers with a distinct advantage over less skilled players when attempting to make appropriate decisions under time constraints.

In summary, it is clear from the research that visual scanning strategy is a major discriminating factor between expert and lesser skilled athletes. Several researchers have found that expert athletes across a variety of sports employ different visual search strategies that allow the athlete to discriminate relevant information from opposing player's actions (Williams, 2000; Williams et al., 2002; Savelsbergh, 2005; Jackson et al., 2006; Laurent et al., 2006; Vaeyens, Lenoir, Williams, and Mazyn, et al., 2007.). The increased ability of expert players to pick-up and utilize visual cues from the environment allows them to better anticipate the movement of an opponent or the flight of a ball in order to speed up their response. Another factor that has been demonstrated to contribute to improved anticipation in expert athletes is knowledge of the situation

Knowledge of situations is a major influencing factor in a player's ability to make fast accurate responses to game like situations. This has wide implications for the testing and training of perceptual skills among athletes. If a test is developed that is specific to a sport, it may be effective in discriminating skill or playing level among that sports players, but may not be so effective among players of another sport. This would be due to a lack of knowledge of the situations in the new sport, which would not allow the athletes to perform as proficiently as they might in a test that was specific to their own sport.

Testing Agility Performance

According to Sheppard and Young (2006) the majority of agility tests in the research focus solely on pre-planned CODS. Having highlighted the importance of cognitive and perceptual factors to sports performance it seems crucial that these aspects are considered with testing agility in order that all aspects of performance are taken into consideration when attempting to discriminate between skilled and lesser skilled performers. In this section, tests of reactive agility and the ability to discriminate between skilled and lesser skilled athletes are discussed.

Unpublished research by Farrow, Young, and Bruce (as cited in Sheppard & Young, 2006) developed a test of reactive agility whereby netball players were required to react to the movements of an opponent projected on a life size screen. The video was initiated when the participants broke a beam on a set of timing gates. They then had to move either left or right in response to the movements on the screen, and the trial was stopped when they broke another set of timing gates in the direction of movement. High performance netball players initiated CODS before the release of the ball due to anticipation of the offensive player's movement. In contrast, low-performance players demonstrated longer decision time and inferior total times. When the decision making component of this test was removed in order to make it a pre-planned CODS test, the test no longer discriminated between the high-performance players and the low-performance players. There was a moderate correlation between these two versions of the test indicating that they were measuring relatively independent qualities. The results of this unpublished investigation have been supported by more recent publications studying tests of reactive agility and their relationship to straight sprint speed and pre-planned CODS as well as the ability to discriminate between skilled and lesser skilled players.

Sheppard, Young, Doyle, Sheppard, and Newton (2006) evaluated the reliability of a test of reactive agility, which involved the athlete standing opposite the tester who was standing on a timing mat. The tester initiated movement thereby starting a timer. The athlete reacted to the tester's movement by running forward towards the tester and then to the left or right in response to the left or right movement of the tester. The timer stopped when the participant triggered a timing beam set up 5 m to either side and 2 m in front of the starting point. The test was demonstrated to have both test-retest reliability and inter-rater reliability, with no difference in results obtained between tester A and tester B. This study also found that the reactive agility test distinguished between a high-performance group and a low-performance group of Australian Rules football players. More traditional speed and CODS tests that did not include a cognitive component did not discriminate between high-performance and low-performance players. Similarly, Gabbett et al. (2008) demonstrated that the same test of reactive agility, as used by Sheppard et al., discriminated between performance levels in rugby league players when straight sprinting speed and CODS did not discriminate between the groups. This evidence further strengthens the need for sport specific agility tests that include all aspects of agility performance.

It is crucial that tests are designed specifically for the sport in which they are to be used due to the specific nature of elite athlete's expertise in identifying visual cues and recognizing patterns of play. Further, it is important that actual performers are used as the 'offensive' players in these tests as 2-dimensional videos do not offer the same visual cues as a 3-dimensional game situation.

Overall Summary

In summary, there is presently no single definition of agility in the literature. For the purposes of this research, agility is defined as an unplanned, rapid, whole-body change of velocity or direction in response to a stimulus. This definition acknowledges both the physical and cognitive components of agility performance. The physical factors that appear to have an effect on agility performance include straight sprinting speed, leg strength and power, anthropometric measurements, and technique. The research into straight sprinting speed indicates that there is no relationship between straight sprint speed and CODS although by contrast, Peterson et al. (2006) and Jullien et al. (2008) demonstrated that leg strength is highly correlated with CODS. Miller et al. (2006) and

Thomas et al. (2009) showed that a period of plyometric training improved CODS performance indicating that there might be a relationship between CODS and reactive power. Although there is no direct relationship between CODS and body composition, Cronin et al. (2003) demonstrated that limb segment length was an influential factor in a lunge indicative of a direction change in racket sports. This could affect an athlete's ability to lower his or her center of mass and perform the necessary technique to efficiently change direction, thus limiting his or her ability to apply medio-lateral forces into the ground.

