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Planned and Unplanned Change of Direction Maneuvers: A Study of Ground Reaction Forces and Lower Limb Kinematic and Kinetic Properties

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PLANNED AND UNPLANNED CHANGE OF DIRECTION MANEUVERS: A STUDY OF GROUND REACTION FORCES AND LOWER LIMB KINEMATIC AND KINETIC PROPERTIES

BY

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To the Dean of the School of Human Performance and Leisure Sciences:

I am submitting herewith a thesis written by Robert Saner entitled " PLANNED AND UNPLANNED CHANGE OF DIRECTION MANEUVERS: A STUDY OF GROUND REACTION FORCES AND LOWER LIMB KINEMATIC AND KINETIC PROPERTIES". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Biomechanics.

Dr. Claire Egret, Thesis Committee Chair

We, members of the thesis committee,
have examined this thesis
and recommend its acceptance:

Accepted:

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Abstract

The purpose of this study was to determine which of two conditions (planned and unplanned) would predispose a change of direction performer to a greater risk of anterior cruciate ligament (ACL) injury. This was done so as to enable trainers, coaches and athletes to better prepare the body for the condition that presented the greater risk, thereby lowering the overall level of potential injury that athletes are exposed to. Variables assessed were that of peak braking forces, peak vertical ground reaction forces (VGRFs), loading rates and peak valgus angles, measured at weight acceptance. Weight acceptance was defined as the period from contact of the foot to maximum knee flexion during the change of direction (COD) maneuver. Male, NCAA, Barry University, Division II athletes ($N = 18$) from the sports of basketball, baseball and soccer volunteered to be a part of the study. A repeated measures, within-subjects multivariate analysis of variance (MANOVA) was performed to assess the differences between planned and unplanned COD maneuvers, within subjects. Significance was displayed between planned and unplanned peak normalized braking forces $F(1,17) = 21.577$, $p<0.001$. In addition, statistical significance was displayed between planned and unplanned VGRFs $F(1,17) = 12.681$, $p = 0.002$. No statistical significance was displayed between the planned and unplanned conditions of loading rate $F(1,17) = 3.968$, $p = 0.063$ and peak valgus angles achieved $F(1,17) = 2.537$, $p = 0.130$. Statistical significance exists between planned and unplanned braking forces and VGRFs, with the unplanned conditions displaying greater values in magnitude during weight acceptance. These findings display the need for coaches, trainers and athletes to train the supporting muscles of the knee and neuromuscular responses more so for unplanned COD maneuvers to reduce injury risk.

Chapter One: Introduction

Modern-day sports, the world over, can be categorized in to two main subdivisions: contact and non-contact sports. Contact sports, as the name implies, involve two or more players coming in to physical contact with one another in order to achieve a desirable team or personal outcome, depending on the objective of the sport (Benedict & Parker, 2014). Non-contact sports require the participants to avoid bodily contact in order to achieve the objective of the sport being played (Benedict & Parker, 2014). Many contact and non-contact sports require participants to avoid defending members of the opposing team. This concept introduces the notion of agility and thus the focus of this study; cutting maneuvers and their risk to anterior cruciate ligament (ACL) injury.

ACL injuries are one of the most common occurring injuries within agility related sports (Jamison, Pan & Chaudhari, 2012). It has been reported by Dempsey et al., (2009) that between 50%-80% of ACL injuries occur during non-contact events within sports. Furthermore, Donnelly et al., (2012) state that one half of non-contact ACL injuries occur during side-step or cutting maneuvers. With this information, it can be postulated that if changes were made to an individual performing such maneuvers, then changes to the level of risk of injury to the ACL during such maneuvers would follow (Jamison et al., 2012). It is estimated that the majority of ACL injuries that do occur, take place during agility related maneuvers that occur within multiple sports (Dempsey et al., 2009).

Sports involving high agility movements such as soccer, American football, rugby and Australian rules are played in their respective countries, all around the World. They are incredibly demanding sports both physically and mentally (Bettle, 2009). Athletes partaking in such sports are required to possess an acute awareness of surroundings, game reading ability, fitness level and agility to aid them in their performances (Gabbet, Kelly and Sheppard, 2008). What all these sports have in common is that they possess the potential for the opposing team to attempt to stop or tackle the player with the ball by presenting themselves as an obstacle. Players are required to avoid this contact or confrontation of an opponent in order to maximize their chances of moving past the opponent and potentially score points for their team. Reilly, Bangsbo and Franks (2000) found that whilst high speed maneuvers only accounted for 11% of the distance covered, the maneuvers were part of the more important segments of game in which scoring was involved. During a game there are two options in the event that a player is presented with the obstacle of an opponent: the first being trying to knock them out of the way by using force, power and momentum of the body, the second being that they can maneuver around the opponent. These maneuvers are usually done at high speed so as to pass the opposing team member or members in the fastest way possible, thereby decreasing the chances of being caught, tackled or blocked.

Agility does not have a global definition. Gambetta (1996, p. 2) defined it as "the ability for a player to change direction and stop and start quickly." However, for the purpose of this study, the definition proposed by Young et al. (2001) stated that, agility is comprised of two key sub-components; speed in changing direction and cognitive factors. In order for an athlete to be agile, their ability to produce force to create a significant change in direction needs to be sufficiently large enough so as to overcome the angle of the approaching obstacle as well as the force of inertia driving them forwards towards the approaching opposition or obstacle (Bettle, 2009).

Studies have looked at the correlations between force production in the form of ground reaction force (GRF) in straight line sprinting, acceleration and agility and the conclusions of the research have varied. Draper and Lancaster (1985) displayed low common variances of only 21% between sprinting in a straight line and agility, whereas Pauole et al. (2000) found significant correlations between men and women when subjected to a 40-yard sprint test and a T-agility test. In a study performed by Julien et al. (2006) it was found that there was a high correlation between leg strength and change of direction speed (CODS) with a 60% difference in variances of CODS. Variation of CODS can be up to 66% and is explained when strength is adjusted to body weight (Bettle, 2009). This demonstrates that the ability of an athlete whom when able to produce higher force, will better overcome the inertia of the body and be able to change direction more effectively, making their CODS more effective. (Bettle, 2009).

Taking into consideration the second key-component of Young et al.'s definition of agility, that being the cognitive part, studies investigating the relationship between preplanned and unplanned change of direction patterns at speed have been performed. This component is particularly relevant to team sports such as American football, rugby, hockey and Australian rules football as coaches plan specific moves for players to execute. Within each move are detailed patterns that each player is required to adhere to in order to successfully complete a structured maneuver. Many of the moves, such as those in American football, have a set number of paces with a pre-planned change of direction for the athlete to follow after a certain number of strides or distance. The difference between pre-planned and unplanned is that the athlete knows which way they are going to change their direction of movement when it is preplanned whereas it is unknown when the player is faced with an approaching obstacle or opponent and has to make a decision in a fraction of a second for the direction that he or she is going to take to avoid the opponent/obstacle. It has been found that when a cognitive component, such as a pre-planned maneuver, is utilized there is increased loading on the knee. This suggests that the technique applied is different (Besier et al.,

2001) to an unplanned motion (Dempsey et al., 2009). Technique can have a large effect on the biomechanical aspects of COD maneuvers as performers of the maneuvers try to attain a maximal velocity post COD (Sheppard & Young, 2006). This in turn would affect the application of forces, particularly the ground reaction forces, and thus aid in demonstrating the differences between planned and unplanned maneuvers (Sheppard & Young, 2006).

Purpose of this study

The purpose of this study is to analyse the kinetic and kinematic patterns of pre-planned and unplanned change of direction maneuvers in collegiate level, D II male athletes. By analyzing the differences, if any exist, between pre-planned and unplanned maneuvers in sport, it will allow for a better understanding of the mechanical aspects at work within a change of direction maneuver. The need for this understanding arises from the necessity to prevent ACL injury. Within the game, there will still be incidences of play where unplanned COD maneuvers are required, however, if an understanding of which condition may pose a greater risk of ACL injury to a player, training methods may be established to implement in practices so as to attempt to safeguard against injury in those circumstances within the game of play.

Hypotheses

When presented with the randomized trials of planned and unplanned direction change, as well as planned or unplanned direction, it was hypothesized that: 1) the unplanned conditions would produce significantly higher vertical ground reaction forces than planned COD maneuvers during weight acceptance, 2) braking forces during weight acceptance of the unplanned condition would be higher than the planned condition 3) loading of the knee would be greater during unplanned change of direction maneuvers during weight acceptance, 4) peak knee valgus angles during COD maneuvers would be greater during unplanned COD maneuvers than in planned COD maneuvers during weight acceptance.

Operational definitions

Agility: Agility is comprised of two key sub-components; speed in changing direction, stopping and starting and cognitive factors.

CODS: Change of direction speed is the speed at which a player or participant can change their original direction by applying sufficient force to overcome their straight line inertia.

GRF: Ground reaction force is the force applied by the ground to the participant or subject by following Newton’s third law; every action has an equal and opposite reaction. It is measured using force plates.

Assumptions

1. It was assumed that all participants would adhere to the testing procedures as requested by the researcher.
2. It was assumed that all participants did not have any undisclosed injuries or medical conditions that could affect the results obtained.

Limitations

1. Participants may not have completed the required tasks at the intensity level specified by the researcher.
2. The lab setting that the performers were tested is not identical to that of a real life, in game, experience.

Delimitations

1. The participant group was comprised of
2. male collegiate level, NCAA division II soccer players on the Barry University Soccer teams.
3. The results obtained were sheer force, braking forces, GRF and kinematic joint angle of the lower limbs.

Variables

1. Braking force – force exerted to decelerate sufficiently for change of direction.
2. Vertical GRFs – vertical force exerted when change of direction maneuver is made.
3. Knee Varus/Valgus – medial or lateral flexion of the knee that predisposes a performer to ACL injury risk.
4. Rate of loading – rate at which the knee is loaded during the change of direction maneuver.

