UNIVERSITY OF CALGARY

Determining the sensitivity of five basketball movements to changes in the construction of basketball shoes

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled " Determining the sensitivity of five basketball movements to changes in the construction of basketball shoes" submitted by Elysia Marie Davis in partial fulfilment of the requirements of the degree of Master of Science.

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Abstract

Basketball is a sport involving many different movements, most of which have not been well defined or quantified in terms of reliability and sensitivity to changes in footwear. To assess the functionality of basketball shoes, reliable and sensitive tests relevant to basketball are needed. Such tests do not currently exist. The purpose of this study was to validate a series of basketball specific movements for use in identifying changes to the biomechanics of basketball athletes as a result of modifications in basketball footwear. Five basketball specific movements were chosen based on the results of an in depth reliability study, and the subsequent sensitivity of these movements to three discrete changes in basketball footwear was measured. The three changes included modifications to the upper stability, shoe forefoot bending stiffness and midfoot bending stiffness. It was determined that (1) the most sensitive movement to changes in upper construction was the Zig-Zag Agility Drill, (2) the most sensitive movements to changes in forefoot bending stiffness were the Shuttle Agility Drill and the Modified V-Cut, and (3) the most sensitive movement to changes in midfoot bending stiffness was The Shuttle Agility Drill. In general, the Lay-Up was not sensitive to any changes in footwear. The Sensitivity Indices tended to correspond to statistically significant changes. However, the most reliable movements did not always correspond to the most sensitive.

Preface

The validation of the use of basketball movements as tests for determining the effectiveness of footwear required both the evaluation of the reliability and sensitivity of specific movements. The reliability of 9 isolated and 3 agility movements specific to basketball have been previously evaluated:

Davis, E.M., Landry, S.C., & Nigg, B.M. (2008). The reliability of kinematic and kinetic variables during isolated and agility basketball specific movements. *A technical report for the adidas Innovation Team.*

The reliability study provided the foundation for investigation of movement sensitivity. Determining the sensitivity of a subset of these reliable movements completed the validation for the use of specific movements as tests to measure the effect of modifications in footwear.

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List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
AAU	Amateur Athletic Union
BW	Body weight
ICC	Intraclass Correlation Coefficient
LUB	Lay-Up movement
NBA	National Basketball Association
NCAA	National Collegiate Athletic Association
SCS	Shuffle and Side Cut movement
SHU	Shuttle Agility Drill
SI	Sensitivity Index
TD	Touch down
TO	Take off
VCM	Modified V-Cut movement
ZIG	Zig-Zag Agility Drill

Chapter One: Introduction

Basketball is one of the most popular sports in North America with an estimated 17,672,000 participants in the United States alone (SGMA, 2009). In addition, the participation is split between males and females almost equally in the college and high school demographic as illustrated with data from the National Federation of State High School Athletics and the National Collegiate Athletic Association (NCAA) (Table 1).

Table 1. Breakdown of male and female basketball participants in the United States in 2007-2008. Data is from the SGMA 2009 Insight Survey.

	High School (2007-2008)		NCAA Basketball (2007-2008)	
Males	55%	548,821	55%	131,962
Females	45%	447,520	45%	108,758
Total		996,341		240,720

During the 48 minute game, National Basketball Association (NBA) athletes jump on average 70 times, varying based on player position. In addition, players run, on average 2.1 miles during a game at an average pace of nine miles per hour, and complete over 1000 walking and shuffling steps (McClay et al., 1994b). These movements are performed while team-mates try to score points, and opponents try to prevent this scoring. For these reasons: diverse participation, complex movements and interaction with other players, studying basketball is quite difficult. Although it is a challenging sport to study, advancing the knowledge about the sport is necessary for the evolution of the game and the equipment used during competition.