Visual scanning strategy and knowledge of situations have been shown to affect an athlete's anticipation in sporting situations. Skilled athletes appear to be more capable of picking up and extracting relevant information from opposition player's movements in order to anticipate their actions. Also, knowledge of situations plays a role in this process as over years of training and competition, athletes are able to build up complex knowledge structures based on past experiences.

There is presently no research in the literature investigating the effects of the addition of cognitive components to agility testing and their effects on technique and ground reaction forces. It is crucial during any CODS movement that athletes are able to apply medio-lateral force into the ground in order to propel themselves in the new direction. If there is a time pressure applied to this movement then it is likely that the athlete will not have time to lower his or her center of mass in order to decelerate and change direction. This will leave the athlete in a more upright stance limiting his or her ability to apply medio-lateral forces into the ground thereby limiting CODS. Therefore, the purpose of this study was to investigate whether the introduction of a cognitive component to a change of direction task would have an effect on the application of medio-lateral and vertical ground reaction forces, the angle of the lower limb at push-off, and movement time in elite college soccer players.

CHAPTER III

METHODOLOGY

Participants

Elite, college soccer players ($N = 18$) were recruited from the University of California, Santa Barbara men's soccer team. This number of participants was smaller than the original desired sample size of 34, due to injury and availability of players. All participants were volunteers. Participants were of similar conditioning level and expertise. All participants participated in a similar volume of training.

Instrumentation

Health history. Participants completed a standard physical activity and readiness questionnaire ([Par-Q]; Canada's Physical Activity Guide to Healthy Active Living, 2002). The information gathered from this questionnaire was used to ensure that participants had no contraindications to intense exercise.

Height and body mass. For the measurement of height and body mass, participants were asked to remove their shoes. Participants wore the attire in which they would be performing the testing for measurement of height and body mass. Height was measured in centimeters (cm) using a mounted stadiometer. Body mass was measured in kilograms (kg) using a Bertec force plate (Bertec corporation, Ohio, USA).

Ground reaction forces. Ground reaction forces were measured in the medio-lateral and vertical planes using a Bertec force plate (Bertec corpotation, Ohio, USA).

Ground reaction force was measured during both the pre-planned CODS test and the reactive agility test.

Lower limb angle. Video camera data were used to measure lower limb angle. This was measured as the angle of the shin on the lateral leg (if moving to the right, shin angle of the left leg was measured) from the ground at push-off. Data were collected using a Dartfish Pro Suite v4.5 video analysis system (Dartfish, Georgia, USA) from the last frame before the foot left the ground at push-off. Shin angle was measured from the posterior aspect of the Achilles tendon in line with the lateral maleolus of the ankle and the popliteal fossa of the knee joint.

Movement time. Movement time was measured using the timer on the Dartfish video analysis system. Movement time was recorded as the time from the first frame of movement to the frame in which the participant's back foot crossed the line to finish the trial.

Response time. Response time was also measured via the Dartfish video analysis system. Response time was measured as the elapsed time between the initiation of lateral movement by the investigator to the initiation of movement in the same direction by the participant. This was measured by recording the time of the first frame in which the investigator initiated lateral movement and the time of the first frame in which the participant initiated movement.

Procedures

Before data collection began, approval for the investigation was sought from the institutional review board of Middle Tennessee State University (see Appendix A).

Permission was sought from the head coach of UCSB men's soccer for his athletes' to participate in this study. Once this approval had been awarded, participants were recruited form the UCSB men's soccer team.

On arrival at the testing facility, participants were asked to read and sign the informed consent form (see Appendix B), which was witnessed by the researcher. Participants then completed the Par-Q, which was reviewed prior to testing. The testing order was: height and body mass, and then either pre-planned CODS then reactive agility, or reactive agility then pre-planned CODS. Participants were given approximately 1 minute to rest between trials on the pre-planned CODS test and the reactive agility test. The two tests were performed consecutively.

Pre-planned CODS. Pre-planned CODS was used to measure the physical attributes associated with agility performance, including ground reaction forces, angle of the lower limb (to indicate technique), and movement speed. The pre-planned CODS test was adapted from the reactive agility test used by Gabbett et al. (2008). The athletes were instructed to start in an 'athletic' position with the knees and hips slightly bent. The arms remained at their sides with a 90 degree bend at the elbow. The athletes started by standing on a force plate with a video camera placed 5 m behind them. Participants were asked to perform a lateral shuffle of 2.5 m from a static start, pushing off on either their dominant or non-dominant leg in random order. Dominant leg was determined by asking the participants which leg they preferred to take a penalty kick with. Each participant performed four trials in each direction with approximately 1 minute recovery between each trial. The athletes were informed before each trial which direction they should perform the movement in order to remove any decision making component. Participants were instructed to initiate movement upon recognizing lateral movement in the video.