Chapter 2: Literature review

In order to best conceptualize the experiment being performed and solidify the idea being addressed, this chapter starts with an anatomical description of the knee and the forces involved to subject an individual to risk of injury when performing a COD maneuver. Following that, an attempt is made to define agility and change of direction maneuvers. Once a final definition of the key concepts has been provided, the subdivisions of the aspect of agility were explored in the literature, those being the cognitive and physical aspects of agility. The cognitive aspects being addressed within the literature review are those of cognition in agility, situational awareness and visual scanning. Moving forward from the cognitive aspect of agility, this literature review addresses the physical aspects that enable agility maneuvers to be performed, such as strength of the lower extremities, straight line sprinting speed and changes of direction (CODs). Leading on from these physical attributes, this review assesses the ground reaction forces that occur during such maneuvers and finally culminating in an overall summary of the literature pertaining to COD maneuvers.

Anatomy of the knee

The knee joint located between the femur and tibia complex allows for posterior flexion of the leg between the aforementioned skeletal structures. Within the knee joint is the patella bone (boney cap located anteriorly to the knee joint), the meniscus of the knee (a fluid filled membranous sack that allows for shock absorption and stabilization during flexion) and multiple ligaments that maintain the positioning of the skeletal structures and functioning of the joint (Blackburn & Craig, 2013). Ligaments within the knee are the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL). Ligaments that are external to the knee joint are the medial collateral ligament (MCL) and the lateral collateral ligament (LCL) that are positioned medially and laterally to the joint as their name indicates. The medial and lateral meniscus is positioned on top of the tibia above the medial and lateral portions of the tibial head. Donnelly et al., (2012) describes the ligamentous composition of the ACL complex within the knee as being comprised of two main bundles: the antero-medial bundle (AMB) and the posteromedial-bundle (PMB). When the knee is flexed, the antero-medial bundle tightens and the posteromedial bundle becomes lax, shifting the orientation of the femoral attachment of the ACL to a more horizontal position (Peterson & Zantop, 2007).

Risk factors for ACL injury

Previous studies have been performed on the ACL and injury to this ligament. There are several factors that elevate the risk of injury to the ACL. These factors are important to assess and understand due to the large influence that they have not only on an athlete’s performance, but in addition, on the teams, schools and organizations that the athlete’s represent (Besier et al., 2001). Since the induction of the Title IX rules that were passed, ACL injury rates have increased dramatically (Hewett et al., 2005). One of the main reasons for this is the increased availability of athletic scholarships to women. Women are 4-6 times more likely to incur ACL injuries than males (Ford et al., 2005). It is reported by that in New Zealand and Australia, ACL injuries cost their healthcare systems approximately 17.4 million dollars and 75 million dollars, respectively (Donnelley et al., 2011). Not to mention, the influence that these injuries have on the United States education system. Large numbers of athletes injured, require days off school to recuperate and recover, or attend physical therapy. This in turn results in days spent away from studying and academic resources being squandered due to an injury (Ford et al., 2005). As such it is important to gain an understanding of the underlying mechanisms of ACL injury and to prevent against them so as not only to protect the athletes participating in these agility related sports, but also protect the organizations and educational systems, as well as financial resources associated with funding these athletes. In order to do so, it is important to know what factors predispose these athletes to risk of injury.

Factors that predispose an individual to risk of ACL injury have been found to be abducted hip angles, decreased knee flexion, externally rotated foot and laterally flexed torso (Dempsey et al., 2009). Other studies have found similar, but slightly differing factors to be responsible for ACL injury. Zazulak et al., (2007) stated that, "valgus positioning of the lower extremity; relative extension with unbalanced weight distribution; and the plantar surface of the foot being fixed in position, away from the center of mass," are causal factors that predispose a performer of a cutting maneuver or side-stepping maneuver to an elevated level of risk of injury (Zazulak et al., 2007. Pp 1123). With this in mind, the importance to investigate these variables and their potential influence to ACL injury is important in order to potentially enable trainers and athletes to best prepare and avoid such factors from occurring during a maneuver.

Defining agility and change of direction maneuvers

Throughout the history and investigation of agility and agility related tasks, multiple attempts have been made to define the term of agility. Definitions have attempted to encompass all the components of perceived agility, however, a trend that appears to occur throughout the literature is that definitions provided pertain mainly to the interest of the research, and not to the global concept of agility. Gabbett et al. (2008) defined agility as the change of direction by a body in response to stimulus.

Whilst this may broadly encompass the idea of what is commonly understood as agility, this definition fails to explore other components that may explain the concept better. This lack of explanation in definitive terms creates both poor understanding, as well as confusion as to what exactly is being measured when agility is the variable being explored. Sheppard & Young (2006), discussed the issue that the lack of clarity in defining the term creates. Addressing the issue, Sheppard & Young (2006) stated that commonly agility is defined as the ability to change direction quickly (Boomfield, Ackland & Elliot, 1994; Clarke, 1959; Mathews, 1973). Again, this basic definition addresses only two of the components of agility; directional change and the rate at which it occurs. To better define agility for the purpose of this investigation, the concept of agility, proposed by Young et al. (2002), states that agility is comprised of both physical and cognitive factors.

Physical factors include speed, acceleration, deceleration, technique and components such as leg strength. The cognitive factors involve reaction time to stimulus and knowledge of situations when performing a COD maneuver (Bettle, 2009). Due to the fact that the COD maneuvers of this study will be performed in a closed environment, knowledge of situations is not a crucial component and thus were not be tested. It is however included in the literature review for the purpose of understanding the cognitive aspects involved. Neither were technique as the purpose of the study is not to assess the varying effects that different techniques have on COD maneuvers, but rather to determine and focus on the effect that a planned or unplanned COD maneuver may have.

In order to best explore these two subcomponent of agility, further exploration of each is important so as to understand the integral role that both the physical and cognitive factors play in performing a COD task.

Cognitive factors

As mentioned in the model proposed by Young et al. (2002), understanding agility requires an intimate appreciation for not just the physical components, but also for the cognitive aspects. These cognitive aspects differ in principal but are integral in understanding the purpose that each plays in facilitating an individual to perform a COD maneuver that is classified under the umbrella term of agility. Young et al. (2002) further elaborated on the cognitive principals of agility, explaining that within the two main concepts, perception and decision-making, are several sub-components such as reaction time to stimulus or situation, knowledge of situation and anticipation.

In a study performed by Gabbett et al. (2008) the use of cognitive factors in agility was utilized in order to determine the skill-level between rugby league players. The study simply divided players in to two groups of skilled or unskilled, depending on their performance when tested on agility related measures. This study highlighted the effect that cognition and cognitive aspects have on the success of an agility maneuver.

Gabbett et al. (2008) tested two graded levels of rugby league players, first grade (elite level) and second grade (sub-elite level) , on their speed, change of direction speed and reactive agility. During their investigation, the experimenters found that there was no significant difference between the player’s speed and change of direction speed. However, there was a significant difference between the player’s reactive agility scores. First grade players demonstrated faster decision time scores, as well as faster movement scores than the second grade players. This means that in the event of the players being confronted with an opposing player the first grade players were able to more effectively perform an agility classified maneuver demonstrating better ability to read a situation and react accordingly so as to avoid the opposition player. (Gabbett et al., 2008; Bettle, 2009). These findings tend to the proposed notion that cognition influences the ability for a player or athlete to either effectively or ineffectively perform an agility or COD maneuver, substantiating the model proposed by Young et al., (2002). Expanding further on the notion of cognition playing an integral role in agility and COD maneuvers, earlier research performed by Challedurai (1976) proposed that there were four main categories that made up the global term; simple, spatial, temporal and universal.

Simple agility tasks refer to a motor task performed that require a pre-planned motor task. Bettle (2009) outlines Chelladurai's (1976) description of a simple task by explaining that a simple agility task requires no spatial or temporal uncertainty. It is planned in terms of spatial awareness and timing and the pre-planned motor task is executed as previously practiced and prepared.

Spatial agility is the term Challedurai (1976) used to define the type of agility task that requires a presence of knowledge of the body in space in relation to other objects or bodies. The term of "spatial" is described in Lee & Schmidt's (2013) book on *Motor Learning and Control* where spatial anticipation is described using the example of a badminton shot. When a drop shot is hit, the player required to return the shot knows that the shuttlecock will fall at the front end of their side of the court, close to the net. As a result, the player required to return the drop-shot needs to position themselves appropriately in the space of the court so as to be able to return the shuttlecock.

Temporal agility is the term used to describe movements that require anticipation of what is going to happen based on the events or stimuli presented to the performer. Bettle (2009), describes temporal agility as “a movement where there is temporal uncertainty, but the movement is pre-planned” (Bettle, 2009. pp 22). Schmidt & Lee (2013), describe temporal anticipation as the ability to predict what is going to happen but without the ability to know when it will occur. The example of a snap in football is used to describe how a defender knows what will happen, but they are uncertain of what will happen based on the opposing quarterback’s timing calls.

Finally, the key concept that is most pertinent to the experiment being performed in this study is that of universal agility. This term of universal agility describes the maneuvers executed when a performer is presented with stimulus, without temporal or spatial certainty (Chelladurai, 1976; Sheppard & Young, 2006; Bettle, 2009). Applying this definition to an example would be if the situation in American football of a running back being confronted by a defensive player of the opposing team and being required to perform an agility COD maneuver in order to avoid the defensive player.

Sheppard and Young (2006), proposed a different conceptual approach to the attempt to include the cognitive factors of agility and COD maneuvers in defining the idea. Sheppard & Young (2006) used a less complicated model when attempting to define agility and COD maneuvers. Rather than subdividing the concept into multiple niches, the terminology used would instead include the cognitive aspects, as well as the physical. In doing so, the description no longer considered movements that required a pre-planned motor program, but rather focused on reactive tasks. As such, this component of reaction includes the cognitive faculties required to execute a COD maneuver that is within the understanding of agility.

Cognition in Agility and COD

Within the cognitive aspects of agility, are two main divisions that affect the performance of agility. As performance is a component being assessed in this study, with particular focus related to effectiveness of planned and un-planned COD maneuvers with respect to ground reaction forces and lower limb kinematics. These two components are extremely pertinent in the understanding of the processes engaged to perform these agility tasks. Besier et al. (2001a; 2001b) described how the ability to react to scenarios under pressure with limited time constraints can have an effect on the kinematics of a COD maneuver. For this reason, the study performed by Besier (2001a;2001b) is of particular importance to this study as it relates directly to the two components that will be dealt with in this section. The two components within the heading of *cognition in agility and COD*, is knowledge of situations and visual scanning. Both relate directly to reaction time, which relates directly to physical output as reaction time is the time it takes for a perceived stimulus to be processed, a motor-program to be selected and the execution of the program to begin (Schmidt & Lee, 2013).