Choosing the right test to quantify the effect of footwear modifications on the athlete and their movements is difficult as the test needs to be relevant to the sport, reliable and sensitive. In addition, for biomechanical analysis, it must be able to be performed in a laboratory setting. Basketball is a sport characterized by many different movements including running, stopping, jumping, and cutting (McClay et al., 1994; McInnes et al., 1995; Abdelkrim et al., 2007; Zhang & Clowers, 2006). The successful execution of these movements includes elements of speed, agility, timing, and ability to change directions (Barfield et al., 2007). As a result, many researchers have used a combination of isolated movements and agility tests to identify skilled basketball players (Simenz et al., 2005) and to test an athlete's performance (Farrow et al., 2005). Understanding the sensitivity of these movements to discrete changes in footwear will aid in the selection of specific movements to evaluate the effectiveness of specific product modifications.

Good tests of footwear performance may provide an improved understanding of the loading situations in specific shoe and movement conditions. Studying defined, isolated movements in a laboratory setting allows for the quantification of variables such as the kinematics and kinetics of an athlete in the absence of confounding variables such as fatigue, other players and/or complex game strategy.

Any measurement tool, whether it is a device, a technique, a method or a protocol used in scientific research must be validated in order for its use to be deemed acceptable. Functional tests to evaluate new basketball footwear designs need to be relevant to the sport, reliably reproduced in a laboratory environment and sensitive to changes in footwear conditions. Currently, no validations of sensitive basketball movements exist. There is the potential for performance enhancement due to changes in footwear for basketball. However, while pushing the boundaries of performance measures, one must also consider the potential for injury. There is little information in the literature about the kinetics and kinematics of different movements within basketball. Thus, more research is needed in this area. Most research has focused on frequency analysis and performance assessment of players, without knowledge of what movements are reliably reproduced in a laboratory environment. Because the development of high performance athletic footwear relies on information about the athletic movements, it is of use to identify and test common basketball movements that are currently used in research as well as those that are utilized by athletes during the game.

Thus, in summary, the current scientific literature related to basketball movements does not provide comprehensive information on whether a test is relevant, reliable and/or sensitive. The relevance of selected test methods is claimed based on general "gut feeling" statements. The reliability of a series of basketball movements in a lab test setting has been assessed in a comprehensive study, available as an internal report (Davis et al., 2008). However, information about the sensitivity of basketball shoe specific movements and variables is not available.

1.1 Purpose

The purpose of this study was to determine the sensitivity of low extremity kinematics and kinetics of 5 different basketball movements to changes in selected characteristics of footwear. Specifically, sensitivity was determined for changes of shoe (a) upper stability, (b) forefoot flexibility and (c) midfoot bending stiffness.

The results of this study will be used to determine a set of basketball movements that can be used as validated tests to quantify changes in basketball footwear.

Chapter Two: Literature Review

Basketball is a multidimensional sport involving many different movement components, some producing high stresses on both the athlete and the basketball shoe. Changes in the footwear have been introduced to increase performance, decrease injury and/or increase comfort of an athlete while playing basketball. To assess the effectiveness of these modifications and to understand how changes to an athlete's footwear can influence his or her movements, basic information about the sport and the movements that make up the sport must be understood.

Research in the biomechanics of basketball can be summarized in three primary categories: the game, the athlete and the influence of products and playing surfaces.

The Game:	Research focusing on the game may answer questions related to the biomechanics of movements performed during the game, injuries related to these movements, physiological requirements of the sport and the strategy of the game.
The athlete:	Research about the athlete may answer the question of how the game and the movement of the individual athlete are affected by gender, age and skill level.
External devices:	Research regarding the influence of external devices may answer questions related to how changing specific footwear characteristics and/or apparel characteristics influences an athlete's performance and/or risk of injury.

This review of the literature focuses on two aspects of basketball research:

(1) research related to the game, specifically studies investigating the biomechanics of basketball movements and assessing basketball performance; and

(2) studies investigating the effect of footwear modifications on the execution of basketball-type movements.