Reactive agility. The reactive agility test was used to measure both cognitive and physical aspects of agility performance as outlined in Chapter two. This test was performed in the same manner as the test of pre-planned CODS with the exception of a decision making component added at the start of the test. This allowed for the measurement of response time in addition to the other physical parameters. For this test, the participant adopted the same starting stance as in the pre-planned CODS test and faced a large screen with video of an investigator performing the different movement scenarios. The athlete was asked to react to the movements of the investigator by performing the 2.5 m lateral shuffle in the direction of movement of the investigator. The investigator performed one of four possible scenarios as outlined in Gabbett et al. (2008). These four scenarios were:

1. Step forward with the right foot and change direction to the left.
2. Step forward with the left foot and change direction to the right.
3. Step forward with the left foot, then the right, and change direction to the left.
4. Step forward with the right foot, then the left, and change direction to the right.

An equal number of each trial was presented to each participant. Participants completed a total of 8 trials, 4 in each direction. Trials were presented to the participants in random order. The average of trials for the dominant and the non-dominant leg were taken for each participant for the purpose of data collection. A trial to the dominant side was classified as any trial in which the athlete pushed off on the dominant leg in order to move in the opposite direction. For example if an athlete was right leg dominant then a dominant side trial would involve the athlete applying lateral force through the right leg and moving to the left. This test has been shown to have high inter- and intra-rater reliability (Gabbett et al., 2008).

For the purposes of data analysis, only trials for scenarios one and two were used. This was decided due to the participants making incorrect decisions as to the direction of travel during scenarios three and four. These errors were not present during scenarios one and two. While accuracy of response is an important facet of reactive agility, it was not the focus of this study and therefore, it was decided to eliminate this component from the analysis.

Statistical Analysis

Descriptive statistics (M, SD) for height and body mass were reported. Independent samples t-Tests were used to assess whether there was an order effect (i.e., pre-planned first or reactive first) and whether there was a dominance effect (i.e., right leg dominant or left leg dominant). A one-way repeated measures multivariate analysis of variance (MANOVA) was used to ascertain differences in medio-lateral ground reaction force, vertical ground reaction force, lower limb angle, and total trial time between a pre-planned CODS test and a reactive agility test. Four one-way repeated measures ANOVAs were used after the MANOVA to determine which variables were influenced by the test condition. The Statistical Package for Social Sciences (SPSS) for Windows, version 12.0 were be used to run all statistical analyses. An alpha of .05 was be used for all statistical procedures.

CHAPTER IV

RESULTS

NCAA division I soccer players participated in this study ($N = 18$). Demographic data used to describe the sample included height and body mass. The mean height of the sample was 178.7 cm (± 18.8 cm). The mean body mass of the sample was 80.30 kg (± 6.15 kg).

There was no order effect between those who received the reactive condition first and those who received the pre-planned condition first on any of the dependent variables (see Table 1 for the independent samples *t*-tests results). Independent sample *t*-tests to determine whether the dominant leg (i.e., left versus right) impacted performance measures were not interpreted because only 2 of the 18 participants were left-dominant.

A one-way repeated measures MANOVA was used to determine whether type of activity (pre-planned or reactive) was related to the four dependent variables, which included lower limb angle, total trial time, medio-lateral ground reaction forces, and vertical ground reaction forces. The overall MANOVA revealed that type of activity was related to the dependent variables, Wilk's $F(4, 14) = 4.21, p = .02$, lambda = .45. Univariate one-way ANOVAs were conducted as follow-up tests in order to determine which of the dependent variables were related to type of activity.

Table 1

Independent Samples t-Test Results for Test of Order Effects

Variables	T	p	M ± SD
Lower limb angle (Degrees)			
Pre-planned	0.56	.58	
Pre-planned first			46.11 ± 3.21
Reactive first			45.04 ± 4.72
Reactive	1.33	.20	
Pre-planned first			44.87 ± 5.1
Reactive first			46.87 ± 2.68
Total trial time (s)			
Pre-planned	0.59	.56	
Pre-planned first			1.15 ± 0.11
Reactive first			1.18 ± 0.12
Reactive	1.34	.20	
Pre-planned first			1.22 ± 0.08
Reactive first			1.29 ± 0.12
Medio-lateral ground reaction forces (N)			
Pre-planned	0.90	.38	
Pre-planned first			779.03 ± 116.42
Reactive first			823.88 ± 94.64
Reactive	0.44	.67	
Pre-planned first			801.45 ± 109.97
Reactive first			774.08 ± 151.21
Vertical ground reaction forces			
Pre-planned	1.37	.19	
Pre-planned first			646.05 ± 186.01
Reactive first			754.92 ± 148.09
Reactive	0.41	.69	
Pre-planned first			729.86 ± 235.38
Reactive first			773.21 ± 213.65

Note. $df = 16$; $n = 9$ *for pre-planned first;* $n = 9$ *for reactive first*

It was determined that total trial time was related to type of activity. None of the other dependent variables were related to type of activity. Table 2 shows the results of the univariate analysis.