Situational Awareness

Situational awareness, also referred to as knowledge of situations is the ability for a player to anticipate the actions of an opposition player, based on the stimuli and surrounding environment at the time of the play being performed. Williams (2000), described situational awareness as the ability for expert performers to use their situational knowledge to predict future events.

In a study performed by Lockie et al., (2013), situational knowledge as a cognitive component was discussed in the influence it has on elite level basketball players. The study found that the higher level basketball players were able to separate themselves from lower level players based on their ability to execute reactive COD maneuvers during varying tests of agility. This lead the experimenters to postulate that it was a combination of experience, training and decision making ability that distinguished the better players from the lower level players when performing the agility tasks, particularly during the reactive agility tasks. Furthermore, Serpell et al. (2010) achieved similar results when attempting to investigate the possibility for a new reactive agility task, using two different levels of rugby league players. It was discovered that higher level players achieved a significantly greater reactive agility test score than did the lower level players with respect to their reactive test times (Serpell, et al., 2010). This difference between higher and lower level players was believed to be a result of the ability for players to discern themselves from each other, based on their experience and awareness of situational demands. The higher level players in rugby league players, just like the higher level basketball players, displayed greater ability to react in a faster time that the lower level players, resulting in a faster reactive time. Carrying forward with these results, this would mean that the higher level players have a greater chance of avoiding a defender or responding more effectively to the same level of defender then the lower level basketball and rugby players would. Circling back to the original concept of an agility maneuver being a task performed with the purpose of reacting to a stimulus, in this case a defender, in order to achieve and effective outcome in change of direction at speed, the concept achieved by the above mentioned studies by Lockie et al. (2013) and Serpell et al., (2010) accurately display the effect that situational awareness may have in an in situ environment (Sheppard & Young, 2006).

Ward & Williams (2003), discovered that visual, perceptive and cognitive skills, when taught for the purpose of development, had significant effects in the outcome of results attained by participants during reactive agility tasks and performance (Ward & Williams, 2003; Bettle, 2009). The study found that anticipatory response and use of situational probabilities were the greatest indicators of performance level, based on situational awareness. This research further confirms the results achieved by Lockie et al., (2013) and Serpell et al. (2010), placing emphasis on the importance of situational awareness within the concept of agility.

Furthermore, situational awareness requires a function performed by the body when receiving stimuli in a visual form. This process, known as visual scanning, is important to the ability for a player to recognise a scenario based on perceived stimuli and react accordingly. Situational awareness and visual scanning have a concomitant relationship with one another in the identification and decision making process for the performance of a reactive agility task or maneuver.

Visual Scanning

Visual scanning, also known as visual search strategy, is the process whereby a performer or player uses particular strategies to predict the outcome of a scenario by interpreting the stimuli received by said player. Successful performance in agility related sports requires not only accurate perception, but also execution (Williams & Davids, 1998; Bettle, 2009). Duncan and Humphreys (1989), described visual search strategy as the selection of important visual stimuli amongst other perceptual stimuli, so as to best enhance the probability of accurately executing a function that has been selectively deemed to be appropriate to the situation requirement Simply stated it is the requirement of a performer to select task relevant information within surrounding non-target information in order to perform a selected response.

Visual scanning strategy, or visual search strategy, is not limiting to a particular set of criteria, nor is it technique specific. Subjects may use different cues to select the desired target such as location, color, movement pattern, joint segments, amongst others (Warren & Warren, 1968; Von Wright, 1970; Duncan & Humphreys, 1989). In doing so, a subject performs a selective filtering process whereby targets are chosen amongst non-targets. The ability for a subject to select information from a field of potentially confounding stimuli, is made possible by the subject continually moving their eyes and heads so as to increase the volume of stimuli taken in, and thus better assess the situation (Williams et al., 1993; Bettle, 2009). This continuous eye movement allows subjects to focus on important information and thus make decisions relevant to the situation (Williams et al., 1993).

Williams (2000), discovered that soccer players used different visual scanning strategies for differing scenarios. In both open play and small closed situations, the players used different scanning strategies to select the important information required to perform a particular maneuver or task. Not only was this difference in strategies noticed within the open or closed nature of play, but also within the number of players that the player being assessed was faced with (Williams & Davids, 1998). In addition to this information, Williams (2000), discovered that offensive players used different scanning strategies to defensive players when selecting important information from the visual field. Similar results were achieved in a study assessing the scanning strategies used by tennis players to anticipate their opponent's next stroke (Williams et al., 2002).

Similar to Williams (2000), Piras et al. (2010), discovered that experienced volleyball players are not only able to distinguish important information in their visual field quicker than non-experienced players, but that the constant use of this skill further hones the ability for information selection when used more often. The study focused on the effect of eye saccades and compared the times with regards to eye tracking, to non-experienced players. Piras et al. (2010), goes on to state in their study that volleyball is a sport requiring quick reactions. By being able to select the appropriate information in a situation quicker, and react faster, the anticipatory effect by skilled players is proven to be greater, thus separating the skilled players from novice individuals.

Bettle (2009), postulated that subjects who performed pre-planned COD maneuvers were likely to perform them with greater speed as the reaction to stimuli and decision making process would be eliminated. Thus, the movement would be more effective as the stimuli provided were not weighted as greatly as those presented to subjects in a reactive COD maneuver scenario. This premise is the very topic under investigation in the research of this study.

It is clear from the literature researched that the ability for experienced players to discernibly select visual information faster than that of novice players, accounts for the separation between the two levels of performers. This elevated skill level accounts for the separation between novices and higher skilled players when situational knowledge or situational awareness is taken in to consideration. The link between situational awareness and visual scanning strategy can easily be made to planned or unplanned COD maneuvers as the success and end result of both conditions is determined by the effect that the visual scanning strategy and knowledge of situations has.

A player’s ability to recognise and react to situations is a crucial component of their overall performance in both reactive agility task testing, as well as on the field of play. The success of a maneuver and player’s ability may be determined by their skill in reading a situation and appropriately reacting based on previously accumulated knowledge of that particular scenario. Such ability by a player can greater distinguish the skill level at which the tasks are performed and the success that is achieved in doing so. However, situational awareness is not the only crucial sub-category of agility tasks that can majorly influence the outcome achieved. Physical attributes function concurrently with the cognitive aspects in performance of agility tasks, both planned and unplanned. As a result, one cannot be deemed to be entirely successful without the other. This leads to the necessity for consideration and understanding of the physical aspects that perform just as significant a role as the cognitive, in successfully performing a COD maneuver or agility related task.

Physical Aspects

Having outlined the cognitive aspects that influence agility and COD maneuvers, in a top-down fashion, it is important to now explore the effects that the physical sub-categories of agility have on the result of a COD maneuver, be it planned or reactive (unplanned). Outlining these sub-categories will shed light on the attributes that may need to be trained in order to enhance agility performance, as well as COD maneuver success.

The majority of research focusing on agility, eludes to change of direction speed (CODS). Whilst CODS and COD maneuvers encompass the same movement pattern, the topic of focus is different and thus the issues influencing planned and unplanned COD maneuvers differences will be addressed in this section of the literature review.

Leg Strength and Power in Relation to COD Maneuvers

Agility, as per the definition provided by Young et al., (2002) is comprised of two key components: cognitive and physical. The physical part of this definition pertains to the necessity for a performer of a COD maneuver to do so at speed. In order for the performance of the COD maneuver to be deemed successful, the performer needs to be able to avoid either an opponent or maneuver around a set object. To achieve success in the task, this would require to performer to produce sufficient force to overcome the inertia of the body and successfully change the direction of movement so as to avoid or circumnavigate a particular object (Gabbet et al., 2007). This overcoming of inertia in the direction of the movement means that the performer must be able to produce sufficient force using the parts of the body involved in the movement execution, primarily the legs (Bettle, 2009; Schot et al., 1995).

There is mixed opinion within the literature regarding leg strength and power and the influence that these two factors have on the ability for a performer to be successful at an agility task or COD maneuver. Baker & Newton (2008), performed a study on rugby league players to determine what factors might distinguish national rugby league level players and second-division rugby league players. The participants were tested on leg strength, leg power, sprinting speed and agility, amongst other variables. The study found that leg strength and power were the most discriminating factors between the national and second-division leagues. Baker & Newton (2008), stated that these two factors were the determining factors that aided players in all facets of the game, including agility. The notion that the greater the maximal power and strength outputs from the legs, the greater the force produced will be when attempting to change direction of motion (Baker & Newton, 2008). However, the article also discusses how the greater overall body mass of the players in the national league would aid them in their power and leg strength output. The issue presented here is the trade-off between mass, power and leg strength output. If the mass is very large in relation to the output, the force may not be sufficient to alter the direction of the large momentum of the body. If the mass is small in relation to the output of power and strength, then the body will change direction more easily as the momentum inertia is less. This of course is dependent on the velocity of the player too.

In contrast to the above-mentioned study, Young, Hawken and McDonald (1996) performed a similar study on Australian football rules players to determine the relationship between speed, strength and agility. The study found that there was no significant correlation between strength and agility. The authors of the study proposed that motor control factors were the reason for this lack of correlation and not just strength or power (Young et al., 2002).

Young et al. (2002) performed a study on a mixed group of athletes composed of tennis players, basketball players, Australian rules players and soccer players. The study sought to investigate the relationship between straight sprint speed, power, strength and agility. The study found that on the tests of concentric power, some of the agility related tasks were significantly negatively correlated to the power output. The researchers postulated that this may be due to the shortened flexion/extension motion that the athletes were performing when changing direction. In conjunction with these results achieved by Young et al., (2002) but in the opposite direction of correlation, Mayhew et al. (1989) found significant positive correlations between leg power and agility test scores amongst football players. The same significant, moderate, positive correlations between power, leg strength and agility were noted in a study performed by Djevalikian (1993), who noted a 0.68 coefficient between the aforementioned attributes amongst female soccer players using a Boomerang agility test and drop-jump performance.

