A COMPARISON OF THE TECHNIQUE OF THE 180° CUTTING MANEUVER PERFORMED ON GRASS AND ON A HARDWOOD FLOOR

By

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A Thesis submitted to the Faculty of Graduate Studies of

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Abstract

The 180° cutting maneuver is commonly seen in field and court sports. In football it is called the button hook, in cricket it is required to score runs. Also, it is found in many agility and fitness tests such as the shuttle run and the 505 agility test. The purpose of this study was to determine the most effective joint movements, velocities and body positions to perform the 180° cutting maneuver by analyzing the execution of the 505 agility drill. Additionally, the study compared the kinematics of the 505 drill performed indoors while wearing running shoes and outdoors while wearing cleats. For this study, twelve athletes executed the 505 drill indoors while wearing running shoes and twelve executed the 505 drill outdoors while wearing cleats. Fifty nine independent variables were measured for each athlete and compared to the athlete's time to complete the test. The indoor athletes had a mean test time of 2.27 seconds and the outdoor group had a mean test time of 2.47 seconds. This was found to be significantly different with a p-value of 0.0001. Correlation analysis and forward stepwise multiple regression analysis was performed on both the indoor group and the outdoor group to determine which variables were significantly related to test time. Trunk forward lean at push off of the jab leg was most highly correlated to test time for the indoor athletes (r= -0.887), however, jab knee flexion at maximum flexion of the jab knee was most highly correlated to test time for the outdoor group (r= -0.748). Several kinematic differences were observed during the deceleration and cutting phases of the skill with fewer differences observed as the athletes accelerated away from the cut. Outdoor athletes could benefit from assuming body position similar to the indoor athletes and attain a greater degree of trunk lean at jab leg touchdown.

CHAPTER I

INTRODUCTION

General Overview

The ability to perform the perfect cut at exactly the right time in sports often leads to substantial rewards. Done right, it can allow a football player to evade his defender in order to catch the winning touchdown of the Super Bowl. It can also be as simple as enabling a 14 year old student to achieve a good score on a high school fitness test such as the shuttle run. A cut can be used to either evade a defender, follow the path of an object such as a football or a baseball or in reaction to the motions of an opponent. The 180° cutting maneuver is different from all other changes in direction as it involves a complete deceleration of the athlete's velocity to zero meters per second before turning and accelerating again. This makes it the most complicated and difficult cut in the field of sports and is therefore, an agility move like no other.

Agility can be defined as the component of fitness that involves changing the direction of a body's velocity quickly, efficiently and accurately (Young et al, 2001). This requires speed, strength, and coordination, abilities which are prevalent in every court and field sport. Speed, a scalar quantity defined as the distance covered divided by the time taken to cover it, is required going into and coming out of the cut or direction change. Strength refers to the total amount of force that can be effectively produced and is required during the cut itself as the muscles of the legs must create large eccentric contractions to decelerate an athlete in full sprint. Eccentric contractions occur when the muscle is lengthening under load. Large concentric contractions are then used to accelerate the athlete again in a different direction. Concentric contractions describe the muscle activity when the muscle is shortening.

However, agility and more specifically, the 180° cut does not merely come from the combination of these inherent abilities. It is a learned skill which involves correct technique. Anyone can simply *perform* a 180° cut but in order to master the biomechanics of the cut the athlete requires a high level of coordination. Without this ability, precious time would be lost, defeating the purpose of a high speed direction change (Craig, 2004).

The development of agility is important for three reasons. First, development of agility may reflect the athlete's improved body awareness and neuromuscular control and a heightened degree of overall athleticism. Second, changing direction at a high velocity produces large forces about the ankle, knee and hip and is therefore a common mechanism of injury. Learning correct cutting mechanics will reduce the risk of injury across all sports and skill levels. Finally, the ability to change direction quickly and efficiently will directly increase the athlete's overall performance in most sports (Vescovi, 2001).

In order to demonstrate good agility, an athlete must possess qualities such as power, and quick reaction time. Power is the rate of work production, calculated as work divided by the time during which the work is done. Reaction time is the interval of time between application of a stimulus (such as the movement of an opponent) and the onset of a response (the athlete's reaction in response the opponent's movement). A defensive player with a slow reaction time will generally not be able to keep up with an opponent no matter how skilled he or she is at an agility drill. So, while agility may simply be defined as the ability to decelerate and accelerate quickly, often with a direction change, it is clear that there are more complex components involved. As a result, there have been several definitions of agility each with a slightly different focus. Some definitions use the ambiguous term 'quickness' while others focus on the strength required to produce changes in direction at a fast pace (Barnes, and Attaway, 1996). Still other definitions emphasize the cognitive processes of decision making and motor learning and their effects on agility (Chelladuri, 1976).

Categorization of Agility

Which sports skills require high levels of agility for an athlete to be successful? An athlete about to throw a discus needs to be agile in order to accelerate from a stationary position to a spinning and throwing motion while maintaining his or her balance and accurately throwing the implement. Likewise, an athlete playing defense during a soccer game will also need to be very agile to react to the offence. Both of these athletes require the attributes of agility; speed, strength, coordination, balance, and power. However, the soccer player requires a higher level of agility to be successful in a sport because he or she has to react to the unknown movements of an opponent. In contrast, the discus athlete does not have to react to an external stimulus before initiating movement. Differentiating between or incorporating the different forms of agility (Table 1.1) has been a problem that the literature has not always addressed (Craig, 2004).

Young et al. (2002) identified agility as consisting of two main components: speed in changing direction and cognitive factors. The authors claim that agility exercises fall into one of two types: those containing an element of decision making, and those that are preplanned and initiated by the athlete. A cognitive factor would be present when a direction or velocity change should occur in response to a stimulus (action of the opponent). A highly skilled athlete will be able to recognize movements of an opponent which precede a cut earlier than an unskilled athlete. This will allow the skilled athlete to anticipate his or her opponent's movements to some degree. A good example of preplanned agility is when an athlete is on offence and is cutting to avoid a defender. A gymnastics floor routine is another good example of when an athlete must execute directional changes at a high velocity but can preplan all his or her actions. Even this categorization does not account for all the variables when trying to describe the different components of agility.

Table 1.1: Classification of agility (modified from Chelladurai, 1976).

Classification	Definition	Examples of sporting skill
Simple	-No spatial or temporal uncertainty. -The athlete can self regulate when and how to move. -Preplanned activities initiated by the athlete.	-Gymnastics routine -High jump -Shot put -Volleyball jump serve -Discus -Diving
Temporal	- Preplanned activity with temporal uncertainty. -Initiated in response to a stimulus (starting gun). -Key component is reaction time of the athlete.	-Sprint start in athletics -Other starts
Spatial	-Preplanned timing of movement with spatial uncertainty. -Athlete receives a visual or audio cue regarding when to react but where or how to react is unknown.	-Volleyball serve receive -Tennis return -Badminton rally
Universal	-Both spatial and temporal uncertainty. -During defense, the athlete cannot anticipate the movements of an opponent or positioning of the other players but must react and move in an undetermined time and direction.	-Basketball -Hockey -Football -Ultimate frisbee -Soccer

Perhaps the most comprehensive definition of agility is that of Chelladurai (1976) who proposed a classification system to distinguish between four different forms of agility. The terms simple, temporal, spatial, and universal were introduced to give a framework to the different levels of agility. These terms are outlined in Table 1.1. Given this framework, tasks can be broken down into their basic components and categorized in order to further understand the aspects involved in the sports skill. It is now possible to see a general progression from the planned to the unplanned, the simple to the complex. However, since Chelladurai, there have been researchers who have continued to ignore the temporal and spatial aspects of agility and have simply distinguished between planned movements and unplanned movements, often referred to as "open" (unplanned) and "closed" (planned) movements (Sheppard, Young, Doyle, Sheppard and Newton, 2006).

Some research has been done with reactive agility in which the athlete must react when a stimulus is presented. An example of this would be a specific cue from the tester or a light bulb to designate a direction change. The athlete can preplan his or her movement but not the timing of the cut. In other words, these tests evaluate an athlete's temporal agility (Sheppard et al., 2006). Similarly, some tests can accurately measure an athlete's spatial agility. This can be done by requiring an athlete to run random patterns around cones in a type of obstacle course. Although field and court sports place a higher emphasis on the universal category of agility, simple, temporal and spatial agility skills are often found in measured agility testing. This is a result of the lack of testing procedures that sufficiently quantify universal agility (Sheppard, et al., 2006). The variability of movements incorporated in universal agility makes it very difficult to design a test that will not allow the subject to preplan a portion of his or her reactions. Research has also shown that unanticipated cutting maneuvers result in a higher stress across the knee and ultimately stress to the anterior cruciate ligament due to the decreased time to execute the appropriate postural changes. Besier, Lloyd, Ackland, and Cochrane, (2001) found that loads experienced on the knee joint during unanticipated cutting were nearly double that of loads experienced on the knee joint during preplanned cutting maneuvers. The values obtained from the unanticipated trials were within the range of loads that have been shown to cause ligament failure.

Consequently, tests which measure the first three categories are common in agility testing with simple agility testing being the norm. Universal agility testing is rare in the average athletic team. Tests which measure simple agility include: the Illinois agility test, the 3-cone test, the pro-agility test and the T-test to name a few. Each of these tests involves running patterns around cones or obstacles and will be outlined in greater detail in Chapter II (Vescovi, 2001).

The most basic of these tests is the 505 agility test (Fig 1.1) (Draper, 1985). It is described as basic, as it only involves one change of direction. The above mentioned tests require several directional changes of differing angles as the athlete maneuvers around the cones. The athlete starts at the first cone, the second cone is 10 m away, and 5 m from that is the third cone, all in a straight line. The athlete accelerates down the line of cones passing the second. When the athlete reaches the third cone he or she makes a 180° turn and accelerates back to the initial starting point. The 5 m zone between the second and third cones is known as the testing zone. It is the goal of the athlete to travel through this area as fast as possible. In this way the athlete's deceleration, 180° turning ability and acceleration are all tested. These are all key components of the athlete's overall agility (Draper, 1985).

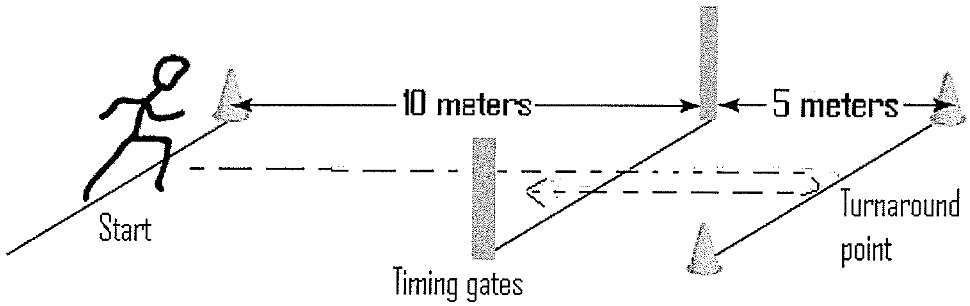


Figure 1.1: A schematic representation of the 505 agility test (Wood, 2005).

This is a preplanned cutting maneuver, or, from Chelladurai's classification, a simple skill. The athlete does not have to react to the motion of an opponent or path of a ball. He or she initiates this drill on the command of the instructor but the main concern is the athlete's time in the testing zone. The athlete knows when to initiate the cut and can plan his or her motions and the timing of the cut.

Mechanics of the 505 agility drill

To create the initial deceleration followed by the acceleration out of the cut the athlete must make use of the impulse-momentum relationship, $Ft=(mv)_1-(mv)_2$ (Hall, 2007). When an impulse acts on a system, the result is a change in the system's total momentum. The change can come from a small force acting over a large period of time or a large force acting over a small period of time. Initially the athlete will attempt to increase his or her ground contact time by increasing both the number of strides taken within the testing zone prior to the execution of the jab step (the last step in the original direction), as well as increasing the duration of the braking phase of each stride. This will lead to a more efficient deceleration as the braking forces will be distributed over a greater period of time resulting in a decreased stress on muscles of the legs. At touchdown of the jab step the athlete will alter the use of the impulse momentum relationship and attempt to produce a high force over a small period of time. This will accelerate the athlete faster in the new direction.

The extent to which the athlete can achieve an aggressive backwards lean and apply horizontal forces to the ground is dependent on the friction coefficient of the interaction between the athlete's footwear and the playing surface. The friction coefficient is the force acting at the area of contact between two surfaces in the direction opposite to that of motion. If the coefficient is too small for the attempted body lean, the athlete will lose footing with the ground and slip. If the coefficient is too large, the chance of injury will increase. Generally, the coefficient of friction should fall within the range of 0.5 - 0.7 (Milburn and Barry, 1998).

Purpose of the Study

The purpose of the study was to determine the most effective movements used by athletes to execute the 505 agility drill performed in two different settings. The first test was conducted on grass and the athletes wore cleats. The second test was conducted on a hardwood floor and the athletes wore running shoes. A secondary purpose was to determine differences in the movement pattern used when the drill is executed on grass and the movement pattern used when the drill is executed on a gym floor. This was done by comparing the measured variables of the indoor group to the measured variables of the outdoor group. Many athletes compete in more then one sport resulting in the need to adapt their biomechanics to different situations. Additionally, many outdoor athletes spend much of their off season training time indoors when outdoor facilities are not available. Knowledge of characteristics of the different playing surfaces will benefit can training and competition. A major outcome of the study was the development of two individual coaching checklists for the performance of a 180° change of direction cutting maneuver: one checklist specific to cutting 180° on grass while wearing cleats, and another specific to cutting 180° on a gym floor while wearing running shoes. These checklists highlight key features of a drill which a coach can look for and correct in their athletes.

Hypothesis

1. There is a negative correlation between time to complete the 505 agility test and linear and angular velocities of the athlete.

2. The athletes performing the skill indoors will demonstrate greater trunk lean and hip and knee flexion angles than their outdoor counterparts.

3. The variables identified as key kinematic components of the skill will be similar between the two testing protocols.

Rationale for the study

The 180° cutting maneuver is a crucial element in many sports. It involves running forward at a high speed, decelerating and stopping, and then running in the opposite direction as fast as possible. In American football it is known as the button hook. In cricket the runners execute this cut as they run between the wickets. It is also common in sports such as ultimate frisbee, soccer, handball, basketball, and netball. Variations of the cut are used in court sports like tennis, squash, and badminton. More importantly, this change of direction maneuver is a critical aspect of many fitness and agility tests. The multistage shuttle run test, also known as the beep test, is widely used to test athlete's VO2 max. Itcan often make the difference between making an elite team and being eliminated. The beep test involves running 20 m, making a 180° cut and running back. The athletes must perform the task repeatedly, increasing the pace of each repetition (Wood, 2005).

Field and court athletes experience short stints of straight running, but they seldom run at top speed for more than 30 meters (Sayers, 2000). The team sport athlete must always be prepared to change direction in response to the actions of the game. This has resulted in a running style adapted from the common track sprint technique.

During the NFL testing camps, athletes are put through a gruelling battery of interviews, drills, and fitness tests. Of the four agility tests used during the NFL testing camps, three incorporate a 180° cut: the 20 yard shuttle, the 60 yard shuttle, and the three cone drill (Wood, 2005). These tests highlight an athlete's ability to make a 180° turn efficiently and effectively. The NBA also uses agility tests with 180° turns to test their athletes at the start of every season. For soccer athletes, it is of critical importance to be able to perform 180° turns on both a gym floor and a soccer pitch since fitness testing and off season leagues are commonly conducted indoors when outdoor space is unavailable.

Figure 1.2: Different styles of the 180° cutting maneuver.

There are variations in technique between athletes at all levels (Fig 1.2) however the literature contains minimal amounts of analysis of the varying techniques. Sayers (2000) reports the athlete should lower the centre of gravity and decrease his or her stride length in preparation for a cut. A more detailed description or an account of the ideal technique is lacking in the literature. Therefore an in depth description of ideal 180° turning technique was needed.

Limitations

1. The analysis of only male subjects in this study does not allow for generalization to their female counterparts. Males and females have slightly different lower extremity anatomy and biomechanics therefore generalization across genders may not be accurate.

Delimitations

1. Each athlete wore his own cleats or running shoes. The different styles and brands of footwear may have slightly different coefficients of friction and thus perform differently during the test.

2. The presence of grass in the outdoor trials made exact measurement of ankle motion immediately prior to and during touchdown difficult.

Definition of terms

Acceleration: The rate of change in velocity changes with respect to time (Hay, 1993). $a = (v_f - v_i)/t$: where a = the average acceleration; v_f = the final velocity; v_i = the initial velocity; and t = time.

Agility: A component of fitness that involves changing the direction of a body's velocity quickly, efficiently and accurately (Young et al., 2001).

Angular acceleration: The rate of change in angular velocity with respect to time. (Hay, 1993). $\alpha = (\omega_f - \omega_i)/t$: where α = angular acceleration; ω_f = final angular velocity; ω_i = initial angular velocity; and t = time.

Angular displacement: A vector measure of the rotation of an object, such as a limb segment, about an axis, such as a joint centre. (Hall, 2007).

Angular velocity: Rate of change of angular displacement or orientation of a line segment (Hall, 2007). $\omega = \text{Ø}/t$: where ω = angular velocity; Ø = angular displacement; and t = time.

Angular momentum: The quantity of angular motion possessed by a body; measured as the product of moment of inertia and angular velocity. (Hall, 2007).

Axis of rotation: Imaginary line perpendicular to the plane of rotation and passing through the centre of rotation (Hall, 2007).

Centre of Gravity: Point around which the mass and weight of a body are balanced, no matter how the body is positioned (Hall, 2007).

Collinearity: **A** statistical term for the existence of a high degree of linear correlation amongst two explanatory variables in a regression model (Hassard, 1991).

Concentric contraction: Describes a muscle contraction involving the shortening of a muscle. Concentric muscle actions are used to produce force against external resistance such as raising a weight and pushing off from the ground while running. This commences when acetylcholine is released within the terminal axon. Acetylcholine receptors in the sarcolemma cause a depolarization of the t-tubule which results in calcium binding with troponin/tropmyosin. This releases the inhibition that prevents actin from binding with myosin. Aided by the energy released from the breakdown of ATP, myosin crossbridge movement occurs and the muscle shortens (McArdle, Katch and Katch, 2001).

Coordination: An organized working together of muscles and groups of muscles aimed at bringing about a purposeful movement such as walking or running (Lefers, 2004).

Cutting maneuver (cut): A quick, forceful movement incorporating a change of direction of an athlete's momentum. This requires the athlete to apply a force to the ground opposite in direction to the new direction of travel.

Eccentric contraction: Describes a muscle contraction involving the lengthening of a muscle. Eccentric muscle actions are used to slow down the motion of a body segment or external resistance. Lengthening occurs as external tension becomes greater than muscle tension. The sarcomeres increase in length and the actin/myosin crossbridges slide back to their original position (McArdle, Katch and Katch, 2001).

Force (F): A push of a pull that produces or prevents motion; the product of mass and acceleration (Hall, 2007). $F = ma$: where F = force, m = mass, a = acceleration

Force plate: A platform generally built rigidly into the floor and interfaced to a computer to calculate kinetic quantities of interest. Designed to transduce ground reaction forces in the vertical, lateral and anteroposterior directions (Hall, 2007).

Friction: A force acting at the area of contact between two surfaces in the direction opposite that of motion (Hall, 2007). $F=\mu R$: where F = friction; μ = the coefficient of friction; and R = the resistive force.

Ground reaction force: Describes the reaction force provided by the support surface on which movement is performed. It is derived from Newton's law of action-reaction (Enoka, 2002).

Impulse: Product of force and the time interval over which the force is applied. (Hall, 2007). $I = Ft$: where I = impulse; F = force; and t = time.

Impulse – Momentum Relationship: When an impulse acts on a system, the result is a change in the system's total momentum. This relationship is derived from Newton's second law (Hall, 2007). $F=ma$ or $F=m((v_2-v_1)/t)$ or $Ft=(mv)_1-(mv)_2$. Where F=force, m=mass, a=acceleration, v=velocity and t=time.

Line of gravity: The shortest line from the centre of gravity of a body to the centre of the earth (Hall, 2007).

Moment Arm: The perpendicular distance (shortest distance between a point and a line) between a force's line of action and an axis of rotation (Hall, 2007).

Moment of Inertia: A body or object's resistance to angular motion (Hay, 1993). It is the product of the mass and the radius of gyration squared, ($I=mk^2$) and is expressed in kilogram meters squared (kg m^2).

Momentum: The quantity of linear motion possessed by a body or object. It is the product of the mass and the velocity, (H=mv) and is expressed in kilogram meters per second (kg m/s) (Hay, 1993).

Power: The rate of work production, calculated as work divided by the time during which the work is done, $W=fd/\Delta t$ (Hall, 2007).

Pressure: The force per unit area over which the force acts, $P=F/A$ (Hall, 2007).

Range of Motion (ROM): The angle through which a joint moves from anatomical position to the extreme limit of segment motion in a particular direction (Hall, 2006)

Speed: A scalar quantity defined as the distance covered divided by the time taken to cover it, Speed $=d/\Delta t$ (Hall, 2007).

Strength: The total amount of force a person can produce.

Stretch Reflex: The response of a muscle to a sudden, unexpected increase in length. Feed back from muscle spindles activates the stretched muscle to minimize the increase in length and contract forcefully. Muscle spindles are stretch sensitive structures which send proprioceptive information to the central nervous system regarding the length of the muscle within which it lies (Enoka, 2002).

Stretch-shortening cycle: An active eccentric contraction followed immediately by forceful concentric contraction of the same muscle. This occurs as elastic structures in series with the contractile component can store energy like a spring after being forcibly stretched. Also, the stretch fires the muscle spindles to produce a reflex contraction of the muscle stretched (Hall, 2007).

Stride frequency: The number of strides per second.

Torque: A rotary effect of a force about an axis of rotation, measured as the product of the force and the perpendicular distance from the force's line of action and the axis. $T=Fd_{\perp}$ (Hall, 2007).

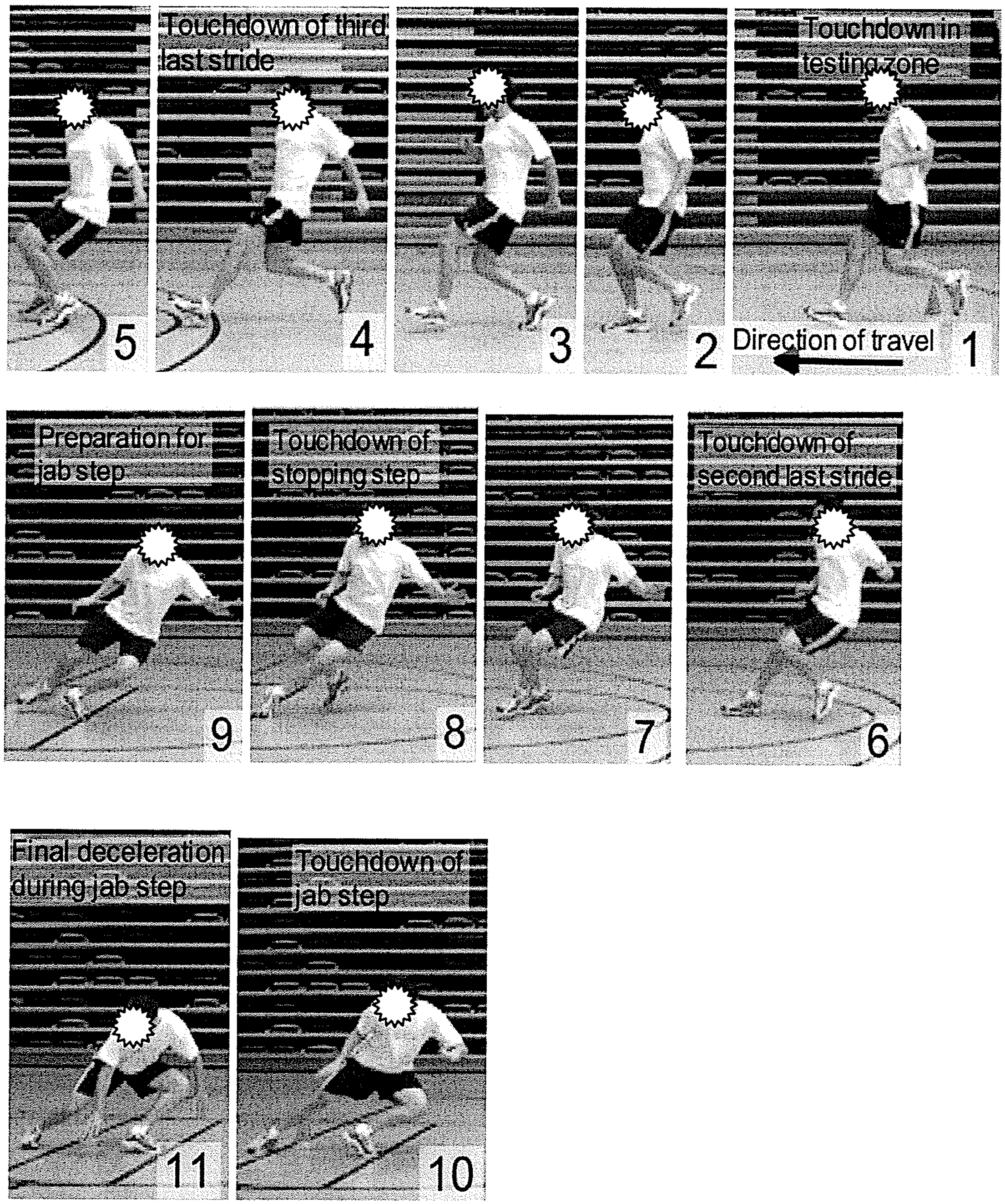
CHAPTER II

REVIEW OF LITERATURE

The 180° cutting maneuver

Athletes of all skill levels and across almost all sports execute the 180° cutting maneuver at some point during training or game play. An experienced athlete will begin to decelerate about 4-5 meters prior to their final turning location. The investigator has observed that athletes adopt a slight backwards lean in order to place the centre of gravity behind the support foot and increase the braking phase of the stride. The athlete will also increase the stride frequency by taking shorter strides with the goal of decelerating the forward velocity. About the time the athlete plants the third last step, the athlete will begin to rotate the hips and shoulders in the direction of the turn. When turning left, the third last step is usually with the right foot. The next step is the stopping step. The athlete will plant the foot approximately perpendicular to the direction of travel and will apply a large braking force by leaning well back from the stopping foot. The jab step is the last stride in the original direction. It is during the jab step that the athlete decelerates his or her forward velocity to 0 m/s. Elite athletes will assist rotation of their hips and shoulders with a forceful swing of their arms to help generate torque to produce angular momentum in them ir body to assist with the direction change.

Acceleration in the new direction comes from a forceful concentric contraction of the athlete's hip and knee extensors of the jab leg. The athlete will rotate his or her hips and shoulders so they are fully facing the new direction within the first 2-3 meters of movement in the new direction. In this position, the athlete has completed the 180° turn and must now accelerate as quickly as possible in the new direction in order to make the turn effective. This is done with skilled sprinting technique which includes forceful hip and knee extension of the support leg, vigorous drive of the contra lateral arm to the support leg and an efficient, high recovery of the swing leg.



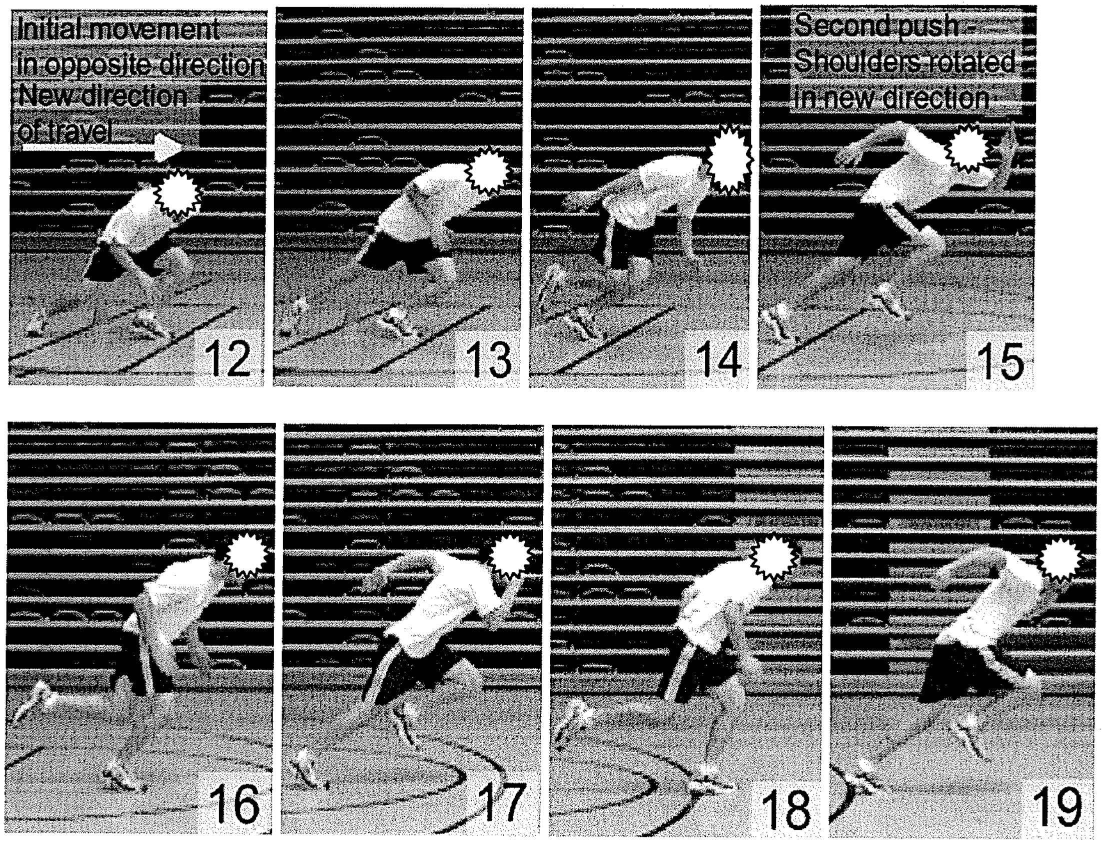


Figure 2.1: Sequenced images of the 180° cutting maneuver.

Analysis of the 505 drill

During normal play, a team sport athlete will generally have approximately 10° -15° of forward lean. As they decelerate they will decrease that to 0° by about 5 meters prior to the final location of the jab foot. They will then adopt a backwards trunk lean maximizing at about -40° from the vertical when outdoors and as much as -60° from the vertical when indoors (Figure 2.2). Body lean is dependent on the coefficient of friction between the playing surface and the shoes, determining differing values from indoor to outdoor. This maximum degree of body lean coincides with the execution of the jab step and serves to place the centre of gravity further behind the foot plant, increasing the braking action experienced during each stride.

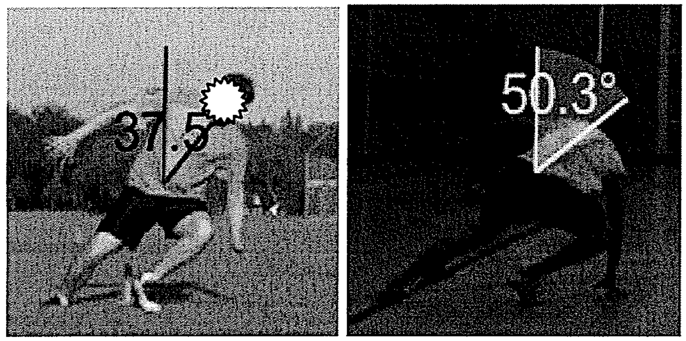


Figure 2.2: Athletes cutting on different surfaces demonstrate different trunk lean angles, with greater trunk lean angles on hardwood floors.

Prior to the direction change, athletes will alter their stride length and frequency by taking shorter, quicker strides, increasing the braking action of each stride to a greater extent. Hip hyperextension will be eliminated from the stride to remove the force producing aspect of the stride. The athletes run with deeper knee flexion of their support leg to lower their centre of gravity in preparation for the change of direction (Figure 2.3). They will not flex the knee of their swing leg as much as during regular running, however, as this will increase the moment of inertia of the limb, essentially slowing down the leg as it recovers under the body.

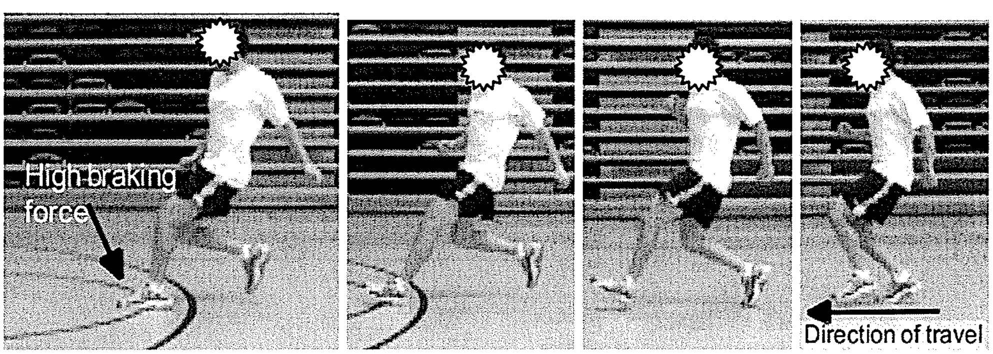


Figure 2.3: Notice the deep knee flexion of the support leg as the athlete prepares to change direction.

Athletes will begin to rotate their trunk and shoulders away from the direction of travel between 2 and 4 meters from foot plant. Rotation of the trunk too early in the skill will cause the hips and ultimately the foot placement of the approach steps to be pointing away from the direction of travel. Although this has not been found to affect performance, it can be used as a visual cue to the athlete's opponent that a cut is about to take place. In turn, it will reduce the uncertainty of the athlete's next move. Ideally, only the second last foot plant should be planted at an angle to the direction of travel. The athlete then rotates around this foot until the hips and shoulders are perpendicular or more to the original direction of travel. From this position the athlete can abduct the outside hip in preparation for the jab step. Abduction angles range from 30° to 50° (Figure 2.4). Similar to trunk lean angles, the coefficient of friction of the playing surface determines the degree of the athlete's hip abduction angle of the plant leg. The jab step has been found to be close to 50% of standing height in length. It has been observed by this researcher that a jab step considerably larger or smaller is a detriment to the performance of the 180° cut. A larger step requires greater eccentric force production from the quadriceps and gluteal muscle groups which delays the force producing phase. A smaller jab step causes the athlete's centre of gravity to move closer to the final foot position, thus increasing the total distance covered by the centre of gravity within the testing zone. A greater distance covered by the athlete's centre of gravity results in an increased time to complete the test.

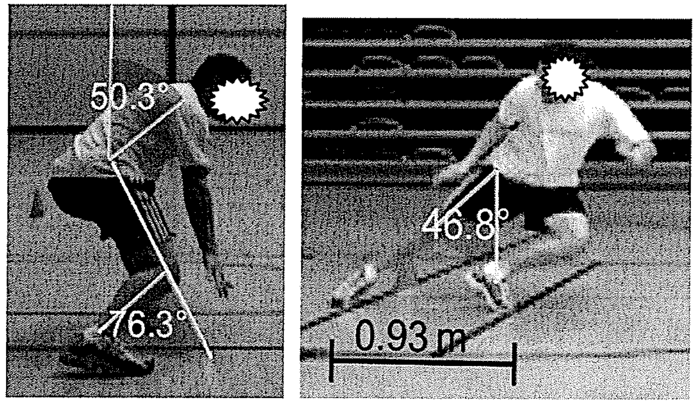


Figure 2.4: Execution of the jab step by a skilled athlete.

There is a strong eccentric contraction in the athlete's gluteus maximus and quadriceps muscle groups as weight is taken on to the jab leg. This is necessary in order for the athlete to come to a complete stop before movement is initiated in the new direction. During outdoor cutting, the athlete will flex the knee to about 80° and will flex the trunk forward to about 45°-65° from the vertical (Figure 2.4). The deeper the knee flexion the athlete achieves, the more the athlete can utilize the stretch reflex mechanism of the knee extensors. In indoor cutting, the athlete will often achieve slightly higher knee and forward trunk flexion angles as a result of the lower coefficient of friction. The lower coefficient of friction will allow the athlete to move the centre of gravity further outside the base of support and utilize a slight and predictable slide across the playing surface. This will essentially keep the centre of gravity further from the location of the planted foot and decrease the distance the centre of gravity travels while the athlete is in the testing zone.

There are two different techniques of performing the 180° cutting maneuver that may be observed after the jab step has been planted, as noted from preliminary investigations by the researcher. Some athletes raise their inside foot, put all their weight on their jab leg and use it as their main push off leg. Another style, common during indoor cutting, is to keep the inside foot planted and use it in conjunction with the jab foot to apply braking forces in the forward direction. As the athlete is braking, he or she will laterally rotate the inside hip and use this leg as the main push off leg instead of the jab leg. If the athlete is turning left, this will be the left hip. This allows the athlete to keep the weight closer to the new direction of travel since the athlete does not fully put all weight onto the jab leg. This will also allow the athlete to distribute the force more evenly between both legs during the final stopping motion as the athlete doesn't take his or her entire weight onto one leg.

As the jab foot is on the ground, the athlete should rotate both shoulders and hips to face the new direction of travel. Failure to do so will usually result in lateral motion of the athlete's centre of gravity at the initiation of movement in the new direction and will ultimately decrease performance of the cut. Less skilled athletes often fail to completely rotate their shoulders and hips in line with the new direction, completing the rotation only during their first stride back in the original direction (Figure 2.5). Consequently, there is often a noticeable amount of lateral motion in the path of the athlete's centre of gravity. Trunk rotation is most efficiently completed with minimal abduction in the shoulders, decreasing the moment of inertia of the upper body about the spine, and increasing the angular velocity of rotation.

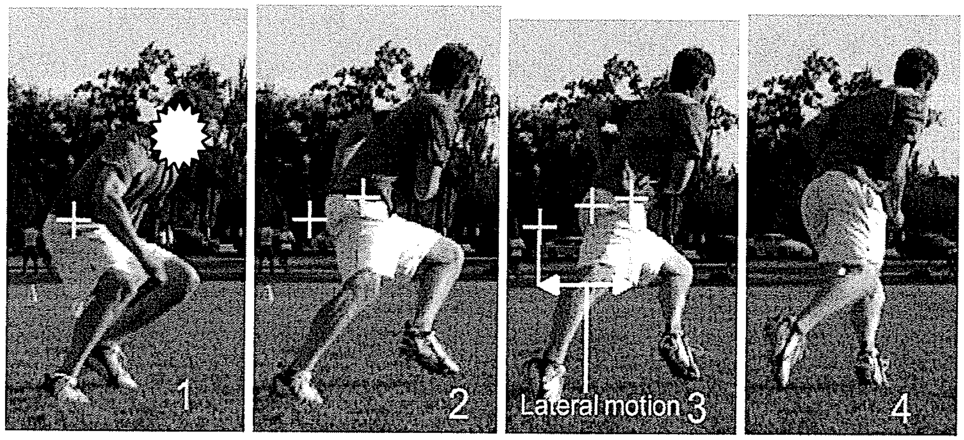


Figure 2.5: Example of a poorly executed cutting maneuver due to the large amount of lateral motion of the athlete's centre of gravity in the first step after the jab step. The centre of gravity was estimated by the location of the hip joint.

The athlete initiates acceleration in the new direction through forceful hip extension, knee extension, and ankle plantar flexion of the push off leg. At this point, the skill resembles that of a track sprint start (Figure 2.6). The field sport athlete will have a slightly less aggressive body lean than the track athlete as they still need to see the play occurring around them.

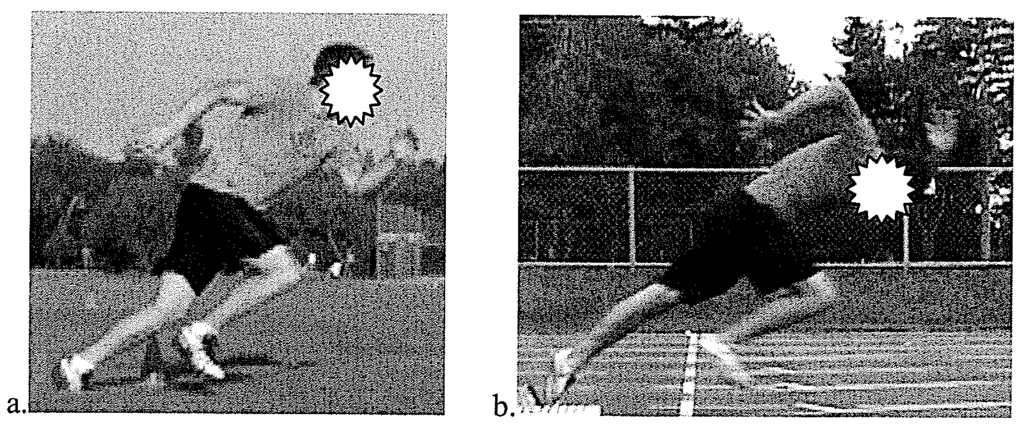


Figure 2.6: An athlete after changing direction in a 180° cut in 2.6a and an elite sprinter exiting the starting blocks in 2.6b

After the initial thrust in the new direction, the athlete's motions should resemble the start of the track sprint, however in field sports the athlete will attempt to attain maximum velocity as quickly as possible, whereas in track sprinting the acceleration phase is taught to be long and controlled in order to reach maximum velocity at an optimal point in the race (Faccioni, 2003). During the first few strides, the athlete's motion comes exclusively from propulsive forces during the support phase of the stride (Sleivert and Taingahue, 2004). The athlete still has a considerable amount of forward body lean causing the foot to touch down behind the centre of gravity thus eliminating the presence of a braking phase of the stride. Also, these motions are produced predominantly from concentric contractions of the hip and knee extensors and ankle plantar flexors (Sleivert and Taingahue, 2004).