Additional one-way repeated measures ANOVA tests were conducted to determine whether the type of activity affected the movement or response phase of the trial. The follow up tests revealed that movement time was similar between pre-planned and reactive trials. Response time was significantly longer for reactive trials as comp between pre-planned and reactive trials. Table 3 contains the results of the follow-up analysis.

Table 2

Type of Activity as a Predictor of Lower Limb Angle, Total Time, Medio-Lateral Forces, and Vertical Force

Dependent Variable	*F*	*p*	Eta^2	*M* ± *SD*
Lower limb angle (degrees)	0.002	.96	.00	
Pre-planned				45.57 ± 3.95
Reactive				45.59 ± 4.16
Total trial time (s)	4.32*	.001	.46	
Pre-planned				1.16 ± 0.11
Reactive				1.25 ± 0.11
Medio-lateral ground reaction forces (N)	0.21	.65	.01	
Pre-planned				801.45 ± 105.48
Reactive				787.77 ± 129.03
Vertical ground reaction forces (N)	1.90	.19	.10	
Pre-planned				700.48 ± 172.45
Vertical				751.54 ± 219.20

Note. $^{*}p < .05$; $df = (1, 17)$ for each one-way repeated measures ANOVA.

Table 3

Type of Activity as a Predictor of Movement Time and Response Time

Dependent Variables	F	p	Eta^2	$M \pm SD$
Movement time (s)	0.61	.45	.03	
Pre-planned				1.26 ± 0.61
Reactive				1.16 ± 0.11
Response time (s)	12.14*	.003	.42	
Pre-planned				0.04 ± 0.04
Reactive				0.11 ± 0.09

Note. $^{*}p < .05$; $df = (1, 17)$ for each one-way repeated measures ANOVA.

CHAPTER V

DISCUSSION

The purpose of this study was to investigate whether the introduction of a cognitive component to a change of direction task would have an effect on the application of medio-lateral and vertical ground reaction forces, the angle of the lower limb at push-off, and total time to complete the task in elite collegiate soccer players. The sample was comprised of 18 NCAA division I men's soccer players.

Background Information

There is no single definition of agility in the literature. The majority of studies focus on the physical aspects of agility and use a definition that addresses these qualities. However, it is important to acknowledge that there are also cognitive components of agility that must be included in any definition of agility. Sheppard and Young (2006) suggested that a comprehensive definition of agility should recognize the perspectives of numerous fields within sport sciences namely, strength and conditioning, motor learning, and biomechanics.

The strength and conditioning perspective deals mainly with the physical aspects of agility. Definitions in the literature pertaining to the physical qualities of agility are varied but include; the ability to change direction, accelerate and decelerate, start and stop, and to maintain balance and control (Baker & Newton, 2008; Barnes et al., 2007; Bloomfield et al., 2007; Little & Williams, 2005; Pauole et al., 2000; Young et al., 2001).

The qualities outlined in the above research have been summarized as CODS (Young et al., 2002), although they do not address the cognitive qualities that have been demonstrated to affect agility performance (Gabbett et al., 2008).

Agility is defined in this study as an unplanned, rapid, whole-body movement with change of velocity or direction in response to a stimulus. Under this definition, a task must be an open skill with no pre-planned response, which has implications for the testing and the training of agility.

In acknowledging that agility includes a cognitive component, it is important to know how the introduction of a cognitive component to a more traditional CODS task affects performance. It is clear that cognitive components do affect performance, but a more clear understanding of which parts of the athlete's movement are affected by its introduction is needed in order to implement high performance training programs. This will allow coaches to move away from more traditional CODS training and towards training methodologies that can be more closely correlated to a specific sport.

To quantify the changes in an athlete's movement, participants' were asked to complete both a pre-planned CODS task and a reactive agility task. In both tasks, the athlete stood in front of a video projection that depicted an investigator moving forward either one or two steps and then moving to the left or to the right. Upon presentation of the lateral movement, the participant had to react and move in the same direction and slide laterally 2.5m to cross a finish line. In the pre-planned trial the participants were informed of which way the investigator would move and as soon as they saw that movement they should initiate their response. In the reactive trials the participants were not instructed which way the investigator would move and would have to read and react to the movement presented.