It is clear to see from the literature that leg strength and power in COD agility tasks have both affirmative and contradictory results. Throughout the literature, such as Young et al., (2002), Djevalikian (1993), Mayhew et al. (1989) and Bettle (2009), other factors have been proposed for the potential confounding results obtained, regardless of the directionality of the correlations observed between the components. Such suggestions include: technique (Young et al., 2002; Bettle, 2009), anthropometry (Djevalikian, 1993; Bettle, 2009), and angle of COD maneuver (Mayhew et al., 1989; Djevalikian, 1993; Young et al., Bettle 2009). Whilst these measures such as straight sprint speed and reactive strength are not measures being tested in the current study, they have shown to be linked to the topic of COD maneuvers, encompassing both planned and unplanned cutting tasks. Thus, their importance and relevance is worth consideration in the performance of this study in order to better conceptualize the factors at play in producing results for both the conditions being tested.

Ground Reaction Forces

Leading forth from leg power and strength in COD maneuvers, is the measure of ground reactions forces (GRFs). GRFs during COD maneuvers are able to provide power output by a participant, derived from computational calculations using force plates and kinematic data.

Ground reaction forces are the resultant forces produced by the ground to maintain a body of mass in dynamic or static equilibrium. The principal of ground reaction forces center around Newton’s third law that states that for every body exerting a force, there is an equal but opposite resultant force, acting on that body. These resultant forces are measured by a piece of equipment known as a tri-axial force plate. Being tri-axial, this means that the force plate can measure forces in three different planes; medio-lateral, anterior-posterior and vertical. This ability gives a user a 3-dimensional representation of the forces occurring when an object crosses over the force plate. Together with the forces produced by a body of mass and the time that these forces are exerted on the force plate, different measures relating to these two variables, can be calculated. This allows for great insight in to movement and force production.

Using such equipment has provided researchers with important information in the attempt to understand the force components involved in COD maneuvers. Studies such as that by Besier et al., (2001) used GRFs to analyse the loading of the knee joint. The force plates provided information on the medio-lateral, vertical and anterior-posterior planes during cutting tasks. Participants were required to run across a mat and over a force plate that then collected the force data. The ground reaction force profiles were then analysed, in conjunction with kinematic data and the loading of the knees during these cutting tasks was then assessed, allowing the researchers to determine the nature in which the joints of the lowers limbs were being loaded (Besier et al., 2001). Furthermore, a study performed by Wheeler & Sayers, (2010) used ground reaction forces to assess the effect that the anticipatory reflex had on ground reaction forces and the success of a COD maneuver. The study focused on the lateral force output by the participants, as the researchers determined that this was the discriminating factor with regards to COD that determined success of the agility related maneuver. The researchers found that the moment of anticipation, prior to contact with the force plate allowed for the participants to establish greater lateral force output, thus producing greater lateral movement and higher success rates for the COD maneuver. What was also noted by Wheeler & Sayers, (2010) was that the hesitation occurring before a reactive COD maneuver, results in performer uncertainty and thus the potential to overcompensate for the perceived slowing down before the plate is exhibited by an exaggerated overloading of the outside leg during the maneuver. This over loading results in a greater force output that is reactive in nature and potentially could be greater in production of lateral movement than that of a pre-determined direction change. This however, was stated to be circumstantial. Young et al., (2006) had a similar experience with COD maneuver testing and drew similar conclusions with regards to the reasoning for this over exaggeration of the lateral force production. Both Young et al., (2006) and Wheeler & Sayers (2010), proposed that several variables may account for this excessive force production in the lateral directions. Firstly it was postulated that the overcompensation may be a result of the perceived lack of speed when hesitating prior to the force plate. Also, the greater lateral force output was thought to possibly be due to participants having a reflex type reaction that was greater in magnitude of force production than that of the pre-determined force output.

The literature pertaining directly to ground reaction force output and differences between reactive and planned seems not to be abundant. GRF studies have been conducted in the search for answers pertaining to reactive agility and pre-planned COD maneuver routes, but there is not a lot of material linking the two. What has been established are specific variables that may fall within the analyses of a GRF output profile, such as that of braking forces and lateral force production.

Braking Forces in COD Maneuvers

Braking forces are an important part of a COD maneuver within the topic of agility. These forces allow for a performer of a COD task to slow the body sufficiently so as to allow the production of force in a direction changing path to overcome that of the inertial force of the body travelling in the original direction. There is no universal definition for the term describing the braking force within agility or COD maneuvers, so for this reason an attempt of a definition was established based on the understanding of the literature. The definition created for the purpose of this study is as follows; braking forces are the forces produced by a participant that are retardant in nature, acting in an opposing direction to the original plane of movement such that the initial velocity of the object is altered in a negative manner relative to the direction of movement.

To the knowledge of the researchers, braking forces have not been investigated to a great degree within the application of agility. However, there are studies that include the analysis of them in their GRF profile interpretations and extraction of this specific information gives insight in to the role that these forces play.

In a study performed by Spiteri et al., (2013) the researchers attempted to assess the relationship between lower body kinematics and GRFs in a planned, 45^0 COD maneuver. The use of GRF profiles was incorporated to assess the effects that the force outputs of participant's had on their effectiveness of COD execution, as well as to determine the factors influencing the maneuvers. The researchers discovered that participant's who were stronger in the lower body based on testing of concentric leg strength and 1 rep max squatting load, were able to produce multiple variables with greater magnitude than those who were weaker. Amongst these variables was greater vertical and horizontal braking force, vertical breaking and propulsive impulse and greater angle of peak braking and propulsive force application (Spiteri et al., 2013). Similarly, Schot et al. (1995) discovered in their research of kinetic forces involved in 90^0 and 45^0 COD maneuvers, that the participants who were able to overcome their inertial momentum upon approach to the force plates, were able to more successfully execute to required COD task. The velocity that participant's performed their running trials at was not restricted, but rather the participants were instructed to rather try and select a pace that was a balance between speed and ability to appropriately change direction. The stronger participants were able to perform the trials at a greater velocity. The researchers noted that within the trials, the stronger participants were able to more effectively change direction in the 45^0 degree COD tasks than the 90^0 COD tasks by up to 40%. Whilst this is not surprising as the requirement for the directional change was not as great in the 45^0 trials, the conclusion was still drawn that the participants with stronger lower limbs were able to maintain a higher velocity average throughout both conditions because of their ability to alter their momentum more quickly than the weaker subjects (Schot et al., 1995).

Jindrich et al. (2005) performed a study on the braking forces involved during COD tasks. The researchers hypothesized that braking forces prevent over-rotation of the body about the vertical axis, during COD tasks. The study focused on the rotation of the center of mass during a directional change task. The role of the center of mass in COD tasks is very important as it is the focal point around which the body is stabilized and balanced in accordance with the direction that the performer is aiming to go. The study noted that without braking forces, the center of mass of the body would be mal-aligned by a range of 1.4-3.0 times what it should be at the point of direction change, resulting in either an unsuccessful direction change or insufficient accuracy in the change of direction with regards to quickness of maneuverability (Jindrich et al., 2005).

Following on from the topic of center of mass, Hewit et al., (2011) discussed the relevance of deceleration within sport specific tasks and the necessity for the performer to be able to achieve sufficient deceleration within the sport they play. The research explored the different demands that different sports may require deceleration for. An example provided was the deceleration required for shot-put compared to that of rugby-league players (Hewit et al., 2011). Rugby-league players are required to avoid opposing players when in possession of the ball. This requires the ability to abruptly decelerate from an initial forward velocity, to a velocity at which a sufficient change of direction can be made, followed by a reacceleration to a velocity in the desired direction. Shot-putters are required to decelerate to a stop, whilst rotating towards the front edge of the allowed circle from which they throw. Both movements are considered agility related tasks as they involve acceleration, deceleration and a change in direction of the body, but the demands for the rate of change of direction are different in nature (Hewit et al., 2011; Bettle 2009).

Braking forces are important in the analysis of COD maneuvers as literature has clearly shown their fundamental role in success of execution. Absent of braking forces, the performers of COD maneuvers would not be able to efficiently and successfully make COD maneuvers in the time required, nor at the velocity required to do so in order to evade an opposing obstacle or person.

Summary

Within the topic of agility are COD tasks. COD tasks pertain directly to a change of a body’s mass from one original direction, to a different trajectory with the intention of avoiding or circumnavigating an object/opposing player. These maneuvers have a wide range of differing variables. Such variables are velocity of change of direction, angle of change of direction, deceleration, acceleration, strength applied or force applied, as well as the cognitive components that are within the change of direction tasks. As previously explored, there are two main types: planned and un-planned. Un-planned pertains to the reactive agility literature and movements that require a decision made by the performer based on stimuli presented. Within this topic are the fields of reaction time, knowledge of situations and visual scanning. For planned maneuvers, it is the predetermination of force output within a particular movement that will create the desired effect of a sufficient change of direction of the participant. All of the aforementioned variables have varying degrees of influence with regards to ACL injury risk.

Within this literature search, there is much supporting evidence towards particular components, as well as conflicting evidence with regards to others. The purpose of this study is to determine the effects that the selected variables have on the effects of planned and un-planned maneuvers. The purpose of which is neither to confirm nor disprove that of previous literature, but rather address the issue of confirming or rejecting the hypotheses put forward by the researcher.

Chapter 3: Methods

Purpose of the Study

The purpose of this study is to determine the effects that either planned or unplanned (reactive) agility maneuvers have on force output, mainly pertaining to ground reaction forces. Determining this effect will provide understanding in to the efficacy of either playing scenario in sports involving agility and thus potentially influence the style of play, according to the findings.

Participants

In the following study, 40 NCAA Division II, male athletes volunteered as participants. Males were selected so as to limit the difference that gender may have on both anthropometrical and biomechanical effects. The ages of the participants ranged fro18 to 27 years. The mean body mass of each subject was 88.62 (± 11.09) and the mean height was 184.58 (± 8.75).

Table 1

Participant's Anthropometric data of Height and Mass

Participant Means	Mean Mass (kg)	Mean Height (cm)	Mean Age (years)
	88.62 (±11.09)	184.58 (±8.75)	20 (±2.56)

The desired target group for this study was that of male, athletes who participate in agility requiring sports. Whilst this focus is limited to male agility athletes in sports offered at Barry University, the applications of this study may broaden to athletes who play other contact sports such as football, rugby league, rugby union, Australian rules football and ice-hockey as all these sports require agility. Whilst women’s leagues exist in all of the aforementioned sports, the majority of research is focused on male players due to the large difference in volume of research between men and women participants, respectively. The biomechanical, anthropometrical and injury research between genders highlights the differences of the sexes in this field and for the reason of eliminating potential extraneous, confounding variables, such as hormonal effect on potential injury risk, males were selected.