Although the athlete is an essential independent variable in basketball research, most studies have adopted the "high-level adult male basketball player" model. Due to this selection, only a small sub-set of the basketball playing population has been addressed. However, it does provide a baseline to pursue other research paths in basketball.

2.1 Basketball Biomechanics

Research currently performed in basketball is often based on descriptive analysis during competition such as quantifying frequency, intensity and distribution of a specific movement component during competition (e.g., McInnes et al., 1995). Other research focuses on the detailed biomechanical analysis of these movements (e.g., McClay et al., 1994a). The following review of basketball biomechanics will focus on the biomechanics of movements, quantifying basketball performance and a brief insight into common injuries incurred by basketball athletes.

2.1.1 Basketball Movements

In a comprehensive study in basketball biomechanics, a kinematic profile of skills in professional basketball players was created (McClay et al.,1994a). The goal of this project was to identify kinematic variables that may influence common injuries and performance in basketball. A secondary purpose of this study was to provide an understanding of the physical requirements of the game and to describe how basketball compares to other forms of intense physical activity.

Non-kinematic factors that may account for increases in basketball injuries in recent years were identified as (a) the increase in height and weight of the athlete, (b) the increased physical nature of the game, and (c) the number of games played. To identify the kinematic factors, the researchers performed 2-dimensional kinematics of the ankle and knee at 5 separate testing facilities on 28 professional basketball athletes (McClay et al., 1994a). The movements analyzed were: running, cutting, starting, stopping, lay-up (take off and landing), jump shot (take off and landing), vertical jump (take off and landing), and lateral shuffle.

McClay et al., (1994a) reported values for sagittal and frontal plane kinematics and angular velocities. Knee flexion was highest during a vertical jump take-off, and reached maximum extension during a jump shot. Knee flexion velocity was highest during a landing from a lay-up, with a magnitude of close to 600 degrees per second. Pronation was defined as a negative angle between two markers on the rearfoot and two markers on the Achilles tendon. Rearfoot pronation was highest during a starting task followed by a running step. During the side shuffle, the rearfoot did not pronate, and reached a minimum of 11 degrees of supination throughout stance. The rearfoot was supinated in 10 of 11 movements at touchdown.

The authors discussed their findings in comparison to running and gymnastics and found differences in the range of motion of basketball players at the knee and ankle compared to the other sport categories. The authors also noted similarities in the kinematics of 8 out of the eleven movements studied, attributing part of this similarity to the large variability within the data set.

One weakness of this study was the small number of trials used for each subject (three trials for each movement for each subject were analyzed). A second limitation was the use of multiple testing facilities. It has been determined that the intra-protocol variability of kinematic variables is between 0 and 4 degrees at the ankle joint, however using different protocols was found to be approximately 25 degrees of rotation at the ankle and 30 degrees at the knee for a given subject (Ferrari et al., 2008). This decreases the ability to draw conclusions from data collected at different facilities, where different protocols are adopted. The researchers compared their results with running and gymnastics in depth, but alluded to the unavailability of other research in basketball to use as a comparison.

The variability in movement patterns observed (McClay et al., 1994a) is not uncommon during the execution of basketball movements. Variability in gross movement patterns of basketball players and the resulting variability in measured kinematics and kinetics have been studied during rapid lateral braking (Stüssi, Stacoff and Tiegermann, 1989). Three common landing patterns were identified by the authors, indicating that even in a specific movement, there are many variations in execution. The three strategies were classified as

(1) the forward lunge, a combination of knee and ankle flexion in the direction of motion; (2) the "neutral O" characterized by landing either on the forefoot or heel; and (3) the toe landing, described by initial contact on the lateral boarder of the forefoot while the tibia is internally rotated. These three strategies were characterized in relation to injury risk, with the forward lunge being deemed the safest, and the toe landing the most dangerous. This study shows the possibility of using landing strategies to evaluate footwear. If an athlete feels stable, he may be more likely to adopt a riskier landing strategy compared to a very safe strategy if he does not feel as stable.