Total Time

Total trial time is made up of two components, response time and movement time. Response time, for the purposes of this investigation, was measured as the time from the first frame of lateral movement from the investigator, to the first frame of movement in the participant. Movement time was measured as the time from the first frame of movement of the participant to the frame in which the participant's back foot crossed the line to finish the task. The speed at which an athlete can complete a movement in sport is a pivotal physical attribute that can, in part, determine an athlete's success within his or her chosen sport. Speed of movement is a common trait among athletes who compete at the highest level of power-based sports. However, the physical act of fast movement or the ability to perform a CODS task faster than another athlete does not necessarily predict success within a sport. Athletes playing at the highest level of sport also perform well on reactive agility tasks, which include a cognitive component. This is due to elite athletes' superior ability to read and react to cues presented by opponents and playing situations (Gabbett et al., 2008).

In the current study, total trial time was significantly different between pre-planned CODS tasks and reactive agility tasks. This supports the hypothesis that athletes would be able to complete CODS tasks faster than they would be able to complete a reactive agility task. To better understand the mechanisms of the decrease in performance, response time and movement time were assessed in order to identify where the decrease in performance occurred. There was no difference in movement time between the pre-planned CODS task and the reactive agility task. It was expected that there would have been an increase in movement time with the introduction of the cognitive component due to the breakdown in movement mechanics when a cognitive component was introduced to a task. However, there was a significant difference in response time between the pre-planned CODS task and the reactive agility task. This was expected due to the increased time necessary to process the stimulus and make a decision as to the appropriate response.

Gabbett et al. (2008) demonstrated that a reactive agility task could be used to distinguish between elite and sub-elite performers. The findings of the present study support the finding that the limiting factor in this type of task is the ability of an athlete to read and react to the visual cues presented and his or her ability to process these cues to formulate a response. The fact that response times were different between the pre-planned and reactive agility tasks can be explained by looking at the demands placed on the athletes' visual scanning strategies and their knowledge of situations. It is likely that the greatest influencing factor in the difference in response time was knowledge of situations. This was due to the fact that the stimulus presented to the participants was the same for both the pre-planned and reactive trials. During both trials, the participants would have been required to identify cues such as lower limb angle and displacement of the center of mass with some certainty before fully executing their own movement. Although not a focus of the present study, it can be assumed that the athletes employed similar visual search strategies to identify these cues. Williams and Davids (1998) suggested that athletes use different visual search strategies for different situations in soccer and it can therefore be assumed that when in a similar situation a player will employ the same search strategy.

Williams (2000) suggested that successful athletes use their knowledge of situations to anticipate future events. This can be applied to the present study in that although the participants' still had to respond to a stimulus, they knew the direction in which they had to travel and so could anticipate the investigators movement. Alain and Proteau (1980) suggested that tennis players evaluated the probabilities of the possible events that could occur, using this evaluation to maximize the efficiency of their subsequent movement. The researchers suggested that players' made an anticipatory response if the probability of success was greater than 70%. It was this initial evaluation that guided the player's anticipatory movement, with confirmatory or corrective movements being made in response to actual events.

In the present study, observational data from the videos of the trials shows that on pre-planned trials, participants would begin anticipatory movements in the direction in which they were going to move when the investigator began moving forward. Then, when the investigator moved laterally, the participants were able to fully commit to the lateral movement to finish the trial. It seems likely that these anticipatory movements were in part responsible for the improved response time in the pre-planned movements. This is reinforced by Ward and Williams (2003), who discovered that measures of anticipatory performance and use of situational probabilities were the greatest predictors of success in youth soccer players. Vaeyens, Lenoir, Williams, and Mazyn et al. (2007)

also found that youth soccer players had faster response times due to their superior knowledge of situations. During the reactive agility tasks, participants would have taken longer to establish the situational probabilities with any degree of certainty and as such would not have had time to initiate any anticipatory response and so would have been forced to wait for the investigators movements before producing a response.

Observational data suggested that the initial response during the reactive agility task was rarely in the direction in which the participants had to travel, but was generally to lower the center of mass in order to be able to travel in either direction before formulating a functional response in the direction of travel. Indeed, it seemed that there were two parts to the reactive agility response. There was an initial non-productive response, which seemed to be an acknowledgement that a response was required, during which the participants lowered their center of mass and split their stance, with no lateral movement. This was followed by a more productive, lateral response in the direction of travel. This was in contrast to the pre-planned task whereby the initial response was an anticipatory response in the direction of travel, followed by a confirmatory response in the direction in which they were supposed to travel.