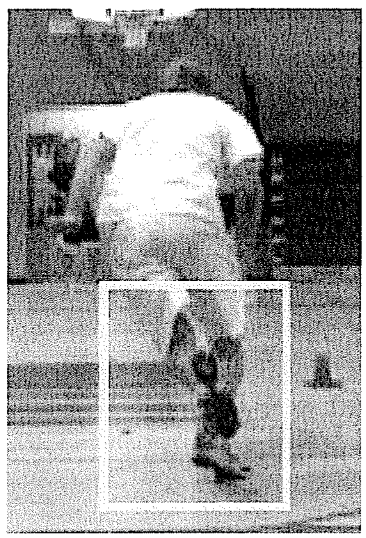


Figure 2.7: The athlete has laterally rotated and adducted his left hip causing an inefficient recovery.

Faccioni (2003) states that a common problem in the starting technique of track as well as team sports athletes is the lateral hip rotation just after toe off and during early recovery of the foot (Figure 2.7). This lateral motion usually leads to hip rotation and, consequently an inefficient and awkward recovery swing. Another problem common to track and field as well as field sport athletes', is the less than full range of motion of the hip and knee extensors. For some athletes this is related to a trunk position which is too erect, or possibly laterally rotating the push off hip. Both of these errors will limit the range of hip extension available to the athlete (Figure 2.8).

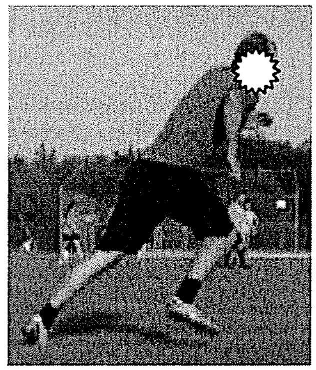


Figure 2.8: The athlete has not maximized hip or knee extension during the propulsive phase of his stride.

Biomechanics applied to the 505 drill

Impulse-Momentum

In mechanical terms, the athlete must produce a large impulse (force x time) (Hall, 2007) during the jab step to produce the fastest change in direction. As the athlete enters the testing zone however the goal is to slow down his or her velocity as quickly and as efficiently as possible. The athlete does this by assuming a backwards body lean and altering the stride pattern. A backwards body lean will move the line of gravity further away in relation to touchdown of the support foot thereby increasing the duration of the braking phase of each stride. The braking phase of the stride is the time when the support foot is in front of the line of gravity. During this time the athlete cannot apply backwards, propulsive forces to the ground to increase velocity in the forward direction. Instead, the athlete applies forward, braking forces to slow down the forward velocity. The athlete also decreases the stride length and increases the stride frequency over the given distance. This way the total duration of the braking action can be increased and deceleration of the forward velocity can occur quickly and efficiently.

By altering the body position and stride pattern the athlete is changing the impulse he or she is applying to the ground and utilizing the horizontal impulse-momentum relationship (Equation 2.1) (Hall, 2007).

$$Ft=(mv)_f-(mv)_i \qquad \text{Equation 2.1}$$

F = Force, t= time, m=mass, v=velocity, mv= momentum

Subscript i indicates an initial time and subscript f indicates a later time. In other words, $(mv)_i$ refers to the momentum of the system before the impulse acts upon it (initial), and $(mv)_f$ refers to the momentum of the system after the impulse acts upon it (final).

This relationship states that when an impulse acts on a system, the result is a change in the system's total momentum (Hall, 2007). Changes in momentum depend on the magnitude and duration of the forces acting on the system. An object's momentum can be changed through a large force acting over a short period of time or a small force acting over a large period of time (Hall, 2007). In the case of an athlete performing the 505 drill, the athlete will attempt to increase the duration of all braking movements while entering the testing zone and approaching the cut. Therefore, to a certain extent, by increasing the number of strides the athlete takes while entering the zone the athlete can apply less force per stride and still adequately decelerate the velocity in preparation for the 180° turn.

The final stride in the forward direction is known as the jab step. It is during this stride that the athlete decelerates all forward velocity to 0 m/s and begins to accelerate in the opposite direction. Again, the athlete will utilize the impulse-momentum relationship but this time will attempt to apply a large force over a small period of time to accelerate quickly in the new direction. Since the mass of the athlete is constant the velocity of the athlete is directly proportional to the magnitude of the impulse exerted in the opposite direction. A greater impulse in the backwards direction results in a greater velocity of the athlete.

To fully understand the impulse momentum relationship it is useful to use an example of how it would apply to an athlete executing the 505 drill. All of the variables can be found from a video analysis of the athlete performing the skill except the force required to alter the momentum of the athlete. The athlete's mass should be recorded prior to filming. Therefore it will be the force that will be determined from the impulse momentum relationship.

Example #1

A male football player has a mass of 80 kg and is traveling at 1.12 m/s (v_i) just prior to touchdown of his jab foot. He must decrease his forward velocity to 0 m/s (v_f) as quickly as possible in order to prepare to accelerate in the new direction. It can be seen from film that this deceleration occurs in 0.13 seconds. Therefore he would have applied -689.2 N of force to the ground in the horizontal direction from touchdown of his jab step until his velocity is 0 m/s. The formula results in a negative value for the force applied. This indicates an eccentric contraction is responsible for the deceleration of the athlete's velocity.

$$Ft = (mv)_f - (mv)_i$$

$$F(0.13s) = ((80\ kg)(0m/s)) - ((80\ kg)(1.12\ m/s))$$

$$F(0.13s) = -\ (89.6\ kg\ m/s)$$

$$F = -\ 689.2\ kg\ m/s^2 \text{ or}$$

$$F = -\ 689.2\ N$$

Example #2

A female soccer player has a mass of 65 kg and is traveling at 2.8 m/s (v_i) just prior to touchdown of her second step in the new direction. Support time of this step is 0.25 s and her velocity after the step is 3.4 m/s (v_f). Therefore she would have applied 156 N of force to the ground in the horizontal direction during support time of the step in question. In this case, the result is a positive value indicating force was produced as a result of concentric contractions.

$$Ft = (mv)_f - (mv)i$$

$$F(0.25\ s) = ((65\ kg)(3.4\ m/s) - ((65\ kg)(2.8\ m/s)$$

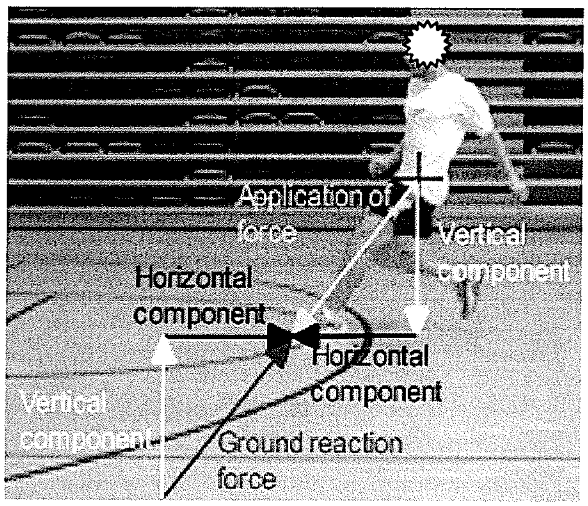
$$F(0.25\ s) = 39\ kg\ m/s$$

$$F = 156\ kg\ m/s^2 \text{ or}$$

$$F = 156\ N$$

Direction of Force Application

When an athlete applies force to the ground at angle between 0° and 90°, the resultant force vector can be broken down into its vertical and horizontal components. However, only the horizontal component of the force acts to propel the athlete forward. The vertical component of the force applied to the ground acts to propel the athlete upwards and to support the athlete's body weight. Therefore, it is the horizontal component of the force vector which the athlete must maximize. This is done through an aggressive body lean which enables the athlete to decrease the force application angle with the horizontal (Figure 2.9). This way, a greater portion of the force vector acts in the horizontal direction. Friction is a major factor which determines the amount of body lean an athlete can achieve. This will be discussed later in the chapter.

a. 

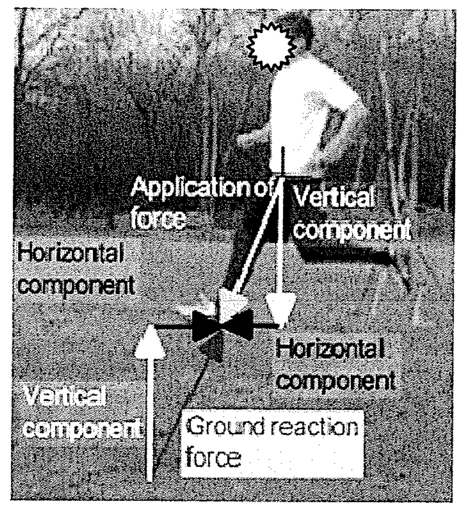
b. 

Figure 2.9: Force vectors and their relationship to braking and propulsion in the 505 drill. Vectors were estimated as the line through the athlete's approximate centre of gravity and the point of force application (Dyson, 1973).

Figures 2.10 and 2.11 are examples of vectograms showing direction and magnitude of ground reaction forces during a running stride. Notice in Figure 2.10 that ground reaction forces at initial foot plant are opposite in direction to the athlete's direction of travel. As the athlete's centre of gravity travels over and past the point of contact with the ground the athlete is able to apply forces in the opposite direction to the direction of travel. This is evident in the enlarged portion in Figure 2.10 as the horizontal component of the ground reaction forces act in the same direction of travel. Figure 2.11 is an example of a vectogram showing a stopping motion. Notice the lack of propulsion phase in Figure 2.11. The athlete attempts to apply all force to the ground in the same direction to the direction of travel. This way, the ground reaction forces acting back through the athlete's body will be opposite in direction to the athlete's direction of travel and serve to decelerate the centre of gravity. Also notice the decreased angle to the horizontal in Figure 2.11 when compared to Figure 2.10. This will result in an increased horizontal component of the resultant ground reaction force vector. In turn, the athlete will experience a greater braking motion during stopping than during a normal running stride.

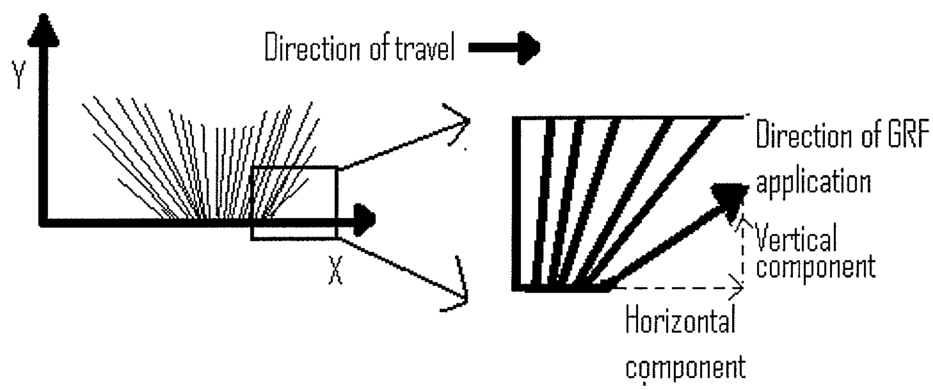


Figure 2.10: Vectogram of ground reaction forces during a running stride (modified from BTS Digivec, 2006).

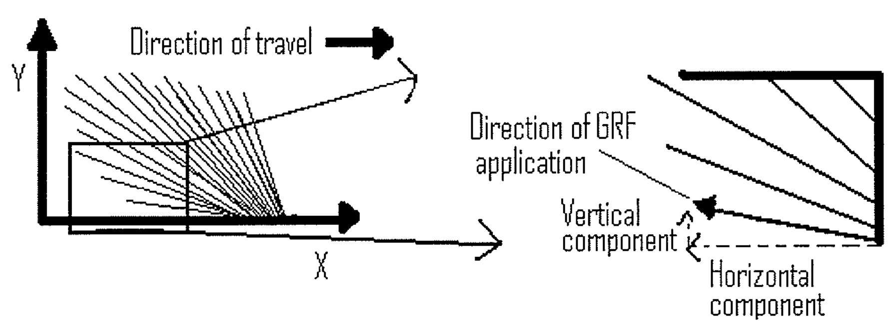


Figure 2.11: Vectogram of ground reaction forces during a stopping motion (modified from BTS Digivec, 2006).

Torque

A torque is a rotary effect of a force about an axis of rotation or the tendency to produce rotation (Hall, 2007). It is calculated as the force acting on a system multiplied by the perpendicular distance of the line of force to an axis of rotation (Equation 2.2).

$$T = F \cdot d_{\perp} \qquad \text{Equation 2.2}$$

T= torque, F= force, $d_{\perp}$= perpendicular distance from the direction of force to an axis of rotation.

The athlete executing the 505 drill must constantly resist this tendency to rotate when entering the testing zone. A torque is produced about the athlete's axis of rotation at the contact point between the foot and the ground. The athlete's forward velocity will cause the tendency for the centre of gravity to rotate over the support foot. The acceleration (or deceleration in the direction of travel) of the athlete's centre of gravity is the force producing the torque. The $d_{\perp}$ refers to the distance from the line of travel of the athlete's centre of gravity to the axis about the athlete's foot. If the athlete fails to counter the torque produced there is an increased chance that the athlete will topple forward over the axis at the support foot. The athlete uses three distinct methods to combat the torque produced about the support foot and the resultant over rotation around the athlete's centre of gravity. First, the athlete applies an impulse to the ground opposite in direction to the direction of travel. This will slow down the athlete's centre of gravity and diminish the effects of the torque (Figure 2.12) (Jindrich, Besier, and Lloyd, 2006).

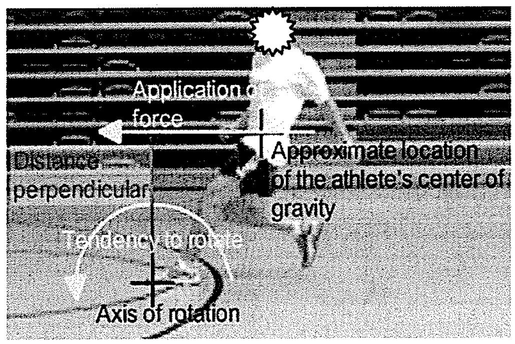


Figure 2.12: The athlete is applying braking forces (impulse) to resist the torque produced at his support foot. This prevents over rotation.

Second, the athlete lowers the centre of gravity by flexing the support knee and increasing the amount of backward body lean. A lowered centre of gravity essentially decreases the distance perpendicular from the application of force to the axis of rotation. An increased body lean will also serve to increase the time over which the athlete can apply an impulse to the ground to combat the torque about the foot. Finally, the athlete will lift the support foot as the centre of gravity travels over it eliminating the torque during a brief airborne phase as the whole body travels forward (Figure 2.13). If the centre of gravity was allowed to pass over the support foot while the foot was still in contact with the ground there would be an increased chance of over rotation.

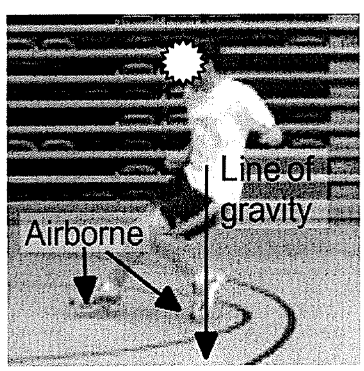


Figure 2.13: Athlete avoids over rotation by lifting his support foot prior to alignment with his line of gravity during the approach.

Example #3

In order to calculate the torque produced as the athlete is braking, the force applied by the athlete's centre of gravity must be calculated using Newton's second law of motion. This states that force equals mass times acceleration (F = ma). Acceleration can be determined through video analysis, and the athlete's mass is recorded. Therefore, if the athlete had a mass of 70 kg and was accelerating at a rate of – 2.4 m/s^2 the force exerted by his or her centre of gravity would be -168 kg m/s^2 or -168 N.

$$F = ma$$
$$F = (70\ kg)(-2.4\ m/s^2)$$
$$F = -168\ kg\ m/s^2 \text{ or}$$
$$F = -168\ N$$

We can use this force in the torque equation. Therefore, if the line of travel of the athlete's centre of gravity was 0.9 meters from the ground the torque produced would be -151.2 Nm.

$$T = F \cdot d_{\perp}$$
$$T = (-168\ N)(0.9\ m)$$
$$T = -151.2\ Nm$$

If the athlete were to lower his or her centre of gravity to 0.8 m the torque would be reduced to -134.4 Nm (-168 N · 0.6 m = -134.4 Nm).

If the athlete does not counter the torque using the methods described earlier, he or she could tumble forward over the support foot. This is especially important during the jab step as the braking force must be great enough to decelerate the athlete to 0 m/s. If the athlete does not apply a large enough impulse prior to the desired location of the jab step to reach a velocity of 0 m/s, the remaining velocity will result in over rotation. The effect of inadequate impulse or braking forces can be seen in

Figure 2.14. The athlete has not applied a great enough impulse to properly decrease his velocity. In this case the athlete has maintained a high centre of gravity increasing the torque experienced by his centre of gravity. Consequently he almost loses his balance over his support foot. He is only able to maintain balance through minor foot adjustments which move the axis of rotation about his foot further to his left. In this way he can increase the time he can apply forces to the ground thus increasing the impulse applied in the opposite direction of travel. If he had lowered his centre of gravity prior to execution of his jab step, the magnitude of the torque would be diminished and he would have an easier time executing the jab step without losing his balance.

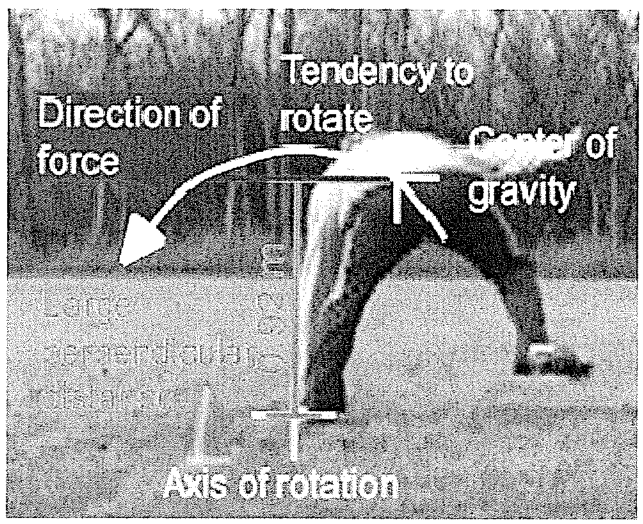


Figure 2.14: Athlete almost loses balance due to torque produced around his support foot.

Moment of Inertia

The moment of inertia of an object is the object's resistance to angular motion (Hay, 1993). It is calculated as the product of the mass of the object and it's radius of gyration squared (Equation 2.3). The radius of gyration of an object is the distance the mass of an object is distributed relative to the axis of rotation (Hay, 1993). In order to find the total moment of inertia of a leg, the moment of inertia of the thigh, shank and foot about the hip axis would be added together (Figure 2.15 and 2.16). The units used to express moment of inertia are kilogram meters squared (kg m²).

$$I = mk^2 \qquad \text{Equation 2.3}$$

I = moment of inertia, m = mass, k = radius of gyration

An athlete executing the 505 drill will attempt to increase the radius of gyration of the lower limb by extending the knee as the athlete approaches the cut. This will increase the limb's moment of inertia and increase it's resistance to rotation. This is desirable while the athlete approaches the turnaround point as the more resistant the limbs are to rotation the slower the rotation of the limb. Conversely, as the athlete exits the turn he or she will strive to decrease the radius of gyration of the legs by increasing the degree of knee flexion in the recovery leg (Figures 2.15 and 2.16). This will decrease the moment of inertia of the leg, making it easier to rotate forward through hip flexion and possibly increase the rate of rotation.

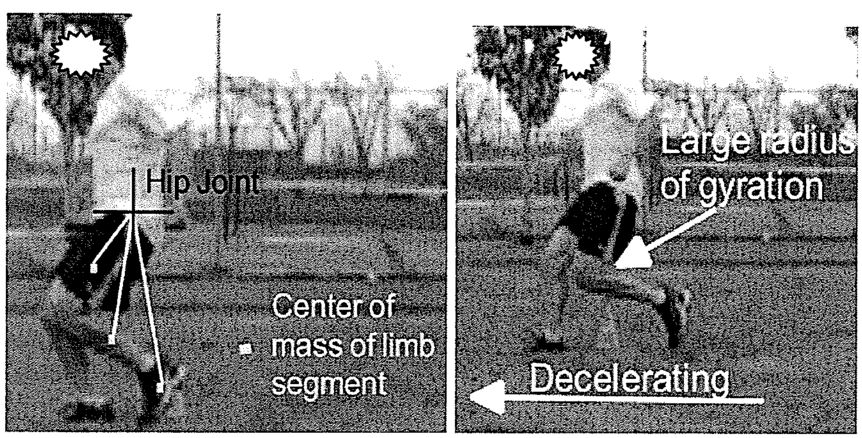


Figure 2.15: The athlete increases the radius of gyration as he approaches the cut.

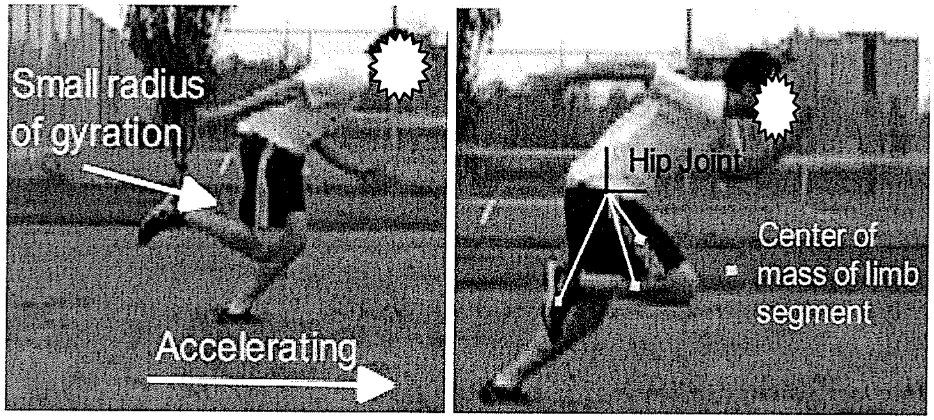


Figure 2.16: The athlete decreased the radius of gyration of his lower limb as he exits the cut.

When the athlete is approaching the cut the range of motion in the shoulders and elbows will be decreased. The athlete will also extend the elbow and abduct the shoulder. This increases the moment of inertia about the shoulder and increases the limb's resistance to rotation. Consequently, the contribution of the arms in increasing ground reaction force is reduced. There is, however, a lot of variation between athletes in regard to arm motions as the athlete approaches the cut and further investigation is required to determine optimal arm actions early in the 505 drill.

Through the cut itself, the athlete should adduct the shoulders placing the upper arms relatively close to the trunk as this will decrease the radius of gyration of the upper body about the longitudinal axis. In turn the athlete will expend less energy rotating through the cut. If the athlete uses the right leg as the main push off leg the left shoulder will flex slightly and the right shoulder will be hyperextend. This places the athlete in a good position to forcefully extend the left shoulder and flex the right shoulder to increase the ground reaction forces experienced opposite to the new direction of travel (Figure 2.17).

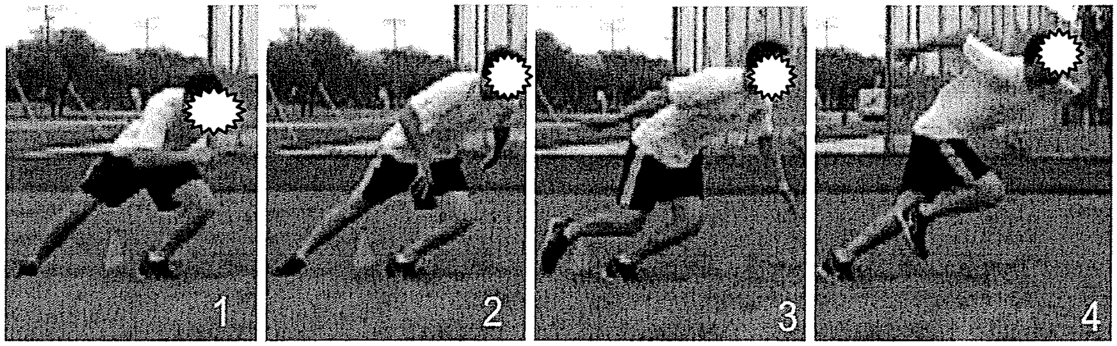


Figure 2.17: The athlete flexes his right shoulder and hyperextends his left shoulder in preparation for the drive in the new direction.

Once the athlete has initiated movement in the new direction he or she will strive to keep the elbows flexed to close to 90° throughout the rest of the drill. There will be some flexion/extension at the elbow joint, but the athlete should minimize this in order to keep the moment of inertia of the arms to a minimum. The athlete's arms will be able to rotate about the shoulders faster if they remain flexed, thus potentially increasing their contribution to ground reaction forces.

Angular Momentum

The amount of angular motion an athlete has is altered by the application of an angular impulse. Angular impulse is the effect of a moment acting on a system over a specific time interval. It is defined as a moment of force (torque) acting over a specific period of time. The relationship between angular momentum and angular impulse is stated in Equation 2.4.

$$Tt = I\omega_f - I\omega_i \qquad \text{Equation 2.4.}$$

T = torque, t = time, I = moment of inertia, ω_f = final angular velocity,

ω_i = initial angular velocity, Tt represents the angular impulse, $I\omega_f - I\omega_i$ represents the change in a subject's angular momentum.

Angular momentum, or the amount of angular motion an athlete has, is constant while they are airborne. This is known as conservation of angular momentum. While the athlete is in contact with the ground a torque can be applied to the ground, which in turn will apply a torque back to the athlete and increase or decrease the angular momentum in a given direction.

In order to determine the angular momentum of a human body the angular momentum of each body segment must be calculated separately and summed to find the total angular momentum (McGinnis, 1999). In a running athlete, the forward angular momentum of one arm and the backward angular momentum of the other cancel out any torque experienced by the upper body about the transverse axis through the shoulder joint. There is also a small amount of clockwise and counter clockwise motion in the arm swing. These angular momenta should cancel, eliminating any rotational motion about the longitudinal axis through the spine (Burt, 1999; McDonald, 1999). Similarly, the motion of the legs will cancel any unwanted angular momentum about the transverse and longitudinal axes. The trunk should not rotate therefore the total angular momentum of a running athlete should be zero while airborne (Figure 2.18).

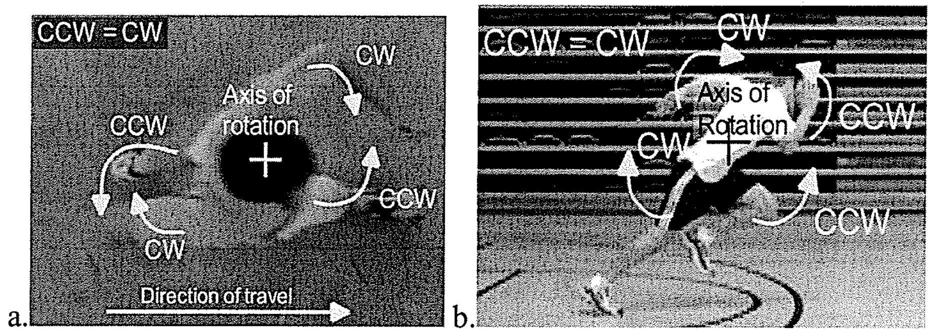


Figure 2.18: Angular momentum in the clockwise and counter clockwise directions are equal about the longitudinal axis in (a) and are equal about the transverse axis in (b).

If, however, the athlete is not skilled in controlling the angular motion of the limbs there could be unwanted rotation produced about either the transverse or longitudinal axes. This results in the trunk rotating with each stride (Burt, 1999; McDonald, 1999). Thus the runner must expend energy, not only to propel himself forward, but also to keep the trunk facing forward. This occurs when the angular momentum in the clockwise direction does not equal the angular momentum in the counter clockwise direction.

An athlete initiating a 180° cutting maneuver must rotate the trunk to align with the new direction of travel. To do this, the athlete will use angular momentum in the arms to assist with the turn. If the athlete were executing a left turn, ideally, he or she would horizontally adduct the left shoulder and extend the right shoulder. As the athlete's jab step is on the ground he or she will horizontally abduct the left shoulder and flex the right shoulder. This will transfer angular momentum from the arms to the trunk to assist in rotating the trunk and hips (Figure 2.19). It should be noted that since the athlete is not airborne, the rotation of the body may be produced through the application of a torque to the ground, however, the motion of the arms may assist the rotation of the trunk thus requiring less muscle action in the legs.

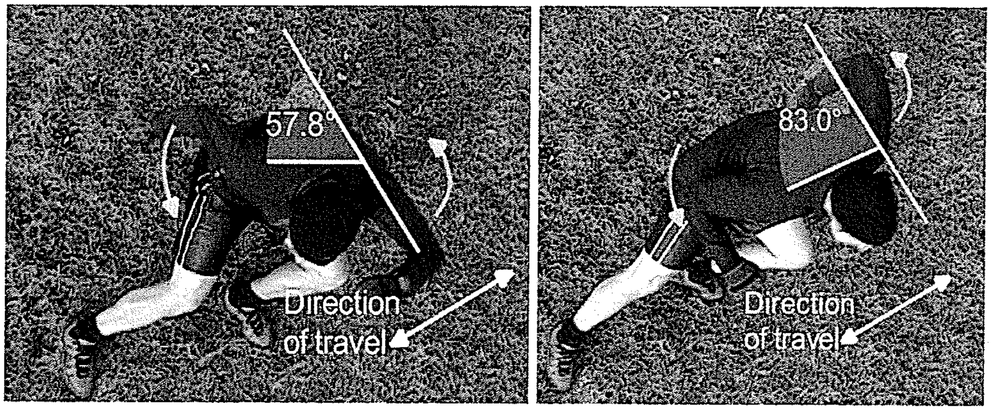


Figure 2.19: The athlete uses the angular momentum in his arms to assist in rotating his trunk through the turn.

Friction

The reason cleats are worn on grass and court shoes are worn in a gym is friction, "friction is a prerequisite for locomotion on earth" (Stucke, Baudzus and Bauman, 1984). Friction forces act at the contact surfaces between two objects enabling horizontal forces to be generated. Consequently, athletes can accelerate and decelerate as they travel horizontally across a surface (Stucke et. al, 1984). Translational friction determines how much force is required for an athlete to lose footing with the ground. In other words, how much force in the horizontal direction between the shoe and surface interface is required to cause a shoe to slide across a surface.

In translational friction, the coefficient of friction is described as a relationship between the normal force (normal force equals the force pushing the objects together) and the horizontal force required to move the object across the surface. On a flat, level surface, normal force is the vertical component of the weight of the object (ie the weight of the athlete). The horizontal force is known as the friction force. Equation 2.5 describes this relationship (Hall, 2007).

$$\mathbf{F} = \mu \cdot \mathbf{R} \qquad \text{Equation 2.5}$$

F = the horizontal or friction force required to translate the object

μ = the coefficient of friction

R = the resistive force (weight of the athlete)

This means that if an athlete weighing 800 Newtons was standing on a surface with a coefficient of friction (μ_s) of 0.5 it would take 400 Newtons of horizontal force to cause the athlete to slide. If the same athlete were to move to a different surface, one with a higher coefficient of friction, say 0.75, it would take 600 Newtons of force to cause the athlete to slide.

The coefficient of friction should fall within a certain range for athletes to perform normal cutting maneuvers. Too low and the athletes will slip too easily causing a reduction of performance and increasing the chance of falls. As well, too high and the shoe/surface interface would not 'give' in situations where the load was too high for the tissues of the body to handle. This too could cause injury. Milburn and Barry (1998) reported that optimal translational friction coefficient values for playing surfaces should fall within the range of 0.5 and 0.7. This study was conducted for rugby athletes so it can be assumed that they were testing cleats on grass. Another study quotes a coefficient value as high as 0.8 in order to optimize performance (Frederick, 1993). This higher value was found when testing basketball shoes on a hardwood floor.

If the playing surface is such that adequate friction cannot be reached using different shoe sole materials, the use of spikes or cleats can be used to increase the coefficient of friction. This provides a "form-locking" situation rather than a "force-locking" situation as with court shoes (Figure 2.20) (Stucke et al., 1984). If the two surfaces are form-locked, the shape of one of the surfaces, the grass, will deform to the shape of the other surface, the cleats. The connection allows the transmission of very high horizontal forces between the two surfaces enabling great accelerations and decelerations (Stucke et al., 1984). When two surfaces are force-locked, the materials in contact are of great importance in the development of friction. Typically, shoes with gum rubber outsoles are used during many court sports. When the shoe and the playing surface are form-locked, the material of the shoe is not as important as the shape and hardness of the cleat and the depth and hardness of the grass mat. (Stucke et. al, 1993).

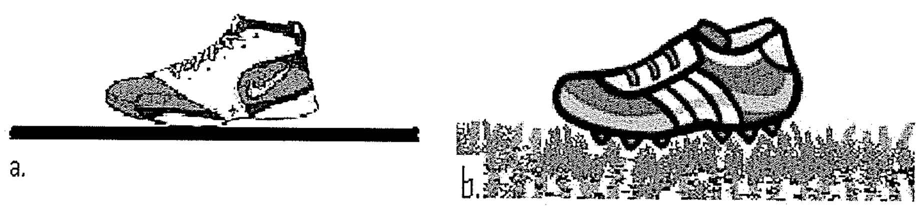


Figure 2.20: Court shoes on hardwood floors force-lock to the surface during running and cutting (a.) whereas cleats form-lock to the grass surface when running and cutting (b.).

Also, contrary to what might seem logical, athletes do not rotate around their foot during running, accelerating and cutting motions including the 180° cutting maneuver. These movements are purely translational therefore rotational friction is not an issue in the prevention of slipping (Frederick, 1993). Notice the position of the jab foot in the sequenced pictures of the jab step in Figure 2.21. The foot remains almost stationary and does not rotate from the time it is planted until the athlete pushes off in the new direction. The rotation described earlier, predominantly occurs in the upper body.

Figure 2.21: Sequenced pictures of a planted jab step. The athlete does not rotate the foot while executing a 180° cut.

Track Sprinting vs. Team Sports Sprinting

There has been a great deal of literature describing the biomechanics of straight sprinting (Blazevich, 1997, Bushnell, 2004), however, the coverage of the biomechanics of running during team sports is limited. It is worth highlighting the key biomechanical differences between field or court running and straight track sprinting. Athletes competing in team sports experience short periods of straight sprinting, but the knowledge of potential, unpredictable changes in direction force an athlete to adjust his or her sprinting technique to assume a better position in order to react quickly to the circumstances of the play (Barnes and Attaway 1996).

Baker (1999) found that professional rugby players demonstrated a foot strike considerably in front of their centre of gravity while track sprinters demonstrated foot strike almost directly below their centre of gravity (Bushnell, 2004). Baker (1999) presumed that this difference resulted from the constant need to change directions in rugby and other field sports. Placing the foot down a greater distance in front of the centre of gravity increases the braking phase of the stride and allows for greater opportunity to change direction.

Elite sprinters are taught to “stand tall and run with an open chest and long trunk” (Sayers, 2000). This position is ideal for sprinting but not practical for the team athlete who must avoid tackles and change directions constantly. If a rugby player were to run with a track posture the athlete would be vulnerable to frontal tackles and would not be as mobile in the horizontal plane (Sayers, 2000). Flexing forward in the trunk allows the athlete to lower his or her centre of gravity in order to prepare for a direction change or collision with an opponent.

Baker (1999) also found that rugby players maintained deeper knee flexion throughout the stride, thus lowering their centre of gravity further. This also allows them to quickly apply lateral forces to the ground when the need to change directions arises. Sayers (2000) reported that elite rugby players used a “relatively low knee lift and high stride rate compared to the classic sprint technique used by specialist sprinters.” Elite sprinters are instructed to achieve a thigh position that is parallel to the ground. Most professional field sport athletes fall 25° to 30° short of this ‘ideal’ position. Fast and low feet assist with balance and increase an athlete’s ability to change direction in the field (Sayers, 2000).

The differences are clearly illustrated in Figure 2.22. Note the upright chest of the sprinter and the forward lean of the soccer player. The soccer player is also planting his foot well in front of his centre of gravity whereas the track athlete will place his foot down almost right under his centre of gravity. The soccer athlete has abducted and medially rotated his right shoulder possibly in preparation to kick the ball. The track athlete strives to keep all forces in the sagittal plane and therefore tries to eliminate any rotation or horizontal flexion/extension of the shoulder girdle.

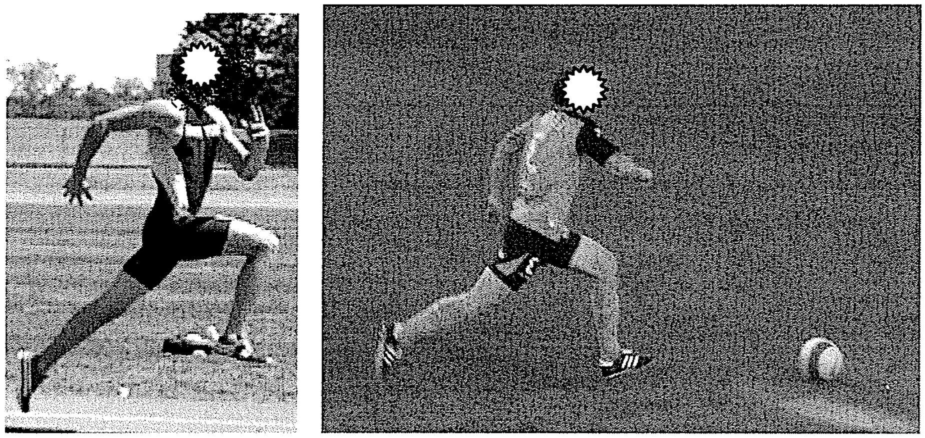


Figure 2.22: An elite track athlete's posture is considerably more erect than that of an elite field sport athlete.

Baker (1999) found that elite rugby players had greater lower abdominal and hip flexor strength when compared to their sprinter counterparts or less experienced rugby players. The author claimed that this afforded them a greater ability to run with a lowered centre of gravity as they will be able to stabilize their pelvis more effectively. They will also have an enhanced capacity to apply lateral forces to the ground with a lowered centre of gravity. The elite rugby players were able to maintain a better body position and execute the cuts at a faster pace. Glasser (1999) reports that stronger abdominals will allow a more effective transfer of force from the upper body to the lower body. As the athlete decelerates, the upper body continues to move forward. A strong core will help decelerate the upper body allowing a faster change of direction. Therefore, it may be concluded that stronger lower abdominals allow an athlete to change direction more quickly and efficiently (Baker, 1999).

In sprinting, the arm drive serves several purposes. It can increase stride rate and ground reaction forces as well as counter rotational forces in the trunk thereby increasing stability and maintaining all forces in the sagittal plane (Bushnell, 2004). Cutting actions require the arms to move in a similar manner to the arm actions during sprinting. This is an area where track sprinting and sprinting with changes of direction share the same principles. Both activities require decreased shoulder abduction angles in order to decrease the moment of inertia of the upper body. In track sprinting, this is done to keep the forces moving forward in the sagittal plane and not rotating in the transverse plane (Bushnell, 2004). With directional changes, these arm motions serve to produce a faster more efficient turn. Just as figure skaters can achieve a higher velocity spin when they bring their arms close to their body, it is suggested that field sport athletes can rotate through a cut faster if their arms are next to their torso (Brown and Vescovi, 2003). If the athlete had a high shoulder abduction angle during the turn, the mass of the upper body would be distributed further from the axis of rotation. This would result in a greater moment of inertia of the upper body and a greater resistance to angular motion. Therefore it would take longer to rotate the upper body in line with the new direction of travel.

Acceleration in the new direction should include arm motions similar to those of a sprint start. Shoulder abduction should be kept to a minimum to decrease the moment of inertia about the longitudinal axis, thus decreasing the forces required to cause rotation. The arm on the same side as the pushing leg should drive forward and remain flexed to 90° at the elbow. This will increase the ground reaction forces created in the opposite direction as the new direction of travel. The opposite arm should also be flexed to 90° at the elbow and hyperextend at the shoulder to stabilize the trunk.