Each participant gave informed consent to participate in the following study and was presented with the opportunity to withdraw from the study at any point should they feel the need or want to do so. Within the informed consent was the stipulation that each participant have full anonymity so as to prevent the possibility for competitive nature between subjects that could alter the validity of the results. The procedures were explained to the participants in full, in a pilot meeting during which they received detailed written explanations of the procedures to be followed during the study.

Instrumentation

Ground reaction force data was captured using two AMTI force plates (AMTI Inc., Watertown, MA). The devices used were operated through Vicon Nexus Software (Vicon, Oxford, U.K.).

Kinematic data was captured using 8 infra-red cameras, with 3-dimensional Vicon V8 vantage camera setup, positioned around the laboratory.

This setup allows for the capturing of the kinetic and kinematic data of the lower limbs during a high speed change of direction, enabling the analysis of force moments, segment velocities and accelerations, center of pressure analysis, vertical and horizontal force analysis and force moment determination. The force plate data displays the forces involved and produced in the lower limbs during a change of direction by calculating the ground reaction force (GRF) which is the inverse dynamic force applied by the ground to the participant (Newton's third law). Together, this data gives an accurate representation of GRF to provide an intimate understanding of the vertical forces involved in a change of direction at speed.

To indicate the required COD visually, the experimenter stood directly behind the force plate and either indicated the directional change required by signaling with the hands or no directional change was given. In the instance that a direction was signaled by the experimenter, participants were required to make a change of direction on the force plate in accordance with the direction presented. In the event of no direction given, the participants were required to continue their motion in straight line over the force plate.

Procedures

Calibration

Before trials commenced, the 3-D cameras were calibrated and the laboratory origin was set in accordance with the Vicon Nexus calibration technique as stipulated by Vicon Nexus. Force plates were calibrated next, also in accordance with the guidelines stipulated by Vicon Nexus.

After calibration was completed, participants were provided with written instructions for the procedures to be performed. In addition, every participant was given a detailed verbal set of instructions to ensure clarity on the procedural measures required.

Participant procedures

Prior to the commencement of any trials, participants were instructed to perform a five minute, self selected warm-up. Participants were informed of the three different conditions of trials that they would encounter during the experiment. The first would be a planned change of direction in which they would be told the direction that they would change their path of motion in, before the onset of the trial. The second was that they would commence the trial and only be given the direction to change by the experimenter, at a distance of two meters before the force plate. The third would be that no change of direction would be given and the participants would be required to simply continue their path of motion and run straight over the force plate.

Planned COD

Before commencing each trial, the experimenter provided the participants with a direction at which they would change upon reaching the force plate. Participants began every trial from a distance of 5m from the center of the force plate. To begin the trial, a command of “go” was given by the experimenter. These prompted each subject to run towards the force plate and make the required directional change, using the outside leg. The outside leg was defined as the leg of the participant that was opposite to the direction that the participants were required to make the COD maneuver in. Trials were performed at a self-selected, game-like pace for each participant so as to best simulate in game conditions. This pace was chosen so as to enable the individualization of each participant, whilst still maintaining an as close to equal level of performance velocity between each condition, per participant. Upon reaching the force plate, participants were required to make a sudden change of direction, off of either their right foot, at a 45^0 angle and continue at sub-maximal, self-selected speed until they were stopped by the soft barrier in the lab. Three trial runs were allowed, per participant, before data capturing began. Each participant performed three valid trials per condition, in both directions.

Un-planned COD maneuver (reactive agility)

Participants were instructed to take position on the starting mark that was 5 meters from the center of the force plate. The participants were not instructed as to the direction change that they should make before the commencement of the trial however, they were instructed to make the change of direction in accordance with the visual stimulus presented in front of them by the experimenter, when the participant was at a distance of 2 meters from the force plate. Upon reaching the signal mark, participants were required to react to the visual stimulus and change direction at 45^0 either to the left (in accordance with the visual stimulus).

Risk of Injury

There was minimal risk of injury presented to the participants involved in the study. The maneuvers being executed were not different in nature to that performed by the participants on a daily occurrence due to the nature of their sport. Participants were made aware of the procedures being performed and potential for risk of injury, prior to commencing the trials. Every participant was made aware in both the informed consent form signed prior to beginning the study, as well as verbally notified prior to the beginning of the trials that they could withdraw at any point in the study should they want or need to.

Randomization of trials

Trials were randomized in order to prevent a potential learned effect from being established by participants. Randomization occurred between both the conditions of planned and un-planned changing of directions, as well as the inclusion of a no change of direction trial in order to prevent the potential for a learned hesitation effect.

Attire for participants

Participants were required to wear tight fitting clothing so as to reduce marker movement or displacement. The purpose of this is to reduce the error between the actual body movements and movement of the clothing.

The male performers were required to wear tight spandex on the lower body, covering only the pelvic region and the upper thighs. Participants were given a long sleeve second skin, spandex garment to wear on the upper body.

Analysis

Force plate data was captured with the Vicon Nexus software and exported to Microsoft excel where kinematic data (marker co-ordinates) and GRFs were analysed to determine peak (maximal) force production, as well as peak braking forces, peak knee valgus angles and rate of loading, all during the period of weight acceptance. Weight acceptance was defined from the point of contact with the force plate, to the peak knee flexion. Mean peak vertical GRFs for each condition of planned and unplanned was then processed through a within subjects, repeated measures MANOVA to determine the interaction between type of cutting motion (planned or unplanned). The same was done for braking forces, knee valgus and loading rates.

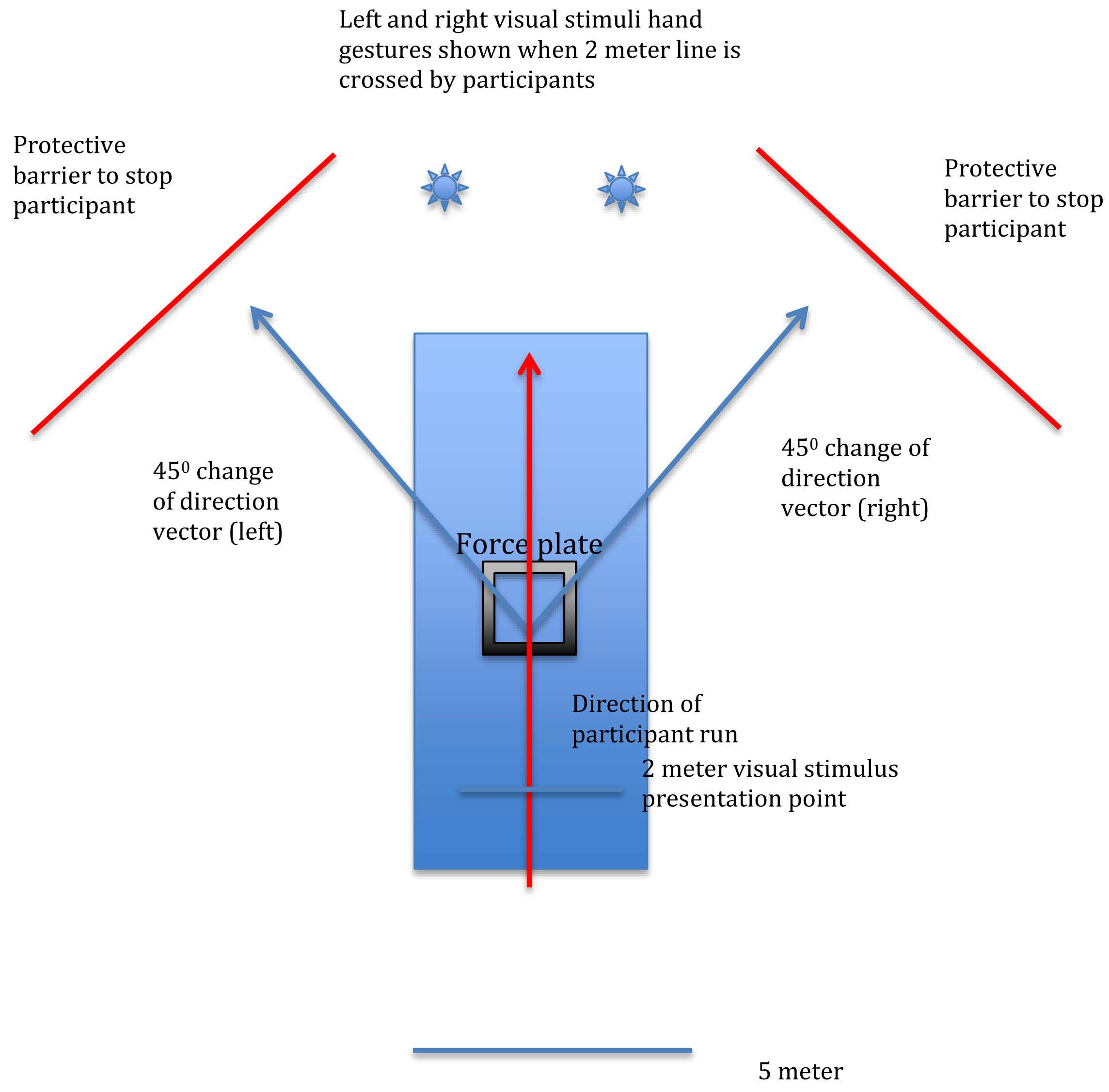

Figure 1: **Diagram of lab procedures executed by participants**

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Appendix A – Journal: Sports Biomechanics

Planned and Unplanned Change of Direction Maneuvers: A Study of Ground Reaction Forces and Lower Limb Kinematic and Kinetic Properties

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ABSTRACT

This study aimed to determine the kinetic and kinematic differences between planned and unplanned change of direction maneuvers in the dominant legs of participants so as to aid in the prevention of risk of injury to the ACL. 18 Male, NCAA, Division II athletes volunteered to take part in the study. Participants were required to perform a COD under two conditions: planned and unplanned. Participants began each trial at a starting mark five meters from the force plate. For the planned condition, participants were notified of the COD required prior to trial commencement. Unplanned required participants to react to a visual stimulus at a mark two meters from the force plate. A seven camera, infrared three-dimensional Vicon Nexus setup was used for kinematic motion analysis and an AMTI force plate was used to record kinetic data. A repeated measures, within subjects MANOVA was performed and significant differences were displayed in the peak braking forces during weight acceptance ($p < 0.001$), VGRFs ($p = 0.002$). No statistically significant difference was noted in loading rates ($p = 0.063$) and peak valgus angles ($p = 0.130$) during weight acceptance. Data suggest that braking forces and VGRFs are significantly greater during unplanned conditions, and loading rate and peak knee valgus is not.