The implications of this finding are that it is clear that coaches and trainers should focus on not only movement speed, but also on reactive agility tasks in training their athletes. Emphasis should be placed on creating reactive agility tasks that are specific to the athletes' sport in order to improve their knowledge of situations. Education should be given to the athletes as to what cues they should look for in the movement of an opponent or a ball in order to allow them to evaluate situational probabilities faster and initiate anticipatory responses and therefore, maximize their efficiency of the overall response. The same is true for the testing of athletes due to the fact that their knowledge of situations is likely to be specific to their sport. Vaeyens, Lenoir, Williams, and Mazyn et al. (2007) suggested that skilled performers have developed elaborate task-specific knowledge structures and efficient encoding and retrieval processes through extensive exposure to their domain over years of practice.

In summary, it appears that movement time is not a limiting factor in reactive agility tasks for these athletes. Although statistically insignificant, the general pattern was a decrease in mean movement time between pre-planned CODS tasks and reactive agility tasks. It is possible that the athletes perceived this as being more like competition and as such were more motivated to 'race' the investigator in the video. It appears that response time was a limiting factor between the two tasks. This was attributed to the increased demands placed on the athletes' anticipatory skills, such as, their ability to read and react to visual cues, process these cues, and formulate an appropriate response. Training and testing should be specific to the athletes sport in order to train and test an athletes knowledge of situations and ability to anticipate future events in their chosen sport.

Lower Limb Angle

Creating small ground angles at the lower limbs is an important aspect of both linear speed and CODS movements. When small ground angles are created it allows athletes to apply more force into the ground in the opposite direction in which they are trying to travel. Besiers (2001a; 2001b) and Sayers (2000) highlighted the importance of decelerating and lowering the center of mass in performing CODS tasks. This lowering of the center of mass allows the athlete to create better ground angles in order to apply force and produce larger ground reaction forces in the new direction of travel.

It was hypothesized that lower limb angle would be smaller in pre-planned CODS tasks as compared to reactive agility tasks. It was thought that this would be due to the more upright posture of athletes entering a reactive agility movement as opposed to a pre-planned movement, which allows the athlete to prepare in advance of the stimulus by starting with a lower center of mass (Besier et al., 2001a; 2001b).

In actuality, there was no difference in lower limb angle between pre-planned CODS tasks and reactive agility tasks. This may be explained by the fact that lower limb angle at push off was measured as opposed to measuring lower limb angle while participants were in their starting stance. It is possible that the lower limb angle at push off would not be affected by the introduction of a cognitive component due to the fact that this is the end product of lowering the center of mass and preparing to accelerate or move in a new direction. Sayers (2000) suggested that athletes in team sports adopt a different sprint technique to that of track and field sprinters, preferring to maintain a lower center of mass in order to improve stability and improve efficiency of change of direction through reducing time taken to decelerate and lower the center of mass. As such, in future research, it would be helpful to examine the differences in starting position between participants and how this relates to movement time between reactive agility tasks and pre-planned CODS tasks. It is reasonable to assume that athletes who have a more upright starting position would have slower movement times due to the fact that they would first have to drop their center of mass before moving in the appropriate direction.

While there was no difference between pre-planned CODS tasks and reactive agility tasks in lower limb angle, this remains an important facet of overall movement efficiency. It is important that as part of an overall agility training regimen, coaches should instruct athletes on starting movements with a low center of mass and smaller ground angles. During reactive agility the athletes should be instructed to produce smaller ground angles on both legs by moving the knees inwards to facilitate movement in either direction.

Medio-Lateral Ground Reaction Forces

Ground reaction forces are the reaction of the support surface to forces applied through the foot and into the ground. The ability of athletes to apply forces into the ground in the opposite direction in which they are trying to travel will directly affect the efficiency of their movements. If athletes' are attempting to perform a maximal lateral agility movement as in this study, then it will be necessary for them to apply a large amount of force in the medio-lateral plane. If they are unable to do so then it is expected that their movement speed will be impaired.

In line with the above hypothesis relating to ground angles, it was hypothesized that athletes would apply more force in the medio-lateral plane in the pre-planned CODS task than in the reactive agility task. It was assumed that if athletes were less able to produce small ground angles then they would not be able to apply as much force in the medio-lateral plane.

The analysis showed that there was no difference in medio-lateral ground reaction forces between the pre-planned CODS task and the reactive agility task. This further helps to explain the lack of a significant difference in movement time between pre-planned CODS and reactive agility tasks. The fact that participants were able to apply equal magnitudes of force into the ground in the medio-lateral plane between pre-planned CODS and reactive agility tasks is likely to be an influencing factor in movement speed, although more research is needed to confirm this. Because the athletes' ground angles were similar between the two tasks, they were able to apply force into the ground at an angle that was sufficient to replicate their force production in this plane from pre-planned to reactive tasks. As with lower limb angle, it remains important that athletes are instructed on exerting force into the ground laterally in order to optimize the efficiency of their movement. This should be done as part of their physical CODS training emphasizing strong ground contacts in order that they produce large ground reaction forces.