The main difference between the track sprinter and the field sport athlete during the acceleration phase is the position of the head and neck. Track sprinters are taught to keep their gaze low through the acceleration phase of the start (Francis, 1997). In field or court sports the athlete must keep the head up at all times to see the surrounding action. The mantra of 'keep your head up' is prevalent through many team sports as it protects the athlete from unanticipated collisions and gives him or her an optimal view of the actions of the opponent.

Additionally, track sprinters strive to accelerate under control in order to reach their top speed only at the optimal point in the race. This is a tactical move to ensure they can avoid a marked decrease in speed due to fatigue and instead maintain their top speed through the finish (Francis, 1997). Team sport athletes seldom run for more than 30 meters at one time so fatigue during each individual drive is not an issue. Therefore, athletes will strive to reach their top speed in the shortest period of time possible. Elite sprinters also have a higher top speed which takes longer to achieve, thus increasing the acceleration phase. They also have the luxury of planning and strategizing their running pattern before the race begins. The agility athlete often does not preplan the short sprints as they occur randomly throughout competition therefore acceleration as fast as possible is desired in almost all situations (Francis, 1997).

Many sports require the athlete to carry or manipulate an implement while running (football, rugby, basketball, field hockey…). This will alter the athlete's stride technique as the arm drive will become unbalanced and less effective (Figure 2.23) (Sayers, 2000). Rugby athletes often carry the ball in front of their body, clenched in both hands. This eliminates the possibility of an arm drive in the sagittal plane and results in the arms and ball moving laterally across the body. In turn this increases trunk rotation in the transverse plane and decreases stride length and overall running speed (Grant et al., 2003). Another way of carrying a rugby ball or football is to cradle it in one arm between the hand and humerus. This allows some semblance of correct arm motions but limits the range of motion of the arm drive again resulting in a decreased running speed (Grant et al., 2003).

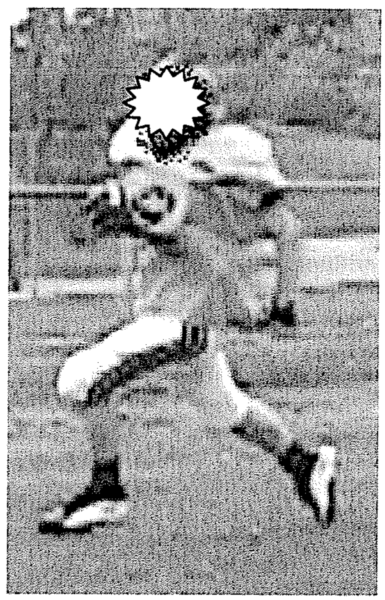


Figure 2.23: Carrying a ball and actions of the opponent decrease the effectiveness of the arm swing as the shoulder cannot go through the optimal range of motion.

Change of Direction Speed

Anecdotally, it may appear that straight sprinting and sprinting with changes of direction are closely related. However, the data to substantiate this assumption is inadequate. Draper and Lancaster (1985) reported a low to moderate correlation (r=0.472) between the Illinois Agility Test and a 20 meter sprint. In other words, those who did well on the 20 meter sprint test did not necessarily do well on the agility test.

Young et al. (1996) reported that as agility tests became more difficult by adding more and sharper turns or by requiring the athlete to dribble a soccer ball, the more drastically the skill differed from straight sprinting. This finding was in keeping with the author's hypothesis that straight sprinting and sprinting with directional changes are in fact quite different skills, requiring different neuromuscular coordination and different biomechanics. For example, a lowered centre of gravity and a more forward flexed trunk occurs during sprinting with directional changes.

Baker (1999) examined the difference between elite and amateur rugby players in terms of their straight sprinting and sprinting with directional changes. Although the study found that the two groups were similar in their straight sprinting, the elite athletes performed better in tests which included planned directional changes. This is in keeping with the hypothesis of Young et al. (1996)

With this evidence it can be firmly stated that straight sprinting is not closely related to sprinting with directional changes. More importantly, straight sprint training does not enhance performance in change of direction tests, as demonstrated by Young et al. (2001). The authors tested 36 men with experience in sports which involved cutting maneuvers in their ability to run a straight 30 m sprint as well as sprints with multiple directional changes. It was not specified whether or not the participants had experience cutting on grass while wearing cleats or indoors wearing running shoes. The tests were all conducted on a wooden floor with the participants wearing running shoes. The subjects were evaluated on their performance of seven different 30 meter sprints. Test 1 was a straight sprint while tests 2 through 7 involved multiple changes of direction, each increasing in the number of directional changes and in the complexity of cutting angles (Figure 2.24) (Young et al., 2001).

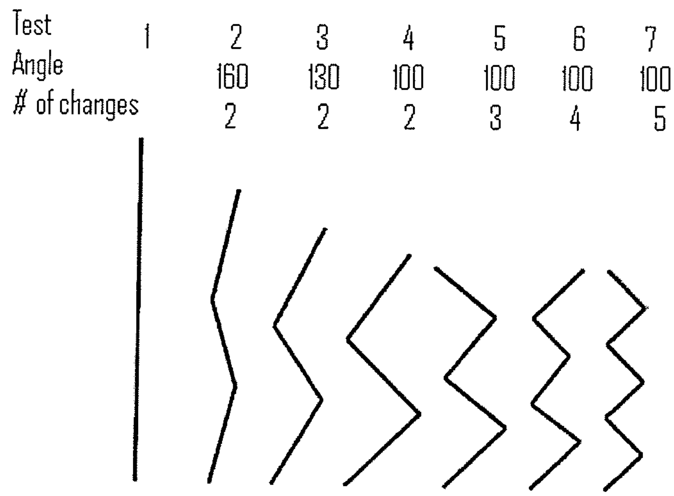


Figure 2.24: Description of seven 30 m tests (Young et al., 2001).

Following a pretest, athletes were separated into three groups: a sprint training group, an agility training group, and a control group. The training groups were required to participate in a six week training program in their respective discipline. Retest analysis indicated that participants of the straight sprint training group improved significantly in tests 1 and 2 only. There was slight improvement in tests 3-7 but improvement decreased as the directional changes became more complex. The reverse trend was apparent in the agility training group. This group showed significant improvement in tests 2-7 with the greatest improvement coming from tests 5-7 and diminishing improvements coming from the less complex tests. No improvement was seen in test 1.

The results of this study reinforce the fact that straight sprinting and sprinting with directional changes are two completely different skills. Young et al. (2001) claimed that the need to adopt a sideways lean in order to apply lateral forces to the ground in order to change direction at a high speed was a significant factor in the differences seen between the three groups. The directional changes also required athletes to make significant adjustments to their stride in order to decelerate and accelerate around the corners in the more complex tasks, (Young et al., 2001) however, the specific biomechanical differences observed were not recorded.

Another consideration pertinent to field and court sports is the execution of cutting maneuvers while manipulating an implement. Dribbling a basketball (Tsitskarsis et al., 2003) or bouncing an Australian Rules football (Young et al., 1996) increases the complexity and decreases its relationship with straight sprinting. Based on this finding, specific skill related tests could increase an athlete's cutting performance while manipulating an implement.

Lower body strength qualities and Change of Direction Speed

There is evidence in the literature that strength and power in the lower body has a positive relationship to straight sprinting performance (Blazevich, 1997; Sheppard, 2003). However, as outlined previously, straight sprinting and sprinting with changes of direction are distinctly different skills (Draper and Lancaster, 1985; Young et al., 1996). Therefore, one cannot extend the relationship between leg strength qualities and sprinting to performance in changing direction. A separate analysis of strength and muscle power in the lower body and its relationship to change of direction speed in skilled athletes is necessary.

Strength characteristics are distinguished using several different testing methods. Muscular strength and its relationship to cutting has traditionally been measured using loaded squat movements (Young et al., 1996) as well as an isokinetic squat (Negrete and Brophy, 2000). Leg power is measured using counter movement vertical jumps (Negrete and Brophy, 2000; Web and Lander, 1983; Young et al., 1996). The ability to utilize the stretch reflex mechanism efficiently is also important. In other words, it is important for an athlete to be able to change from an eccentric contraction to a concentric contraction very quickly. This is measured using depth jumps from various heights (Roozen, 2004; Young et al., 2002).

Young et al. (1996) found low correlations ($r=0.01$) between muscular strength and performance in a 20 meter sprint with 90° directional changes. When analyzed against the counter movement vertical jump, Young et al. (1996) also found low correlations ($r= -0.01$) between strength and change of direction speed. These results mimic Web and Lander's (1983) results which measured vertical jump and performance in an "L-run." Here too, the relationship between strength and change of direction speed was found to be non-significant. Therefore, based on these findings, it can be concluded that strength and power in the lower body may not be closely related to performance of a change of direction test.

Other agility tests

As mentioned earlier, the 505 agility test is one of many agility tests used in athletics. It can be thought of as the most basic of agility tests as it only includes one cut or change in direction, however, the cut is a full 180° turn making it the most complex single change in direction, as the athlete must come to a complete stop and accelerate from a stationary position. Most other agility tests involve running and shuffling patterns around cones or lines. Some tests are a certain length of time and performance is based on the number of repetitions performed (Wood, 2005). Other tests have the athlete run a certain pattern around the cones or lines with performance on the time to complete the task. These tests include the Illinois agility test, the T-test, the hexagon test and the 3 cone test.

The Illinois Agility test

The Illinois agility test, the T-test, the Pro agility test, and the Hexagon test are some of the usual agility tests used in the sporting world (Wood, 2005). The Illinois Agility test is very well known as a standard test in many sports. It involves running a complex pattern around cones involving 10 directional changes. The test is set up in a 5 by 10 meter rectangle. Inside the rectangle is a line of 4 cones each 3.3 meters apart. The athlete begins the test lying on the stomach with the nose on the starting line and hands on the ground. On the 'go' cue from the tester, the athlete zig-zags through the course as indicated in Figure 2.25 without knocking over any of the pylons. The tester starts a stopwatch at the word go and stops the stopwatch as the athlete crosses the finish line. The start and finish lines can be switched in order to vary the direction the athlete must turn (Wood, 2005).

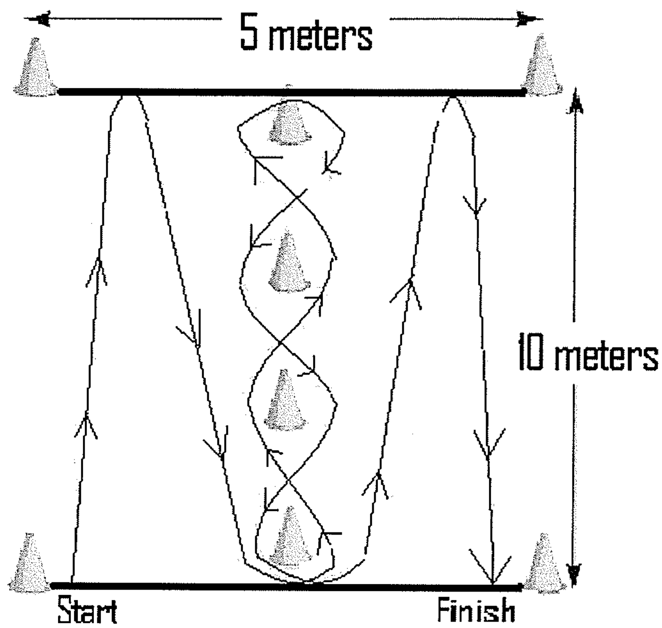


Figure 2.25: A diagram of the Illinois agility test (Wood, 2005).

The Illinois agility test is easily administered and requires very little equipment. Results can vary based on timing inconsistencies and can be overcome with the use of timing gates. Since it involves cutting in different directions and different angles it is a good measure of an athlete's overall agility. However, the tester cannot distinguish between the athlete's skill at each individual cut. Below is a list of norms for 16-19 year old athletes executing the drill on a gym floor. Wikipedia reports the world record for the Illinois agility test is Paul Jones of Australia with a time of 11.42 seconds.

Table 2.1: Norms for 16-19 year old athletes performing the Illinois agility test (Wood, 2005).

Gender	Excellent	Above Average	Average	Below Average	Poor
Male	<15.2 s	15.2 - 16.1 s	16.2 - 18.1 s	18.2 - 18.3 s	>18.3 s
Female	<17.0 s	17.0 - 17.9 s	18.0 - 21.7 s	21.8 - 23.0 s	>23.0 s

The T-Test

The T-test (Wood, 2005) tests an athlete's forward, lateral shuffling, and backwards movement. In this test, four cones are placed as illustrated in Figure 2.26. The athlete starts at cone A. On the command of the timer, the athlete sprints to cone B and touches the base of the cone with the right hand. The athlete then turns left and shuffle sideways to cone C, and also touches its base, this time with the left hand. Then the athlete shuffles sideways to the right to cone D and touches the base with the right hand. The athlete then shuffles back to cone B touching with the left hand, and runs backwards to cone A. The stopwatch is stopped as the athlete pass cone A (Wood, 2005).

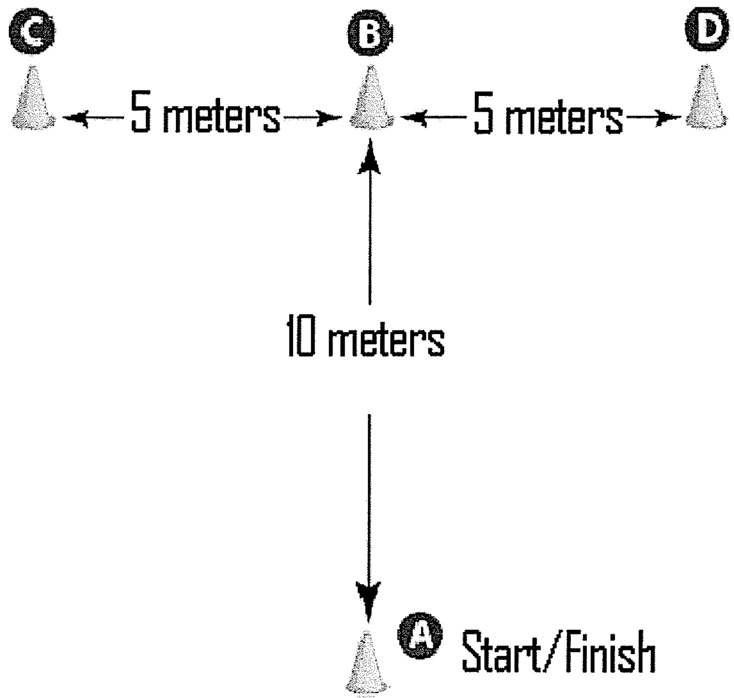


Figure 2.26: A diagram of the T-test for agility (Wood, 2005).

The trial will not be counted if the subject crosses one foot in front of the other while shuffling, fails to touch the base of the cones, or fails to face forward throughout the test. Generally, the test is conducted 3 times. The athlete's best time of three successful trials to the nearest 0.1 seconds is recorded. Table 2.2 reports scores for adult team sport athletes

Table 2.2: Norms for adult team sport athletes in the T-test for agility (Wood, 2005).

	Males (seconds)	*Females (seconds)*
Excellent	< 9.5	< 10.5
Good	9.5 to 10.5	10.5 to 11.5
Average	10.5 to 11.5	11.5 to 12.5
Poor	> 11.5	> 12.5

The Hexagon agility test

The aim of the Hexagon agility test is to test an athlete's ability to move short distances with maximum speed while maintaining balance (Wood, 2005). This test requires a hexagon shape marked out on the floor. The length of each side should be 60.5 cm, and each angle should work out to be 120 degrees. The athlete being tested starts with both feet together in the middle of the hexagon facing the front line. On the command 'go', they jump ahead across the line, then back over the same line into the middle of the hexagon. Then, continuing to face forward with feet together, jump over the next side and back into the hexagon. This pattern is continued until the athlete is back to the original position (Figure 2.27). This is counted as one revolution. The drill continues until the athlete has completed three full revolutions. In order to increase the accuracy of the test it should be completed both clockwise and counter clockwise and the athlete's average time recorded for further comparison (Wood, 2005).

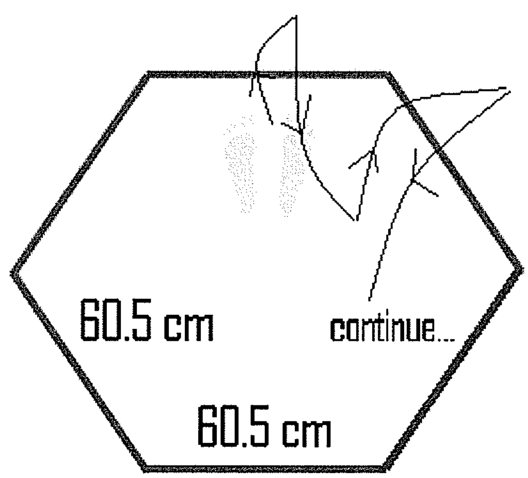


Figure 2.27: Diagram of the Hexagon agility test (Wood, 2005)

The test should be stopped and started over if the athlete commits any of the following faults: does not face forward throughout the duration of the test, the athlete jumps over the wrong line, the athlete lands on a line, the athlete gallops over the line (jumps without feet together), or the athlete loses balance. Table 2.3 lists normative values for 16-19 year old athletes (MacKenzie, 2004).

Table 2.3: Norms for 16-19 year old athletes performing the Hexagon test (MacKenzie, 2004).

Gender	Excellent	Above Average	Average	Below Average	Poor
Male	<11.2 s	11.2 - 13.3 s	13.4 - 15.5 s	15.6 - 17.8 s	>17.8 s
Female	<12.2 s	12.2 - 15.3 s	15.4 - 18.5 s	18.6 - 21.8 s	>21.8 s

The 3 cone shuttle drill

The 3 cone shuttle drill is incorporated in the NFL fitness testing and often simply called the NFL drill (Wood, 2005). This drill tests an athlete's 90° and 180° turning ability both to the right and to the left. Three marker cones are placed to form an "L." with a cone at the corner and at each end 5 meters apart (Figure 2.28). The athlete starts by getting down in a three-point stance next to cone #1. On the command 'Go', the athlete runs to cone #2, bends down and touches the base with the right hand. Then the athlete turns and runs back to cone #1, bends down and touches the base with the right hand. The athlete then runs back to cone #2 and around the outside of it, weaves inside and around cone #3 and makes a 90° cut at cone #2 before finishing at cone #1. The player must run forward around cone #3, as opposed to strictly stopping and starting in the opposite direction. The athlete is timed with the best performance out of two trials recorded as the athlete's score. Elite NFL athletes can complete this drill in about 6.6 seconds with some of the slower athletes requiring 8.3 seconds. (Bryant, 2006).

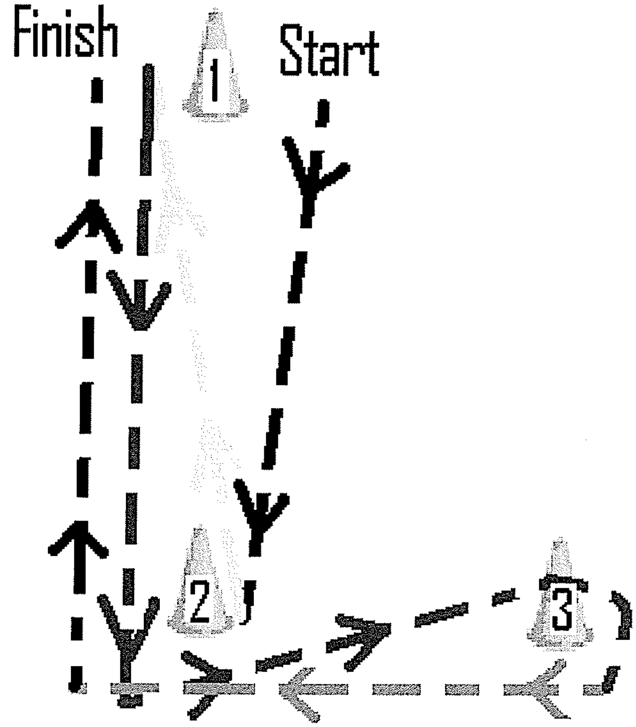


Figure 2.28: Diagram of the 3 cone drill. Note, the distance between the pylons is 5 meters (Wood, 2005).

The above descriptions outline some of the many tests used to measure agility in athletics. There are countless more tests employed by coaches around the world, some designed by individual coaches for their own personal use. Since agility tests often incorporate many turns of different angles and directions, they are difficult to analyze from a biomechanical point of view. Each change in direction would have to be addressed separately resulting in many, many variables. The 505 drill was not chosen for its ability to measure an athlete's overall agility, but rather as a gauge of an athlete's ability to perform a 180° cutting maneuver.

CHAPTER III

METHODS

Subjects

The subjects which participated in this study were healthy, male athletes with experience in a sport played with running shoes on a gym floor or experience in a sport played with cleats on grass. The participants had all participated at a high level in a sport that competed with either cleats on a grass surface or running shoes on a hardwood floor. This included, for example, participation on an inter-university soccer, basketball or volleyball team or a provincial ultimate frisbee team. A total of 24 athletes were filmed, 12 for each trial. The athletes were between the ages of 18 and 30. Before filming took place, the athletes signed a written informed consent form acknowledging their participation in this study and stating their agreement allowing the data to be used to analyze the skill. See sample consent form in the Appendix. None of the athletes were under the age of 18, therefore parental signatures were not required. It was made clear to the athletes that the study was voluntary and that any athlete may choose to end participation at any point during the testing session.

Filming Technique

Outdoor filming took place at the Canadian Mennonite University soccer field over three filming sessions in fall 2007. Indoor filming took place in the Canadian Mennonite University gym over two filming sessions in January 2008 as well as one session in the Investors Group Athletic Centre at the University of

Manitoba. A three camera set up was used to capture the actions of the athletes while in the testing zone of the 505 agility drill. All three cameras were Canon digital camcorders with built-in image stabilizers and manual camera set up options to increase the quality of the video. One Canon GL2 camera was set up approximately 8 meters in front of the turnaround point. This camera was used to analyze the athlete's motions in the frontal plane as well as actions performed during the rotational aspect of the skill (hip abduction, shoulder abduction, trunk rotation, etc.). The second Canon GL2 camera was set up approximately 10 meters to the side of the testing zone and perpendicular to the line of travel of the athlete. This camera captured motions in the sagittal plane. Linear and angular velocities of the athlete and limb segments (hip extension angular velocity, knee extension angular velocity, trunk flexion, etc.) were also calculated from this camera view. These cameras were secured on tripods to ensure their stability.

A third camera, the Canon Optura was suspended above the testing zone (Fig 3.2) and captured the movements of the athlete in the transverse plane (shoulder rotation, angle of foot plant). The Optura camera was attached to a pole, 3 meters in length, which was supported by a step ladder and controlled by a filming assistant. The overhead camera was connected to a Toshiba A100 laptop via a 4 to 4 pin fire wire. The laptop utilized the "In the Action" mode of Dartfish Team Pro 4.5.9 to provide live footage from the camera and ensure that the desired video footage was captured. Unfortunately, due to the unexpected extreme trunk lean of the indoor athletes, the overhead view did not capture trunk rotation in the transverse plane resulting in the elimination of three variables for the indoor group. These variables were: trunk rotation relative to the new direction of travel at jab step touchdown, trunk rotation relative to the new direction of travel at jab push off and range of motion of trunk rotation during the jab step. Due to the high velocity of the athlete's motions, the cameras had a shutter speed of $1/500^{th}$ of a second to eliminate blurring.

In conjunction with the video, Brower's Intermediate Beam timing gates (Draper, Utah, 2007) were utilized to increase the accuracy of measuring the athlete's time in the 5 meter testing zone. The timing gates began calculating the time when the subject crossed a sensor and counted the time until the subject crossed the sensor again. Results from the timing gates ensured accurate velocity measurements of the athlete's movement. Timing gates were not available for use during one indoor filming session. These athletes had their time recorded using the Dartfish timing tool. Accuracy was confirmed with side by side comparison of the video to athletes with timing gate data. The current author believes this confirmation was adequate to ensure accurate times for all athletes involved in this study.

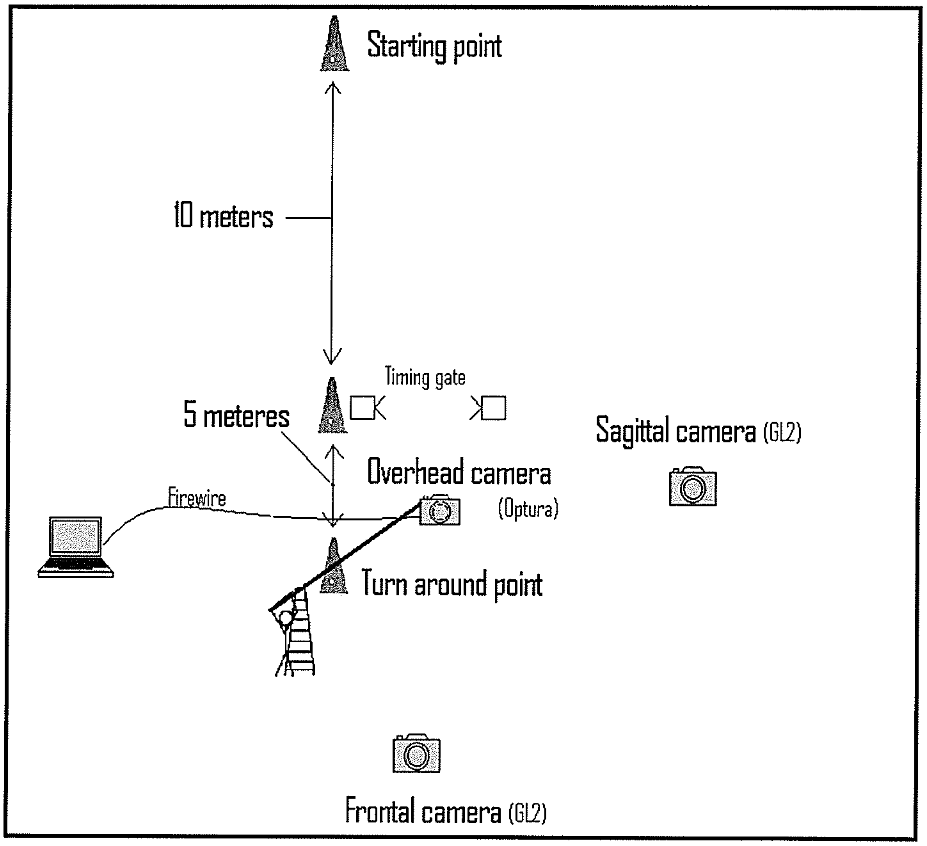


Figure 3.1: Overall set up of test conditions.

From these three camera views (frontal, sagittal, and transverse), the major joint angles and velocities were measured using the Analyzer mode available in the Dartfish Team Pro 4.5.9 software program. The Dartfish Analyzer mode allowed the investigator to make drawings on the film, compare different videos side by side, and advance the film frame by frame to pick out fine details of the athlete's performance.

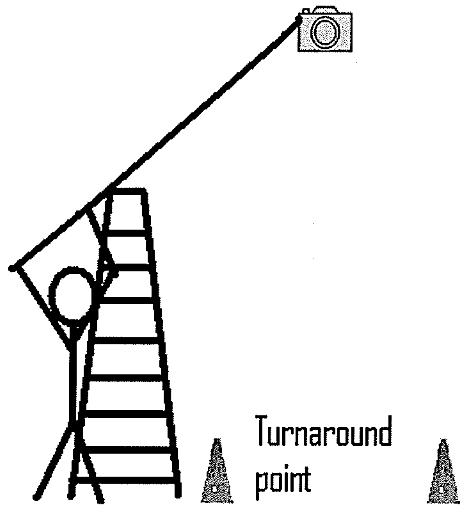


Figure 3.2: Diagram of the overhead camera. A step ladder was used to support the camera pole above the turnaround point.

Filming Protocol

The participants in the study were instructed to perform the 180° cut as they would normally in practice or during a game. Furthermore, each subject was instructed to attempt to pass through the testing area in the shortest period of time possible. Each subject was given 2-3 practice attempts to become familiar with the test protocol and to practice placing his jab foot on the desired turnaround location. Each athlete performed the test three times. The fastest testing time of each athlete was identified as the trial to be included in the study. The athletes were removed out of regular practice in groups of two to complete the test or a separate filming session was scheduled to ensure the inclusion of at least 12 athletes per group. Adequate rest was given in between trials to ensure fatigue did not affect the test results. Athletes began at the 15 meter mark and, at the investigator's command, ran to the zero mark (the turnaround point) and accelerated through the testing zone as fast as possible.

The athlete had completed a successful trial if they ran completely through the testing zone. If no part of the athlete's jab foot touched the turnaround line the test was deemed a failure and rerun. The sessions were conducted in succession to ensure camera set up, shutter speed, zoom, and focus remained the same for all trails.

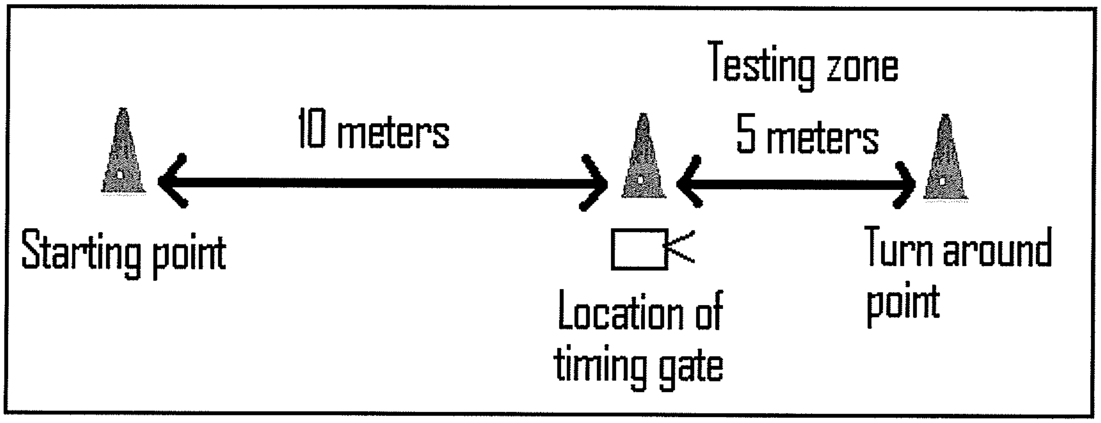


Figure 3.3: Pylon and timing gate orientation for the 505 agility test.

Digital Video Analysis

The footage obtained from all of the cameras for the best trial was imported into the Toshiba laptop computer using the Dartfish "In the Action" feature. Video analysis was used to collect quantitative data from the video comparing the techniques employed between the 180° cut outdoors wearing cleats and indoors wearing court shoes. The primary variables of interest were the time the athlete spent in the testing zone as well as instantaneous velocities of the athletes at 1, 2 and 3 meters from the turnaround point. The data gathered from the timing gates provided an accurate account of the athletes' time in the testing zone. The timing gates were not available for use during one indoor filming session. For the 4 athletes filmed during this session, the Dartfish Timing tool was used to determine the time to complete the test. Further, to ensure accuracy, an athlete with a similar time and timing gate results was placed next to the athletes with missing times using the Dartfish Side by Side function. This confirmed the accuracy of the Dartfish Timing tool. Dartfish software was used to determine the athletes' velocity at 1, 2 and 3 meters from the turnaround point. Several other variables, described in a later section, were also collected in order to create a biomechanical framework which was used to compare the cutting techniques employed by the two groups. These variables were also measured and analyzed using Dartfish software.

The Dartfish software (www.dartfish.com) includes a variety of tools which can be utilized to measure various distances and angles, and to create tables to measure velocities. As a result, critical joint angles and distances can be measured allowing for the calculation of angular and linear velocities.

All the collected video from the study was imported onto a Toshiba A100 laptop using the Dartfish "In the Action" setting. Importing allows the video to be played through a camcorder into the computer with the use of a 4 pin to 4 pin firewire. Once the video was imported, it was manipulated using the "Analyzer Mode." The "Analyzer Mode" contains, among other features, an angle drawing tool, distance tool, and data table which was used for all quantitative analyses. Drawing tools were also used for qualitative analysis to highlight key features of the athlete's performance. All critical joint angles were measured in addition to angular and linear velocities. Joint measurements were calculated as the joints deviation from anatomical position. See Figure 3.3 for examples of these measurements. The "Analyzer Mode" also allows the different camera views to be viewed at the same time through a split screen mode. This allows the frontal and sagittal views to be seen at the same time. Pictures of important points in the skill were taken using the "Dartfish Clipboard" feature in order to display differences in technique.

Additionally, the videos were synchronized using the "Dartfish Timeline" feature which allows the video to be synched up to the nearest 1/60th of a second. Once the video had been set up in the "Analyzer Mode", the video could be played frame by frame at 60 frames per second for a qualitative analysis.

Variables Analyzed

The key variables that were measured were taken from the beginning of the last step prior to placement of the jab step until the end of the push off phase of the 1st step after the jab step. This was to ensure that the kinematic data of the athlete's final deceleration and initial acceleration through the skill was captured. Analysis of the footage revealed the joint angles of the hip and knee of the touch down leg as well as the hip and knee extension of the push off leg for the last step leading up to the jab step and the first step following the jab step could be measured. The degrees of trunk and shoulder rotation at various points of the skill were also measured. All variables which were measured are included in Table 3.1.

Table 3.1: List of variables measured

Phase of the Skill	**Variables Measured**
Dependent Variable	➢ Time in testing zone (seconds) ➢
Touchdown of last step	➢ Trunk lean relative to vertical (degrees) ➢ Front hip flexion (degrees) ➢ Front knee flexion (degrees) ➢ Length of step (meters)
Jab step touch down	➢ Trunk lean relative to vertical (degrees) ➢ Trunk lateral flexion (degrees) ➢ Back knee flexion (degrees) ➢ Jab knee flexion (degrees) ➢ Jab hip flexion (degrees) ➢ Foot plant relative to direction of travel (degrees) ➢ Abduction of jab hip (degrees) ➢ Shoulder rotation relative to the direction of travel (degrees) * ➢ Length of last step (meters) ➢ Contralateral shoulder flexion (degrees) ➢ Contralateral shoulder abduction (degrees) ➢ Ipsilateral shoulder flexion(degrees) ➢ Ipsilateral shoulder abduction (degrees)
Max flexion of jab step	➢ Trunk lean relative to vertical (degrees) ➢ Trunk lateral flexion (degrees) ➢ Back knee flexion (degrees) ➢ Jab knee flexion (degrees) ➢ Jab hip flexion (degrees)
Jab step push off	➢ Trunk lean relative to vertical (degrees) ➢ Back knee flexion (degrees) ➢ Jab knee flexion (degrees) ➢ Back hip flexion (degrees) ➢ Jab hip flexion (degrees) ➢ Shoulder rotation relative to the direction of travel (degrees) * ➢ Shoulder range of motion during jab support time (degrees) * ➢ Support stance time (seconds) ➢ Contralateral shoulder flexion (degrees) ➢ Contralateral shoulder abduction (degrees)*** ➢ Ipsilateral shoulder flexion(degrees) ➢ Ipsilateral shoulder abduction (degrees)
Max flexion of 1st step	➢ Trunk lean relative to the vertical (degrees) ➢ Length of step(meters) ➢ Lateral distance of first step (meters)

	➢ Support knee flexion(degrees) ➢ Support hip flexion (degrees)
End of 1st step push	➢ Support hip flexion/extension (degrees) ➢ Support knee extension (degrees) ➢ Support ankle plantarflexion (degrees) ➢ Support stance time (seconds)
Angular Velocity	➢ Hip ext. velocity of jab push (degrees/s) ➢ Knee ext. velocity of jab push (degrees/s) ➢ Hip ext. velocity of first push (degrees/s) ➢ Knee ext. velocity of first push (degrees/s) ➢ Hip ext. velocity of second push (degrees/s) ➢ Knee ext. velocity of second push (degrees/s)
Additional variables	➢ Number of approach strides prior to jab step ➢ Hand / Ground contact during the cut ** ➢ Velocity 3 meters before turnaround point (m/s) ➢ Velocity 2 meters before turnaround point (m/s) ➢ Velocity 1 meter before turnaround point (m/s) ➢ Velocity 1 meter after turnaround point (m/s) ➢ Velocity 2 meters after turnaround point (m/s) ➢ Velocity 3 meters after turnaround point (m/s)
* Outdoor athletes only ** 1 = yes, 0 = no - Spearman's rank correlation and Chi squared tests were conducted as the variable was not continuous (Hassard, 1991). *** Some athletes adducted their shoulder placing their arm in front of their body. This made the measurement hidden from both camera angles. It was then recorded as 0° of abduction.	

Using the 180-degree system, all joint angles were measured using the Dartfish Team Pro 4.5.9 Analyzer angle tool. In anatomical position, according to the 180-degree system for measuring joint angles, all joints are in a position of zero degrees and any deviation from anatomical position was measured. Deviation from anatomical position in the posterior direction was referred to as hyperextension and labeled as negative flexion, i.e. 14.5° of shoulder hyperextension was labeled -14.5° of shoulder flexion. When measuring the position at the ankle, the 180-degree system considers a neutral ankle (perpendicular to the tibia) as the position of zero degrees and, therefore, any movement up or down was recorded as degrees of dorsiflexion or plantarflexion, respectively. Trunk rotation was measured through the use of the overhead camera. Rotation was measured as a change in position of the shoulder girdle relative to the horizontal line representing neutral (or perpendicular to the direction of travel). For the one categorical variable, ground/hand contact during the jab step, a "1" was assigned to the athlete if contact was made, and a "0" was assigned to the athlete if no contact was made. This is in keeping with methods outlined in Hassard (1991) in regards to categorical variables.

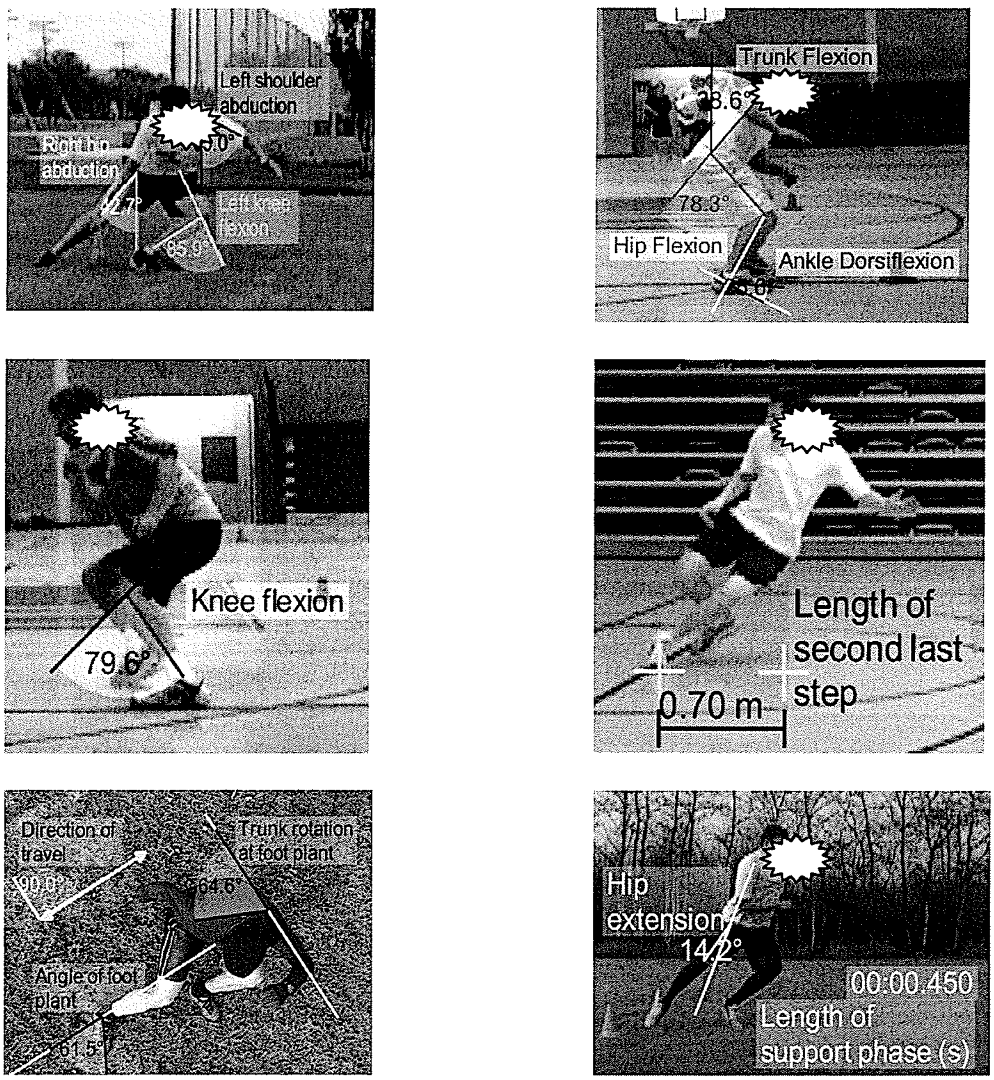


Figure 3.4: Examples of measurement variables and the use of Dartfish software.