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Change of direction maneuver; planned and unplanned; vertical ground reaction forces; braking forces; loading rates, peak valgus angles; weight acceptance

Introduction

Modern-day sports, the world over, can be categorized in to two main subdivisions: contact and non-contact sports. Within these two divisions, another two arise: contact and non-contact events. These events refer to a particular incident during a game where a defensive player is either made contact with by an offensive player, or avoided whilst attempting to execute a particular goal. Depending on the sport being played, the body parts subjected to risk of injury will vary. However, the knee is one of the most at risk joints for injury, due to it being such an important joint for locomotion, in particular, the anterior cruciate ligament (ACL) (Bettle, 2009). ACL injuries are one of the most common occurring injuries within agility related sports, such as soccer, Australian Rules football or rugby (Jamison, Pan & Chaudhari, 2012). It has been reported by Dempsey et al., (2009) that between 50%-80% of ACL injuries occur during non-contact events such as a change of direction maneuver, within sports. Furthermore, Donnelly et al., (2012) state that one half of non-contact ACL injuries occur during side-step or cutting maneuvers performed in agility related sports. During these types of maneuvers, it has been determined that a collaboration of several particular joint functions can predispose a performer to greater risks of injury. Those factors are abducted hip angles, decreased knee flexion, externally rotated foot and laterally flexed torso (Dempsey et al., 2009).

Knee valgus angles are a crucial variable in the level of strain placed on the ACL (Hewett et al., 2005). In their 2005 study on biomechanical factors of neuromuscular control and valgus loading of the knee, Hewett et al., (2005) sought to determine the distinct variables that influence ACL injuries by assessing the presence or absence of particular neuromuscular control factors displayed by performers. This research was performed in an attempt to come up with a particular set of criteria to determine which athletes would be more predisposed to ACL injury risk. The researchers found that female athletes who displayed poor levels of neuromuscular control pertaining to the knee and its valgus moments occurring during change of directions, were at a greater risk of ACL injury than those who displayed better control of the lower extremities during the same maneuvers (Hewett et al., 2005).

Markolf et al., (1995) performed a study assessing the anterior shear force and knee varus/valgus moments with regards to their influence on ACL strain in kadaveric knees. The findings of such research displayed that a 100N anterior shear force and 10Nm knee valgus moment subjected significant strain levels to the ACL ligaments of the knees tested and thus were deemed to be important mechanical factors in the risk to ACL injury (Garrett & Yu., 1995).

In addition to these factors that predispose performers to an elevated risk of ACL injury, the factor of loading rate is also a contributor to injury risk (Hewett et al., 2005). Loading rate is important as during agility related sports, much of the maneuvers performed are done at high speed. Reilly, Bangsbo and Franks (2000) performed a study on soccer players and found that whilst high speed maneuvers only accounted for 11% of the distance covered, the maneuvers were part of the more important segments of game in which scoring was involved. High speed results in increased force application over time. This increased force application influences the rate of application as the time that the maneuvers executed in is also decreased, being at a higher speed (Griffin et al., 2000).

With this information, it can be postulated that if changes were made to an individual performing such maneuvers, then changes to the level of risk of injury to the ACL during such maneuvers would follow (Jamison et al., 2012).

The purpose of this investigation was to assess the difference in knee valgus angles, braking forces, loading rates and vertical ground reaction forces, all of which are contributing factors to the level of injury risk that performers are subjected to when participating in agility related sports. As such, the notion behind this research is to explore the two different conditions and attempt to determine which might be potentially more harmful to performers. In doing so, this information could allow for a better understanding of the protective mechanisms that can be established to prevent this elevated risk of injury by altering the biomechanics of a participant, in training, and thus altering the kinetic and kinematic performance during a change of direction maneuver. Trainers, coaches and athletes alike will be able to better prepare themselves through means such as strength training of the supporting muscles of the knee in the lower extremities, technique and body positioning training for change of direction maneuvers for such scenarios, and thus decrease the risk of injury to the ACL.

The hypotheses proposed for the purpose of this research were that: 1) the unplanned conditions would produce significantly higher vertical ground reaction forces than planned COD maneuvers during weight acceptance, 2) braking forces during weight acceptance of the unplanned condition would be higher than the planned condition 3) loading of the knee would be greater during unplanned change of direction maneuvers during weight acceptance, 4) peak knee valgus angles during COD maneuvers would not be greater in either condition during the period of weight acceptance.

Methods

Participants

Eighteen, NCAA Division II, male athletes volunteered as participants in this study. Participants were recruited using flyers posted around the Barry University campus, as well as through the Campus Recreation Center. Males were selected so as to limit the difference that gender may have on both anthropometrical and biomechanical effects. The ages of the participants ranged from 18 to 27 years with a mean age of 20 (±2.56) years. The mean body mass of each subject was 88.62kg (±11.09) and the mean height was 184.58cm (±8.75). Participants came from three different sports at Barry University: 12 basketball players , 2 soccer players and 4 baseball players. Inclusion criteria were: a) participant had to be involved in an agility related sport; b) be older than eighteen years of age; c) attend Barry University as a full-time student; d) have no history of knee injury and be cleared to participate in their normal sporting routine, by the athletic trainer at Barry University. After receiving a detailed verbal and written instruction of the procedures required for the study, participants were given an informed consent form to sign. The informed consent complied with the ethical standards set forth by the Institutional Review Board of Barry University. The study was approved by the Institutional Review Board of Barry University.

Procedures

Participants were tested on an original assessment protocol. Participants were tested individually, on one specific day, in an indoor Motion Analysis Centre Laboratory. At the beginning of testing, anatomical measurements of the lower body were taken. Leg length from the greater trochanter straight down to the floor in millimeters, knee width through the joint line of the knee in millimeters and ankle width through the calcaneus in millimeters, as well as body mass in kilograms and height in millimeters were all taken and put in to the subject model created for each participant. Subject models were created for each participant using the Vicon Nexus Software (Vicon, Oxford, U.K.). After measurements were taken, participants were instructed to perform a warm-up that they would usually perform in their respective discipline for a minimum of five minutes, such as cross over stepping for soccer or dynamic stretching for basketball. Post warm-up, sixteen reflective markers were placed on the lower body in accordance with the Oxford Lower Body PlugIn Gait model (marker placement can be found in figure 1 – separate attachment).

Once markers were placed on the participants in the appropriate anatomical locations, the participants were granted three practice trials to ensure they were familiar with the procedures of the different conditions. Following the practice trials, participants began the testing procedure where data was captured for analysis.

Participants were to perform 15 trials in total; change of direction to the left, to the right and running straight over the force plate, ensuring they hit the X-marked locus on the force plate. Conditions would be that of planned, unplanned or straight. For all trials, participants were instructed to begin on a mark five meters from the center of the force plate. For the unplanned conditions, participants were told the direction change required, prior to commencement of the trial. For the unplanned condition, participants began the trial from the designated start mark and were given a visual cue at a 2 meter mark from the center of the force plate, to the direction desired by the experimenter using a hand signal to the left or right. All changes of direction were required to be executed on the AMTI force plate (AMTI Inc., Watertown, MA) used and the angle of change of direction was 45^0 to that of the original direction of movement, to either the left or right. For the planned conditions, participants were informed of the direction change required and told to begin the trial when instructed to by the experimenter. The participants were required to begin running from the 5 meter start mark and make a change of direction on the x-mark on the force plate, at a 45^0 angle to the left or right. Participants were to make the change of direction off of the outside leg which was defined as the leg opposite to the change of direction required to be made (eg: change of direction to the left meant striking the force plate with the right leg, and a change of direction to the right meant use of the left foot striking the force plate when executing the change of direction maneuver). (Visual representation of COD path can be seen in Figure 2). The conditions were counterbalanced by introducing a condition that required no change of direction and for the participants to run straight over the force plate, planting their foot on the force plate and continuing their path.

Velocity of participants was measured using the velocity function of the right anterior superior iliac spine marker. The velocity of participants had to be within a 5% margin of error from their initial trial velocity recorded.

Materials and Instruments

Kinetic data was analysed using a single AMTI force plate (AMTI Inc., Watertown, MA) which recorded force output data (at 960 Hz) in the anterior/posterior, medial/lateral and vertical axes, measured in newtons. Kinematic data was captured using seven infra-red cameras, with 3-dimensional Vicon (Vicon, Oxford, U.K.) V8 vantage camera setup, positioned around the laboratory operating at 240Hz.

The dependent variable selected for kinematic analysis was that of the peak valgus angle achieved during weight acceptance (measured in degrees). Weight acceptance was defined as the point of contact by the foot, to maximal knee flexion during the change of direction maneuver (Worthen-Chaudhari, et al., 2013).

The dependent variables selected for kinetic analysis were that of braking forces (BFs), vertical ground reaction forces (VGRFs), and loading rates which were calculated by the equation below.

These variables were selected as per previous works done by (Bettle, 2009; Dempsey et al., 2009).

$$\text{Loading rate (BW/s)} = \frac{\text{Peak VGRF (N) / time to reach peak VGRF (ms)}}{\text{body weight (N)}}$$

Statistical Analysis

Descriptive statistics are expressed as mean (SD). All data was screened for appropriate distributions of normality, prior to analysis.

A within subjects, repeated measures MANOVA was used to compare the conditions of planned and unplanned between one another on the right side for all participants. Only the right leg data was used as all participants were right leg dominant, thus eliminating the need for comparison to the left as the focus of the study was of the dominant leg.