Vertical Ground Reaction Force

Vertical ground reaction forces are particularly important in tasks that require vertical jumping or force production. In tasks that require lateral movement, such as CODS tasks or reactive agility tasks, it is important that there is a positive ratio of vertical to medio-lateral ground reaction forces. While it is still important to have some vertical ground reaction forces to ensure that there is enough flight time to maintain stride length, if there is too much vertical force applied, then the ground reaction forces will increase in the vertical plane. If vertical ground reaction forces are above optimal levels then the athlete will be propelled vertically and, as such, will have reduced horizontal flight time and therefore distance.

It was hypothesized that vertical ground reaction forces would be higher during the reactive agility task than during the pre-planned change of direction task. This was in line with the suggestion by Besier et al. (2001a; 2001b) that athletes may have a more upright posture when performing reactive agility tasks therefore making it more likely that they would have larger ground angles and so would apply greater force in the vertical plane. Also, with athletes starting in a more upright posture and having a time restriction on their movement it would be likely that they would have to lower their center of mass more quickly, thus producing higher vertical ground reaction forces.

However, analysis showed that there was only a small non-significant increase in vertical ground reaction forces between the pre-planned CODS task and the reactive agility task. This can, in part, be attributed to the fact that the lower limb angle was the same between the pre-planned and reactive tasks. There may be a discrepancy between these results and those of Besier et al. (2001a; 2001b) due to the fact that the athletes in the present study started from a static position and the athletes in the previous study were moving when the direction change was initiated. It may have been easier for participants in the present study to start with a lower center of mass, which would have lead to smaller ground angles and reduced vertical ground reaction forces.

It is important to recognize that there is still a lot of importance to be placed on vertical force production in lateral movement. If athletes are instructed to apply too much medio-lateral force as compared to vertical force then they will not be able to move as far as athletes who have a better ratio of medio-lateral and vertical ground reaction forces. Achieving the optimum ratio of force applied into the ground is something that should be part of a periodized year round physical preparation program

Overall Conclusions

The purpose of this study was to investigate whether the introduction of a cognitive component to a change of direction task would have an effect on the application of medio-lateral and vertical ground reaction forces, the angle of the lower limb at push-off, and total trial time in elite collegiate soccer players. A one-way repeated measures MANOVA determined that type of activity (pre-planned or reactive) was related to the four dependent variables. Univariate one-way ANOVAs, conducted as follow-up tests, indicated that total trial time was significantly different between the pre-planned CODS task and the reactive agility task. The *t*-tests revealed that this difference could be attributed to response time being longer in the reactive agility task than in the pre-planned CODS task. No other significant differences were detected.

The difference in response time between pre-planned CODS and reactive agility in the context of this study was largely attributed to knowledge of situations. The fact that the participants knew which way they were going to move in the pre-planned CODS task allowed them to evaluate the situational probabilities with certainty thus enabling them to formulate anticipatory responses in the correct direction. These anticipatory responses were measured as the initiation of their response to the stimulus, thus reducing their response time.

Future research should attempt to use a larger sample size in order to increase the statistical power of the results and reduce the influence of individual differences on the results. A larger sample size may yield different results with the same protocol. Also, future research should investigate the difference between those who have a more upright starting posture and those who have a lower center of mass at the presentation of the stimulus. Between subjects differences in lower limb angle at push off and ground reaction forces would be another area of interest for future studies into the field of agility.

The findings of this study have significant implications for the testing and training of athletes competing in team and individual sports who are required to perform agility movements in response to a stimulus. First, coaches should emphasize sport and situation specific reactive agility training as part of their overall athletic performance program. This will better aid them in their preparation for competition in elite level sport. Second, despite the lack of a significant difference between pre-planned CODS tasks and reactive agility tasks, the physical attributes associated with CODS should still be a large part of the athletic performance program. Education in this area should focus on creating small ground angles at the lower limb as well as applying force into the ground with solid ground contacts in order to ensure large ground reaction forces. Even though research has shown there not to be a difference in high level and lower level athletes in their physical attributes, it must be emphasized that well rounded abilities in both physical and cognitive aspects of agility performance are desirable at the top level of competition in any sport.

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APPENDIXES

APPENDIX A

Middle Tennessee State University Institutional Review Board Form

April 21, 2009

Names:	Mr. Jeremy Bettle, Dr. Jennifer Caputo
Protocol Title:	"Changes in movement kinematics between reactive agility movements and pre-planned agility movements."
Protocol Number:	09-257
Email addresses:	jezbettle@gmail.com, jcaputo@mtsu.edu

Dear Investigator(s),

The MTSU Institutional Review Board (IRB), or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110.