Variables measured from maximum flexion of the stance phase until the end of the push off phase determine the range of motion experienced at each joint through the force producing phase of the skill. The Dartfish "data table" allowed for the calculation of angular velocities of the hip and knee during extension of the first two push off phases following the jab step. Angular velocities were measured by taking the range of angular displacement and dividing by the elapsed time; $\omega=\theta/t$.

Statistical Analysis

Means and standard deviations for each of the variables were calculated for the twelve subjects in each group. The variables for the two groups were compared using t-tests to determine if significant differences existed. This enabled the investigator to determine whether there were any kinematics difference between the two groups. T-tests were used to compare each individual variable to the specific variable of the other group. Since 56 t tests were performed the risk of a Type I error was high. Using a p value of 0.05, one test out 20 will be significant simply by chance. To combat this risk, a False Discovery Rate (FDR) correction was used to decrease the chance of finding significance when no significance existed (Narum, 2006) (Equation 3.1). By using the FDR correction, the p value is decreased in order to make for a more stringent test.

$$\alpha \Big/ \sum_{i=1}^{k} \left(1/i \right) \qquad \text{Equation 3.1.}$$

$\boldsymbol{\alpha} = 0.05$ $\boldsymbol{k}$ = number of comparisons $\boldsymbol{i}$ = the interval steps

With an example of 60 comparisons and an $\alpha = 0.05$, α is divided by the sum of $1/1 + 1/2 + 1/3 + 1/4 + 1/5 \ldots 1/60 = 0.05/ 4.6799 = 0.0108$. The most common correction to control for multiple tests is the Bonferroni correction. This was not used because as the number of tests increases, the risk of a Type II error increases with the use of a Bonferroni correction factor (Narum, 2006). In other words, when Bonferroni is used, you run the risk of not finding a significant difference when one exists because α becomes very small as the number of tests increases. With the example listed above, using a Bonferroni correction, the α would be determined by 0.05/60 and the project would have $\alpha = 0.0008$. An FDR correction is less stringent than a Bonferroni correction and therefore the study can maintain adequate power while still accounting for multiple tests.

Next, a Pearson's correlation analysis was conducted to determine if collinearity existed between any of the independent variables and the dependent variable of test time (Hassard, 1991). Collinearity refers to a high degree of correlation between two variables. For example, if athletes who display a large amount of trunk lean also tend to have lower test times then they are said to be collinear. In this case it would be a negative relationship because as one variable increases (trunk lean), the other variable decreases (test time).

The main goal of the study was to determine the technique variables which produce the best test time for the 505 drill indoors and outdoors. A forward stepwise multiple regression analysis was conducted in order to eliminate any variables which were not found to be significant predictors of test time. The forward stepwise multiple regression analysis provided a list of variables which were considered to be significant contributors to the dependent variable, test time (Hassard, 1991). During the first step, one variable was selected from the list of independent variables to determine which was the most significant predictor of test time. Once the first step was completed, all of the remaining independent variables were tested again against the dependent variable to determine which one had the next greatest contribution. The regression analysis continued this process until the list of independent variables no longer provided a significant contribution to the prediction of test time at which point an equation was produced showing all of the independent variables which were determined to be significant. The forward stepwise multiple regression analysis was conducted on the indoor and outdoor trials separately in order to determine which variables are considered significant contributors to test time indoors and which are considered significant contributors to test time outdoors.

Since regression analysis cannot distinguish collinearity, (Der and Everitt, 2006) not all variables were entered into the analysis. First, the investigator selected 20 variables for each group which were determined to be most important variables for the execution of the test. Next, a correlation matrix was created with these variables and each variable's resulting r values were summed. The variables with the largest sums of r values were eliminated. This served to eliminate variables which were highly correlated with other selected variables. A list of 11 variables was produced for the indoor group and a list of 10 variables was produced for the outdoor group, and the regression analysis was conducted on only these variables. This process of eliminating variables was determined by the investigator as any form of standardized variable elimination is cautioned against (Der and Everitt, 2006). Each study is different and therefore there is no acceptable uniform way to eliminate variables.

In order to ensure the researcher was capable of correctly utilizing the Dartfish software, a Reliability Test was conducted. This consisted of the researcher repeatedly measuring several variables of a randomly chosen subject over multiple days. The first set of measurements were taken in February, 2008, while the next four trials were conducted on: July 14, 16, 19 and 22 of 2008. Next, the different data sets were compared using an ANOVA test to determine whether there was a significant amount of 'between groups' variation. In other words, were the different data collection trials similar enough to ensure the data was consistent? Failure to find a significant difference meant that the researcher possessed adequate skill in consistently measuring variables using Dartfish software.

CHAPTER IV

RESULTS

Chapter four will describe the results of the statistical analysis and outline several key factors which were found to be important in a successful 180° cut at high speeds. The difference found between the indoor trials and the outdoor trials will also be outlined. The height, age and weight of the participants in the study are outlined in Table 4.1 below.

Table 4.1: Descriptive characteristics of subjects.

	Indoor Athletes N = 12				**Outdoor Athletes N = 12**			
	Mean ± SD		**Range**		**Mean ± SD**		**Range**	
Age (years)	21.50	1.56	19.00	24.00	24.60	3.90	20.00	30.00
Height (m)	1.85	0.03	1.80	1.90	1.80	0.05	1.70	1.90
Weight (kg)	82.23	3.99	75.00	88.60	79.30	6.84	70.40	93.40

Comparison of Means and Standard Deviations

One purpose of the study was to determine the difference between the indoor group and the outdoor group. The following section describes the means and standard deviations for the two groups in the study as well as the results of the independent t-tests which were performed. The False Discovery Rate correction was used to account for the performance of multiple tests yielding a p value of 0.0108 instead of 0.05. The section is broken down into the key phases of the skill that were highlighted in the methods section, beginning from the last step before the jab step until push off of the first step in the new direction. Additional linear and angular velocities were also analyzed.

Table 4.2: T-test comparisons of means and standard deviations of the test times for indoor and outdoor athletes (*$p \leq 0.00108$).

Variable	**Indoor Athletes n = 12**		**Outdoor Athletes n = 12**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Test time (s)	2.27	0.05	2.49	0.14	-4.78	**0.0001***
Time to max flexion of jab step (s)	1.01	0.07	1.18	0.09	4.99	**0.0001***
Percent of total time (%)	44.57	1.24	47.47	0.66	2.65	**0.01***

Table 4.2 outlines the differences between the two groups' time to complete the test. The mean time for the indoor athletes to complete the test was 2.27 seconds while the mean for the outdoor group to complete the test was 2.49 seconds. Also highlighted is the time to reach maximum flexion during the jab step. This was chosen as it will coincide with the furthest distance the athlete's centre of gravity will travel into the testing zone. Additionally, it should also coincide with the time during which the athlete's velocity reaches 0 m/s. The mean time for the indoor athletes to reach this point was 1.01 seconds whereas the mean time for the outdoor athlete's was 1.18 seconds. This time was then translated into a percentage of the athlete's total time to complete the test. If the percentage had been 50%, it would indicate that the athletes spent exactly the same amount of time decelerating into the cut as they did accelerating out of the cut. The mean value for the indoor athletes was 44.57% and the mean value for the outdoor athletes was 47.47%. This indicates that athletes

in both groups reached the zero point, or halfway location in the test prior 50% of their total test time. The test time and split time relationships are displayed graphically in Figure 4.1.

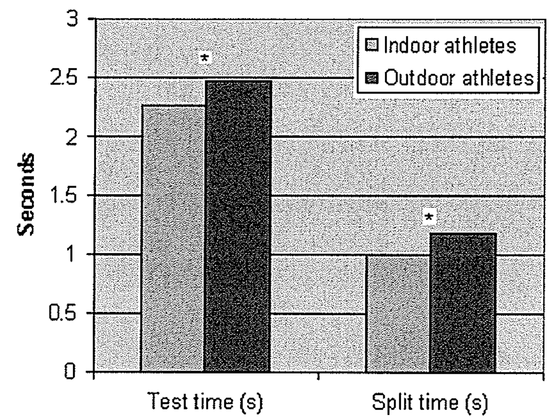
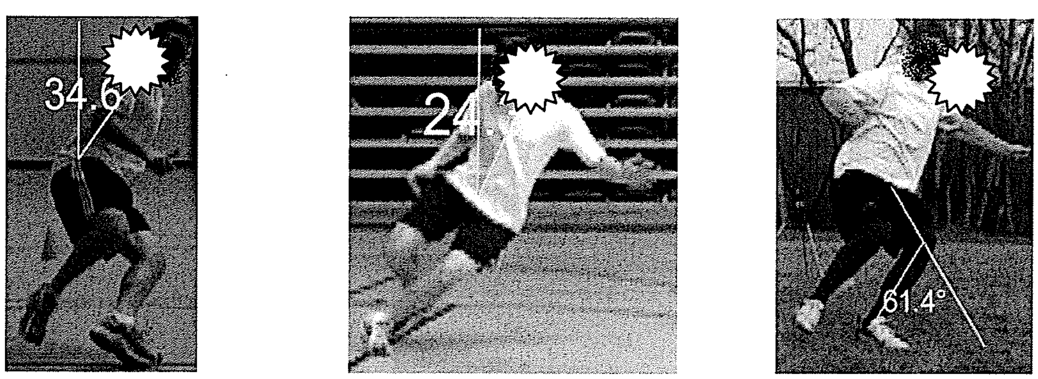


Figure 4.1: Comparison of the mean times to complete the test as well as the time to reach maximum flexion of the jab step (split time) (*p ≤ 0.0108).

Phase 1: Last step

In the last step, five variables were measured. The variables as well as the means and standard deviations for both the indoor and outdoor trials are presented in Table 4.3. Based on a p-value of 0.0108, none of the variables was shown to be significantly different.



Trunk forward flexion of 34.6° | Trunk lateral flexion of 24.3° | Knee flexion of 61.4°

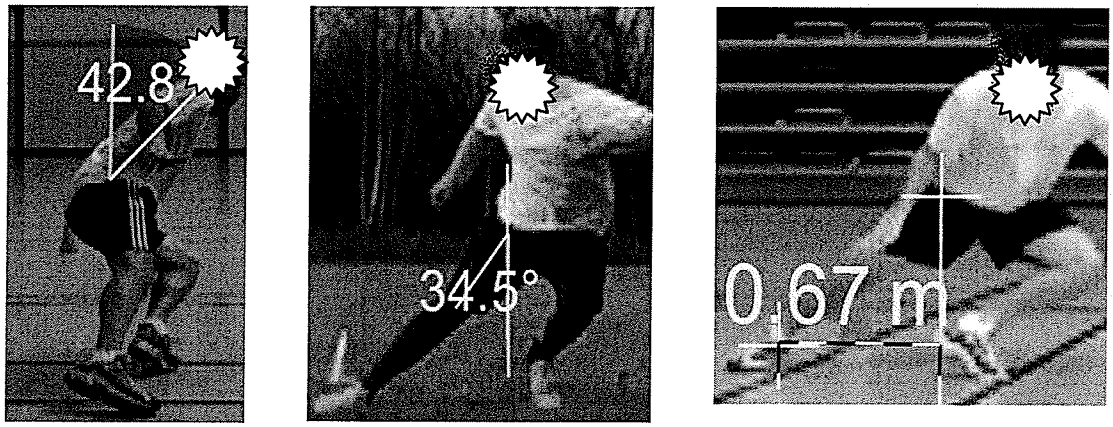
Figure 4.2: Three important variables measured during the last step before the jab step.

Table 4.3: T-test comparisons of means and standard deviations of the measured variables in the last step before the turnaround point (*p $\leq$ 0.0108).

Variable	Indoor Athletes n = 12		Outdoor Athletes n = 12		t-value	p-value
	Mean	SD	Mean	SD		
Trunk lateral flexion (deg)	-19.27	14.30	-18.00	10.53	-0.25	0.80
Contact knee flexion (deg)	71.83	21.19	71.19	20.95	0.07	0.90
Contact hip flexion (deg)	84.28	20.67	80.76	13.07	0.50	0.96
Length of step (m)	0.71	0.40	0.51	0.39	1.20	0.24
Forward trunk lean (deg)	39.17	14.69	24.18	19.30	2.15	0.04

Phase 2: Jab step touch down

At touch down of the jab step, thirteen variables were measured. Comparisons of the means for the measured variables are presented in Table 4.4. The variables which were calculated to be significantly different between the two groups were: trunk lean relative to the vertical, abduction of jab hip, lateral distance from jab hip to jab heel and ipsilateral shoulder flexion. The mean angle of trunk lean from the vertical for the indoor group was 50.58° while the mean angle of trunk lean for the outdoor group was only 27.85° (Figure 4.5).



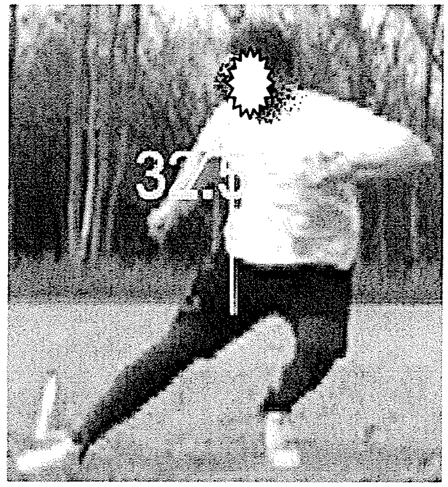
Forward trunk lean | Hip abduction | Lateral distance from hip to heel

Figure 4.3: Three significant variables measured at touchdown of the jab step.

The athlete's abduction of their jab hip was also found to be significantly different with a p-value of 0.002. The mean hip abduction angle for the indoor group was 18.88° and the mean hip abduction angle for the outdoor group was 38.02° (Figure 4.6). Similarly, the next significant variable was the lateral distance from the jab hip to the jab heel which had a p-value of 0.0002. The mean distance for the indoor group was 0.64 m whereas the mean distance for the outdoor group was only 0.55 m (Figure 4.7). Finally, the last variable that was significantly different between the two groups at touch down of the jab step was shoulder flexion on the ipsilateral side as the jab step (Figure 4.8). The indoor group had a mean shoulder flexion angle of 26.17° while the outdoor group had a mean flexion angle of -23.48° (Figure 4.7). The negative value indicates that the outdoor athletes generally hyperextended their shoulder back behind their body as opposed to flexing it forward in front of their body as was common for the indoor athletes.

Table 4.4: T-test comparisons of means and standard deviations of the measured variables at touchdown of the jab step (*$p \leq 0.0108$).

Variable	**Indoor Athletes n = 12**		**Outdoor Athletes n = 12**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Trunk lean relative to the vertical (deg)	50.58	19.25	27.85	14.36	3.28	**0.003***
Trunk lateral flexion (deg)	-24.52	19.46	-16.32	12.75	-1.22	0.24
Stopping knee flexion (deg)	107.95	12.54	95.03	18.59	1.10	0.28
Jab knee flexion (deg)	50.57	21.53	41.45	10.89	1.31	0.20
Jab hip flexion (deg)	78.89	18.88	63.10	18.07	2.10	0.047
Foot plant relative to the direction of travel (deg)	86.93	13.72	76.36	19.52	1.54	0.14
Abduction of jab hip (deg)	18.88	13.93	38.02	12.21	-3.58	**0.002***
Length of step (m)	0.69	0.14	0.70	0.20	-0.04	0.97
Lateral distance from jab hip to jab heel (m)	0.64	0.05	0.55	0.04	4.47	**0.0002***
Contralateral shoulder abduction (deg)	37.09	26.67	33.20	33.70	0.31	0.76
Contralateral shoulder flexion (deg)	26.44	27.87	36.68	27.79	-0.90	0.38
Ipsilateral shoulder abduction (deg)	16.45	15.67	34.41	38.52	-1.50	0.15
Ipsilateral shoulder flexion (deg)	26.17	43.61	-23.48	42.26	2.83	**0.001***



Abduction of the ipsilateral shoulder

Figure 4.4: Shoulder abduction was a significant variable measured at touchdown of the jab step.

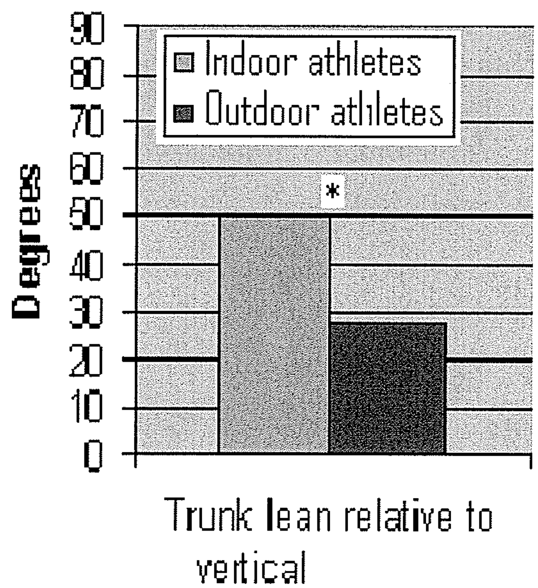


Figure 4.5: Comparison of the mean angles of trunk lean relative to the vertical indicating the significant difference between the two groups (*p ≤ 0.0108).

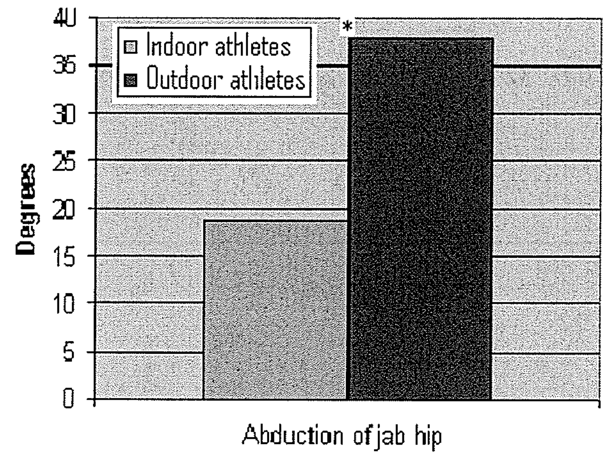


Figure 4.6: Comparison of the mean angles of abduction of the jab hip indicating the significant difference between the two groups (*p $\leq$ 0.0108).

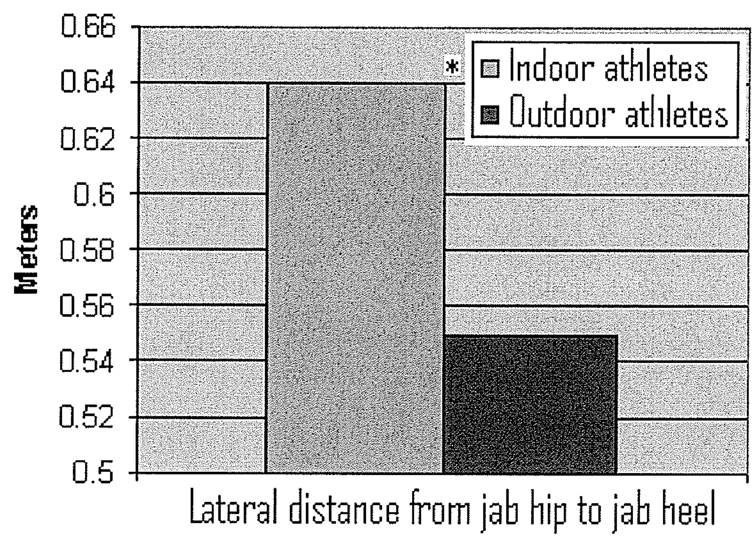


Figure 4.7: Comparison of the mean lateral distances from the jab hip to the jab heel indicating the significant difference between the two groups (*p $\leq$ 0.0108).

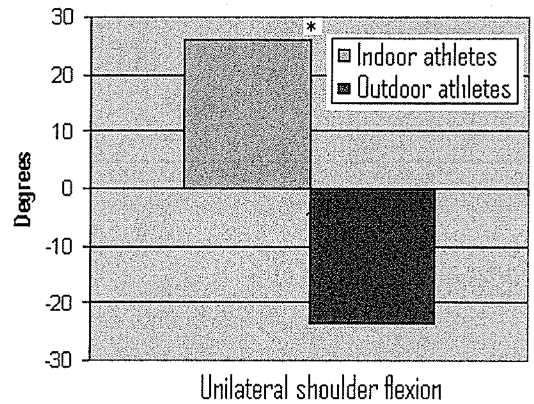
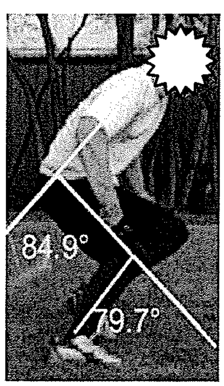


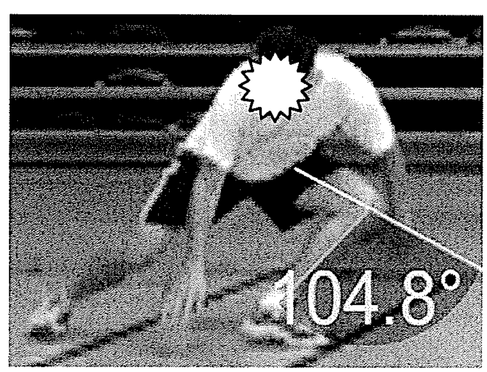
Figure 4.8: Comparison of the mean angles of shoulder flexion on the ipsilateral side to the jab step indicating the significant difference between the two groups (*$p \leq 0.0108$).

Phase 3: Maximum flexion of the jab step

Five variables were measured during maximum flexion of the jab step: forward trunk lean, trunk lateral flexion, stopping knee flexion, jab knee flexion and jab hip flexion. Of these five variables, only one was found to be significantly different between the indoor and outdoor groups (Table 4.5). Indoor athletes had a mean lateral flexion angle of -29.42° and outdoor athletes had a mean lateral flexion angle of -6.39° (Figure 4.10). The negative values recorded for lateral trunk flexion indicate that the athletes flexed away from the direction of the turn.



Hip and knee flexion



Stopping knee flexion

Figure 4.9: Two variables measured at flexion of the jab step.

Table 4.5: T-test comparisons of means and standard deviations of the measured variables during maximum flexion of the jab step (*$p \leq 0.0108$).

Variable	Indoor Athletes n = 12 Mean	SD	Outdoor Athletes n = 12 Mean	SD	t-value	p-value
Forward trunk lean (deg)	61.37	16.07	46.74	14.09	2.37	0.03
Trunk lateral flexion (deg)	-29.42	11.35	-6.39	26.88	-2.73	**0.01***
Stopping knee flexion (deg)	107.97	13.44	95.53	20.56	1.75	0.09
Jab knee flexion (deg)	64.58	25.08	70.92	8.60	-0.83	0.42
Jab hip flexion (deg)	88.04	22.10	87.82	17.25	0.03	0.98

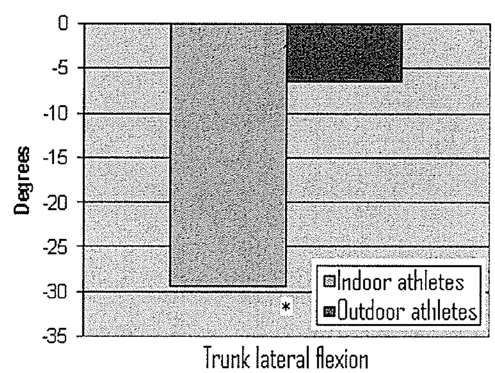
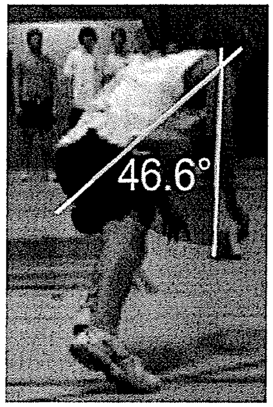


Figure 4.10: Comparison of the mean angles of trunk lateral flexion indicating the significant difference between the two groups. The negative value indicates that flexion is away from the jab step (*$p \leq 0.0108$).

Phase 4: Jab step push off

Ten variables were selected and compared at the push off of the jab step. Of these ten variables two were found to be significantly different between the indoor and outdoor trials. Trunk lean relative to the vertical and contralateral shoulder abduction and were significantly different with a $p \leq 0.0108$. Indoor athletes had a mean forward trunk lean of 57.3° whereas outdoor athletes had a mean forward trunk lean of only 38.7° (Figure 4.12).



Ipsilateral shoulder flexion

Contralateral shoulder abduction

Figure 4.11: Two variables measured at push off of the jab step.

Shoulder abduction of the contralateral limb to the jab step was seen to be highly significantly different with a p-value of 0.00015. Indoor athletes had a mean abduction angle of 19.84° while outdoor athletes demonstrated 29.37° of abduction in their shoulder (Figure 4.12).

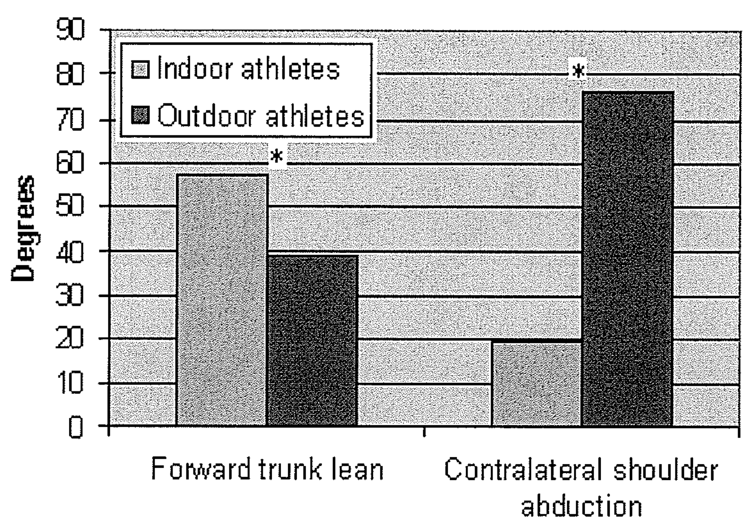


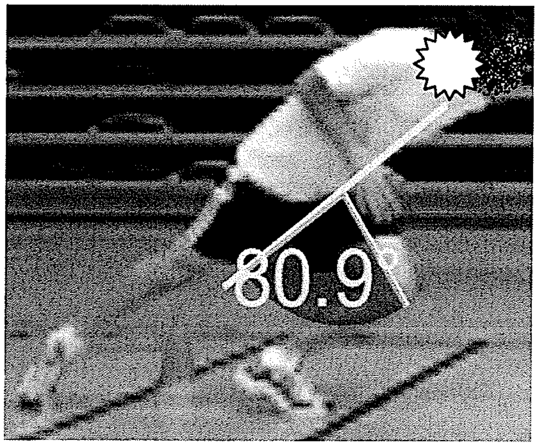
Figure 4.12: Comparison of the mean angles of trunk lateral flexion and shoulder abduction of the contralateral limb to the jab step (*p ≤ 0.0108).

Table 4.6: T-test comparisons of means and standard deviations of the measured variables at push off of the jab step (*p ≤ 0.0108).

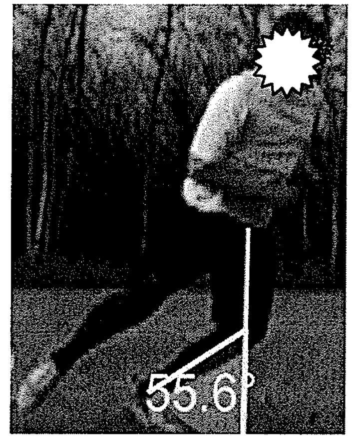
Variable	Indoor Athletes n = 12		Outdoor Athletes n = 12		t-value	p-value
	Mean	**SD**	**Mean**	**SD**		
Forward trunk lean (deg)	57.3	15.72	38.73	7.35	3.71	**0.001***
Stopping knee flexion (deg)	93.35	6.48	85.72	11.21	2.04	0.053
Jab knee flexion (deg)	27.21	11.36	26.38	11.05	0.18	0.86
Jab hip flexion (deg)	29.47	19.62	34.14	31.12	-0.44	0.66
Stopping hip flexion (deg)	86.57	14.60	75.38	26.58	1.28	0.21
Support stance time (s)	0.36	0.09	0.42	0.12	-1.68	0.10
Contralateral shoulder abduction (deg)	19.84	31.10	76.38	29.37	-4.58	**0.0001***
Ipsilateral shoulder abduction (deg)	27.35	26.69	23.68	27.98	0.33	0.74
Contralateral shoulder flexion (deg)	28.8	50.25	-16.54	46.09	2.30	0.03
Ipsilateral shoulder flexion (deg)	7.96	24.07	5.28	27.65	0.25	0.80

Phase 5: Maximum flexion of the first step

Five variables were measured during maximum flexion of the first step in the new direction. Of these five variables, three were found to be significantly different between the indoor and outdoor trials (Table 4.7). Trunk lean relative to the vertical, support knee and hip flexion were significantly different with a p ≤ 0.0108. Indoor athletes had a mean forward trunk lean of 58.74° whereas outdoor athletes had a mean forward trunk lean of only 39.41°, (Figure 4.13) which were significantly different.



Hip flexion



Knee flexion

Figure 4.13: Two variables measured at maximum flexion of the first step in the new direction.

Another significant difference was found in support knee flexion. Indoor athletes had a mean support knee flexion angle of 86.34° while outdoor athletes demonstrated 70.63° of flexion in their support knee (Figure 4.15). Hip flexion in the same limb was significantly different with a p-value of 0.0097. Indoor athletes had a mean hip flexion angle of 76.44° and outdoor athletes had a mean hip flexion angle of 55.43° (Figure 4.14).

The results from the comparison of this key position are in keeping with the second hypothesis of the project which states: "The athletes performing the skill inside demonstrate higher trunk lean and hip and knee flexion angles than their outdoor counterparts." Greater hip and knee flexion angles during the first step in the new direction will allow the indoor athletes more time and distance with which to apply force to the ground. This results in the application of a greater impulse on the ground and in turn a higher velocity as the athlete exits the testing zone.

Table 4.7: T-test comparisons of means and standard deviations of the measured variables at maximum flexion of the first step in the new direction (*p ≤ 0.0108).

Variable	**Indoor Athletes n = 12**		**Outdoor Athletes n = 12**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Forward trunk lean (deg)	58.74	15.77	39.42	11.74	3.40	**0.003***
Length of step (m)	0.70	0.13	0.76	0.19	-0.97	0.34
Lateral distance of the first step (m)	0.08	0.12	0.09	0.17	-0.26	0.80
Support knee flexion (deg)	86.34	11.73	70.63	14.14	2.96	**0.007***
Support hip flexion (deg)	76.44	16.31	55.43	19.88	2.83	**0.001***

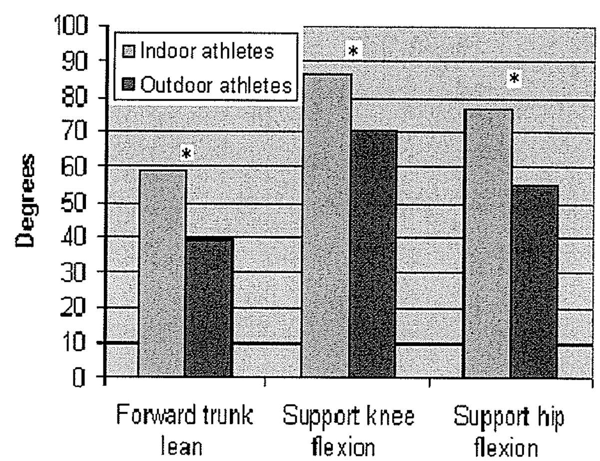
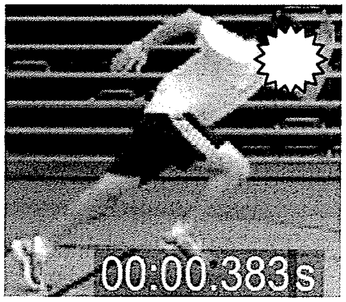


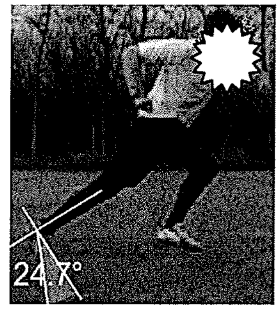
Figure 4.14: Comparison of forward trunk lean, support knee flexion and support hip flexion at maximum flexion of the first step in the new direction (*p ≤ 0.0108).

Phase 6: Push off of the first step

At the end of the first step, four variables were measured for indoor and outdoor groups. Two of these variables are shown in Figure 4.16. These were: support hip hyperextension, support knee flexion, support ankle plantarflexion and support stance time. The means and standard deviations are compared in Table 4.8. After t-tests were conducted, none of the variables were found to be significantly different between the indoor and outdoor trials.



Support stance time



Ankle plantarflexion

Figure 4.15: Two variables measured at push off of the first step in the new direction.

Table 4.8: T-test comparisons of means and standard deviations of the measured variables at push off of the first step in the new direction (*p ≤ 0.0108).

Variable	**Indoor Athletes n = 12**		**Outdoor Athletes n = 12**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Support hip hyperextension (deg)	21.46	10.17	22.28	23.53	-0.11	0.91
Support knee flexion (deg)	23.50	8.44	23.83	11.99	-0.08	0.94
Support ankle plantarflexion (deg)	34.01	9.03	32.58	7.88	0.41	0.69
Support stance time (s)	0.37	0.17	0.30	0.11	1.23	0.23

Phase 7: Linear velocity and additional variables

The linear velocity of the athletes in both groups was measured at one meter intervals prior to and after the turn in order to evaluate the athlete's deceleration and acceleration (Figure 4.16). The means, standard deviations and results from the t-test are outlined in Table 4.9. None of the measurements were found to be significantly different between the indoor and outdoor groups.

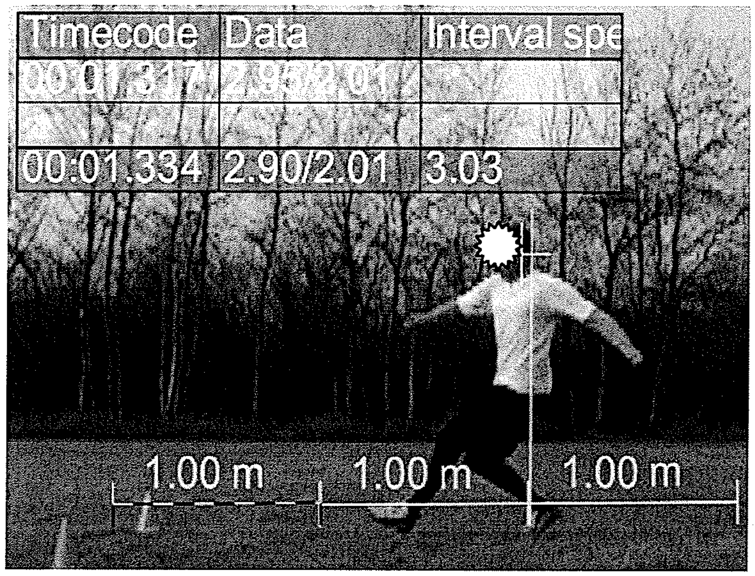


Figure 4.16: Linear velocity of 3.03 m/s measured at 2 meters from the turnaround point.

The number of ground contacts prior to the jab step was measured for the indoor and outdoor, however, a significant difference was not found between the groups. Hand/ground contact was also evaluated during the cut. The athletes were not instructed to touch or not touch the ground as they cut. Instead they were told to perform the cut as well as possible. In keeping with the style outlined in Hassard (1991), when dealing with categorical variables, a "1" was assigned to the athletes who contacted the ground with their hand and a "0" was assigned to the athletes who did not contact the ground with their hand. A Chi square test with a Yates correction was performed on the resulting data. Seven out of the indoor athletes touched the ground during the cut whereas only 2 of the outdoor athletes touched the ground during the cut. This was not a significant difference as the p value was only 0.025.

Table 4.9: T-test comparisons of means and standard deviations of the measured velocities in one meter intervals prior to and just after the turn (*$p \leq 0.0108$ was not found).

Variable	**Indoor Athletes n = 12**		**Outdoor Athletes n = 12**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Velocity 3 m prior to the turn (m/s)	5.42	0.42	4.87	1.07	1.67	0.11
Velocity 2 m prior to the turn (m/s)	4.41	0.40	4.26	0.65	0.69	0.50
Velocity 1 m prior to the turn (m/s)	2.64	0.79	2.75	0.78	-0.34	0.73
Velocity 1 m from to the turn (m/s)	2.05	0.72	2.35	0.61	-1.10	0.28
Velocity 2 m from to the turn (m/s)	3.75	0.54	3.39	0.68	1.43	0.17
Velocity 3 m from to the turn (m/s)	4.48	0.45	4.08	0.49	2.07	0.0503

Table 4.10: T-test comparisons of means and standard deviations of ground contacts prior to the jab step and hand/ground contact during the cut (*$p \leq 0.0108$).

Variable	**Indoor Athletes n = 12**		**Outdoor Athletes n = 12**		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Ground contacts prior to the jab step (#)	4.08	0.79	4.75	0.87	-1.97	0.06

Figure 4.17 is an extreme example of the different cutting styles between the indoor and outdoor groups. The athlete on the left has a very low centre of gravity with a high abduction angle at the jab hip and displays a high amount of trunk flexion which enable him to make ground contact with his hand. The athlete on the right has a high centre of gravity with a trunk that is still fairly upright thus making hand / ground contact impossible.

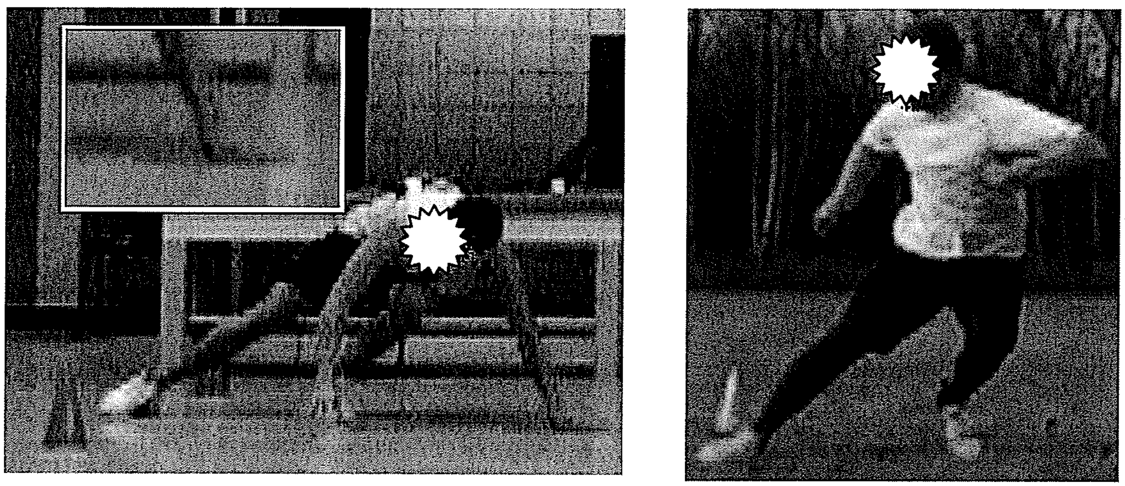


Figure 4.17: Differences in hand / ground contact between indoor and outdoor groups.

Phase 8: Angular velocity of hip/knee extension during propulsive phase

Hip and knee extension velocities were measured for the propulsive phase of the jab push off as well as the first and second steps in the new direction (Figure 4.18). The means, standard deviations and t-test results are displayed in Table 4.11. A significant difference between the groups was not found for any of the variables.

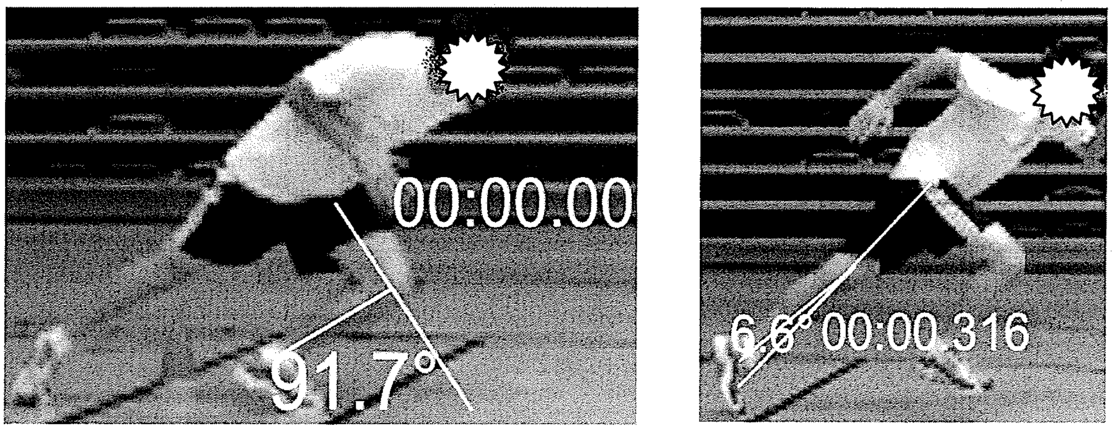


Figure 4.18: Knee extension angular velocity was calculated by dividing the range of motion at the knee by the time during which the motion occurred. This athlete demonstrates 85.1 degrees of knee extension over a period of 0.316 s. Therefore his knee extension angular velocity was 269.3 °/s.