All variables were tested against their counterpart conditions (planned BF, unplanned BF; planned VGRF, unplanned VGRF; planned loading rates, unplanned loading rates; and planned knee valgus angles, unplanned knee valgus angles). Wilk’s Lambda was used to assess the significance of effects within-subjects, displaying whether there was significance between conditions within subjects.

An alpha level of $p = 0.05$ was selected for significance testing.

Results

Table 1 displays the demographic data for participants. Table 2 displays mean and standard deviation, normalized values for the planned and unplanned condition variables. Wilk’s lambda displayed a significant difference in the within-subjects effects test. Wilk’s Lambda = 0.381 [$F(4,14) = 5.692$, $p = 0.006$].

Table 1: *Participant's Anthropometric data of Height and Mass*

Participant Means		
Mean Mass (kg)	Mean Height (cm)	Mean Age (years)
88.62 (±11.09)	184.58 (±8.75)	20 (±2.56)

Notes: Group mean mass (kg), group mean height (cm) group mean age (years).

Table 2: *Descriptive statistics of four variables used for analysis.*

Variables	Planned		Unplanned			
	Mean	Std. Dev.	Mean	Std. Dev.	Δ mean.	*p-value*
Norm Braking Forces (%)	41.51	23.04	56.36	29.93	14.85	0.000
Norm VGRFs (%)	220.84	35.39	258.97	62.41	38.13	0.002
Loading Rates (BW/s)	6.79	0.91	6.92	0.84	0.13	0.063
Peak Valgus Angle (deg)	10.96	4.76	12.51	6.74	1.55	0.130
Time During Weight Acceptance (sec)	0.063	0.013	0.075	0.017	0.012	0.000

Notes: (Norm Braking Forces %) represent the normalized peak braking forces during the period of weight acceptance when executing the change of direction step. Values were normalized using bodyweight. (Norm VGRFs %) represent the normalized peak vertical ground reaction forces normalized to bodyweight. Loading rats are represented in bodyweight's per second during weight acceptance. Peak valgus angle represents the maximum valgus experienced during weight acceptance. Weight acceptance was defined as the period from contact with the force plate to the maximum knee flexion angle experience during performance of the change of direction maneuver. Time during weight acceptance is measured in seconds and refers to the period of time from foot contact with the force plate to peak knee flexion, post contact.

For univariate testing, significance was observed between planned and unplanned conditions for normalized peak braking forces [$F(1,17) = 21.577$, $p<0.001$].
The condition of vertical GRFs displayed a significant effect difference between the planned and unplanned conditions $p< 0.05$ [$F(1,17) = 12.681$, $p = 0.002$].
For the conditions of maximum valgus angles achieved during weight acceptance, no significance was displayed $p > 0.05$ [$F(1,17) = 2.537$, $p = 0.130$]
There was no significant effect displayed between the conditions of planned and unplanned for the variable of loading rate [$F(1,17) = 3.968$, $p = 0.063$].
Significance was found between the conditions of planned and unplanned change of direction for time spent reducing force between contact and peak weight acceptance [$F(1,17) = 6.951$, $p<0.001$].

Discussion and Implications

The purpose of this study was to determine the difference in level of risk of injury to the ACL between anticipated and reactive agility maneuvers performed at a 45^0 angle. In determining the difference, if any, sports practitioners, trainers and athletes alike would be able to better prepare for either condition through training and strengthening of the muscles involved in the execution of the maneuvers and thus decrease risk of ACL injury to the performer. The results obtained confirmed some of the proposed hypotheses and rejected others.

The study used only the dominant side as all participants were right leg dominant, resulting in the lack for a need of comparison between the dominant and non-dominant sides, as done previously (Besier et al., 2001).

Statistical significance was found between the conditions of planned and unplanned normalized peak braking forces. The unplanned condition displayed significantly greater braking forces. This significance confirmed the proposed hypothesis that it would be greater in the unplanned condition. Furthermore, these findings concur with previously established research by Wheeler & Sayers (2010) whom discovered that the reactive agility tasks produced greater braking forces as a result of the hesitation reflex that caused participants to pull back and reduce velocity in the forward direction so as to allow for more time to process the change of direction required and make the maneuver efficiently. The findings from this research also confirmed the studies done by Schot et al., (1995) and Spiteri et al., (2013) whom both assessed reactive agility maneuvers through agility related tests, such as the T-test, and determined that the hesitation reaction significantly decreased participant's initial velocity prior to and upon striking the mark required to make a change of direction.

In this study significance was also found in the VGRFs produced between the two conditions. The VGRFs produced in the unplanned condition appear to be greater in most cases, thus confirming the hypothesis that the VGFs would be greater in the unplanned condition. This was deemed to be a result of the reactive nature of the maneuver, resulting in an over-compensation mechanism exhibited by the participants to make up for the initial perceived loss of velocity prior to executing the maneuver. This proposed notion and the results obtained, confirm the ideas proposed by Young et al., (2002) and Wheeler and Sayers (2010) that the slowing down of the participants prior to execution of the maneuver allowed for the generation and requirement for perceived need to emphasize acceleration during the maneuver of a reactive change of direction. This in turn resulted in greater VGRFs produced.

Statistical significance was not found for both the maximum knee valgus angles achieved during weight acceptance, nor for the loading rates achieved during weight acceptance. The lack of statistical significance for the maximum knee valgus angle achieved during weight acceptance leads to the rejection of the initial hypothesis that during weight acceptance, the unplanned condition would have a greater value than that of the planned condition. This finding confirms that of a study performed by Donnelly et al., (2012) that tested the effect that a season of Australian Rules Football had on participants knee kinematics during a 45^0 change of direction maneuver. The study found no statistically significant differences between planned and unplanned change of direction maneuvers.

No significance was found either for the normalized loading rates during weight acceptance. These findings contradict that of previous work performed by Besier et al., (2001) and Dempsey et al., (2009) whom studied the effect that technique had on the loading rates of the knee during cutting maneuvers. In their studies, it was found that unplanned or reactive cutting maneuvers produced greater loading rates at the knee and these loading rates magnitude was dependent on the technique used by each participant for the required trial. As such, the hypothesis that loading rates would be greater during weight acceptance of the unplanned condition than that of the planned is rejected. This finding lead the current study to propose the notion that the results obtained were directly influenced by the effect of technique used for each individual trial. A noted difference was witnessed during the unplanned trials as participants would often perform two consecutive steps on an ipsilateral foot prior to making contact with the force plate, or they would shorten their stride length prior to making contact with the force plate, shuffling their feet before executing the change of direction maneuver. As a result, the loading rates were directly affected by an inconsistency in the approach and execution of the change of direction.

When assessing the time taken during weight acceptance for each condition, statistical significance was achieved, showing that participants spent significantly longer in the period of weight acceptance during the unplanned change of direction maneuver. These findings affirm the ideas proposed by Wheeler & Sayers (2010) that the extended period of time spent in the weight acceptance phase of the maneuver is a result of the need for cognitive processing of the change of direction required. Assessing the findings of the research performed in this study leads to more than one implication worth noting. Firstly, the significant results found for braking forces and vertical ground reaction forces at weight acceptance being greater in the unplanned condition provides information that will enable trainers and athletes to not only prepare more for reactive agility tasks, but also to strengthen the supportive structures of the knee in particular such as the quadriceps and hamstring complexes to accept loading bearing better during the eccentric phase of the maneuver. This can be achieved through neuromuscular, technical and strength training (Bettle, 2009). Little & Williams (2005) performed testing on the leg strength of soccer players to determine the effect that leg strength had on agility and the risk it predisposed athletes to of ACL injury. Testing found that those participants with stronger quadriceps, as well as proprioceptive scores on testing measures, exhibited lower risk factors to knee injury and ACL tear.

Secondly, it is important to focus on the aspect of technique. Whilst this study did not specify or utilize any specific technique, the complete lack of doing so emphasizes the necessity for appropriate technique coaching and neuromuscular control training to be performed to potentially reduce the risk of injury to the ACL as the varied results experienced display the need for uniformity in order to reduce the potential for particular variables to become elevated in nature and thus increase injury risk. Bettle (2009) displayed a significant difference between the loading rates experienced by the lower extremities, particularly at the knee, when performing both planned and unplanned COD maneuvers with differing techniques. The research performed assessed hip alignment in relation to the torso and lower extremities, torso rotation and angle of the leg in relation to the direction of the foot.

Furthermore, the importance of the unplanned condition in regards to the applicability of such a change of direction condition in a real life scenario needs to be discussed. According to the work of Reilly, Bangsbo & Franks (2000), agility comprises only 11% of a game, but this percentage most often results in an advantageous outcome for a particular team. Within this proposed 11%, the majority of maneuvers executed are likely to be of an unplanned nature due to the demands and construct of sports. As such, the unplanned conditions of such studies, like this one, are critical in the understanding of risk of injury and the need to attempt to prevent said injury through mechanisms of training and neuromuscular control.

All of the above mentioned research, together with the results obtained from this research, can assist in the prevention of ACL injury and trainers, coaches and athletes can utilize such scientific data to do so through preventative measures of strengthening supportive structures, bettering technique and establishing proper neuromuscular control when performing such maneuvers. Emphasis most importantly should be placed on the training of the reactive condition so as to best prepare athletes for the in game scenario that is most likely to occur. In doing so, the likely of injury during a game will be reduced as the performer of a change of direction maneuver will be less likely to subject the lower extremities to conditions that are extreme in nature in relation to that which they have prepared for in practice.

Conclusion

This research displayed significance in braking forces and vertical ground reaction forces when normalized, during the period of weight acceptance when performing an unplanned COD maneuver compared to a planed COD maneuver. Furthermore, important implications were explored to reduce risk of injury such as technique and neuromuscular control, highlighting the importance of both to minimize injury risk and lower ACL injury rates.

Future research needs to be conducted in the area of the effects noted between dominant and non-dominant legs in COD maneuvers for planned and unplanned conditions to assess the extent of injury risk in which variables and what side is greater exposed to risk of injury.