Approval is conditionally granted provided written consent is obtained from the appropriate legal guardian(s) or parent(s) of minors selected to participate in the study. Approval is granted for one (1) year from the date of this letter for **34** participants.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. **If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance (c/o Tara Prairie, Box 134) before they begin to work on the project.** Any change to the protocol must be submitted to the IRB before implementing this change.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918.

You will need to submit an end-of-project report to the Office of Compliance upon completion of your research. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions.

Also, all research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,

Joseph C Hawkins (electronically signed)

Joseph C. Hawkins, Member
MTSU Institutional Review Board

APPENDIX B

Informed Consent Form

Principal Investigator: Jeremy Bettle
Study Title: changes in movement kinematics between a pre-planned change of direction speed task and a reactive agility task.
Institution: Middle Tennessee State University

Name of participant: ____ Age: __________

The following information is provided to inform you about the research project and your participation in it. Please read this form carefully and feel free to ask any questions you may have about this study and the information given below. You will be given an opportunity to ask questions, and your questions will be answered. Also, you will be given a copy of this consent form.

Your participation in this research study is voluntary. You are also free to withdraw from this study at any time. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

For additional information about giving consent or your rights as a participant in this study, please feel free to contact Tara Prairie at the Office of Compliance at (615) 494-8918.

1. **Purpose of the study:**
   You are being asked to participate in a research study to investigate whether introduction of a cognitive component to a change of direction task will have an effect on the application of medio-lateral and vertical forces, the angle of the lower limb at push-off, and movement time in lateral movements.

2. **Description of procedures to be followed and approximate duration of the study:**
   On arrival at the facility you will be asked to complete a heath history form and will then be assessed for height, body mass, and body composition. Body composition will be measured by determining the thickness of a fold of skin at seven sites. Following these assessments you will complete a general warm-up followed by a warm-up more specific to the movement test.

   Following the warm up you will be asked to complete two trials involving lateral movements. The first trial will involve a pre-planned movement to both the left and right, or dominant and non-dominant side. The second trial will involve reacting to a stimulus presented by the investigator and moving in the laterally same direction as the presented stimulus.

   It is expected that this will take approximately 45 minutes to one hour.

3. **Expected costs:**
   There will be no costs associated with participation in this investigation.

4. **Description of the discomforts, inconveniences, and/or risks that can be reasonably expected as a result of participation in this study:**
   The risks associated with this study include minor muscle soreness associated with plyometric type movements, and muscle strains or pulls. The movements will be similar to those performed during soccer practice.

5. **Unforeseeable risks:**
   There are no unforeseen risks associated with this study

6. **Compensation in case of study-related injury:**
   There will be no compensation for injury sustained while participating in this investigation.

7. **Anticipated benefits from this study:**

a) The potential benefits to science and humankind that may result from this study are that this study will provide coaches with a great deal of information pertaining to individual athletes limiting factors in agility performance. This will improve the design of agility training programs, making them more individualized, thus improving team performance.

b) The potential benefits to you from this study are that you will be fully evaluated across a range of performance characteristics and will receive individualized feedback based on the results of the testing protocol on areas that could potentially improve soccer performance.

8. **Alternative treatments available:**
   You will be required to complete all conditions within the study.

Compensation for participation:
There will be no compensation for participating in the study.

9. **Circumstances under which the Principal Investigator may withdraw you from study participation:**
   You will be withdrawn from the study if it is discovered that you have any lower extremity injury or if your full effort is not put forth in all trials.

10. **What happens if you choose to withdraw from study participation:**
    You are free to withdraw from the trial at any time before, during, or after the investigation without consequence.

11. **Contact Information.** If you should have any questions about this research study or possibly injury, please feel free to contact Jeremy Bettle at 805-893-7859 or my Faculty Advisor, Dr. Jennifer Caputo at 615-898-5547 or Tara M. Prairie, Compliance Officer at 615-494-8918.

12. **Confidentiality.** All efforts, within reason, will be made to keep the personal information in your research record private but total privacy cannot be promised. Your information may be shared with MTSU or the government, such as the Middle Tennessee State University Institutional Review Board, Federal Government Office for Human Research Protections if you or someone else is in danger or if we are required to do so by law

    Only the named investigators will have access to testing data. Participants will be identified by number rather than by name. Only the investigators will be able to link the participants name to their number.

    All files will be kept in a locked filing cabinet to which only the principal investigator will have access. All electronic data will be kept on a password protected computer to which only the principal investigator has access. After three years all paper documentation will be shredded and electronic files will be deleted.

13. <u>STATEMENT BY PERSON AGREEING TO PARTICIPATE IN THIS STUDY</u>
I have read this informed consent document and the material contained in it has been explained to me verbally. I understand each part of the document, all my questions have been answered, and I freely and voluntarily choose to participate in this study.

____________________ ____
Date Signature of patient/volunteer

Consent obtained by:

____________________ ____
Date Signature

____
Printed Name and Title