Table 4.11: T-test comparisons of means and standard deviations of hip and knee extension velocities of the jab push off and first and second step in the new direction (*p ≤ 0.0108).

Variable	**Indoor Athletes** n = 12		**Outdoor Athletes** n = 12		**t-value**	**p-value**
	Mean	**SD**	**Mean**	**SD**		
Hip extension velocity of the jab push (°/s)	215.10	61.84	240.29	62.81	-0.99	0.33
Knee extension velocity of the jab push (°/s)	285.39	71.97	278.45	50.22	0.27	0.79
Hip extension velocity of the first step (°/s)	250.07	50.38	204.11	63.20	1.97	0.06
Knee extension velocity of the first step (°/s)	279.38	56.79	242.42	77.94	1.33	0.19
Hip extension velocity of the second step (°/s)	284.94	74.21	278.92	77.48	0.19	0.85
Knee extension velocity of the second step (°/s)	256.48	57.88	248.70	62.53	0.32	0.75

Kinematic Relationships of Performance Variable with Test Time

The main purpose of the study was to determine which variables were strongly related to the athlete's test time. A Pearson's product moment correlation analysis was performed for both the indoor and outdoor groups separately in order to determine which variables in each skill were significantly related to the athlete's test time. Upon completion of the correlation analysis, all of the variables were entered into a forward stepwise multiple regression equation, for the indoor and outdoor groups separately, in order to determine which variables had the strongest predictive effect on the athlete's test time.

Correlation Analysis for the Indoor Group

Table 4.12 shows 10 variables which have a significant correlation to the indoor group's test time at $p \leq 0.05$. The variables which were identified as having a significant relationship to test time were trunk forward lean during jab push off, trunk forward lean during flexion of the first step in the new direction, stopping knee flexion during jab touchdown, jab knee flexion during maximum flexion of the jab knee, trunk lateral flexion to the right during the last step, ipsilateral shoulder abduction during jab touchdown, trunk forward lean during the last step before the jab step, contact hip flexion during the last step before the jab step, ipsilateral shoulder abduction during the push off of the jab step and trunk lateral flexion at jab step touchdown.

Table 4.12: Variables which demonstrated the strongest correlation to test time for the indoor athletes *$p \leq 0.05$; ** $p \leq 0.005$.

	Correlation (Indoor Athletes)	
	n = 12	
Variable	r-value	p-value
Trunk forward lean during jab push off (deg)	- 0.887	0.001**
Trunk forward lean during flexion of first step (deg)	- 0.798	0.005**
Stopping knee flexion during jab TD (deg)	- 0.719	0.01*
Jab knee Flexion during max flexion of the Jab knee (deg)	+ 0.714	0.01*
Trunk lateral flexion during the last step (deg) (+ ipsilateral, - contralateral)	+ 0.696	0.01*
Ipsilateral shoulder abduction at jab TD (deg)	+ 0.690	0.01*
Trunk forward lean during last step (deg)	- 0.669	0.02*
Contact hip flexion during last step (deg)	- 0.668	0.02*
Ipsilateral shoulder abduction during jab push off (deg)	- 0.662	0.02*
Trunk lateral flexion at jab TD (deg)	+ 0.656	0.02*

The variable which showed the highest correlation to test time in indoor athletes was trunk forward lean during jab push off. This variable was found to have a negative correlation (-0.887) with the athlete's test time, meaning that the greater the athlete leans forward from the vertical as he pushes off with his jab leg, the less time it will take to complete the test. Trunk forward lean is also highly correlated right before and right after the turnaround point. That is, during the last step before the jab step ($r = -.669$, $p \leq .02$) as well as flexion of the first step in the new direction ($r = -.798$, $p \leq .005$). Both key positions also have a strong, negative correlation with test time. The proximity of these positions (last step before the jab step, jab push off and flexion of the first step in the new direction) likely resulted in the angle of trunk lean being significant in both cases. This emphasizes how important trunk lean is to test time as it is highly correlated at three key positions. Figure 4.19 represents the relationship at jab push off graphically.

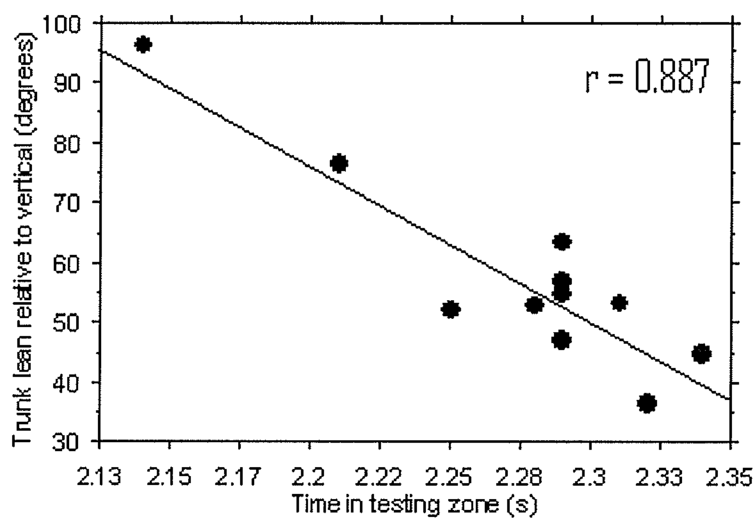


Figure 4.19: Relationship between test time of indoor athletes and trunk lean relative to the vertical at jab step push off ($r = -0.887$) ($p \leq 0.001$).

Stopping knee flexion during jab touchdown was also shown to have a strong, negative correlation to test time (-0.719). This indicates that greater knee flexion of the stopping or contralateral knee was associated with a decreased test time. This relationship was significant at $p \leq 0.01$ and is displayed graphically in Figure 4.20.

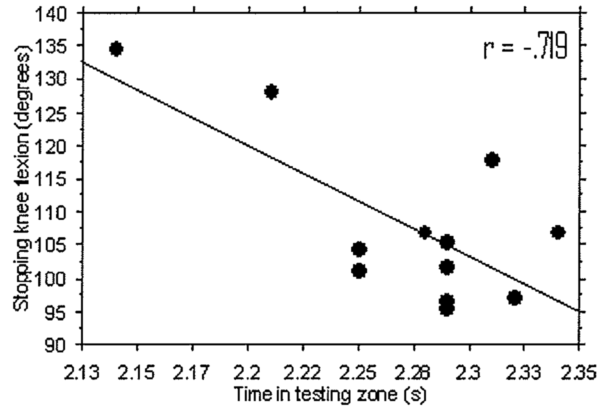


Figure 4.20: Relationship between stopping knee flexion during jab touchdown and test time for the indoor athletes (r = -0.719) ($p \leq 0.01$).

Interestingly, jab knee flexion during max flexion of the jab knee was shown to have a strong *positive* relationship with test time. This indicates that those athletes who did not achieve a large amount of knee flexion in their jab knee were associated with higher test times. This relationship was significant at $p \leq 0.01$ and is displayed graphically in Figure 4.21.

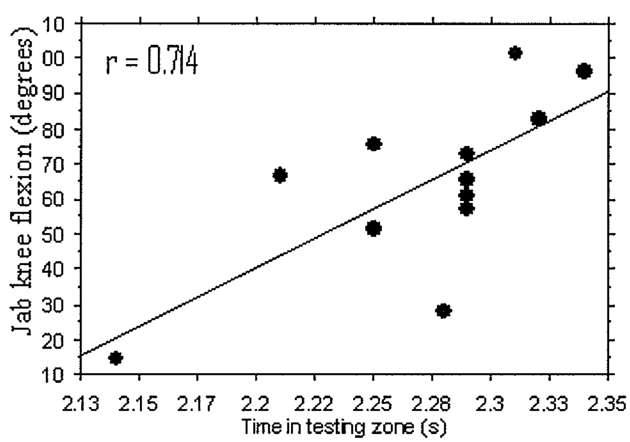


Figure 4.21: Relationship between jab knee flexion during max flexion of the jab knee and test time for the indoor athletes (r = +0.714) ($p \leq 0.01$).

Trunk lateral flexion in the ipsilateral direction to the jab during the last step before the jab step (side flexion away from the turn) was found to be significantly correlated to test time ($r = +0.696$) at a level of $p \leq .01$. This means that those athletes who turned left and had a high amount of lateral trunk lean to the left generally performed well in the test. This relationship is presented graphically in Figure 4.22. Additionally, contralateral trunk lateral flexion at jab touchdown was also found to be highly correlated with test time ($r = +0.696$) at a significance level of $p \leq .02$.

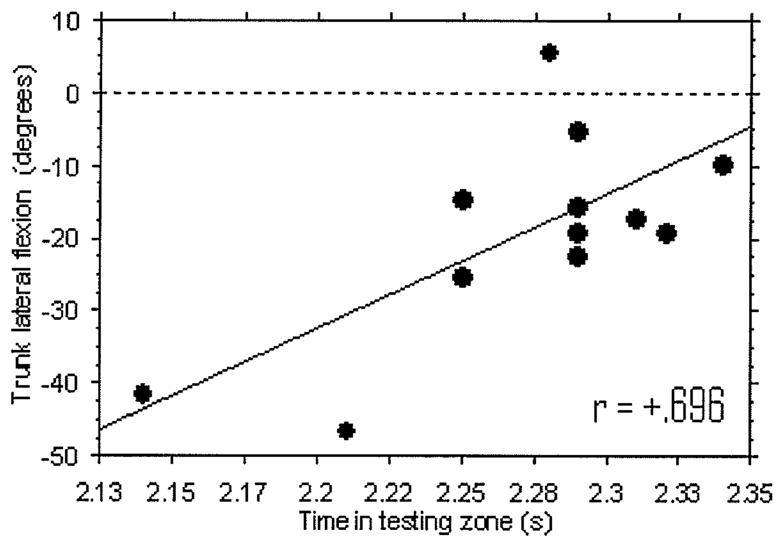


Figure 4.22: Relationship between trunk lateral flexion in the contralateral direction to the jab during the last step and test time ($r = +.696$) ($p \leq 0.01$).

Ipsilateral shoulder abduction at jab touchdown had a strong positive relationship with test time. Therefore, an athlete wishing to decrease his test time should also strive to decrease his shoulder abduction of the ipsilateral side to the jab at the beginning of the jab step. This relationship was significant at $p \leq .01$ and is represented graphically in Figure 4.23.

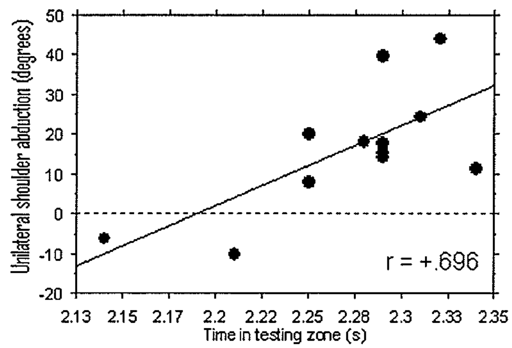


Figure 4.23: The relationship between ipsilateral shoulder abduction at jab touchdown and test time (r = +.696) ($p \leq .01$).

Contact hip flexion during the last step before the jab step was negatively correlated with test time (r = -.668) with a significance level of $p \leq .02$. This hip flexion will serve to lower the athlete's centre of gravity as he approaches the turn. Therefore, a greater amount of hip flexion of the contact leg is associated with a decreased test time. This relationship is presented graphically in Figure 4.24.

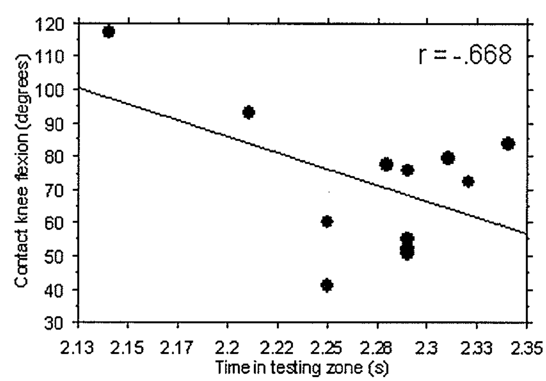


Figure 4.24: The relationship between contact hip flexion during the last step before the jab step and test time (r = -.668) ($p \leq .02$).

Correlation Analysis for the Outdoor Group

Following the correlation analysis of the indoor athletes, a correlation analysis was performed on the variables from the outdoor athletes in order to determine which variables were strongly correlated with the athlete's test time (Table 4.13). Ten variables were shown to be significantly correlated to the athlete's test time. The variable with the most significant relationship to test time was knee flexion of the jab leg at touchdown of the jab step. This variable had a strong, negative correlation (r = - 0.748) and was significant at $p \leq 0.005$, indicating that athletes which maintained a relatively *unflexed* knee during the jab step were also shown to perform well in the test (Figure 4.25). Other variables with a high correlation to test time were: linear velocity one meter before the turnaround point, the lateral distance from the jab hip to the jab heel at jab touchdown, support stance time of the jab foot and ipsilateral shoulder abduction at jab touchdown.

Table 4.13: Variables demonstrating the strongest correlation to test time for the outdoor athletes. (* $p \leq 0.05$) (** $p \leq 0.005$).

	Correlation (Outdoor Athletes) n = 12	
Variable	r-value	p-value
Jab knee flexion at jab TD (deg)	- 0.748	0.005**
Velocity one meter before turnaround point (m/s)	+ 0.703	0.01*
Distance from jab hip to jab heel at jab TD (m)	- 0.697	0.01*
Support stance time of the jab foot (s)	+ 0.562	0.05*
Ipsilateral shoulder abduction at jab TD (deg)	- 0.560	0.05*

The second most highly correlated variable with time for the outdoor athletes was their linear velocity one meter before the turnaround point. This was positively correlated with test time (r = +.703). This suggests the athletes that were able to decelerate most efficiently prior to the jab step were generally able to complete the test in the shortest amount of time. This relationship is significant at a level of $p \leq 0.01$ and is displayed graphically in Figure 4.26.

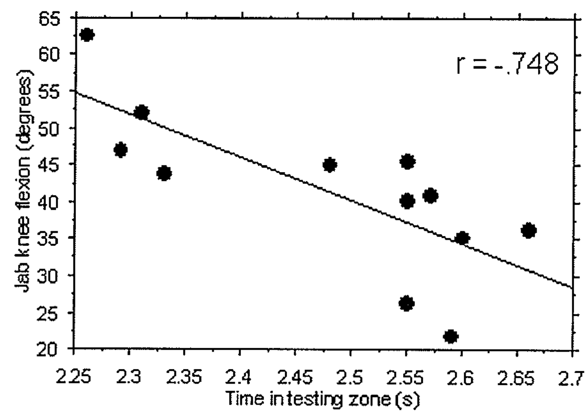


Figure 4.25: The relationship between jab knee flexion at jab step touchdown and test time ($p \leq 0.005$).

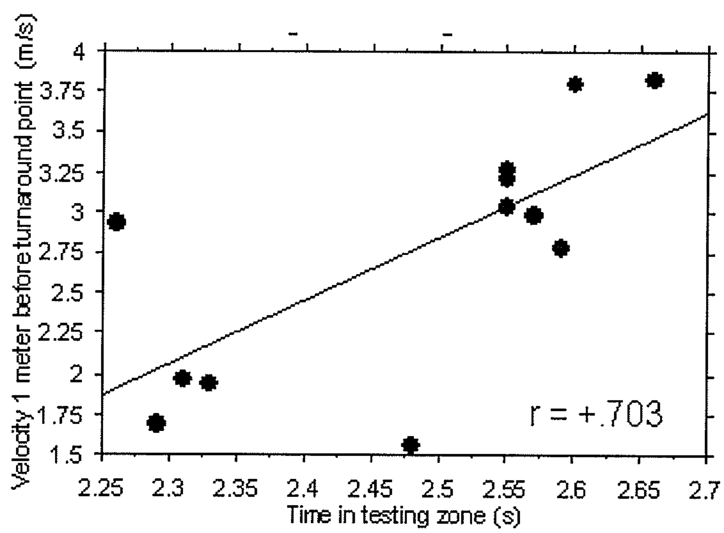


Figure 4.26: The relationship between test time and the athlete's linear velocity one meter prior to the turnaround point ($p \leq 0.01$).

The lateral distance from the athlete's jab hip to their jab heel at jab touchdown was negatively correlated with test time (r = -.697). This suggests that if the athlete can plant his jab foot further from his hip, he should be able to perform well on the test. This relationship is significant to a level of $p \leq 0.01$ and is presented visually in Figure 4.27

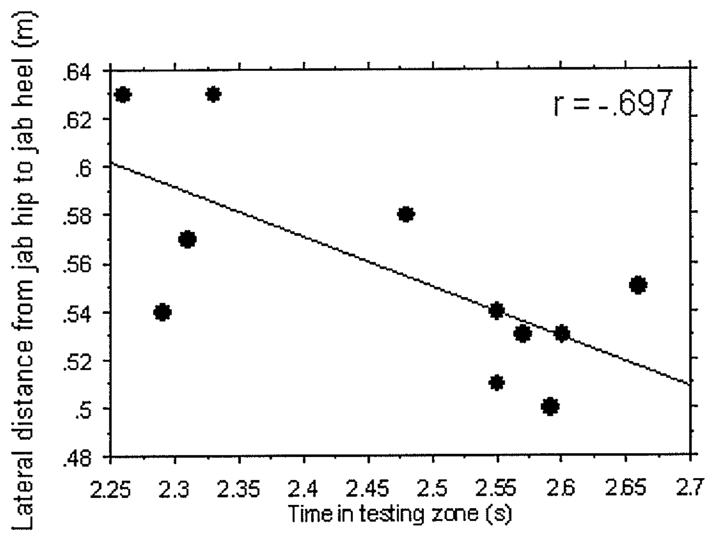


Figure 4.27: The relationship between test time and the lateral distance between the jab hip and the jab heel at jab TD ($p \leq 0.01$).

Another variable with a strong correlation to test time is support stance time of the jab foot ($r = +.562$). This is positively correlated with a significance level of $p \leq 0.05$ suggesting that a decreased support stance time will decrease the athletes test time. This relationship is presented graphically in Figure 4.28.

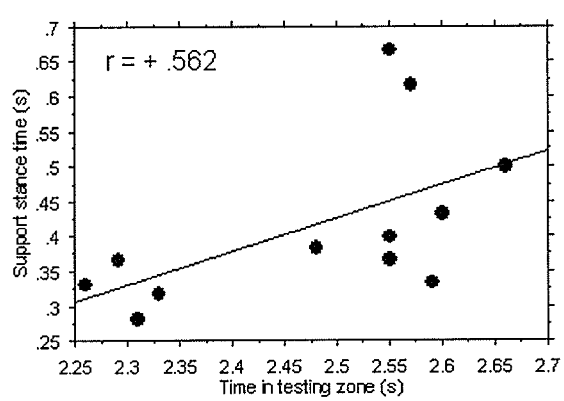


Figure 4.28: The relationship between support stance time of the jab foot and test time ($p \leq 0.05$).

The final variable which was significantly correlated to test time for the outdoor group was ipsilateral shoulder abduction at jab touchdown (r = -.560). This was significant at a level of $p \leq 0.05$ and is presented graphically in Figure 4.29.

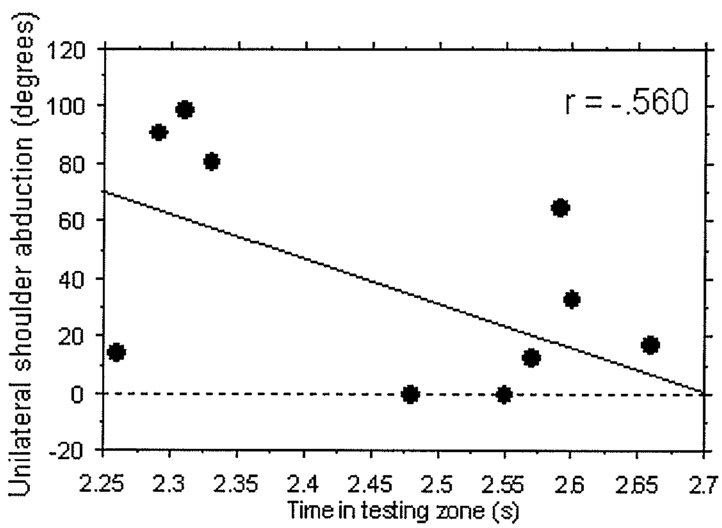


Figure 4.29: The relationship between ipsilateral shoulder abduction at jab step touchdown and test time ($p \leq 0.05$).

Stepwise Multiple Regression Analysis

The next step in the statistical analysis of the study was performing two separate stepwise multiple regression analyses on the indoor athletes and outdoor athletes in order to determine the effect of each variable on test time. Only 11 variables were entered into the regression analysis as it was recommended that fewer variables be entered into the analysis than there are subjects in the study. The indoor regression equation does not account for the variables relating to trunk rotation relative to the direction of travel (as measured by the overhead camera). It was found that subjects in the study displayed considerably more trunk lean than those in the pilot study and therefore the measurements could not be taken accurately by the overhead camera.

Regression Equation for the Indoor Group

Regression analysis of the indoor athletes identified four variables, trunk lean relative to the vertical at push off the jab step, hip extension velocity of the jab step push, jab knee flexion at maximum flexion of the jab knee and trunk lateral flexion during the last step before the jab step. These variables could account for 95.7% of the variation in test time and are shown in Table 4.14.

Table 4.14: Summary of the variables which were selected by the stepwise multiple regression analysis for the indoor athletes.

Variables	Coefficient	Std. Error	Std. Coefficient	F
Trunk lean relative to the vertical (jab step push off)	-0.001	0.001	-0.253	1.74
Hip extension velocity (jab step push off)	-0.00016	0.000077	-0.179	4.14
Jab knee flexion (maximum flexion of the jab knee)	0.001	0.00028	0.533	16.71
Trunk lateral flexion (last step before jab step TD)	0.002	0.01	0.416	6.45

The four variables identified in Table 4.14 explain test time to an $r^2 = 0.957$. The regression equation for the prediction of test time is expressed in Figure 4.31.

Regression equation for indoor athletes:

$$y = 2.311 - 0.001x_1 - 0.00016x_2 + 0.001x_3 + 0.002x_4$$

Where: y = test time

Intercept = 2.311

x_1 = Trunk lean relative to the vertical (jab step push off)

x_2 = Hip extension velocity (jab step push off)

x_3 = Jab knee flexion (maximum flexion of the jab knee)

x_4 = Trunk lateral flexion (last step before jab step TD)

Figure 4.30: Regression equation for indoor athlete's test time.

This equation was found to be accurate in predicting test time for indoor athletes. Indoor athlete #1 had a test time of 2.25 s. When the selected variables were entered into the equation for indoor athlete #1 the resulting test time was found to be 2.21 s.

Regression Equation for the Outdoor Group

Regression analysis of the outdoor athletes also identified four variables, linear velocity of the athlete one meter before the turnaround point, linear velocity of the athlete one meter after the turn around point, hip extension velocity of the jab step and support stance time of the jab step. However, only 88.8% of the variation in test time in the outdoor athletes is accounted for. The four variables are shown in Table 4.15 and the regression equation is displayed in Figure 4.31.

Table 4.15: Summary of the variables which were selected by the stepwise multiple regression analysis for the outdoor athlete.

Variables	Coefficient	Std. Error	Std. Coefficient	F
Linear velocity one meter before the turn	0.092	0.027	0.514	12.059
Linear velocity one meter after the turn	0.124	0.032	0.537	15.386
Hip extension velocity of the jab push	-0.001	0.00031	-0.461	11.413
Support stance time of the jab step.	0.349	0.174	0.298	4.017

The four variables identified in Table 4.15 explain test time to an $r^2 = 0.888$.

The regression equation for the prediction of test time is expressed in Figure 4.32.

Regression equation for outdoor athletes:

$$y = 2.036 + 0.092x_1 + 0.124x_2 - 0.001x_3 + 0.349x_4$$

Where: y = test time

Intercept = 2.036

x_1 = Linear velocity one meter before the turn.

x_2 = Linear velocity one meter after the turn.

x_3 = Hip extension velocity of the jab push.

x_4 = Support stance time of the jab step.

Figure 4.31: Regression equation to outdoor athlete's test time.

This regression equation was found to be an accurate equation for the prediction of outdoor athletes test times. Outdoor athlete #1 had a test time of 2.31 s. When the selected variables for outdoor athlete #1 were entered into the equation the predicted test time was also 2.31 s.

Reliability Test

In order to test the reliability of the investigators ability to measure variables using Dartfish video analysis software, nine variables for one athlete were selected and measured repeatedly over several days. The first trial was conducted in February, 2008, while the next four trials were conducted on: July 14, 16, 19 and 22 of 2008.

Based on the ANOVA test conducted on the collected data it can be concluded that there is no significant difference between the different testing times (Table 4.16 and 4.17).

Table 4.16: Results of the reliability test.

Variable	Mean	S.D.	Minimum	Maximum	Range
Last step TD					
Trunk lateral flexion	-14.86	0.59	-15.70	-14.10	1.60
Contact knee Flexion	61.86	1.03	60.40	63.00	2.60
Contact hip flexion	73.54	0.93	72.30	74.50	2.20
Length of step	0.24	0.01	0.23	0.24	0.01
Trunk lean	33.32	1.11	32.10	34.80	2.70
Fist step push					
Stopping hip extension	21.54	0.90	20.10	22.50	2.40
Support knee flexion	30.00	1.23	28.20	31.40	3.20
Support ankle plantarflexion	28.24	0.90	27.00	29.10	2.10
Support stance time	0.36	0.00	0.36	0.37	0.01

Table 4.17: ANOVA table for reliability test

Sum of Variance	Sum of Squares	Degrees of freedom	Mean Squares	F
Between	2.279	4	0.57	0.000913
Error	2.495	40	623.80	
Total	4.774	44		

When the determined F value was compared to a table of significant F values using 4 and 40 degrees of freedom (Hassard, 1991), it can be concluded that there is no significant difference between the testing trials and that any variation is simply a matter of chance.

CHAPTER V

DISCUSSION

Introduction

The 505 drill performed indoors and outdoors are skills which require controlled movements, power and superior technique; however, due to the differences in playing surface it is probable that differences in technique may occur. The purpose of this study was to determine the most effective body movements and body positions to perform the fastest 505 drill indoors and the fastest 505 drill outdoors for male athletes. Emphasis was placed on determining the key kinematic variables which are associated with minimizing test time. It is important to identify which variables play an important role in determining test time in order to determine which variables should be emphasized when teaching this cut to developing athletes or in coaching it with more advanced athletes.

This study analyzed the last step before the jab step, touchdown of the jab step, maximum knee flexion of the jab step, push off of the jab step and the first step in the new direction. Additional variables such as the linear velocity of the athlete at different points during the test as well as angular velocities of the athlete's hip and knee extension were also analyzed through the use of Dartfish 4.5.2 video analysis software. Following the measurement of variables, statistical analysis was performed in order to determine which variables differed between the two groups, which variables were strongly correlated to the athlete's test time for the two groups separately, and which variables were determined to be the best predictors of test time for each of the two groups separately.

Test time

The difference in average test time between the indoor group and the outdoor group was 0.22 seconds. This was significantly different, especially when the range of test times is examined, 0.2 seconds for the indoor group and 0.4 seconds for the outdoor group. The investigator did not foresee such a large difference in test times and therefore did not include this variable in the hypothesis. Based on the increased coefficient of friction between grass and cleats, the assumption was that the outdoor group would be able to perform the test faster than the indoor group as they would have been able to apply more lateral force to the ground without the risk of slipping. The indoor group however, made use of the decreased coefficient of friction by allowing their jab foot to skid across the turnaround point in a controlled manner. They were, therefore, able to keep their center of gravity further from the turnaround point than the indoor group by increasing their trunk lean away from the jab foot. This served to decrease the total linear distance covered by their centre of gravity. With this in mind, it can be seen that, despite similar linear velocities between the groups, the indoor groups traveled a shorter distance and therefore completed the drill in a shorter time.

To the experienced athlete, however, this should not make a difference in a game situation but is simply a reality of the different situations. When playing defense against another athlete the feet of the opponent are generally not the concern of the defender. Rather, an athlete will watch his opponent's torso position in order to anticipate a directional change (Sheppard et al., 2006). In other words, it will be the displacement of their center of gravity which will measure the quality of their directional change and not the linear distance that their feet travel. With more advanced tools, the researcher may have been able to design a test which more accurately measured the movements of an athlete's centre of gravity. Such a test would have had more specific sport applications, but would have required more advanced technology than was available. With this in mind, it can be seen that despite the decreased test time of the indoor athletes, the overall effectiveness of a cut performed indoors versus a cut performed outdoors may not differ.

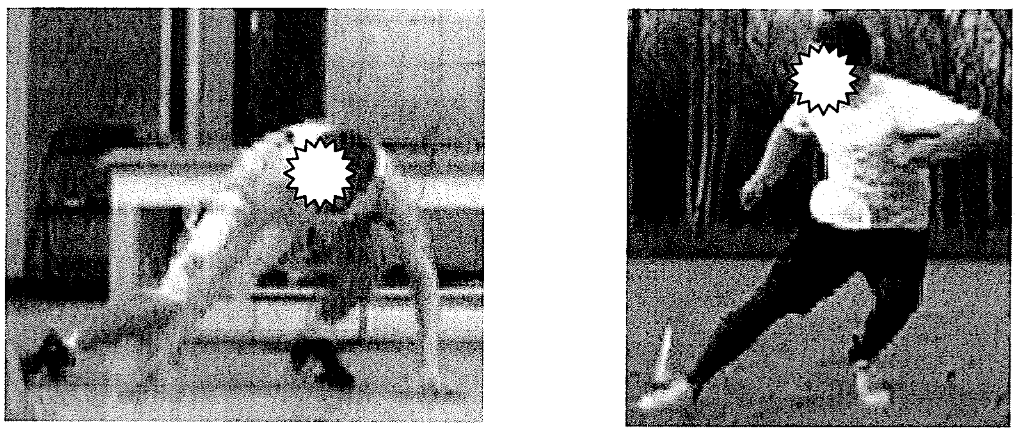


Figure 5.1: The indoor athlete on the left has used a controlled skid and an increased body lean.

Last step

By the time the athlete reached the last step prior to the jab step he will have already begun to rotate his hips and shoulders up to about 90° away from the direction of travel (Goodman, 2008). In turn, foot plant of the last step before the jab step is placed almost 90° from the direction of travel (Figure 5.1). In terms of deceleration of the body, this is not an ideal position from which the athlete can apply force to the ground. The investigator believes that much of the eccentric force will come from the hip abductors with minimal contribution coming from the hip and knee extensors.

Additionally, more of the force will be taken up by the ligaments of the hip and knee (Goodman, 2008). However, if athletes were to lean away from the cut they might also be able to utilize their strong hip and knee extensors as well to help control the eccentric contraction during deceleration rather than primarily just their hip adductors.[1] With a low laterally flexed trunk position, the athlete can flex at the hip and knee and 'crumple' in opposition to the forward momentum (Figure 5.2). From an upright position, flexion at the hip and knee will serve to lower the athlete's centre of gravity which will aid in deceleration, but will not directly resist the athlete's forward momentum. Additional research conducted using electromyography technology on athletes performing the 180° cut would be required to confirm this assumption. Such a study would be able to estimate muscle activation intensity and timing during the cut.

Currently, no studies could be found that examined the role of the hip adductor muscles during change of direction maneuvers or side shuffling locomotion. Most electromyographical research conducted on the hip adductor muscles have examined the muscles of the hip and knee during forward walking (Lee and Hilder, 2008; Lyons et al., 1983), or running (Mann et al., 1986). Lee and Hilder as well as Lyons et al. found that the hip adductors were most active during loading response in forward walking. The loading response phase of the walking cycle is the time period between initial contact of the heel until contralateral toe off (Nordin and Frankel, 2001). This phase does not have an equivalent phase during cutting or side shuffling as the lateral

[1] It is assumed that the muscles used in hip adduction would eccentrically control this forced abduction based on their orientation in the body. The adductor magnus and, adductor longus are the primary muscles acting during hip adduction as they have origins on the inferior ramus of the pubis and the body of the pubis. They insert primarily on the medial surface of the femur along the pectineal line and linea aspera. The adductor brevis, pectineus and gracilis muscles also aid in hip adduction.

portion of the foot tends to contact the ground first rather than the heel. Mann et al. (1986) found that the adductor longus muscle showed minimal activity during forward jogging, running or sprinting. The main difference between forward ambulation and cutting or side shuffling is the plane in which the hip joint acts. During walking and running, the hip moves primarily through the sagittal plane about the left right axis. At touchdown of the stopping foot during the 180° cut, the athlete's body has rotated approximately 90° to the direction of travel placing the action of the hip in the frontal plane. Hip abduction and adduction occurs in the frontal plane about the anterior posterior axis making it difficult to apply the conclusions of the previously mentioned studies to the current investigation.

This is in keeping with a study conducted by Young et al. (2001) in which athletes were instructed to run a zig zag pattern. Those athletes who achieved the highest scores on the test also had the tendency to lean to the side as they completed the cut. Young speculated that the benefit of the increased lean was that it allowed the athletes to apply forces to the ground in a more horizontal direction. Rotation away from the direction of travel will also stress the stabilizing muscles of the trunk a great deal (Baker 1999). If the athlete is turning left (Figure 5.2), he will use primarily the left internal obliques and the right external obliques to initiate this action. These muscles must be adequately strengthened for the athlete to make this rotation as fast as possible. Weak obliques will not allow for an aggressive turn at a high running velocity.

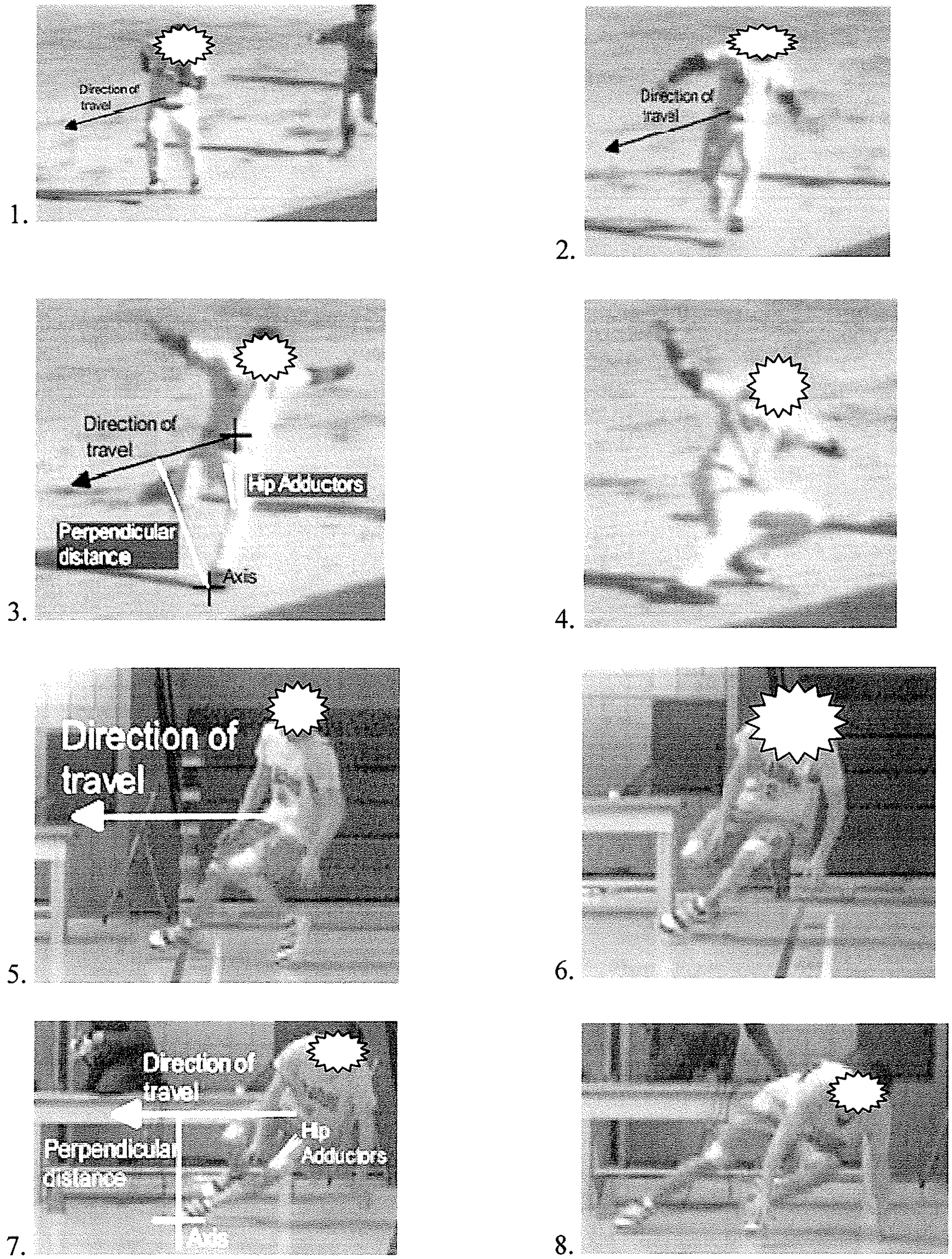


Figure 5.2: Notice the differences between the cutting styles of these two athletes. The athlete the sequence pictures 1-4 must control his deceleration primarily with his hip adductors whereas the athlete in pictures 5-8 can also use his hip and knee extensor muscles eccentrically to assist with the deceleration of his forward momentum.

It is clear in Figure 5.2 that for the baseball athlete executing the 180° cutting maneuver while avoiding a run down, the torque produced by his forward momentum about the axis at his foot will eccentrically stress his left hip adductors. The athlete in the lower pictures, however, is able to control the deceleration with both his adductors as well as his strong hip and knee extensors due to the lateral lean away from the cut. The aggressive lean places the direction of eccentric force in a plane closer to the line of action of the indoor athlete's left knee and hip extensors (Figure 5.3). Therefore, he can use these muscles to control this deceleration. The baseball athlete, however, can make minimal use of the eccentric contraction of his hip and knee extensors due to the angle of force application. He is in a more upright position while maintaining a relatively extended knee. This means that all of the force will be taken up by his left hip adductors and not his stronger quadriceps and gluteal muscles.

Calahan et al. (1989) reports that young men can generally produce a maximum concentric muscle torque in hip extension of about 151 Nm whereas only 93 Nm can be produced during hip adduction. Cheng and Rice (2005) reported knee extensor torque could reach as high as 267 Nm in young men, further supporting the idea that leaning away from the cut and utilizing greater hip and knee flexion will activate stronger muscles to eccentrically control the deceleration.

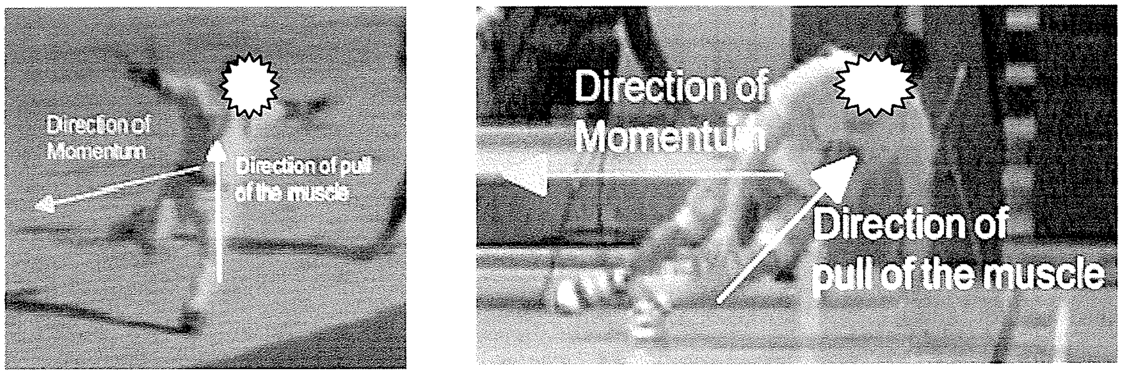


Figure 5.3: The direction of the athletes' forward momentum is closer to the line of pull of the quadriceps muscle if the athlete leans away from the cut as seen in the indoor athlete on the right.