Acknowledgements

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Figure 1: Oxford Lower-body Plugin Gait marker placement graphic

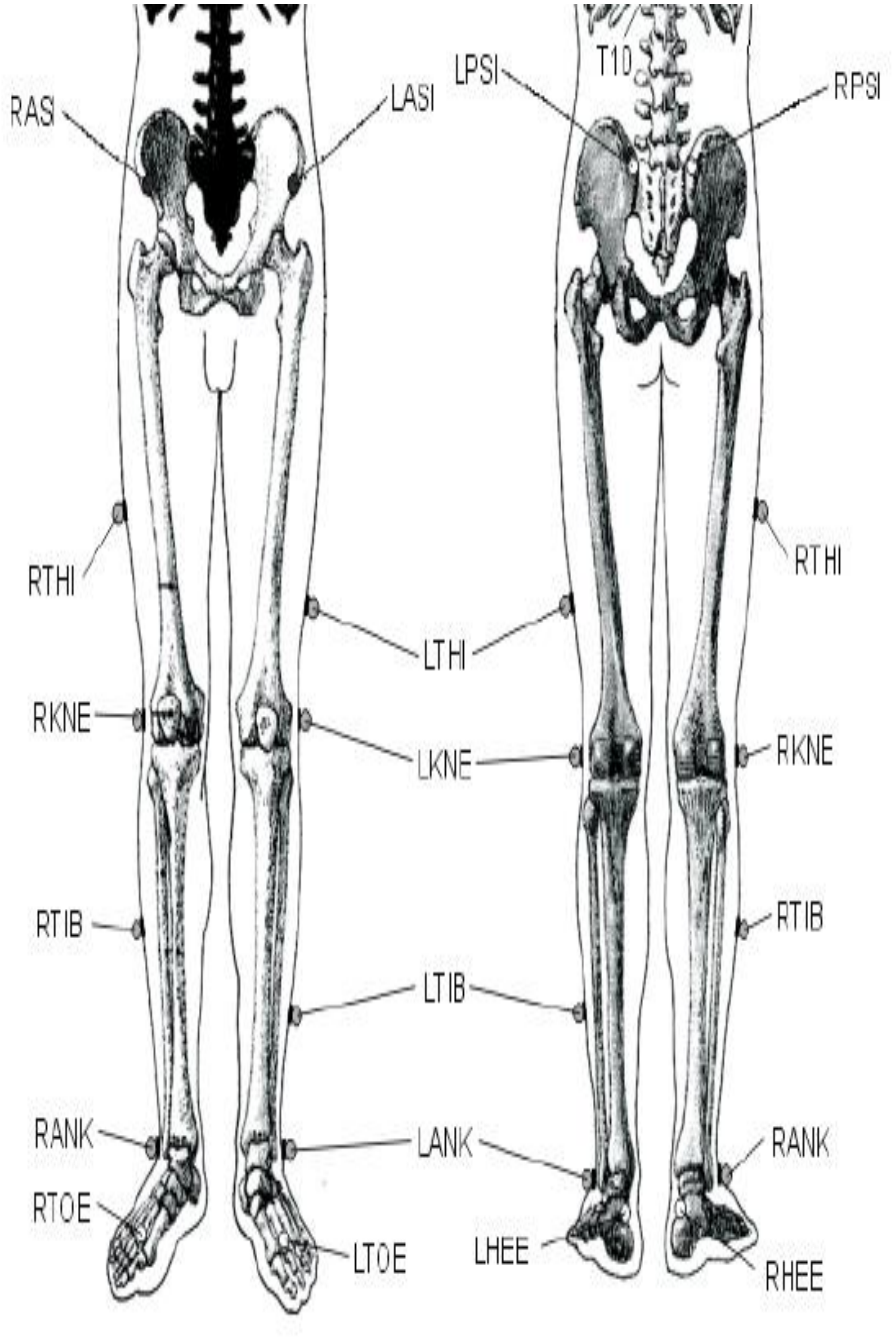

Figure 2: Diagram of the layout of experimental procedure in lab

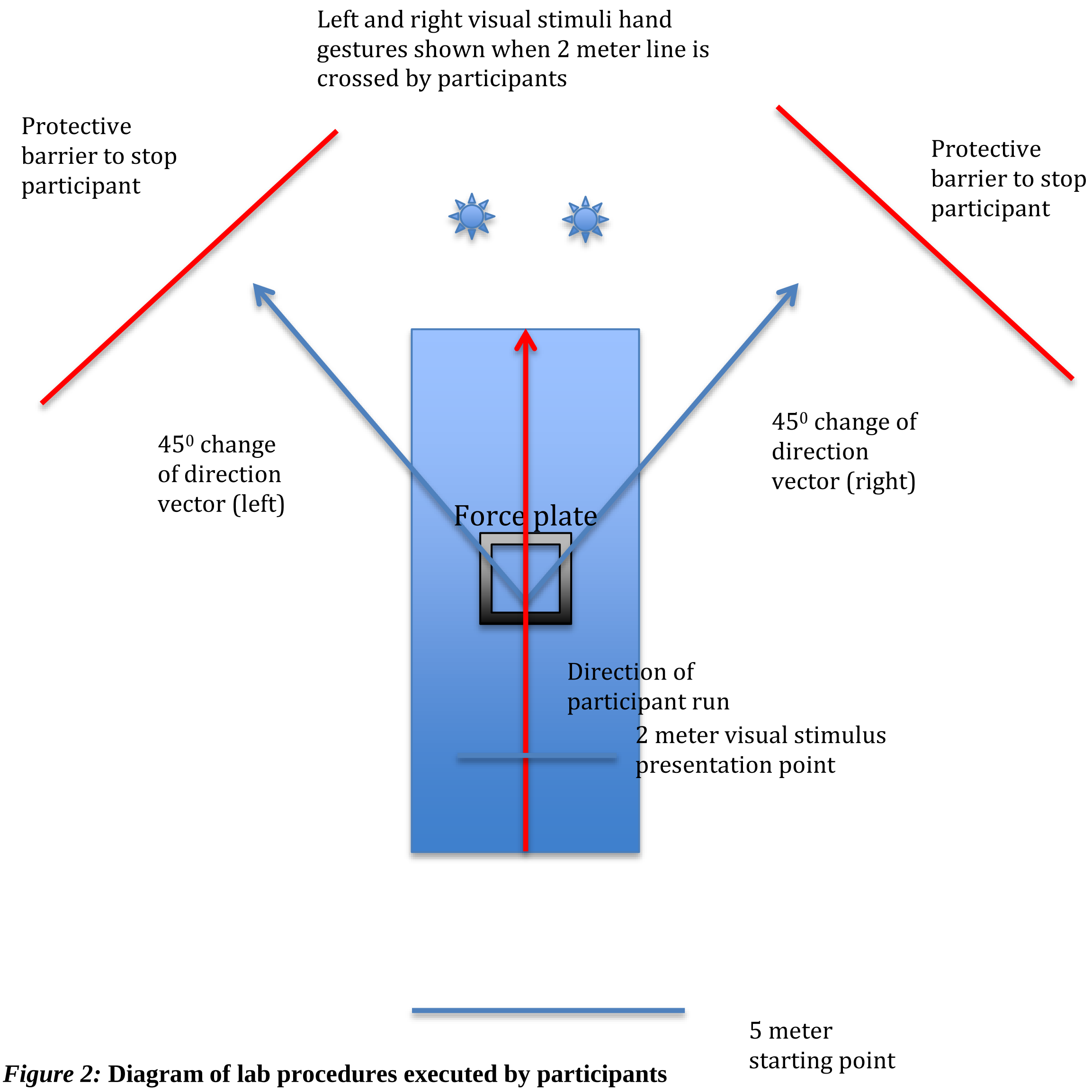

Figure 2: **Diagram of lab procedures executed by participants**

Appendix B:

Barry University
Informed Consent Form

Your participation in a research project is requested. The title of the study is Planned and Unplanned Change of Direction Maneuvers: A Study of Ground Reaction Forces and Lower Limb Kinematic and Kinetic Properties. The research is being conducted by Robert Saner, a student in the Human Performance and Leisure Sciences department at Barry University, and is seeking information that will be useful in the field of Biomechanics. The aims of the research are to identify whether planned or unplanned change of direction maneuvers have a lower rate of loading and sheer forces on the knee in conjunction with lateral knee angles, to determine which condition would have the lowest risk of injury. In accordance with these aims, the following procedures will be used: 3D motion analysis system VICON infrared cameras, force plates, and reflective markers. We anticipate the number of participants to be 40. Participants will be required to wear tight fitting spandex shorts, a tight fitting spandex shirt and sneakers. The clothing will be provided by the experimenter, not the shoes. In addition, each participant will have sixteen lower body, reflective markers placed on their lower limbs and pelvic area.

Participants will be required to perform 15 trial runs in the lab, making changes of direction to the left and right in a planned and unplanned fashion, as well as a series of three control runs where no change of direction is required. In order to be considered as a participant, potential participants must be male, 18 years or older, athletes in the sports of tennis, baseball, soccer or basketball and cleared of any injury by the athletic training staff at Barry University.

If you decide to participate in this research, you will be asked to do the following: be present for a screening and overview of what is to be expected as well as to participate completing one session of change of direction maneuvers that will take 45 to 90 minutes to complete.

Your consent to be a research participant is strictly voluntary and should you decline to participate or should you choose to drop out at any time during the study, there will be no adverse effects associated.

There are minimal risks involved in participating in this study; the equivalent to that of training for the sport the participant is involved in. There are no known benefits. Risks are minimized by the providing of protective barriers to halt motion, post change of direction, as well as the appropriate verbal and visual demonstration of procedures required. In the unlikely event of an injury, the athletic trainers of Barry University will be the first responders and on hand to assist with any injury.

As a research participant, information you provide will be held in confidence to the extent permitted by law. Any published results of the research will refer to group values only and no names will be used in the study. Data will be kept in a locked file in the researcher's office, separate from concent forms and data that may link an individual to a set of results. All 3D motion analysis data will be numerically coded without the use of names. Your signed consent form will be kept separate from the data. All data and consent forms will be destroyed after 5 years, upon completion of the study.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Robert Saner, at (727) 479-5770 or at robert.saner@mymail.barry.edu, my advisor, Dr. Claire Egret, at (305)899-3064 or at

CEgret.barry.edu, or the Institutional Review Board point of contact, Barbara Cook, at (305)899-3020 or at BCook@barry.edu. If you are satisfied with the information provided and are willing to participate in this research, please signify your consent by signing this consent form.

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Robert Saner and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment.

______________________________ ______________________________.

Signature of Participant Date Researcher Date