The fitness tests conducted by Major League Baseball do not include tests of the athlete's 180° turning ability (Wood, 2005), but evidently, these athletes need to execute the skill from time to time. A player in the outfield would be a similar example of an athlete performing with cleats on a grass surface but they would rarely if ever perform a 180° cut. However, they are constantly accelerating from a stationary position in an unknown direction, so training to react and move would be beneficial. The surface of the infield is different than either of the surfaces tested in this study but would have similar characteristics to a grass surface. In both situations the shoe is form locked to the surface allowing a considerable amount of horizontal force application. The run down in between bases is a good example of an athlete completing a 180° cutting maneuver and it should be recommended to baseball athletes to train this particular movement.

The importance of a sideways lean is emphasized as the regression analysis highlighted trunk lateral flexion during the last step before the jab step as a key indicator of test time for the indoor group. For every 1 degree increase in the angle lateral trunk flexion there was a 0.002 second decrease in the athlete's test time. At first glance, this may appear to be quite a small difference. However, the range of trunk lateral flexion values for the indoor group was over 50°, so the differences can become significant. Additionally, the range of test times is also quite small. All of the indoor athletes had a test score between 2.14 seconds and 2.34 seconds yielding a range of 0.2 seconds. With these values in mind the small coefficients in the regression equation become more easily understandable.

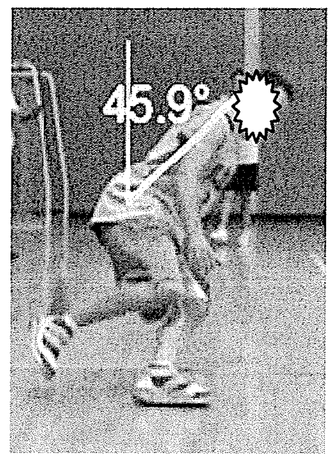


Figure 5.4: The indoor athlete on the right demonstrates more forward trunk lean than the outdoor athlete on the left.

The indoor group was able to attain a slightly greater position of forward trunk lean than the outdoor group at this point (Figure 5.4). The indoor group had a mean trunk lean angle of 39.2° whereas the outdoor group had a mean trunk lean angle of 24.2°. These values were not found to be significantly different at the adjusted p value of 0.0108 but were significantly different at the more commonly used p value of 0.05. A greater trunk lean served to lower the athlete's centre of gravity and allow him to apply a more sideways force to the ground which is closer to the horizontal plane than the more upright outdoor athletes. This advantage is confirmed by the literature (Young, 2001) as well as the correlation analysis which determined that both forward and lateral trunk lean were significantly correlated with lower test times for the indoor group. Both of these values essentially lower the athlete's center of gravity.

It should be noted that a position of deep forward and lateral flexion will stress the stabilizing muscles of the trunk a great deal (Baker 1999). Without adequate strength in the erector spinae muscle group and internal and external obliques the athlete will have trouble maintaining the ideal trunk position going into the cut. An athlete with a strength deficit in these trunk muscles will not be able to forcefully exit this position. Therefore a more upright position will be more effective as the athlete can't extend through such a large range of motion in a short amount of time.

Another benefit of an increased trunk forward lean angle is the substantial stretch it places on the gluteal muscles. If you actively stretch a muscle it will produce more positive work than if it were concentrically contracted without a stretch (Enoka, 2002). Therefore, the gluteals will contract with more force as the athlete exits the cut. This is because during the stretch shortening cycle; elastic energy is stored in the series elastic and parallel elastic components of the muscle fiber which increases the force of the following concentric contraction. This reaction is similar to an elastic band snapping back to its original length after being stretched. Not only will the resulting concentric contraction be more forceful, the time to maximum contraction will be decreased creating a much more powerful movement (Enoka, 2002). For the indoor group, the amount of hip flexion was also significantly correlated to lower test times. Since the stretch experienced by the gluteal muscles comes from a combination of hip flexion and trunk forward lean, it can be concluded that indoor athletes have a greater advantage over their outdoor counterparts in the utilization of the stretch shortening cycle of their hip extensors.

The technique of keeping the athlete's centre of gravity low is *the* most common theme in agility related literature. This topic has been widely described by Jeffreys (2008), Sayers (1998, 2000) and Sheppard and Young (2005). These studies reiterate the fact that a low centre of gravity places the athlete in a more controlled position as well as allow the athlete to apply forces to the ground in a lateral direction rather than primarily vertical as would be the result of a more upright body position. Not only is it stressed as a contributing factor to produce forces which are more in line with the horizontal direction, but it will also place the athlete under greater control as a lowered centre of gravity is one of the elements in a stable athlete (Hall, 2007). An athlete may be fast, but if they cannot move under control, their effectiveness will be limited in a game situation (Cook, 2003).

For the outdoor group, the only variable significantly correlated to test time at this point in the skill was the athlete's linear velocity one meter prior to the turn around point. This was a strong, negative correlation indicating that those athletes who had a high linear velocity generally performed better on the test. For an athlete to have a large amount of linear velocity and still be able to decelerate to, and accelerate from a stationary position, he must have a great amount of control in his stopping motion (Cook, 2003). It can be assumed then, that an athlete who is not as adept at stopping will not carry as much linear velocity into the turn, to ensure full control is maintained. Over the length of the entire test, this will decrease the athlete's average velocity and decrease his test time. The importance of the outdoor athlete's velocity just prior to the turnaround point is emphasized by the fact that it was the only variable from this key position to be selected in the regression equation to predict test time. For every 1 m/s increase in the athlete's velocity, there will be a 0.092 increase in the athlete's test time emphasizing the importance of a controlled deceleration to the turnaround point.

For the field or court sport athlete, it is important to disguise the cut until the very last second prior to the change of direction move. An out of control athlete will not execute the cut effectively or efficiently. . Therefore, decreasing the linear in exchange for increased control will aid the athlete in completing the cut (Cook, 2003).

Jab step touchdown

At touchdown of the jab step, four of the thirteen variables measured were found to be significantly different between groups at a p value of 0.0108, the first being forward trunk lean. This low position carries all the advantages of a lower centre of gravity and an increased stretch on the gluteal muscles as outlined earlier. Additionally, abduction of the jab hip and lateral distance from the jab hip to the jab heel were found to be significantly different between the groups, with the indoor group only displaying an average of 18° of hip abduction verses 38° of abduction for the outdoor group. The indoor group had a greater distance between their jab hip and jab heel at 0.64 m whereas the outdoor group showed a distance of 0.55 m. The amount of trunk lateral flexion between the groups was different but not significantly so. However, the investigator believes it was different enough to skew the measurements of hip abduction since the abduction angle is measured from the line of the trunk (Figure 5.5). If the measurements were not taken from true abduction but rather as a measurement of the upper leg and a standardized plane, such as the vertical, the measured angles would have been much closer as seen in Figure 5.5 and 5.6. The position displayed by the indoor group will allow them to utilize their hip and knee extensor muscles as well as their hip adductors to eccentrically control the final deceleration and subsequent acceleration rather than primarily their hip adductors. This is substantiated by the fact that trunk lateral flexion was found to be highly correlated to test time for the indoor athletes at touchdown of the jab step. It is interesting that the groups had very similar angles between their femur and the vertical. It is possible that there is an optimal angle between the leg and the playing surface which will allow for maximum force transfer while maintaining a level of safety for the athletes. Further investigation of various angles and the associated speed would be required to determine what that optimal angle would be.

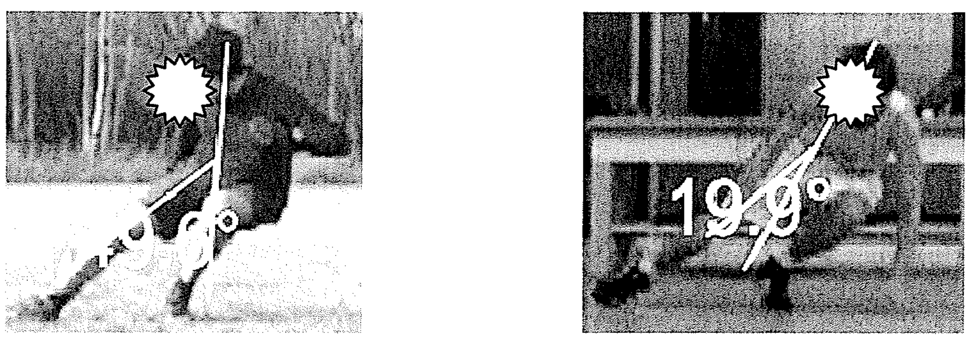
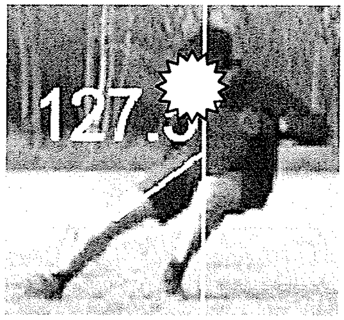


Figure 5.5: Hip abduction as a measurement in relation to the midline.



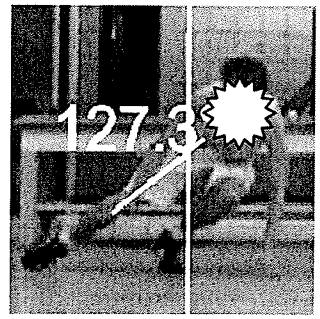


Figure 5.6: Measurement of upper leg position relative to the vertical.

Interestingly, the lateral distance from the jab hip to the jab heel was found to be different between the two groups (Figure 5.7). This could be due to the difference in height between the indoor group and the outdoor group. As reported, the indoor group had a mean height of 1.85 m whereas the outdoor group had a mean height of 1.8 m. The difference in heights between the two groups was found to be significantly different, however, considering the indoor group consisted of basketball athletes and the outdoor group consisted of soccer and ultimate frisbee athletes, this height difference was less than expected. For the purpose of the drill, the greater the distance from the jab hip to the jab heel will allow the indoor athlete to keep his centre of gravity further from the turnaround point thus moving the centre of gravity a shorter distance within the testing zone.

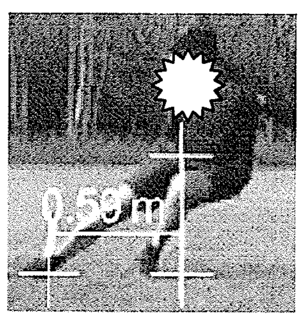


Figure 5.7: The lateral distance from the jab hip to the jab heel was significantly correlated to test time for the outdoor athletes.

The lateral distance from jab hip to jab heel was found to be significantly correlated to test time with a p value of 0.01. This is the one example in which the outdoor group was found to keep the centre of gravity as far from the turnaround point as possible while still completing the test as prescribed. Although lateral trunk lean was not highlighted as significantly aiding in the outdoor athlete's test time, a significant amount of trunk lean will make it easier for the athlete to maximize their performance with this variable and, consequently, their overall performance in the test.

For the indoor group, there was a strong negative relationship between stopping knee flexion (in the leg opposite the jab step) and test time. The negative relationship means that the indoor athletes which had a greater degree of knee flexion in the stopping knee at jab step touch down also tended to perform better in the test. For the indoor group, it is this leg that is generally supporting the weight of the body while the jab foot is on the ground. It is also the leg that will produce most of the power as the athlete exits the cut. Therefore, placing the quadriceps and muscles as well as the hamstring and gluteal muscles on a stretch will increase their ability to contract forcefully as the athlete pushes out of the cut. If these muscles are not strong enough to apply maximal force through the entire range of motion the athlete will not be able to attain such a low position. If this is the case, it would be beneficial to the athlete's performance to decrease their knee flexion in the stopping leg in order to exit the cut as fast as possible. Also, a stretching and strengthening program would be recommended in order increase the strength and flexibility of their hip and knee extensor muscles.

For the outdoor group, however, there was a significant negative correlation between the amount of flexion in their jab knee and test time. In other words, those athletes who had more flexion in their jab knee generally achieved a faster time in the test. These findings are not in agreement with each other. Through qualitative observation the researcher believes that this is because the indoor group tended to use their stopping leg as their main push off leg as they exit the cut. Therefore, they would want to increase the hip and knee flexion prior to pushing off in order to elicit the proper stretch reflex. The athletes of the outdoor group, however, normally used their jab leg as their main push off leg as they exit the cut. This can account for the importance placed on *stopping knee* flexion for the indoor group and the *jab knee* flexion for the outdoor group. There were some outdoor athletes whose movements mimicked those of the majority of indoor athletes as they appeared to use their stopping leg as their primary push off leg. The researcher believes that keeping the stopping foot in contact with the ground throughout the cut and then pushing off with this leg will produce the fastest test times as the athlete will be able to control the descent with both legs instead of just one. Further investigation with a larger sample size would be required to confirm this suggestion.

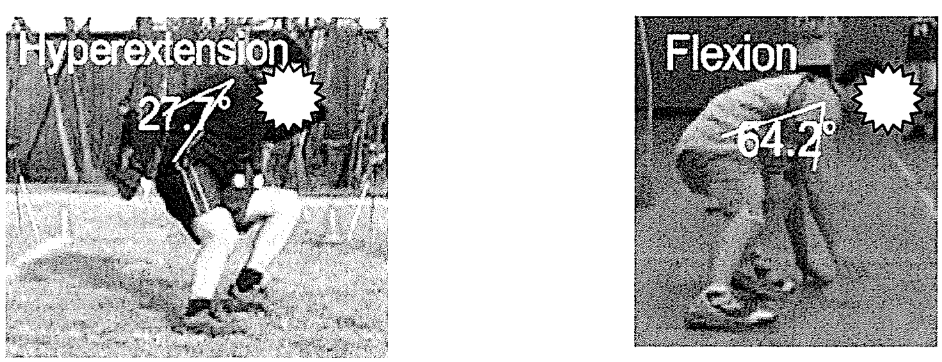


Figure 5.8: Differences in shoulder position at touchdown of the jab foot.

At touchdown of the jab step, there was also a significant difference in the amount of shoulder flexion achieved by the athlete in the ipsilateral shoulder to the jab step. The indoor group had a mean shoulder flexion angle of 26.2° and the outdoor group had a mean shoulder *hyperextension* angle of 23.5° (Figure 5.8). This means that on average, the outdoor group extended their shoulder placing their upper arm in a position behind their torso. In this skill, it would be beneficial for the indoor group to adopt a style similar to the outdoor group. In a hyperextended position, the athlete can forcefully drive the arm forward as the opposite leg drives out, through hip flexion, away from the turnaround point. From a position of shoulder hyperextension, the athlete has an increased range of motion available through which to flex the shoulder forward. In turn this will increase the forces applied to the ground in the backwards direction and the ground reaction forces applied back to the athlete will also be larger.

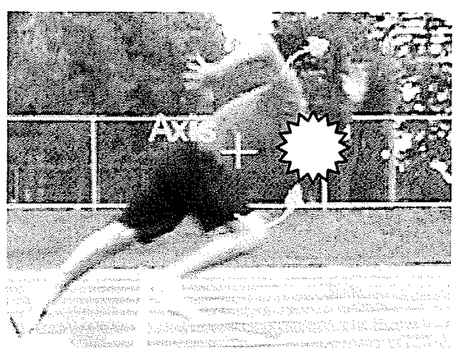


Figure 5.9: As the right shoulder hyperextends in the clockwise direction, there will be a counterclockwise reaction in the right hip.

This motion is similar to the motion of elite sprinters when exiting the blocks in a race (Figure 5.9). Sprinter's shoulders assume a position of shoulder hyperextension as the ipsilateral hip is flexed. In doing so the athlete makes use of the Newton's

Third Law of Angular Motion. This law states: "for every torque that is exerted from one body on another there is an equal and opposite torque exerted by the second body on the first" (Hay, 1993). The most common illustration of this occurs when an athlete applies a torque to one part of the body by contracting a muscle or group of muscles causing a limb to rotate around a joint. The equal and opposite reaction to this torque must be applied somewhere else in the body causing a different limb to rotate or apply a force to an external object. If the athlete is in contact with the ground, the resulting torque can be transferred to the ground resulting in no further rotation. If the athlete is airborne the angular momentum must remain constant as an airborne athlete cannot increase or decrease the total angular momentum (Hay, 1993). Therefore, rotation of one limb must result in rotation of another part of the body equal in magnitude and opposite in direction to the initial rotation. A clockwise rotation of one body part must be accompanied by a counterclockwise rotation of another body part about a similar or parallel axis.

At this point in the skill the athletes are not airborne as they are preparing for push off of the jab leg. However, in this position (Figure 5.9) the athlete is only in contact with the ground with the very tip of his toes making it difficult to produce torques which will help aid flexion of the right hip. Therefore, aggressive hyperextension of the right shoulder will indeed aid in the flexion of his right hip causing his body parts to react very much like an athlete in an airborne situation. Since the shoulder moves in the clockwise direction about the left right axis, there will be a reaction equal in magnitude and opposite in direction about this or another axis somewhere else in the body. In this case a clockwise torque produced by right shoulder hyperextension is taken up by a counterclockwise torque produced by right hip flexion.

Many of the athletes appeared to cease any type of conscious arm movement about halfway into the testing zone. The investigator believes that additional research should be conducted on the specific role of arms while decelerating and turning during the 180° cut. This research could be similar to the current study with an emphasis on the role of the arms. More subjects would be required in order to ensure the inclusion of several athletes who are highly skilled at the 180° cut. This study should incorporate the use of a force plate to record the changes in ground reaction forces that occur during the jab step with a more forceful or faster arm swing.

One trend that was noted for the outdoor athletes was the abduction of both shoulders approximately timed to touchdown of the second last step (Figure 5.4 and 5.10). The reason for this is unknown, but it is suspected that the athletes were elevating their shoulder girdle in preparation to rotate their trunk to the side in the beginning stages of the cut. Elevating the shoulder girdle assists with trunk rotation by lifting the clavicle away from its resting position on top of the first rib allowing the trunk to rotate more freely (Hamill and Knutzen, 1995). Following trunk rotation, there was a tendency for the contralateral shoulder to the jab leg to horizontally flex and the elbow to flex. This will, in turn, cause the equal and opposite reaction in the lower body (Hay, 1993) causing the jab leg to rotate forward about his longitudinal axis in preparation for jab step touch down. The tendency of moving into shoulder abduction followed by horizontal adduction and elbow flexion was especially prevalent in the athletes who achieved a slight airborne phase just before jab step touchdown. While airborne, their angular momentum must remain constant, therefore in order to rotate their right side counterclockwise about their longitudinal axis they must create a torque equal in magnitude and opposite in direction in some other part of their body. The clockwise motion of the left shoulder aids in this rotation.

Figure 5.10: Shoulder abduction in preparation for jab step touchdown. The athlete in the third frame is airborne therefore must horizontally adduct his left shoulder and flex his left elbow creating a clockwise torque in order to cause his right side to rotate in the counterclockwise direction around his longitudinal axis.

Additional variables measured at this point in the test were the number of ground contact points prior to the jab step and hand/ground contact. Both were found to be approaching significance and the researcher believes that a greater number subjects would have yielded a different result. The outdoor group had an average of 4.75 ground contacts prior to the jab step and the indoor group had an average of only 4.08. This was to be expected as the outdoor group must decelerate to a greater degree prior to the jab step as they cannot make use of a short slide as seen in the indoor group. Therefore, many athletes from the outdoor group adopted a form of stutter step deceleration as they approached the jab step. The indoor group generally displayed more of a normal running stride with a very aggressive hop into the jab step.

There was a difference in hand/ground contact between the groups, but it was not found to be significant (Figure 5.11). Since the indoor athletes attained a much lower position of trunk forward and sideways lean, many of them had to brace themselves with their hand against the floor in order to prevent falling. Most of the outdoor athletes did not come close enough to the ground to be concerned with the chance of falling therefore did not attempt to touch the ground. Initially, the researcher expected there to be a larger difference between the groups as it is very rare to see an athlete touch the ground while cutting outdoors. Two outdoor athletes touched the ground during the outdoor test and this was higher than expected. Seven indoor athletes touched the ground during the test which was fewer than expected.

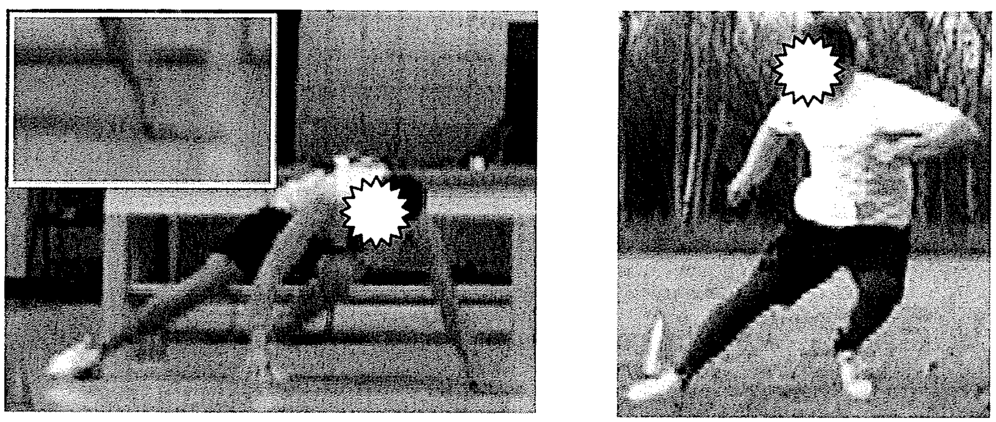


Figure 5.11: Differences in hand / ground contact between indoor and outdoor groups.

The National Football League uses a battery of fitness tests called the *NFL Combine* including four running tests. Three out of these four tests incorporate the 180° cutting maneuver: the 20 yard shuttle, the 60 yard shuttle and the 3 cone drill (Figure 5.12) (Wood, 2005). During these tests the athletes are required to touch the turn around line with their hand before they accelerate in the new direction (Figure

5.13). This was not required in the testing protocol for this study, but the investigator now believes that it would have been beneficial to the athlete's test score. It would have forced the athletes to lower their centre of gravity by increasing their trunk lean as well as hip and knee flexion. This position would eccentrically load the hip and knee extensor muscles producing a stronger contraction. Also, a lower position would take advantage of force application to the ground in a more horizontal direction.

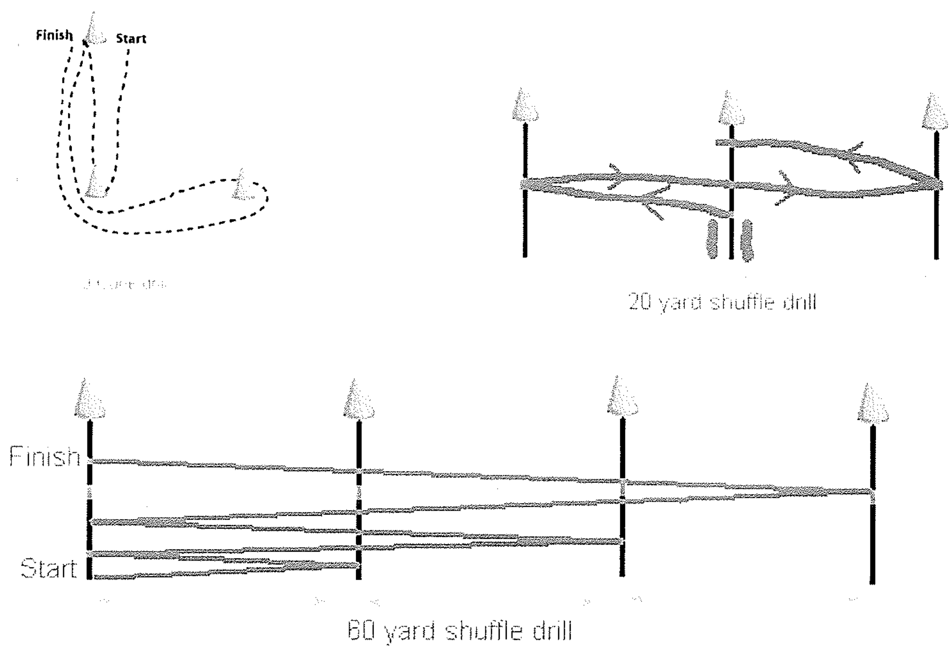


Figure 5.12: Three agility tests used by the NFL, all of which incorporate a 180° cutting maneuver.

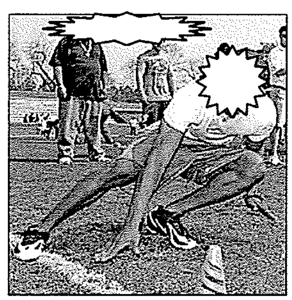


Figure 5.13: An athlete completing the NFL combine. Touching the turnaround line is mandatory and produces a low and efficient stopping position.

Maximum flexion of the jab knee

Maximum flexion of the jab knee should coincide with the athlete reaching a velocity of 0 m/s, or, the halfway point in the skill when the centre of gravity stops moving in one direction and starts moving in a new direction. As described earlier, the athletes do not reach this position at the halfway point in their time, but rather at about 44% for the indoor group and about 47% for the outdoor group. This timing was found to be significantly different, but the fact that both groups reached this point before 50% of their test time emphasizes the importance of the deceleration phase. In the deceleration phase of the cut, a substantial eccentric stress is placed on the muscles of the legs (Cook, 2003). If the deceleration is not performed efficiently and under control, the athlete runs the risk of decreasing the effectiveness of the cut as well as increasing the chance of injury. An athlete who is highly skilled at stopping his forward motion will have more time to set up, change direction and accelerate in the new direction (Cook, 2003). Although there was no correlation between the time the athletes required to reach maximum knee flexion of the jab knee and test time, an athlete who can decelerate under more control should be able to complete the test in a faster time (Cook, 2003).

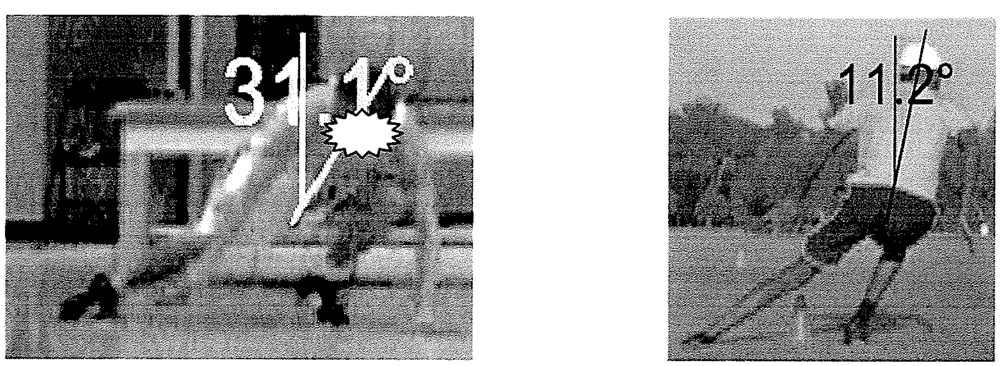


Figure 5.14: Lateral trunk flexion at maximum knee flexion of the jab step.

The comparison of trunk lateral flexion between the two groups was approaching significance with a p value of 0.0122. The mean lateral trunk flexion for the indoor group was -29.4° whereas the outdoor group had a mean angle of -2.7°. The negative value refers to the fact that they were leaning away from their jab foot. The increased lateral lean of the indoor group will help keep their centre of gravity further from the turnaround point. The lean is facilitated by the predictable slide across the hardwood floor. The combination of cleats on grass does not offer the ability to slide as the two surfaces are form locked to each other rather than force locked as is the situation indoors (Stucke et. al, 1984). Initially, the researcher believed that the small amount of slide in the indoor trials would hamper the athletes in completing the test. Instead, this slide turned out to allow them to utilize a more efficient stopping position because they had a greater trunk lean away from the cut (Figure 5.14).

It was also observed that five of the outdoor athletes demonstrated trunk lateral flexion in the positive direction, or towards their jab foot (Figure 5.15). This could be related to lack of stopping skill or a sign of weak abdominals, especially the internal and external obliques of the side away from the lean. This excessive lean towards the jab foot will decrease the athlete's control and deceleration through the cut. Weak or soft abdominals will not allow for a full transfer of force from the lower body to the upper body through the cut. Glasser (1999) and Sayers (1998) report that stronger core muscles will increase an athlete's change of direction speed. As the lower body decelerates the upper body[2] will continue to travel forward with its initial forward

[2] For this study the upper body is defined as including the all body structures above and including the 12th thoracic vertebrae. The lowest attachment sites for the internal and external obliques are on the 12th rib. This rib is attached to the axial skeleton at the 12th thoracic vertebrae. The lower body will be defined as all body structures below and including the 1st lumbar vertebrae.

momentum. Once the athlete plants the jab foot, the lower leg essentially stops moving. The upper leg would continue to move in the original direction of travel but is stopped by the muscles and ligaments that cross the knee. The upper body will also maintain its forward momentum. The athlete must rely on the muscles of the core to decelerate the forward momentum of the upper body. It is the abdominals which transfer the stopping action from the lower body to the upper body and help to decelerate the upper body. Therefore, if the muscles of the core are not strong, the upper body will continue to move forward over the pelvis increasing the chance of over rotation. Also, this muscle weakness will produce a negative effect on the athlete's proficiency in performing the cut. This leads to a tendency to lift the stopping foot as seen in Figure 5.9. With the stopping foot unweighted, the athlete must use the jab foot as the primary push off foot, or take the time to replant the stopping foot and flex the hip and knee into a position from which the athlete can adequately apply force to the ground.

Figure 5.15: An athlete demonstrating improper control of his trunk muscles by leaning too far toward his jab step.

The difference between the two groups' forward trunk lean at maximum flexion of the jab knee was also approaching significance with a p value of 0.027. As outlined earlier, this has been a consistent difference between the groups and enables the indoor group to lower their centre of gravity and apply more horizontal forces to the ground as they execute the cut.

An unexpected finding was the high positive correlation between jab knee flexion and test time at maximum flexion of the jab knee for the indoor group. Originally, it was expected that, since increased knee flexion places a greater stretch on the knee extensors, deeper knee flexion would be beneficial. However, with the observation that the indoor group did not normally use the jab leg as their main push off leg when exiting the cut, it is clear that maintaining a relatively unflexed knee at this point in the skill will keep the athlete's centre of gravity further from the turnaround point. Furthermore, for the indoor group, flexion of the jab knee was determined by the regression equation to be one of the predictors of test time. For every 1 degree increase in knee flexion, there was a 0.001 s increase in the athlete's test time. This finding emphasizes the importance of generating force from the stopping leg, and not the jab leg for the indoor athletes.

The recommendation that athletes complete a skill with an extended knee can be dangerous to the health of the supporting structures of the knee such as the anterior cruciate ligament, and the posterior cruciate ligament. The anterior cruciate ligament is commonly torn when an athlete is stopping from a high speed or changing directions quickly. This is because it attaches to the medial aspect of the lateral femoral condyle, within the intercondylar notch, and the anterior, medial aspect of the tibia plateau (Hamill and Knutzen, 1995). When an athlete decelerates into a position as seen in Figure 5.15, there is a high shear force between the femur and tibia in the lateral direction of the athlete's jab knee. This causes the anterior cruciate ligament to lengthen. Without proper control and flexing during this deceleration the athlete is at risk of tearing the ligament. The posterior cruciate ligament attaches to the anterior, lateral aspect of the medial aspect of the femoral condoyle and the posterior, lateral aspect of the tibia plateau (Hamill and Knutzen, 1995). An athlete who loses full control would run the risk of tearing the posterior cruciate ligament in the stopping knee as the shearing force is now causing the femur to slide medially over the tibia. Athletes who demonstrate deeper knee flexion are able to take up more of the force exerted on the knee joint by the muscles surrounding the joint. However, athletes who maintain an extended knee will experience these forces primarily in the ligaments. If the loads are high enough, it could lead to rupture of the ligaments. Muscles are stronger than ligaments and more adept at handling high deceleration forces.

The anterior cruciate ligament is most commonly injured at approximately 30° of knee flexion and the posterior cruciate ligament is most commonly torn between 45°-60° of flexion (Hamill and Knutzen, 1995). The average angles of knee flexion were greater than these values at 64° and 88° respectively, but it would be likely that some athletes would maintain knee flexion angles within the high risk limits. Therefore, with the issue of safety in mind, the current researcher would choose not to highlight the particular finding of a more extended jab knee to coaches interested in increasing their athlete's ability to perform the 180° cutting maneuver.

Jab step push off

There were ten variables measured at push off of the jab step. Of these, only two were found to be significantly different between the indoor group and the outdoor group, trunk lean relative to the vertical and contralateral shoulder abduction. The amount of trunk lean has been discussed in detail, and the advantages of lowering the athlete's center of gravity and keeping it further from the turnaround point holds true for this key position also. Additionally, forward trunk lean for the indoor group at this point in the skill was highlighted as being strongly correlated with test time. Not only was it highly correlated, but it was also selected in the regression equation as a significant predictor of test time for the indoor group. For every 1 degree increase in trunk lean there was a 0.001 second decrease in test time, further emphasizing the importance of maintaining a low center of gravity through the cut.

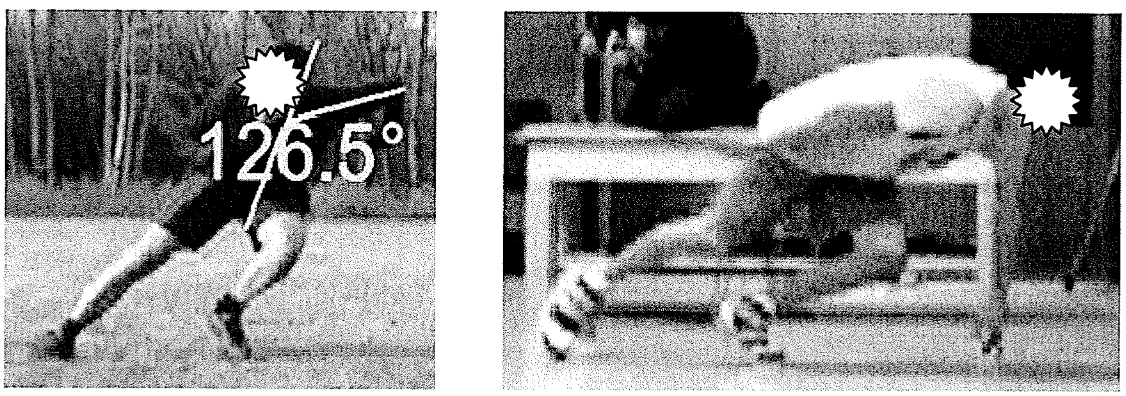


Figure 5.16: Differences in contralateral shoulder position at push off of the jab step. The angle of abduction is hidden by both the frontal and sagittal view for many of the indoor athletes.

As mentioned in the methods section, if the athletes horizontally *adducted* their arm in front of their body (Figure 5.16) instead of abducted their arm out to the side, the measurement was generally hidden from the camera. Instead of estimating the *adduction* angle it was recorded as 0° of *abduction*. This only occurred in the indoor group with 6 out of the 12 athletes demonstrating a position of adduction of their contralateral shoulder. Consequently, the difference between the groups was diminished slightly. However, the difference was still highly significant with a p value of 0.00015 (Figure 5.16). The indoor athletes generally attained the position of shoulder adduction through a severe trunk lean away from the cut, contact with the ground with their hand and then trunk rotation in line with the new direction. This caused their hand to horizontally adduct under and in front of their trunk. Therefore, this action was a factor in enabling the athletes to attain the high degree of trunk lean with out falling over as some athletes braced themselves against the floor to prevent falling.

However, a result of the position of shoulder flexion and horizontal adduction places the contralateral shoulder to the jab leg in a less than ideal position when the athlete is accelerating away from the cut. If the shoulder is in a position of adduction and slight flexion, placing the arm in front of the body, it will not be in a good position to forcefully extend in relation to the forceful extension of the opposite leg. If the shoulder is abducted at push off of the jab step, the inertial lag of the arm will cause the position of shoulder abduction to become shoulder extension as the body rotates to face the new direction of travel (Figure 5.17).

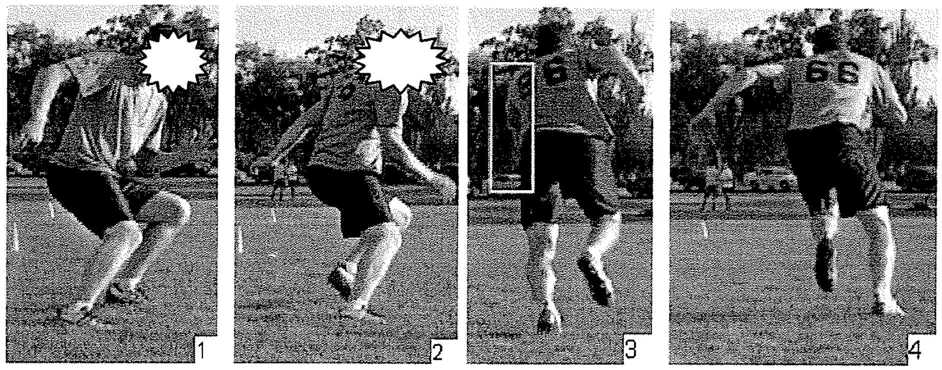


Figure 5.17: As the athlete exits the cut he adducts his left shoulder bringing his arm in front of his body. This is not a beneficial position for his arm as his shoulder cannot rotate into hyperextension but can only abduct out to the side in response to his left hip

Following jab step push off, the jab leg is forcefully flexed forward at the hip. To mimic the motions of a sprinter, the contralateral shoulder should then forcefully flex in order to increase the ground reaction forces applied to the ground by the push off leg. As mentioned earlier, the investigator recommends further research into the role of the arms during a 180° cutting maneuver as many of the athletes appeared to stop any type of conscious arm movements as they approached the cut. Additionally, there was no mention of the role of the arms while performing a 180° cut in any of the literature reviewed. Bezodis et al. (2007) outlines the role of the non-kicking side arm in the place kick in rugby athletes and its contribution to controlling total angular momentum of the body during the kick. Elite athletes tended to display a more consistent motion of the non kicking side arm. Research on arm motions should be conducted on athletes as they rotate through a cut as well as to further understand the relationship of the arms in a 180° cut and how they contribute to angular momentum of the athlete as well as ground reaction forces.

For the outdoor group, there was a significant, positive correlation between support stance time of their jab step and test time. Therefore, those athletes who were able to spend as little time as possible in the support phase of their jab step generally performed the drill in less time. This was an expected correlation as it is a good example of the principle of impulse momentum described earlier. It is evident that if an athlete can minimize the duration of their jab step, they can optimize the tradeoff between magnitude of force and duration of force application. Recall, impulse equals force multiplied by time (Hall, 2007). As time of force application is increased, during a cutting maneuver or vertical jump, the amount of force which is generated is usually reduced.

An athlete must apply muscle torques in order to create the necessary changes in body position in order to effectively push off from the jab step. This is done through an application of a muscle force at some distance to an axis of rotation at a joint. Since the torque produced at a joint equals the moment of inertia of the rotating limb multiplied by the angular acceleration of the limb ($T = I\alpha$), there are a limited number of ways in which an athlete can increase torque to produce increased acceleration of limbs. Without changing the mass of a limb, an athlete cannot change the moment of inertia of the limb segment about an adjacent joint. The angular acceleration of the limb may only be increased if the athlete becomes stronger and is able to produce a greater amount of contractile force in the muscle, thus increasing the torque. Since torque produces angular acceleration of a limb, the greater the muscle torque the greater the angular acceleration.

The athlete can, however, increase the time period over which the torque is applied to the joint thus increasing the angular impulse. Angular impulse equals torque multiplied by the time of torque application and serves to alter the angular momentum of a system ($Tt = I\omega_f - I\omega_i$) (Hay, 1993). A method an athlete can use to increase the angular impulse is to increase the time of torque application. This can be done through an increased angular displacement of the joints of the jab leg. For example, instead of going into 60° of hip and knee flexion prior to push off of the jab leg, the athlete could flex to 90° at the hip and knee. If the athlete then extends the hip and knee of the jab leg to full extension, the angular displacement will be increased causing a slight increase in time of torque application. This increased angular impulse will produce an increased angular velocity of the limb segments.

An increase in the duration of the torque application also serves to increase the duration of the application of the linear force by the athlete to the ground. This product of force and time is known as a linear impulse ($Ft = mv_f - mv_i$) (Hay, 1993) and serves to alter the linear momentum of the athlete. In this case, application of a linear impulse allows the athlete to accelerate quickly away from the turnaround point. Refer back to pages 30-33 for sample equations and examples of how the impulse momentum relationship relates to the 180° cutting maneuver. Despite the fact that a decreased duration of support stance of the jab step was seen to increase the athlete's performance in the 505 test, an athlete *can* positively affect test performance if a force is applied to the ground over a greater period of time. Alternatively, the athlete could increase force output by producing a more forceful contraction over a shorter period of time, increasing impulse by increasing force output rather than time.

Decelerating from a high velocity while maintaining control of the body is one of the hardest skills to master (Cook, 2003), as the athlete must manage high eccentric muscle forces produced from the deceleration from a high forward velocity. The longer it takes the athlete to ultimately slow down to a velocity of 0 m/s, the longer the athlete will spend in the support stance of his jab foot. Not only was support stance time highly correlated to test time, it was also found to be a significant predictor of test time in that it was highlighted in the regression equation. For every 0.01 s increase in support stance time, there was a 0.00341 second increase in test time for the outdoor group.

The investigator proposes a breakdown of the support stance of the jab step into three phases. The first is the deceleration of the body's forward momentum from touchdown of the jab step until the athlete reaches a linear velocity 0 m//s. This deceleration is characterized by high eccentric contractions in the muscles of the legs and trunk. If this phase is not executed properly or under control, the second phase of the jab step will be increased. The second phase (Figure 5.18) is brief period of time during which the athlete experiences very little movement forward or backward, but simply repositions the body into a position from which to apply force in the backwards direction. In highly skilled athletes who demonstrate great body control through the cut, this phase should be almost nonexistent. The third phase of the jab step involves acceleration in the new direction. This is accomplished primarily through forceful hip and knee extension. In order to decrease the duration of the jab step all three phases must minimized.

Athletes with problems in the deceleration phase tend to have slower test times as they cannot control the final stopping motion of their jab step as effectively as those with optimal deceleration (Cook, 2003). Figure 5.18 is a good example of an athlete with poor control during the support phase of the jab step and he consequently had one of the longest support stance times of 0.617 seconds. The athlete is on the verge of over rotation about his jab foot and had to make several small adjustments in order to prevent too much over rotation about his jab foot. For example, after he planted his jab foot he picked up his heel and rotated it past the turnaround point about 8 centimeters. This allowed him to maintain his centre of gravity over his base of support. Also, he lifted and abducted his stopping leg slightly in order to maintain balance by shifting his centre of gravity backwards. These adjustments negatively affected his overall test time as he had to recover his balance before he was able to achieve a position from which he could apply forces in the opposite direction.

Figure 5.18: This athlete has not properly controlled his deceleration as he has rotated too far over his jab foot. Consequently, the support stance time of his jab foot was considerably longer than the average.

An additional variable that was produced in the regression formula was the hip extension velocity for both indoor and outdoor groups. It is understandable that it is the one variable the groups had in common in their regression formulas. Powerful hip extension is a key factor in the success of almost every sport (Rippetoe and Kilgore, 2005) and the execution of the 180° cut is no exception. For the outdoor group, for every 1 °/s increase in hip extension velocity there was a 0.001 second decrease in the athlete's test time. For the indoor group the coefficient was considerable smaller. For every 1 °/s increase in hip extension velocity for the indoor group there was a 0.00016 second decrease in the indoor athlete's test time. This finding emphasizes the importance of hip extensor strength and power through the 180° cutting maneuver.

Maximum flexion of the first step in the new direction

Only five variables were measured during maximum knee flexion of the first step in the new direction, but three of them were significantly different with a p value of 0.0108. These include trunk lean relative to the vertical as well as support hip and knee flexion (Figure 5.19).

The average angle of hip flexion for the indoor group was 76.4° and the average angle of hip flexion for the outdoor group was 55.4°. It is advantageous to have a greater amount of hip flexion as this will place the hip extensor muscles under additional stretch. Consequently, they will contract with greater force due to the stretch shortening cycle as mentioned earlier (Enoka, 2002). Similarly, the average knee flexion angle for the indoor group was 86.3° whereas the average angle of knee flexion for the outdoor group was 70.6°. Here, too, more knee flexion would be an asset as it would provide for a larger range of motion with which to apply force to the ground as well as increase the stretch on the knee extensor muscles.

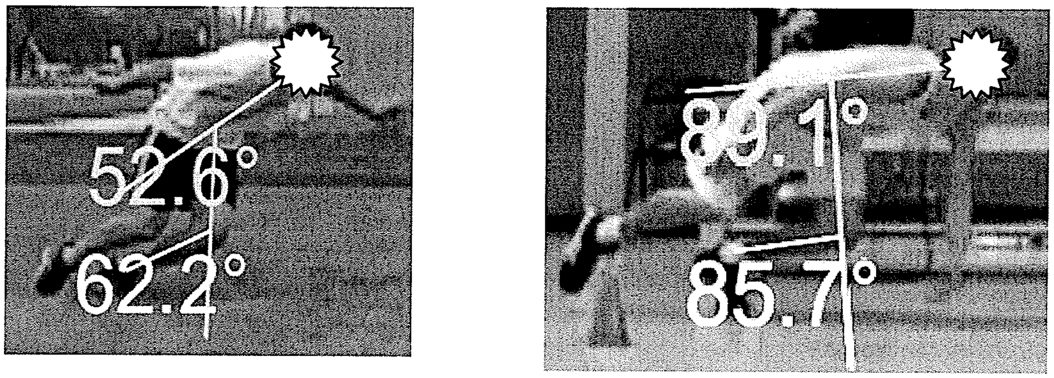


Figure 5.19: Differences between hip flexion (yellow) and knee flexion (white) during the first step in the new direction.

Again, for the indoor group, trunk forward lean was found to be significantly correlated to test time indicating that those who were able to maintain a more horizontal trunk position generally did better in the test. This is in line with what Sleivert and Taingahue, (2004) describe in the starting position in elite sprinting. A large, forward lean will allow the athlete to place his foot down behind his centre of gravity which will completely eliminate any braking phase of the stride. Additionally, it will increase the range of motion available for hip extension.

End of first stride in the new direction

Four variables were measured at the end of the first stride in the new direction, hip and knee flexion, ankle plantarflexion as well as support stance time. None of these variables were significantly different between the indoor and outdoor groups. This was not unexpected by the researcher as the indoor and outdoor athlete's movements should begin to mimic regular sprinting by this point in the test (Figure 5.20).

For the outdoor group, however, the linear velocity of the athlete one meter from the turnaround point was a significant predictor of test time as determined by the regression equation. For every 1 m/s increase in linear velocity at a distance of 1 meter from the turnaround point there was a decrease in test time of 0.124 s. This further emphasizes the importance of a quick turn for the outdoor group. The athlete's linear velocity 1 meter before the turn, support stance time and linear velocity 1 meter after the turn all came up as contributors of test time stressing the importance of the actual turning motion over the approach and the exit of the turn. The importance of reaching top speed as soon as possible is echoed by several researchers in the area of agility and speed training. Bloomfield et al. (2007), Jeffreys (1998) and Sayers (1998) all stress the importance of rapid acceleration for the field or court sport athlete. Track sprinters do not strive to reach maximum velocity as soon as possible as their goal is to maintain their highest velocity for as long as possible.

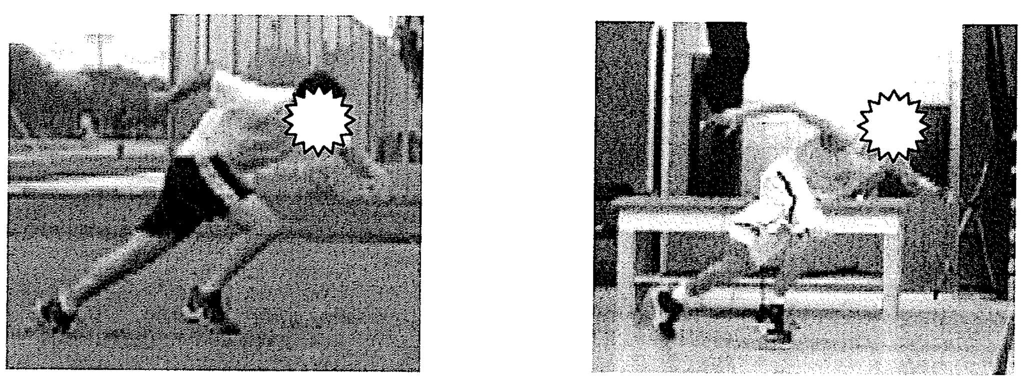


Figure 5.20: There were no significant differences found between the groups at the end of the first stride in the new direction.

Linear and angular velocities

As previously discussed, linear velocity of the athlete was calculated 3, 2 and 1 meters prior to the turnaround point as well as 1, 2 and 3 meters after the turnaround point. Additionally, hip and knee extension angular velocities were measured for the push off of the jab step and the first two following steps. None of the linear or angular velocities were found to be significantly different between the groups although there were some differences in their importance in test time prediction as outlined earlier. The fact that none of the linear or angular velocity variables were different was an unexpected result as the test scores between the groups were significantly different. There may have been too much variance within the variables measured to determine a significant difference between the groups linear and angular velocity measures. The fact that the indoor athletes were able to keep their centre of gravity further from the turnaround point, could also account for this non significance. The indoor group would have covered a shorter distance in a shorter time than the outdoor athletes while maintaining similar instantaneous and average linear and angular velocity. A sample calculation is seen in Figure 5.21.

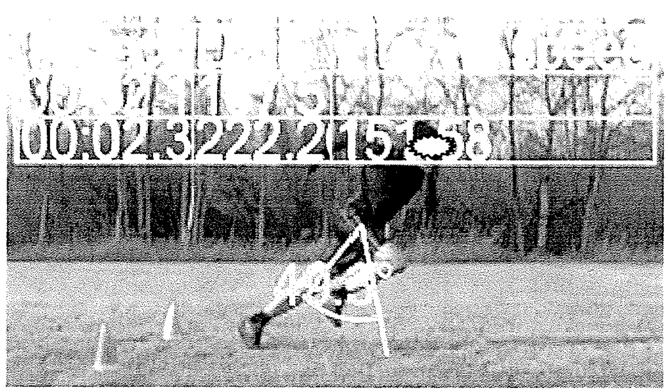


Figure 5.21: An example of angular velocity of hip extension as calculated in Dartfish.

Regression Equations to Predict Velocity

In order to verify the multiple regression equations for both the indoor and outdoor groups, the researcher entered the variable values for several of the subjects into the regression equations. This allowed the researcher to determine the ability of the equation to predict the same velocity or a similar velocity as the velocity actually calculated for that subject in the study. Table 5.1 has identified the predicted velocities for several of the subjects in the indoor group. Table 5.2 has identified the predicted velocities for several of the subjects in the outdoor group.

Table 5.1: Predicted velocities for indoor athletes in the current study

Variables	Coefficients	Subject 1	Subject 3	Subject 5
Trunk lean (jab push off)	-0.001	52.40	47.20	36.40
Hip extension velocity (jab push off)	-0.00016	234.30	182.00	237.30
Jab Knee Flexion (maximum flexion of the jab knee)	0.001	51.70	57.30	82.90
Trunk lateral flexion (Last Step touchdown)	0.002	-14.80	-5.20	-19.10
Intercept	2.311	2.31	2.31	2.31
Predicted Time (sec)	_	2.24	2.28	2.28
Actual Time (sec)	_	2.25	2.29	2.32

Table 5.2: Predicted velocities for outdoor athletes in the current study

Variables	Coefficients	Subject 1	Subject 3	Subject 5
Velocity 1 m before turn	0.092	1.97	1.94	1.56
Velocity 1 m after turn	0.124	1.82	2.47	2.30
Hip ext velocity (jab push)	-0.001	218	235.6	115.3
Support stance time of jab step	0.349	0.28	0.32	0.38
Intercept	2.036	2.036	2.036	2.036
Predicted Velocity (sec)	_	2.31	2.39	2.48
Actual Velocity (sec)	_	2.31	2.33	2.48

It should be noted that the predicted test score values for both the indoor and outdoor groups are very close to the actual measurements. This finding suggests that the regression equations have been successful at predicting the test outcomes. This is a result of the selection and measurement of meaningful and relevant variables.

Conclusion

The difference between an indoor athlete and an outdoor athlete performing a 180° cut is substantial. The indoor athlete generally has a much lower and backwards leaning trunk position and can approach the cut with a short slide across the gym floor which will enable the athlete to utilize the strong muscles of the hip and knee extensors. This is due to the fact that the line of force between the athlete's centre of gravity and the point of contact with the ground is closer to the horizontal plane and more in line with line of pull of these muscles. An indoor athlete trying to increase his or her proficiency at completing a 180° cut should stress a low position of the centre of gravity and a strong push off of the inside or stopping foot.

Outdoor athletes generally complete the cut with a higher centre of gravity and have the tendency to lift the stopping foot and use the jab leg as the main push off leg. This should be avoided if possible. It is sometimes the result of strength deficiencies in the athlete's trunk stabilizing muscles such as the internal and external obliques as well as the transverse abdominis. Specific exercises targeting these muscles should be performed to fix this problem. The outdoor athlete wishing to increase their performance in the cut should focus on minimizing the length of time the jab step is on the ground as well as reaching a high velocity as soon as possible as they exit the cut. Powerful hip extension as the athlete exits the turnaround point is crucial for athletes across both situations.

The research presented here is of some value to the skills of coaching football, soccer, basketball and any other sport that requires rapid change of direction maneuvers as there currently is a lack of information on the topic of the 180° cutting maneuver. This cut is performed by countless athletes in testing situations and in the case of the NFL combine, can sometimes make the difference between gaining or losing a multimillion dollar contract. The investigator believes further research is required on the specific role of the arms during the cut and would suggest that a larger sample size be recruited to conduct such a project.

Chapter VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The 505 drill performed indoors and outdoors are two skills which have the same goal of trying to alter the athlete's forward momentum by 180° in as short a time as possible. The purpose of this study was to determine the most effective body movements and body positions to perform the fastest 505 drill indoors and the fastest 505 drill outdoors in conditioned male athletes. Video analysis was performed on both the indoor and outdoor groups by measuring key kinematic variables and performing statistical analysis in order to determine any differences which may be present between the two groups. It was hypothesized that there would be a negative correlation between the measured linear and angular velocities and the athlete's test time. Additionally, the variables highlighted as key contributors to test time would be similar between the indoor and outdoor athletes. A secondary purpose of the study was to determine the kinematic differences between the indoor and outdoor groups.

Data were collected from a total of 24 subjects on six separate filming sessions: including athletes from the Canadian Mennonite University Men's soccer, basketball and volleyball teams, the University of Manitoba men's basketball team and the Manitoba provincial ultimate frisbee team. Twelve indoor athletes and twelve outdoor athletes participated in the study, with all athletes considered skilled for their age being either prospective or current members of elite sports programs.

A three camera set up was utilized during the filming session, capturing video from the sagittal, frontal and transverse views. The video was then imported into a

Toshiba Laptop through Dartfish video analysis software and was stored there throughout the analysis.

Six key positions were highlighted during the cut; touchdown of the last step, touchdown of the jab step, maximum flexion of the jab step, push off of the jab step, flexion of the first step in the new direction and push off of the first step in the new direction. Fifty nine variables were measured during these positions. Five variables were measured at touchdown of the last step, 14 variables were measured at touchdown of the jab step, 5 variables were measured at maximum flexion of the jab step, 12 variables were measured at push off of the jab step, 5 variables were measured at flexion of the first step in the new direction and 4 variables were measured at push off of the first step in the new direction. Additional variables measured were the athletes' linear velocity at 3, 2, and 1 meters before and after the turnaround point as well as the athletes' hip and knee extension velocity as they exit the cut. The angles of trunk rotation and range of motion were not measured for the indoor athletes as the unexpected angle of trunk lean made this angle hidden from the camera. The data collected allowed the researcher to analyze several aspects of the cutting technique and determine where similarities and differences may occur between the two groups. Statistical analysis was performed on the measured variables through the use of t-tests, Pearson's Product-Moment Correlation and Forward Stepwise Multiple Regression analysis.

Due to missing data points, the angles of trunk rotation relative to the direction of travel for the indoor group were not included in the statistical analysis. The results of the statistical analysis will be summarized below with many statistical differences occurring between the two groups.

T-Tests

Statistical analysis of the two groups revealed several differences in technique, with the majority of these differences associated with the angle of forward and lateral flexion of the trunk.

Last step before the jab step

Five variables were measured during the last step prior to touchdown of the jab step. Of these variables, however, none were found to be significantly different between the two groups. This was not an unexpected finding as the athletes movement patterns still displayed some semblance of a normal running style. This style is fairly similar between athletes running indoors and those running outdoors, therefore differences would be minor.

Touchdown of jab step

At touchdown of the jab step, thirteen variables were measured. Of these, four proved to be significantly different between the indoor and outdoor groups. The variables calculated as significantly different were: trunk lean relative to the vertical, abduction of jab hip, lateral distance from jab hip to jab heel and ipsilateral shoulder flexion.

The indoor athletes proved to maintain a lower centre of gravity by attaining a higher degree of forward trunk lean than the outdoor group. This serves to create a more stable athlete, as well as enable the athlete to apply force to the ground in a more horizontal direction than if the athlete were in an upright position. Additionally, the indoor athletes managed to keep their centre of gravity further from the turnaround point by maximizing the lateral distance between their jab hip and their jab heel. This is crucial in a testing situation as it will allow the athlete to travel a shorter, horizontal distance within the testing zone. This may not translate to increased cutting performance in the field, but when looking at the 505 drill as simply a test, can serve to increase the athletes test score. This can be clearly understood with an example. If two athletes executed the test and managed to attain identical horizontal velocity measures, the athlete who was able to travel a shorter distance would have a decreased test score.

It would seem that since the indoor group managed a greater lateral distance between their jab hip and jab heel that they also had a greater degree of jab hip abduction, but this was not the case. Despite the lack of significance in hip abduction, the indoor group also had a greater mean trunk lateral flexion angle. Since hip abduction is measured as the deviation of the hip in the frontal plane from the spine and not from the vertical, any amount of lateral flexion in the trunk will decrease the measured angle of hip abduction.

There was a significant difference in the shoulder position of the ipsilateral shoulder to the jab step between the two groups. The outdoor group generally displayed a position of shoulder hyperextension and the indoor group displayed a position of shoulder flexion. For the outdoor group, this is a result of the tendency of touching the ground through the cut. The position of the shoulder of the outdoor group is more desirable as it allows the athlete to forcefully hyperextend the shoulder to increase ground reaction forces and aid in hip flexion.

Maximum flexion of the jab step

Five variables were measured during maximum flexion of the jab step: forward trunk lean, trunk lateral flexion, stopping knee flexion, jab knee flexion and jab hip flexion. Of these five variables, only one was found to be significantly different between the indoor and outdoor groups. The indoor athletes had a significantly greater degree of trunk lateral flexion away from the jab step. This served to lower the athlete's centre of gravity as well as keep it further from the turn around point. Due to this trunk lean, the indoor athletes were able travel a shorter horizontal distance and still complete the test as instructed. Additionally, the investigator suggested that an increased lateral lean away from the jab step also places the athlete in a more desirable position from which to utilize the hip and knee extensor muscles to control the final deceleration as well as acceleration away from the cut. The importance of trunk lateral flexion was also highlighted in the regression equation for the indoor athletes as greater lateral flexion resulted in a shorter test time.

Jab step push off

Ten variables were selected and compared at the push off of the jab step. Of these ten variables, only two were found to be significantly different between the indoor and outdoor trials. Trunk forward lean relative to the vertical and abduction of the contralateral shoulder to the jab step were significantly different between groups. The indoor groups had a greater mean forward trunk lean than the outdoor group which, as discussed earlier, will lower the centre of gravity enabling the athlete to execute the cut under greater control. However, the outdoor group had a greater mean contralateral shoulder abduction angle. The investigator believes this will facilitate a more effective arm swing as the athlete exits the cut. If the shoulder is abducted, the inertial lag of the arm should place it in a position of shoulder flexion as the athlete rotates to face the new direction. In turn, the athlete will be able to forcefully extend the shoulder in order to increase ground reaction forces as well as aid in hip flexion.

Flexion of the first step

Five variables were measured during maximum flexion of the hip in the first step in the new direction. Of these five variables, three were found to be significantly different between the indoor and outdoor trials. Trunk lean relative to the vertical, support knee and hip flexion were significantly different. Indoor athletes maintained a greater forward trunk lean than the outdoor athletes. As discussed, this will serve to lower the athletes centre of gravity and allow for a more horizontal push against the ground, but since the athlete is now accelerating in the new direction, it will also serve to increase the range of motion of hip extension as the athlete pushes back against the ground. A larger range of motion or hip extension allows the athlete to apply force for a greater period of time consequently increasing the impulse in the backward direction.

Support, or stopping knee flexion was considerably greater in the indoor group. This was an anticipated difference as the indoor athletes demonstrated a lower position in general through the cut. This difference also served to place the indoor group in a more advantageous position from which to apply force in the backwards direction. The centre of gravity will be lowered through deeper knee flexion and the range of motion of the knee will be increased for the push away from the cut.

Push off of the first step in the new direction

Four variables were measured at push off of the first step in the new direction, however none of them were found to be significantly different between the two groups. This was not an unexpected finding as the athletes' movements resemble a normal running stride by this point in the skill. Additionally, none of the variables from this phase of the skill were highlighted as being significantly correlated to test time or chosen as significant predictors of test time by the regression analysis. It would seem, then, that the crucial element for effectively completing the 505 drill is the rate at which an athlete can execute the actual change of direction maneuver with less of an emphasis on the acceleration away from the cut.

Kinematic Relationships with Test Time

Correlation analysis was conducted on all variables to determine which variables were significantly correlated to the athlete's test time

Indoor Athlete Correlation Analysis

The results of the indoor correlation analysis determined 10 of the variables to be significantly related to the athlete's test time. During the last step, contact hip flexion and trunk lateral flexion away from the cut as well as forward trunk lean were significantly correlated to test time. All three had negative correlations indicating more flexion in the hip and trunk would produce a shorter test time. At touch down of the jab step, three variables were found to be significantly correlated to test time.

These were; stopping knee flexion, ipsilateral shoulder flexion to the jab leg and lateral trunk flexion. At maximum knee flexion of the jab knee, the only variable that was significantly correlated to test time was flexion of the jab knee. This, however, was a positive correlation indicating that a greater degree of flexion will increase the athlete's test time. Or, decreasing knee flexion in the jab knee will decrease the test time. At push off of the jab step trunk forward lean and shoulder abduction of the unilateral shoulder to the jab leg were found to be correlated to test time. Trunk forward lean was also significantly correlated to test time at push off of the first step in the new direction. This further emphasizes the importance of a low trunk position while executing the 180° cut on a hardwood floor.

Outdoor Athlete Correlation Analysis

The correlation analysis for the outdoor athletes determined 5 variables to be significantly correlated to test time. At touchdown of the jab knee, jab knee flexion, the lateral distance from the jab hip to the jab heel and shoulder flexion of the ipsilateral shoulder to the jab leg were significantly correlated to test time. Jab knee flexion was negatively correlated to test time indicating that athletes who maintained a relatively unflexed knee would perform better on the test. Also, the greater the distance from the jab hip to the jab heel generally resulted in a shorter test time. Both variables serve to keep the athletes centre of gravity further from the turnaround point and therefore allow the athlete to cover a shorter distance within the testing zone.

Two additional variables that were significantly correlated to test time were linear velocity of the athlete one meter before the turnaround point and duration of support stance of the jab step. These findings were expected, but the investigator believes they could be highly dependent on the strength of the athlete. In order for an athlete to maintain a high linear velocity just before execution of the cut but also have the strength and control to minimize the time the jab foot is on the ground, the athlete must be very strong and powerful to push off the jab foot quickly after touchdown.

Stepwise Multiple Regression Analysis

A forward stepwise multiple regression analysis was conducted in order to determine which variables were important predictors of test time. Separate regression equations were determined for both the indoor group and the outdoor group.

Indoor Athlete Regression Analysis

The regression equation to predict the athlete's test time included four variables that explained 95.7% of the test time. These variables included trunk lean relative to the vertical at jab step push off, hip extension velocity at jab step push off, jab knee flexion at maximum flexion of the jab knee and trunk lateral flexion at touchdown of the last step before the jab step.

Outdoor Athlete Regression Analysis

The forward stepwise multiple regression analysis performed on the outdoor group selected four variables which were able to predict 88.8% of the athlete's test time. The four variables selected were: the athlete's linear velocity one meter before the turnaround point, the athlete's linear velocity one meter after the turnaround point, hip extension velocity of the jab leg at push off of the jab leg and support stance time of the jab foot. All four variables selected for the outdoor group have an element of control and power to them. This may be harder to change than variables related to technique such as the measured kinematic variables.

Conclusions

Based on the findings of this study, the following conclusions appear to be justified:

1. Indoor athletes completed the 505 test in a shorter time than the outdoor athletes.

2. Indoor athletes demonstrated a greater degree of trunk forward lean throughout the skill which enabled them to have a lower center of gravity compared to their outdoor counterparts.

3. Indoor athletes were able to keep their centre of gravity further from the turnaround point through a slight slide across the gym floor, a greater degree of abduction in their jab hip and a lateral lean away from the cut. This allowed them to travel a shorter linear distance within the testing zone.

4. Indoor athletes had a greater degree of hip and knee flexion in their support leg at flexion of the first step in the new direction. Consequently, they had a larger range of motion of hip and knee extension through the first push in the new direction.

5. Indoor athletes generally displayed a greater degree of lateral trunk lean away from the jab step than the outdoor athletes. Furthermore, the indoor athletes that exhibited a large degree of lateral trunk flexion were more successful at the test than the indoor athletes that only had a moderate amount of lateral trunk flexion.

6. Indoor athletes in this study who maintained a relatively unflexed jab knee at maximum flexion of the jab knee achieved a shorter test time than those who displayed a greater degree of knee flexion in the jab knee.

7. The greater trunk flexion of the indoor athletes facilitated contact with the ground with one or both of the athlete's hands.

8. Outdoor athletes who managed to maintain a high linear velocity one metre before the turnaround point tended to perform better on the test.

9. Outdoor athletes that had a shorter duration of support stance of their jab foot generally achieved a shorter test time than the outdoor athletes with a longer duration of support stance of their jab foot.

10. Outdoor athletes that attained a higher linear velocity one meter after the turnaround point performed better on the test than those that attained a slower linear velocity one meter after the turnaround point.

11. Athletes of both groups tended to achieve a shorter test time when they displayed a high angular velocity of hip extension as they pushed off from their jab foot.

Recommendations

The following recommendations are suggested for future studies conducted on the 180° cutting maneuver.

1. Future studies should use several accelerometers on the athlete's body. This will give very reliable data on the athletes velocity throughout the test and not just at certain points within the testing zone.

2. Greater attention should be paid to the role of the arms in the 180° cutting maneuver. Use of a force platform would enable the investigator to determine how the ground reaction forces are altered with different arm actions.

3. A study conducted on athletes who participate in both the indoor and outdoor groups would allow for paired data and help to determine the effects of a different surface type on cutting technique within the same athletes.

4. The use of in shoe force transducers would be able to distinguish the relative contributions of the jab foot and the stopping foot during double support of the jab leg. The force transducers would also give reliable temporal analysis of when a foot is weighted or unweighted. The current study only evaluated foot contact or non contact.

5. The current study evaluated the cutting technique of university caliber athletes. It would be beneficial to compare this information to a group of elite (professional or Olympic level) athletes performing the 505 drill.

6. Future studies need to include more subjects to ensure significant results and better generalization to a wider range of subjects. Such a study could include females to give a gender comparison as well.

7. Additional research should be conducted on the different types of footwear worn by the athletes. The current study assumed all court shoes were the same and all cleats were the same. There may have been slight variations in the coefficient of friction between the different shoes worn by the athletes. Further research should be conducted to determine the differences this makes on the technique used in the 180° cut.

Coaching Recommendations

Cutting technique, in both indoor and outdoor athletes, plays an important role in the overall ability of an athlete to succeed at the elite level. In order for developing athletes to improve in an efficient manner it is important that coaches and athletes understand the effects of technique flaws. Technique should be strongly stressed at an early age in order to correct any improper or potentially dangerous movement patterns before they become engrained in the athletes. Consequently, some coaching recommendations have been made based on the findings of this study:

1. Athletes need to emphasize a low trunk position through the cut. This means a high degree of both forward and lateral trunk lean in order to optimize the angle at which the athlete can apply force to the ground as well as create a highly stable athlete. One way to encourage a low trunk position is requiring the athletes to touch the ground when performing the cut in a drill or training situation.

2. Coaches should stress the difference between maintaining contact with the stopping foot throughout the jab step and lifting the stopping foot. Contact with the ground should be encouraged while the jab step is on the ground.

3. The movement of the arms should remain in the sagittal plane during the deceleration and acceleration phases of the test.

4. Outdoor athletes need to minimize the duration of support stance time of their jab foot. This will require great control of the final deceleration and acceleration away from the cut.

5. All athletes involved in sports requiring fast change of direction maneuvers should incorporate exercises to increase the angular velocity of hip extension into their strength and conditioning program. This would include squat jumps, box jumps and other plyometric exercises. Additional exercises to increase core strength and stability should also be included in a strength and conditioning program.

References

Aguinaldo, A. (2007). Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *Journal of Applied Biomechanics*, 23, 42-51.

Baker, D. (1999). A comparison of running speed and quickness between elite professional and young rugby league players. *Strength and Conditioning Coach,* 7(3), 3-7.

Barnes, M. & Attaway, J. (1996). Agility and conditioning of the San Francisco 49ers. *Strength and Conditioning,* 118, 10-16.

Besier, T., Lloyd, D., Ackland, T., & Cochrane, J. L. (2001). Anticipatory effects of knee joint loading during running and cutting maneuvers. *Medicine and Science in Sports and Exercise,* 33, 1176 – 1181.

Bezodis, N. Trewartha, G. Wilson, C. & Irwin, G. (2007). Contributions of the non-kicking-side arm to rugby place-kicking technique, *Sports Biomechanics*, 6(2), 171-186.

Blazevich, T. (1997). Resistance training for sprinters (part 1): Theoretical considerations. *Strength and Conditioning Coach*, 4(3), 9 – 12.

Bloomfield, J., Polman, R., O'Donoghue, P., Mcnaughton, L. (2007). Effective speed and conditioning methodology for random intermittent dynamic type sports. *Journal of Strength and Conditioning Research,* 21(4), 1093-1100.

Brown, T. & Vescovi, J. (2003). Efficient arms for efficient agility. *National Strength and Conditioning Association,* 25(4), 7–11

Bryant, R. (2006). Inside the numbers (offense). *NFL Draft Blitz*. Retrieved November 2, 2007. From http://www.nfldraftblitz.com/insidethenumbers.htm

BTS Digivec. (2006). Retrieved November 27, 2007. From http://www.zflomotion.com/software/bts_digivec.php.

Burt, M. (1999). Running biomechanics. *Do it Sports Network.* Retrieved November 2, 2007. From http://www.doitsports.com.

Bushnell, T. (2004). *A biomechanical analysis of sprinters vs. distance runners at equal and maximal speeds.* MSc Thesis. Brigham Young University. Retreived November 8, 2008, from Brigham Young University Digital Thesis.

Calahan, T. D., Johnson, M. E., Liu, S. & Chao, Y. S. (1989). Quantitative measurments of hip strength in different age groups. *Clinical Orthopaedics and Related Research,* 246, 136-145.

Chelladuri, P. (1976). Manifestations of agility. *Canadian Association of Health, Physical Education and Recreation,* 42, 36-41.

Cheng, A. J. & Rice, C. L. (2005). Fatigue and recovery of power and isometric torque following isotonic knee extensions. *Journal of Applied Physiology*, 99, 1446-1452.

Craig, B. W. (2004). What is the scientific basis of speed and agility? *Strength & Conditioning Journal,* 26(3), 13-14.

Cook, Gray. (2003). *Athletic body in balance.* Champaign, IL. Human Kinetics.

Der, G. & Everitt, B. (2006). *Statistical analysis of medical data using SAS.* Boca Raton, FL: Chapman and Hall/CRC.

Draper, J. & Lancaster, M. (1985). The 505 test: A test for agility in the horizontal plane. *The Australian Journal for Science and Medicine in Sport*, 17(1), 15–18.

Dyson, G. (1973). *The mechanics of athletics.* London: University of London Press.

Enoka, R. (2002). *Neuromechanics of Human Movement* (3rd ed.). Champaign, Ill: Human Kinetics.

Faccioni, A. (2001). Speed development for team sport athletes. *The New Zealand Coach.* 6(1), 10-13.

Francis, C. (1997). *Training for speed.* Canberra, Australia: Faccioni Speed and Conditioning Consultants.

Frederick, E. C. (1993). Optimal frictional properties for sport shoes and sport surfaces. In: J. Hamill; T. Derrick & T. Elliott (Ed.), *Biomechanics Sports XI, Proceedings of the International Society of Biomechanics in Sports* (pp. 15-21). Amherst, MA.

Glasser, J., Caterisano, A., & Brown, W. (1999). Off-season training for women's softball. *National Strength & Conditioning Association,* 21(4), 54-59.

Goodman, C. (2008). Improving agility techniques. *National Strength and Conditioning Association's Performance Training Journal*, 7(4), 10-12.

Grant, S., Oommen, G., McColl, G., Taylor, J., Watkins, L., Friel, N., Watt, I. & McLean, D. (2003). The effect of ball carrying method on sprint speed in rugby union football players. *Journal of Sports Sciences,* 21, 1009–1015.

Hall, S. J. (2007). *Basic biomechanics* (5th ed.). New York, NY: McGraw-Hill Higher Education.

Hamill, J. & Knutzen, K. (1995). *Biomechanical basis of human movment.* Media PA.: Lippincott Williams and Wilkins.

Harrison, D. & Comyns, T. (N.D.). Biomechanics of the sprint start. Retrieved November 2, 2007 From http://coachesinfo.com/article/219/.

Hassard, T. (1991). *Understanding biostatistics*. St. Louis: Mosby.

Hay, J. G. (1993). *The biomechanics of sports techniques* (4th ed.). Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Heidt, R., Dormer, S., Cawley, P., Scranton, P., Losse, G. & Howard, M. (1996). Differences in friction and torsional resistance in athletic shoe-turf surface interfaces. *American Journal of Sports Medicine*, 24(6), 834-842.

Holden, J.P., & Cavanagh, P. R. (1991). The free moment of ground reaction in distance running and its changes with pronation. *Journal of Biomechanics,* 24, 887-897.

Illinois agility test. (2007). Retrieved November 2, 2007 from: http://en.wikipedia.org/wiki/Illinois_agility_test

Jeffreys, I. (2008). Movement training for football. *United Kingdom Strength and Conditioning Association.* 2, 14-23.

Jindrich, D., Besier, T. & Lloyd, D. (2006). A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics,* 39, 1611–1620.

Lee, S.J., & Hilder, J. (2008). Biomechanics of overground verses treadmill walking in healthy adults. *Journal of Applied Physiology,* 104, 747-755.

Lyons, K., Perry, J., Gronley, J., Barnes, L., & Antonelli, L. (1983). Timing and relative intensity of hip extensor and abductor muscle action during level and stair ambulation: an EMG study. *Physical Therapy Journal*, 53(10), 1597-1605.

Mackenzie, B. (2004). Performance evaluation tests. *Brianmac Sports Coach.* Retrieved November 2, 2007. From http://www.brianmac.co.uk.

Mann, R. A., Moran, G. T., & Dougherty, S. E. (1986). Comparative electromyography of the lower extremity in jogging, running and sprinting. *American Journal of Sports Medicine,* 14(6), 501-510.

McArdle, W., Katch, F., & Katch, V. (2001). *Exercise physiology* (5th ed.). Baltimore, MD: Lippincott Williams and Wilkins.

McDonald, C. (1999). Newton and Dyson pumped-up on Hill and Cavagna. *Track Coach,* 149, 4758-4762.

McGinnis, P. (1999). *Biomechanics of sport and exercise.* Champlaign, Il: Human Kinetics.

Milburn, P., & Barry, E. (1998). Shoe-surface interaction and the reduction of injury in rugby union. *Sports Medicine, May;* 25(5), 319-327.

Narum, S. (2006). Beyond bonferonni: less conservative analysis for conservation genetics. *Conservation Genetics*, 7, 783-787.

Negrete, R., & Brophy, J. (2000). The relationship between isokinetic open and closed kinetic chain lower extremity strength and functional performance. *Journal of Sports Rehabilitation,* 9, 46 – 61.

Nordin, M. & Frankel, V. (2001). *Basic biomechanics of the musculoskeletal system.* Baltimore, MD.: Lippencott Williams and Wilkens.

Rippetoe, M & Kilgore, L. (2005). *Starting strength.* Wichita Falls, TX.: Aasgaard Company.

Roozen, M. (2004). Resisted agility. *Performance Training Journal,* 4(3), 23-24.

Sayers, M. (1998). Running techniques for running rugby. *Applied Sports Knowledge.* Retrieved December 11, 2008, from http://www.ask.net.au/resources.html

Sayers, M. (2000). Running technique for field sports players. *Sports Coach.* 23(1), 26–27.

Sheppard, J. (2003). Strength and conditioning exercise selection in speed development. *Strength and Conditioning Journal, 25*(4), 26 – 30.

Sheppard, J.M., Young, W.B., Doyle, T.L.A., Sheppard T.A., & Newton R.U. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *Journal of Science and Medicine in Sport,* 9(4), 342-349.

Sleivert, G. & Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. *European Journal of Applied Phyisology.* 91, 46-52.

Stucke, H. Baudzus, W. & Bauman, W. (1984). "On friction characteristics of playing surfaces." In *Sport Shoes and Playing Surfaces*, E.C. Frederick, Ed., Champaign, Ill: Human Kinetic Publishers, Inc. 87-97.

Tsitskarsis, G., Theoharopoulus, A., & Garefis, A. (2003). Speed, speed dribble and agility of male basketball players playing in different positions. *Journal of Human Movement Studies,* 45, 21–30.

Valiant, G., Cooper, L. & McGuirk, T. (1986). Measurements of the rotational friction of court shoes on an oak hardwood playing surface. In P. Allard, M. Gagnon (Eds.), *Proceedings of the North American Congress on Biomechanics* (p 295-296). Chicago, Illinois.

Vescovi, J.D. (2001). Agility. *NSCA Strength and Conditioning online Journal,* Retrieved Augest 23, 2007 from http://www.nsca-lift.org.

Webb, P., & Lander, J. (1983). An economical fitness testing battery for high school and college rugby teams. *Sports Coach,* 7(3), 44 – 46.

Wood, R. J. (2005). The 505 agility test. *Rob's Home of Fitness Testing*. Retrieved September 26, 2007. From http://www.topendsports.com/testing.

Young, W. B., Hawken, M., & McDonald, L. (1996). Relationship between speed, agility, and strength qualities in Australian rules football. *Strength and Conditioning Coach,* 4(4), 3 – 6.

Young, W. B., McDowell, M. H., & Scarlett, B. J. (2001). Specificity of sprint and agility training methods. *Journal of Strength and Conditioning Research,* 15(3), 315 – 319.

Young, W., James, R., & Montgomery, I. (2002). Is muscle power related to running speed with changes of direction? *Journal of Sport Medicine and Physical Fitness,* 43, 282-288.

Appendix A

Ethics Approval

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APPROVAL FOR SERVICES

23 January 2008

TO: **Marion Alexander**
Faculty of Physical Education

FROM: **Stan Straw, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Approval for Services to Elite Canadian and Manitoba Athletes**

Film Analysis of the Skills of Elite Canadian and Manitoba Athletes has been approved for 2008.

Bringing Research to Life

Appendix B

Informed Consent Forms

Guidelines for Informed Consent

Research Project Title: A comparison of the technique of the 180° cutting maneuver performed on grass and on a hardwood floor.
Researcher(s): Brad Gerbrandt. and Advisor: Marion J.L. Alexander, professor, Faculty of Physical Education and Recreation Studies

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Outline of the Study:

The purpose of this study is to examine the cutting technique as performed outdoors on a grass surface while wearing cleats as well as the cutting technique performed on a hardwood floor wearing running shoes, in order to determine the key movements of cutting technique and assist coaches in improving the technique of their athletes. You are either currently a member of an elite team, or are considered to be a prospect for membership in this elite program.

Methodology:

You will be filmed, on one occasion, while practicing at the CMU soccer field or gymnasium, using filming equipment from the Biomechanics Laboratory in the Faculty of Physical Education. All practices are administered by the coach and the investigator, who will instruct you regarding the skills to perform. Prior to filming you, the filming procedures will be explained. You will be asked to perform the skills as you normally would in a competitive situation, and your techniques will be filmed. You must provide informed consent for the study prior to filming. All filming procedures will be organized and administered by the graduate student, Brad Gerbrandt, who will be assisted by the principal investigator, Dr. Marion Alexander and other qualified graduate students.

Video cameras will be used to film the athletes. The investigator will instruct you regarding which skills are to be performed while the cameras are filming. The cameras will continue to film you until all of the skills of interest have been performed

When filming is completed, the videos will be analyzed by the principal investigator and the graduate students working on the project. The types and ranges of motion in each of the skills, as well as selected linear and angular velocities in each of the skills will be described. The technique descriptions developed from this analysis will eventually be published in a thesis titled "A comparison of the technique of the 180° cutting maneuver performed on grass and on a hardwood floor."

Risk:

There is no additional risk involved in this study, as you will perform the skills as you would normally perform them in a practice situation. The cameras will be out of the way, and will not interfere in any way with your performance of the skills.

Confidentiality:

The film will be viewed only by the researchers involved in the study, the coaches, and by the athletes in the study. The amount of data available to the athletes will be determined by the coaches. The data derived from the film will be available to the coaches and athletes in order to help to improve performance. The video films and all of the research data will be kept in the Biomechanics laboratory. No one will have access to the footage or data except the principal investigator and the research assistants. It is possible that the technique analysis data will be published in a technical journal, however the identity of all subjects in the study will be kept confidential.

Signature:

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

<u>Principal Researcher</u>: Marion J.L. Alexander, Professor, Faculty of Physical Education and Recreation Studies, Ph 474 8642

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122.

Participant's name (print)	Signature	Date
Parent/Guardian (if under 18 years of age)	Signature	Date
Researcher and/or Delegate	Signature	Date

Appendix C

Pilot Study

Pilot Study

Introduction

The purpose of the pilot study was to collect video from two subjects demonstrating each of the tasks of interest for this study. The group included two athletic males, similar in age and ability to the desired research group. The pilot study also provided the investigator with the opportunity to test the methods which were utilized during the thesis, including camera setup and filming protocol. A final purpose of the pilot study was to determine the similarities and differences that may exist between the 180° cutting maneuver executed outside while wearing cleats and inside wearing court shoes. Filming for the pilot study was conducted on three separate occasions. Athlete "A" was filmed on August 19, 2007, outdoors at the Assiniboine Park in Winnipeg, Manitoba and indoors on September 12, 2007, at the Canadian Mennonite University gym, in Winnipeg, Manitoba. Athlete "B" was filmed cutting outdoors at the University of Manitoba practice soccer field, and indoors at Investors Group Athletic Centre at the University of Manitoba. Both sessions for athlete "B" were held on October 3, 2007.

Methods

Subjects

The two athletes volunteered for the project and were chosen for their experience playing a variety of team sports which involve running and cutting both outdoors while wearing cleats and indoors while wearing running shoes. The subjects were provided an adequate amount of time to warm up to ensure optimal performance and to decrease the chance of injury. They were also given 2-3 practice attempts to ensure accuracy of the jab step and some practice in the test.

Filming Technique

During the filming, a camera positioned approximately 8 meters away and perpendicular to the line of travel was used to capture the motions of the athlete in the sagittal plane. A second camera, positioned in front of the athlete's line of travel and approximately 10 meters away, was used to capture movements in the frontal plane. Additionally, an overhead camera was set up to capture the motions of the athlete in the transverse plane. The sagittal and frontal cameras were positioned to allow for the cameras to be located at a 90° angle to each other. This allowed for a three dimensional view of the motions performed by the subjects in the study. All cameras were set to a minimum shutter speed of 1/500th of a second to allow for an adequate amount of light to be exposed to the video while preventing any blurring of the subjects during the cutting tasks.

Experimental Procedure

The subjects were instructed to sprint down the line of cones and make a 180° cut at the turnaround point, ensuring that at least one foot became parallel with the final cone before movement in the opposite direction was initiated. Attempts in which the athlete over or under shot the turn around point were deemed failed attempts and were repeated.

Results

When video analysis was conducted between the 180° cutting technique utilized indoors and outdoors, the results showed differences and similarities in regards to their mechanics. The following table (Table 3.2) shows the results for the variables which were measured during the pilot study.

Table 1. Kinematic variables measured from pilot study.

Position	Athlete A Outdoor	Athlete B Outdoor	Outdoor Average		Athlete A Indoor	Athlete B Indoor	Indoor Average
TD of last step							
Trunk lean relative to vertical (degrees)	-3.00	40.10	18.55		-8.20	27.80	9.80
Front knee flexion (degrees)	11.00	63.50	37.25		4.60	72.40	38.50
Front hip flexion (degrees)	49.20	80.80	65.00		38.90	70.90	54.90
Length of step (m)	1.62	0.82	1.22		2.02	1.02	1.52
Jab step touch down							
Trunk lean relative to vertical (degrees)	21.20	5.20	13.20		26.80	35.00	30.90
Trunk lateral flexion (degrees)	10.50	20.60	15.55		4.90	17.50	11.20
Left knee flexion (degrees)	122.70	100.50	111.60		125.80	107.00	116.40
Jab knee flexion (degrees)	35.30	36.40	35.85		46.30	29.80	38.05

Jab hip flexion (degrees)	90.20	81.00	85.60		85.00	50.90	67.95
Foot plant relative to direction of travel (degrees)	63.50	115.40	89.45		92.20	94.50	93.35
Abduction of jab hip (degrees)	49.40	42.50	45.95		43.90	46.80	45.35
Trunk rotation relative to the direction of travel (degrees)	62.00	97.20	79.60		60.90	90.30	75.60
Length of last step (degrees)	1.15	0.78	0.97		0.98	0.93	0.96

Max flexion of jab step							
Trunk lean relative to vertical (degrees)	32.20	69.60	50.90		34.40	50.70	42.55
Trunk lateral flexion (degrees)	9.10	16.30	12.70		4.80	23.80	14.30
Back knee flexion (degrees)	124.70	82.30	103.50		102.10	90.00	96.05
jab knee flexion (degrees)	68.80	85.50	77.15		67.10	90.20	78.65
Jab hip flexion (degrees)	103.00	109.60	106.30		104.00	78.60	91.30

Jab step push off							
Trunk lean relative to vertical (degrees)	32.60	45.50	39.05		28.20	50.40	39.30
Back knee flexion (degrees)	74.30	82.90	78.60		69.20	92.90	81.05
Jab knee flexion (degrees)	14.30	33.60	23.95		39.10	20.30	29.70
Jab hip flexion (degrees)	95.10	26.60	60.85		79.00	24.50	51.75
Back hip flexion (degrees)	16.60	50.10	33.35		48.70	85.90	67.30
Trunk rotation relative to direction of travel (degrees)	38.80	15.70	27.25		60.20	21.00	40.60
Trunk ROM during jab support (degrees)	79.20	67.10	73.15		58.90	68.70	63.80
Support stance time (s)	0.43	0.50	0.47		0.42	0.45	0.43

Max flexion of 1st step							
Trunk lean relative to the vertical (degrees)	22.10	45.50	33.80		40.70	50.40	45.55
Length of step (m)	0.92	0.42	0.67		1.11	1.12	1.12
Lateral distance of first step (degrees)	0.50	0.00	0.25		0.15	0.00	0.08
Support knee flexion (degrees)	65.10	82.90	74.00		69.80	92.90	81.35
Support hip flexion (degrees)	28.10	50.10	39.10		44.60	85.90	65.25

End of 1st step push							
Support hip hyperextension (degrees)	8.5 Hyper ext	8.8 flexion	0.1 flexion		9.20	15.8 flexion	3.3 flexion
Support knee flexion (degrees)	8.90	13.50	11.20		20.40	14.10	17.25
Support ankle plantarflexion (degrees)	49.20	44.60	46.90		26.70	40.40	33.55
Support stance time (s)	0.25	0.55	0.40		0.28	0.92	0.60

Additional variables							
Number of approach strides	3.00	4.00	3.50		3.00	4.00	3.50
Time in testing zone (s)	2.60	2.66	2.63		2.50	2.42	2.46
Velocity 3 meters before turnaround point (m/s)	4.70	4.19	4.45		5.24	4.93	5.09
Velocity 2 meters before turnaround point (m/s)	3.80	3.83	3.82		4.22	4.25	4.24
Velocity 1 meter before turnaround point (m/s)	2.95	2.74	2.85		2.71	2.45	2.58

Velocity 1 meters after turnaround point (m/s)	1.81	3.02	2.42		2.06	3.27	2.67
Velocity 2 meters after turnaround point (m/s)	3.18	4.30	3.74		3.96	4.47	4.22
Velocity 3 meters after turnaround point (m/s)	4.21	5.43	4.82		4.39	5.03	4.71

Angular velocity of hip/knee during propulsive phase							
Hip ext. velocity of jab push (degrees/s)	263.50	200.00	231.80		248.00	221.10	234.60
Knee ext. velocity of jab push (degrees/s)	258.50	279.50	269.00		280.00	237.10	258.60
Hip ext. velocity of first push (degrees/s)	184.20	263.80	224.00		171.00	355.20	263.10
Knee ext. velocity of first push (degrees/s)	356.00	373.30	364.70		233.90	471.50	352.70
Hip ext. velocity of second push (degrees/s)	229.50	344.60	287.10		145.50	338.80	242.20
Knee ext. velocity of second push (degrees/s)	288.00	314.00	301.00		267.50	248.70	258.10

The results show that on average, the 505 drill is performed 0.17 s faster when conducted indoors while wearing running shoes. This is a result of slightly higher instantaneous velocities approaching the cut as well as when exiting the testing zone. Therefore, the indoor trial saw the athletes decelerate and accelerate faster than the outdoor trials. Trunk lean was also considerably increased in the indoor trial at touchdown of the jab step as well as maximum flexion of the first step in the new direction. This is a sign that the indoor trials allow the athlete to lower his centre of gravity to a lower level when compared to outdoor trials, making direction changes easier. Support stance time of the jab step was an average of 0.033s shorter for the indoor trials. This could be one of the most important variables measured as it indicates how quickly the athlete was able to decelerate his forward velocity to 0 m/s and then accelerate again from a stationary position.

However, trunk rotation at the push off phase of the jab step was less in line with the new direction of travel for the indoor trial. This will often result in lateral motion of the athlete's centre of gravity increasing the time required to pass through the testing zone. Further, it will increase the athletes' recruitment of his hip abductor muscles instead of his larger hip extensor muscles to push off from the jab step. Also, the angular velocities of hip and knee extension of the push off from the jab step and first two strides in the new direction were generally greater for the outdoor trials. However, this could be a result of the decreased stride length of each of the first strides in the new direction for the outdoor trials.

A larger sample size proved to yield slightly different results, however, the main goal of the pilot study was not to draw conclusions regarding the differences between the testing trials. Instead, the goal of the pilot study was to provide the investigator with the opportunity to ensure that protocol and filming techniques would be adequate for data collection during the thesis. The investigator was able to measure the variables of interest using the three camera set up as outlined above. The pilot study provided useful feedback to the investigator in regards to the method and protocol for filming, as well as the rationale for the study of attempting to maximize the effectiveness of the 180° cutting maneuver when competing on grass or on a gym floor.

Appendix D

Subject Characteristics

Subject Characteristics

Subject	Variables		
Indoor athletes	**Age**	**Height**	**Weight**
I 1	19	186	86.36
I 2	20	190	85.45
I 3	22	188	86.36
I 4	21	185	81.82
I 5	23	184	82.73
I 6	23	190	88.64
I 7	19	180	75.00
I 8	22	181	77.27
I 9	22	188	81.82
I 10	21	185	80.00
I 11	24	186	81.82
I 12	22	182	79.55
Mean	21.50	185.42	82.23
Outdoor Athletes			
O 1	21	175	80.90
O 2	29	180	82. 3
O 3	30	186	79.50
O 4	27	181	93.40
O 5	27	182	68.20
O 6	22	172	70.40
O 7	21	180	76.40
O 8	20	185	80.90
O 9	22	178	82.30
O 10	20	180	75.00
O 11	28	183	80.90
O 12	29	185	84.10
Mean	24.67	181	79.27

Appendix E

Indoor Athletes Raw Data

Indoor Subjects (Test Results)														
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Time in testing zone (s)	2.25	2.28	2.29	2.31	2.32	2.34	2.29	2.29	2.29	2.21	2.25	2.14	**2.27**	**0.05**
Split time (time to maximum knee flexion)	1.08	1.05	1.02	1.02	1.15	1.07	0.95	1.00	0.93	0.98	0.97	0.93	**1.01**	**0.07**
Percent of total time	0.48	0.46	0.45	0.44	0.50	0.46	0.41	0.44	0.41	0.44	0.43	0.43	**0.45**	**0.03**

Indoor Subjects (TD of Last step)														
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Trunk lateral flexion* (degrees)	-14.80	5.60	-5.20	-17.10	-19.10	-9.80	-22.40	-15.50	-19.10	-46.70	-25.40	-41.70	**-19.27**	**14.30**
Contact knee flexion (degrees)	60.40	77.90	52.70	79.70	72.60	84.00	51.30	55.10	76.10	93.10	41.40	117.60	**71.83**	**21.19**
Contact hip flexion (degrees)	73.50	111.40	77.60	69.60	65.40	76.70	85.00	60.40	84.20	122.30	70.10	115.20	**84.28**	**20.67**
Length of step (m)	0.24	0.38	0.99	0.43	0.51	0.35	0.71	0.64	1.44	0.47	1.35	0.95	**0.71**	**0.40**
Forward trunk lean (degrees)	32.60	65.90	35.50	24.60	23.20	24.60	35.30	25.00	45.10	57.30	43.80	57.10	**39.17**	**14.69**

	Indoor Subjects (Jab step TD)													
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Trunk lean relative to vertical (degrees)	46.50	70.70	36.50	32.20	20.40	38.00	49.80	35.70	65.20	86.50	66.40	59.10	**50.58**	**19.25**
Trunk lateral flexion* (degrees)	-33.10	9.30	4.40	-20.70	-24.50	-12.10	-24.40	-21.50	-28.70	-59.40	-34.50	-49.00	**-24.52**	**19.46**
Stopping knee flexion (degrees)	101.20	106.90	96.40	117.90	97.00	106.90	105.30	95.40	101.60	128.10	104.30	134.50	**107.96**	**12.54**
Jab knee flexion (degrees)	25.00	42.50	40.90	48.20	60.20	105.10	53.80	47.20	54.40	35.00	25.90	68.70	**50.58**	**21.53**
Jab hip flexion (degrees)	59.50	103.90	62.60	60.70	56.80	104.30	76.40	67.00	84.40	110.00	80.60	80.50	**78.89**	**18.79**
Foot plant relative to direction of travel (degrees)	95.40	102.30	87.80	86.50	81.30	76.80	110.20	82.60	73.80	99.10	87.80	59.60	**86.93**	**13.72**
Abduction of jab hip (degrees)	5.30	35.60	39.90	16.10	15.70	46.80	13.00	10.80	17.70	7.20	11.30	7.20	**18.88**	**13.93**
Length of last step (m)	0.93	0.58	0.63	0.67	0.70	0.54	0.81	0.76	0.73	0.67	0.85	0.42	**0.69**	**0.14**
Dist from jab hip to jab heel (m)	0.65	0.65	0.72	0.64	0.59	0.74	0.64	0.63	0.59	0.64	0.58	0.59	**0.64**	**0.05**
Contralat shoulder abd (degrees)	92.80	0.00	41.70	41.80	65.50	7.00	11.90	20.20	29.80	61.50	39.40	33.50	**37.09**	**26.67**
Contralat shoulder flexion (degrees)	59.20	16.90	0.00	3.80	13.40	36.10	66.40	0.00	55.70	64.30	1.50	0.00	**26.44**	**27.87**
Unilat shoulder abd (degrees)	20.10	18.20	39.80	24.30	44.10	11.50	18.00	14.40	15.20	-10.00	7.90	-6.10	**16.45**	**15.67**
Unilat shoulder flexion (degrees)	-8.50	70.70	34.30	-35.30	-50.90	-2.20	55.40	4.40	55.80	85.80	49.10	55.50	**26.18**	**43.61**

Indoor Subjects (Maximum knee flexion of jab step)														
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Trunk lean relative to vertical (degrees)	54.30	68.00	47.10	54.60	40.40	47.10	67.00	40.60	83.20	83.90	79.00	71.30	**61.38**	**16.08**
Trunk lateral flexion* (degrees)	-44.00	-24.10	-21.10	-18.80	-14.20	-32.40	-38.40	-35.20	-18.70	-49.40	-36.20	-20.50	**-29.42**	**11.35**
Stopping knee flexion (degrees)	103.10	132.00	107.70	94.20	121.10	105.60	103.00	99.10	102.20	93.60	101.10	133.00	**107.98**	**13.44**
Jab knee flexion (degrees)	51.70	28.40	57.30	101.60	82.90	96.20	73.00	61.10	65.90	66.70	75.40	14.80	**64.58**	**25.08**
Jab hip flexion (degrees)	79.70	91.60	73.10	108.30	74.10	96.10	104.90	60.50	101.90	113.10	110.30	42.90	**88.04**	**22.10**

Indoor Subjects (Jab step push off)														
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Trunk lean relative to vertical (degrees)	52.40	52.90	47.20	53.30	36.40	45.00	56.80	54.90	63.70	76.60	52.10	96.30	**57.30**	**15.72**
Stopping knee flexion (degrees)	100.50	91.90	88.80	103.10	95.10	90.80	82.10	90.00	92.60	91.10	89.60	104.60	**93.35**	**6.48**
Jab knee flexion (degrees)	20.50	28.10	26.30	17.80	28.80	59.90	22.00	26.70	14.80	23.30	31.40	26.90	**27.21**	**11.36**
Jab hip flexion (degrees)	10.50	17.90	24.60	21.60	4.80	57.50	68.70	18.40	26.30	36.90	17.30	49.10	**29.47**	**19.62**
Stopping hip flexion (degrees)	73.90	66.80	74.30	98.80	73.10	100.80	99.30	78.90	89.90	100.70	73.30	109.00	**86.57**	**14.60**
Support stance time (s)	0.42	0.27	0.45	0.48	0.45	0.28	0.32	0.35	0.33	0.28	0.30	0.22	**0.35**	**0.09**
Contra lat shoulder abduction (degrees)	0.00	102.60	0.00	18.50	17.20	38.70	50.90	0.00	0.00	0.00	10.20	0.00	**19.84**	**31.09**
Uni lat shoulder abduction (degrees)	15.60	18.00	0.00	14.00	17.20	19.00	0.00	35.70	42.30	88.70	12.00	65.70	**27.35**	**26.69**
Contra lat shoulder flexion (degrees)	65.00	0.00	-44.80	-20.00	52.70	37.70	20.80	-42.10	69.20	77.10	12.50	117.50	**28.80**	**50.25**
Uni lat shoulder flexion (degrees)	-23.80	-15.80	4.00	0.00	0.00	55.20	35.50	0.00	-7.90	22.30	-10.30	36.50	**7.98**	**24.07**

Indoor Subjects (Maximum knee flexion of the first step in the new direction)														
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Trunk lean relative to the vertical (degrees)	52.40	52.90	49.60	59.10	35.10	45.00	49.60	62.00	74.70	66.80	61.40	96.30	**58.74**	**15.77**
Length of step (m)	0.63	0.72	0.55	0.85	0.77	0.71	0.66	0.91	0.69	0.82	0.47	0.63	**0.70**	**0.13**
Lateral distance of first step (degrees)	0.20	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.16	0.05	0.00	0.22	**0.08**	**0.12**
Support knee flexion (degrees)	100.50	91.90	72.90	88.60	93.20	90.80	84.80	89.20	77.80	79.10	62.70	104.60	**86.34**	**11.73**
Support hip flexion (degrees)	73.90	66.80	55.10	84.20	62.00	100.80	69.30	81.10	81.20	76.30	57.60	109.00	**76.44**	**16.31**

Indoor Subjects (Push off of the first step in the new direction)														
Variables	**I 1**	**I 2**	**I 3**	**I 4**	**I 5**	**I 6**	**I 7**	**I 8**	**I 9**	**I 10**	**I 11**	**I 12**	**Mean**	**S.D.**
Support hip hyperextension (-) flexion (+) (degrees)	21.50	18.40	18.10	42.80	10.90	26.40	12.40	13.30	24.70	8.20	26.50	34.30	**21.46**	**10.17**
Support knee flexion (degrees)	29.60	10.20	22.30	31.20	21.00	39.90	14.50	23.80	28.40	16.00	16.60	28.50	**23.50**	**8.44**
Support ankle plantarflexion (degrees)	28.90	38.50	39.70	45.20	29.20	11.50	31.50	37.00	39.00	40.10	40.30	27.20	**34.01**	**9.03**
Support stance time (s)	0.37	0.65	0.22	0.30	0.28	0.27	0.27	0.35	0.30	0.70	0.20	0.55	**0.37**	**0.17**

Indoor Subjects (Additional variables)														
Variables	I 1	I 2	I 3	I 4	I 5	I 6	I 7	I 8	I 9	I 10	I 11	I 12	Mean	S.D.
Number of ground contacts prior to jab	4.00	5.00	3.00	5.00	4.00	5.00	4.00	4.00	3.00	5.00	3.00	4.00	**4.08**	**0.79**
Ground hand contact (1=yes, 0=no)	0.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	**0.58**	**0.51**
Velocity 3 meters before turnaround point (m/s)	5.28	5.91	5.59	5.41	5.63	4.79	6.10	5.67	4.90	5.54	5.41	4.82	**5.42**	**0.42**
Velocity 2 meters before turnaround point (m/s)	3.42	4.50	4.77	4.29	4.63	3.90	4.56	4.31	4.70	4.49	4.84	4.56	**4.41**	**0.40**
Velocity 1 meter before turnaround point (m/s)	2.70	3.20	2.94	3.44	2.57	1.83	3.95	1.70	3.50	1.52	2.48	1.89	**2.64**	**0.79**
Velocity 1 meters after turnaround point (m/s)	2.35	2.58	1.83	3.13	2.71	1.33	2.97	1.63	1.07	2.32	1.32	1.34	**2.05**	**0.72**
Velocity 2 meters after turnaround point (m/s)	3.38	4.42	4.42	3.74	3.60	2.79	4.23	3.01	4.06	4.17	3.90	3.32	**3.75**	**0.54**
Velocity 3 meters after turnaround point (m/s)	4.39	5.51	4.82	4.27	4.16	4.04	4.37	3.77	4.81	4.40	4.65	4.58	**4.48**	**0.45**

Indoor Subjects (Angular velocity of hip/knee extension)														
Variables	I 1	I 2	I 3	I 4	I 5	I 6	I 7	I 8	I 9	I 10	I 11	I 12	Mean	S.D.
Hip ext. velocity of jab push (degrees/s)	234.26	171.30	182.00	209.20	237.30	167.20	190.00	140.70	227.00	185.30	378.90	258.00	**215.10**	**61.84**
Knee ext. velocity of jab push (degrees/s)	193.05	247.40	238.00	317.60	314.20	209.60	262.40	199.00	293.30	379.00	374.10	397.00	**285.39**	**71.97**
Hip ext. velocity of first push (degrees/s)	172.90	199.10	240.00	234.50	245.90	260.00	282.70	236.30	220.60	346.20	228.40	334.20	**250.07**	**50.38**
Knee ext. velocity of first push (degrees/s)	327.50	343.50	259.00	263.00	342.10	206.30	332.00	224.70	170.40	305.70	272.40	306.00	**279.38**	**56.79**
Hip ext. velocity of second push (degrees/s)	427.30	232.50	296.70	308.70	332.30	263.00	310.90	135.50	283.50	198.30	285.50	345.10	**284.94**	**74.21**
Knee ext. velocity of second push (degrees/s)	319.10	225.00	256.00	219.90	261.60	253.00	261.70	175.90	393.90	190.00	279.50	242.10	**256.48**	**57.88**

Appendix F

`Outdoor Athletes Raw Data

Outdoor Subjects (Test Results)														
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Time in testing zone (s)	2.31	2.26	2.33	2.59	2.48	2.57	2.29	2.55	2.55	2.55	2.60	2.66	**2.48**	**0.14**
Split time (s) (time to maximum knee flexion)	1.14	1.02	1.01	1.20	1.20	1.29	1.21	1.10	1.26	1.18	1.27	1.24	**1.18**	**0.09**
Percent of total time	0.49	0.45	0.43	0.46	0.48	0.50	0.53	0.43	0.49	0.46	0.49	0.47	**0.47**	**0.03**

Outdoor Subjects (TD of last step)														
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Trunk lateral flexion (degrees)*	-13.00	-14.60	-16.80	-16.20	-25.30	-16.70	-23.30	-12.70	-12.10	-28.10	3.00	-40.10	**-17.99**	**10.53**
Contact knee flexion (degrees)	94.00	87.20	79.80	77.60	81.30	63.10	74.30	68.40	77.20	76.90	11.00	63.50	**71.19**	**20.95**
Contact hip flexion (degrees)	88.40	90.00	66.20	102.90	83.10	83.70	82.50	77.70	83.90	80.70	49.20	80.80	**80.76**	**13.07**
Length of step (m)	0.25	0.39	0.48	0.30	0.53	0.38	0.58	0.30	0.39	0.09	1.62	0.82	**0.51**	**0.39**
Forward trunk lean (degrees)	27.80	26.40	25.60	47.50	-5.30	9.80	29.10	25.40	27.70	-11.70	30.70	57.20	**24.18**	**19.30**

	Outdoor Subjects (Jab step TD)													
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Forward trunk lean relative to vertical	22.50	40.30	30.10	61.60	13.40	24.00	39.10	22.20	27.10	27.60	21.20	5.20	**27.86**	**14.36**
Trunk lateral flexion (degrees)*	-14.50	-2.10	-20.60	-20.80	-44.50	-16.50	-16.40	-19.30	-16.20	-14.80	10.50	-20.60	**-16.32**	**12.75**
Stopping knee flexion (degrees)	113.60	118.50	69.70	84.10	106.50	108.60	77.40	82.00	78.20	78.60	122.70	100.50	**95.03**	**18.59**
Jab knee flexion (degrees)	52.10	62.70	43.90	21.90	45.10	40.90	47.00	40.20	26.40	45.50	35.30	36.40	**41.45**	**10.89**
Jab hip flexion (degrees)	40.70	78.80	60.20	86.40	68.60	48.20	65.50	48.80	38.20	50.60	90.20	81.00	**63.10**	**18.07**
Foot plant relative to direction of travel (degrees)	60.50	54.50	73.10	112.60	67.80	65.50	76.70	62.50	81.70	82.50	63.50	115.40	**76.36**	**19.52**
Abduction of jab hip (degrees)	30.00	49.50	26.60	13.40	31.50	58.20	30.00	43.20	41.20	40.70	49.40	42.50	**38.02**	**12.21**
Trunk rotation relative to new direction of travel (degrees)	136.30	124.40	123.30	96.80	123.50	128.90	137.40	92.80	139.80	134.30	62.00	97.20	**116.39**	**23.92**
Length of last step (m)	0.49	0.66	0.71	0.89	0.70	0.62	0.79	0.61	0.51	0.49	1.15	0.78	**0.70**	**0.19**
Dist. from jab hip to jab heel (m)	0.57	0.63	0.63	0.50	0.58	0.53	0.54	0.54	0.54	0.51	0.53	0.55	**0.55**	**0.04**
Contralat shoulder abd (degrees)	28.10	57.50	50.30	38.80	17.60	29.10	66.80	40.40	-24.00	-36.00	58.20	71.60	**33.20**	**33.77**
Contralat shoulder flexion (degrees)	0.00	27.70	35.20	50.30	31.40	26.40	22.00	32.00	90.90	40.60	83.70	0.00	**36.68**	**27.79**
Unilat shoulder abd (degrees)	99.00	14.40	80.60	64.60	0.00	12.80	91.00	0.00	0.00	0.00	33.50	17.00	**34.41**	**38.53**
Unilat shoulder flexion (degrees)	0.00	-22.70	-49.50	-33.30	47.50	-9.50	-87.80	-40.30	-65.60	-20.30	-53.90	53.70	**-23.48**	**42.26**

Outdoor Subjects (Maximum knee flexion of the jab step)														
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Trunk lean relative to vertical (degrees)	36.10	52.30	44.20	69.90	59.80	52.70	34.50	42.80	29.10	37.70	32.20	69.60	**46.74**	**14.09**
Trunk lateral flexion (degrees)*	-24.70	11.60	-32.00	-16.10	-53.70	45.00	-20.10	-19.70	-9.10	16.70	9.10	16.30	**-6.39**	**26.88**
Stopping knee flexion (degrees)	116.10	104.70	76.10	89.10	102.70	118.40	114.30	78.50	78.50	61.00	124.70	82.30	**95.53**	**20.56**
jab knee flexion (degrees)	65.70	72.80	64.80	61.20	55.60	67.10	78.20	75.00	75.90	80.40	68.80	85.50	**70.92**	**8.60**
Jab hip flexion (degrees)	62.80	104.50	80.60	114.50	77.50	94.30	76.80	85.40	63.70	81.20	103.00	109.60	**87.83**	**17.25**

	Outdoor Subjects (Push off of the jab step)													
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Trunk lean relative to vertical (degrees)	40.70	47.50	32.10	36.90	55.00	31.90	36.80	37.20	30.70	37.80	32.60	45.50	**38.73**	**7.35**
Stopping knee flexion (degrees)	82.90	83.10	84.40	84.00	76.20	80.00	102.00	73.90	94.20	110.70	74.30	82.90	**85.72**	**11.21**
Jab knee flexion (degrees)	48.40	20.00	8.80	31.50	19.00	31.80	23.10	39.10	21.10	25.90	14.30	33.60	**26.38**	**11.05**
Jab hip flexion (degrees)	50.40	62.80	42.90	14.90	61.00	47.70	0.00	17.40	-5.20	-3.90	95.10	26.60	**34.14**	**31.12**
Stopping hip flexion (degrees)	87.30	95.40	80.50	71.30	112.70	79.30	79.10	45.50	85.30	101.40	16.60	50.10	**75.38**	**26.58**
Trunk rotation relative to new direction of travel (degrees)	68.30	91.80	28.20	22.90	48.60	50.30	14.60	19.70	33.50	45.40	38.80	15.70	**39.82**	**22.99**
Trunk ROM during jab support (degrees)	68.00	32.60	95.10	73.90	74.90	78.60	122.80	73.10	106.30	88.90	79.20	67.10	**80.04**	**22.36**
Support stance time (s)	0.28	0.33	0.32	0.33	0.38	0.62	0.37	0.37	0.67	0.40	0.43	0.50	**0.42**	**0.12**
Contra lat shoulder abduction (degrees)	36.20	124.10	85.60	41.40	51.40	82.10	69.60	49.80	122.60	74.80	103.60	75.40	**76.38**	**29.37**
Uni lat shoulder abduction (degrees)	0.00	29.70	51.00	35.70	0.00	-31.70	43.60	35.50	39.10	64.00	-9.30	26.60	**23.68**	**27.98**
Contra lat shoulder flexion (degrees)	0.00	-47.70	0.00	0.00	-10.00	-42.50	-9.60	104.70	-82.70	-26.00	-54.90	-29.80	**-16.54**	**46.09**
Uni lat shoulder flexion (degrees)	-18.60	9.80	-9.20	0.00	-33.20	46.40	0.00	39.70	17.00	-40.40	18.30	33.60	**5.28**	**27.65**

Outdoor Subjects (Maximum flexion of the first step)														
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Trunk lean relative to the vertical (degrees)	38.80	37.30	45.80	38.10	71.10	32.80	37.40	37.50	34.10	32.50	22.10	45.50	**39.42**	**11.74**
Length of step (m)	0.48	0.78	0.84	0.82	0.99	0.92	0.90	0.52	0.78	0.80	0.92	0.42	**0.76**	**0.19**
Lateral distance of first step (degrees)	0.24	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.30	0.00	0.50	0.00	**0.10**	**0.17**
Support knee flexion (degrees)	57.00	50.60	70.00	79.10	56.20	81.70	99.30	58.70	68.60	78.30	65.10	82.90	**70.63**	**14.14**
Support hip flexion (degrees)	27.20	72.20	55.60	66.70	93.70	57.30	73.50	31.80	52.20	56.80	28.10	50.10	**55.43**	**19.88**

Outdoor Subjects (Push off of the first step)														
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Support hip hyperextension (degrees)	30.40	-6.40	-5.30	9.70	12.10	45.90	61.20	41.80	37.80	40.40	8.50	-8.80	**22.28**	**23.53**
Support knee flexion (degrees)	51.60	17.40	15.10	19.40	14.10	27.60	29.00	37.80	27.30	24.30	8.90	13.50	**23.83**	**11.99**
Support ankle plantarflexion (degrees)	22.00	33.80	32.80	31.20	31.30	27.70	32.50	22.10	34.30	29.50	49.20	44.60	**32.58**	**7.88**
Support stance time (s)	0.20	0.25	0.27	0.33	0.48	0.27	0.30	0.20	0.27	0.23	0.25	0.55	**0.30**	**0.11**

Outdoor Subjects (Additional variables)														
Variables	**O1**	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**	**Mean**	**S.D.**
Number of ground contacts prior to jab step	6.00	5.00	5.00	5.00	4.00	5.00	5.00	4.00	5.00	6.00	3.00	4.00	**4.75**	**0.87**
Ground hand contact (1=yes, 0=no)	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	**0.17**	**0.39**
Velocity 3 meters before turnaround point (m/s)	5.00	5.42	5.39	5.20	4.82	5.66	5.39	5.32	5.24	5.71	2.60	2.66	**4.87**	**1.07**
Velocity 2 meters before turnaround point (m/s)	4.00	4.55	2.90	4.86	3.42	4.20	4.85	5.00	3.75	4.72	4.70	4.19	**4.26**	**0.65**
Velocity 1 meter before turnaround point (m/s)	1.97	2.93	1.94	2.79	1.56	2.98	1.69	3.22	3.27	3.04	3.80	3.83	**2.75**	**0.78**
Velocity 1 meters after turnaround point (m/s)	1.82	1.21	2.47	3.50	2.30	1.91	2.66	1.97	2.66	1.97	2.95	2.74	**2.35**	**0.61**
Velocity 2 meters after turnaround point (m/s)	4.18	3.40	2.98	3.71	2.88	3.56	3.14	4.16	3.93	3.96	1.81	3.02	**3.39**	**0.68**
Velocity 3 meters after turnaround point (m/s)	4.68	4.00	3.36	3.80	4.27	4.00	4.07	4.90	4.44	4.00	3.18	4.30	**4.08**	**0.49**

Appendix G

Indoor Cutting Checklist

Indoor Cutting Checklist

Approach

- Indoor athletes will benefit from lowering their centre of gravity within the last few strides before the turnaround point. This allows for maximum stability and ensures the athlete can push off the ground in a lateral direction.
- The athlete should initiate trunk rotation in the direction of the turn about 2-3 meters prior to the turnaround point. Trunk rotation too early can give away the athlete's intentions and trunk rotation too late may lead to an inefficient cut.

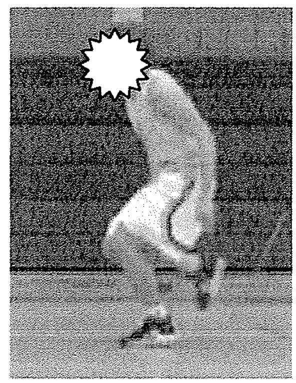

Figure 1: Note how the athlete has lowered his centre of gravity through deep knee flexion of his support leg. This is done in preparation for the cut.

The Cut

- The final step prior to touchdown of the stopping step and jab step is often a very long step or small jump. This allows the athlete to maintain a high horizontal velocity before the ultimate stopping action (Figure 2).
- It is important for the indoor athlete to utilize a small skid onto the jab step. This enables the athlete to attain a high degree of lateral lean further lowering the centre of gravity and decreasing the angle of force application. A low angle of force application will aid in stopping the athlete quickly and efficiently.

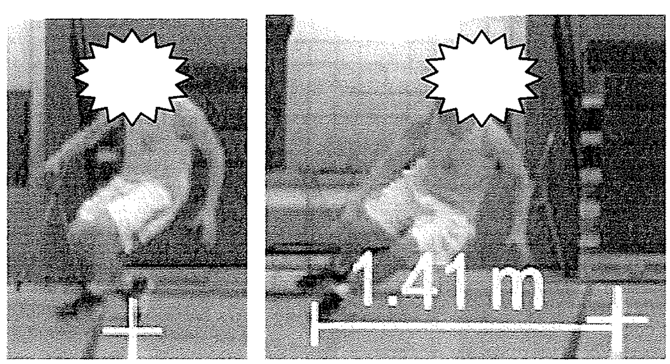

Figure 2: The athlete jumps onto his stopping foot prior to the touchdown of the jab leg.

- Additionally, the athlete should attain a high degree of forward trunk lean through the cut. This will also serve to lower the athlete's centre of gravity and increase the stability of the athlete.
- As the athlete decelerates to a forward velocity of 0 m/s the stopping knee should be maximally flexed. This serves to maintain a low centre of gravity but also to prestretch the hip and knee extensor muscles. A muscle that is stretched will contract with a high amount of force allowing the athlete to accelerate quickly away from the cut (Figure 3).

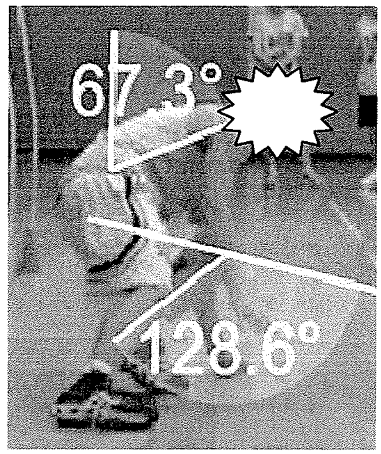

Figure 3: The athlete has flexed his trunk forward to 67° and has flexed his stopping knee to 128°.

- In order to maintain balance, many athletes support a portion of their body weight with one hand on the ground during support stance of the jab foot. This allows for an increased body lean away from the cut while also enabling the athlete to keep his centre of gravity away from the turnaround point. Therefore, the athlete can complete the test as required but allow his centre of gravity to travel a shorter distance within the testing zone (Figure 4).

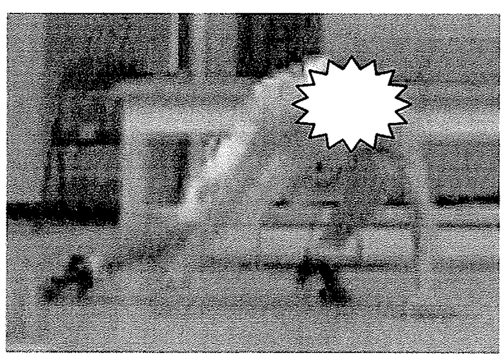

Figure 4: The athlete supports his upper body with his hand during support stance of the jab foot.

Acceleration away from the cut

- The athlete should strive to accelerate away from the cut as fast as possible. Powerful hip extension of the jab leg has been found to increase the athlete's performance on the test as it allows the athlete to reach a high horizontal velocity very quickly.
- After the athlete exits the cut the motions of the hips and shoulders should be primarily in the sagittal plane. The further the athlete gets from the cut the more the test resembles a sprinter exiting the blocks during a race. Any movement out of the sagittal plane is generally seen as wasted energy.

Appendix H

Outdoor Cutting Checklist

Outdoor Cutting Checklist

Approach

- Outdoor athletes will benefit greatly from lowering their centre of gravity within the last few strides before the turnaround point. Generally, athletes performing the 180° cutting maneuver on grass do not lower their centre of gravity far enough to execute the cut most effectively. A low centre of gravity allows for maximum stability and ensures the athlete can push off the ground in a lateral direction.
- The athlete should increase stride frequency in order to take several smaller steps prior to the turnaround point. These stutter steps will increase the total time during which the athlete can apply breaking forces to the ground.

Figure 1: The athlete takes several stutter steps in order to decelerate as he approaches the turnaround point.

The Cut

- The athlete should carry as much horizontal velocity into the cut as possible. This will create large eccentric forces in the jab leg at final deceleration therefore the athlete must be adequately trained in order to maintain control through the cut.
- A low centre of gravity and a lateral trunk lean will enable the athlete to keep the centre of gravity far from the turnaround point. This will result in a shorter distance traveled by the centre of gravity within the testing zone.
- An increased angle of hip abduction of the jab hip will also aid in keeping the athlete's centre of gravity away from the turnaround point.

Figure 2: The athlete is demonstrating a good lateral lean away from the cut.

- As the athlete decelerates to 0 m/s the jab knee should flex to about 90°. This will adequately stretch the muscles that extend the hip and knee. A stretched muscle contracts with more force than an unstretched muscle.
- In order to increase the velocity of the turn itself, the athlete should keep the shoulders in a relatively adducted position. This will decrease the moment of inertia about the longitudinal axis and allow for a faster turn.
- The athlete should try to keep both feet on the ground throughout the final cutting maneuver. This will allow the athlete to control the final deceleration with both legs instead of just one. There is a tendency to lift the stopping leg due to an unbalanced body position which should be avoided.

Figure 3: The athlete is not balanced and must lift the stopping foot in order to regain balance.

Acceleration away from the cut

- Athletes should try to minimize the time the jab step is on the ground. This is only possible if the athlete is under full control and strong enough to decelerate and accelerate from a stationary position quickly.
- Hip extension velocity is important in all sports. It has been found to greatly influence an athlete's test time. Athletes should participate in additional weight training in the form of squats, and plyometrics in order to increase their ability to forcefully extend the hip at push off of the jab step.
- Athletes should try to reach a high linear velocity as soon as possible after pushing off from the jab foot. This will benefit game time situations as athletes generally execute the 180° cut in order to evade or pursue an opponent.