In addition to gaining an understanding of the kinematics of basketball movements, the external forces generated during various sport specific movements have been studied in detail. A ground reaction force profile of basketball players was presented in a related manuscript to the kinematic profile of basketball players (McClay et al., 1994b). External vertical forces of up to 8.9 body weights (BW) were reported during landing from a lay-up (with both feet in contact with the force plate at some time). If the average mass of a typical basketball player is considered, it can be expected that external peak vertical forces around 8000 N could be experienced by an athlete during landing from a lay-up. The other two landings measured (jump shot and vertical jump landings) produced vertical peak forces of 6.0 BW and 4.3 BW, respectively. Peak medial forces were observed during a cutting movement and side shuffle with magnitudes of 1.0 BW and 1.4 BW, respectively.

External forces were also analyzed during the performance of a small subset of three basketball movements: cutting, shuffle and stop (Valiant and Eden, 1992). External forces were analyzed in relation to the traction coefficients required to perform each movement. The coefficient of friction, calculated as the ratio between vertical and horizontal components of the ground reaction force, gives an indication of the required traction to complete a given movement. The cutting movement produced lateral forces of 1.37 BW, occurring shortly after touchdown during the impact phase of the movement. The authors recorded a corresponding vertical force of 2.57 BW, creating a coefficient of friction of 0.53. Rapid stops resulted in anterior forces of up to 1.89 BW, and a vertical component of 3.31 BW, resulting in a friction coefficient of 0.85. This research showed that rapid stopping movements require more traction than rapid cutting movements.

Valiant and Cavanagh (1985) measured external forces of 10 basketball players landing from a jump. Two of the ten subjects landed with a midfoot strategy and produced vertical forces of up to 6 BW. The remaining eight subjects landed with a toe-heel contact pattern. The magnitude of the average initial impact force was 1.31 BW and the average second impact corresponding to the heel contact was 4.1 BW.

In addition to movement biomechanics, physiological data from basketball players during competition can help in understanding the athletic requirements of the sport. The physiological demands of basketball have been previously assessed using a sample of 28 under-19 athletes (Abelkrim et al., 2007). Heart rate and blood lactate concentration were recorded throughout a basketball game. The amount of time performing high-intensity activities varied based on player position, with Guards spending significantly more time performing high-intensity movements than Centers. Movements were categorized into various run types (sprint, jog, etc.), levels of intensities and jumping. This makes it difficult to discern time spent performing specific movements during competition, but does give an indication of the type of movements. Lactate levels were highest at halftime for all positions and Guards had higher heart rates throughout the game as compared to Forwards and Centers. This study also showed that the first and third quarters of a basketball game are played at a higher level of intensity than the second and fourth. The first and third quarters were also characterized by a degraded performance which the authors attribute to the increased physiological load.

These four studies provide the baseline knowledge of the kinematics and external forces experienced by basketball athletes during basketball specific movements. They allow for comparison of basketball to different sports, as well as within the sport to identify movements that result in high magnitudes of forces and large ranges of joint motions (McClay et al., 1994a and 1994b). This information has the potential to influence the guidelines for product, such as in the noted required coefficient of traction during different movements (Valiant and Eden, 1992). Additionally, when the large differences in external reaction forces depending on landing strategy were measured, the need for footwear cushioning to be optimized for both the heel and forefoot landing strategies was identified. With the exception of Abelkrim (2007), these biomechanical studies are 15 to 25 years old, which further emphasizes the need for supplementary information of the biomechanics of basketball movements, using up to date methods and equipment.

2.1.2 Basketball Performance

Performance enhancement of athletes is of great interest to both the athlete and the manufacturer of sport equipment. In basketball, quantifying this performance is not simple but multifactorial in nature. When discussing the performance of a team sport such as basketball it is necessary to break general performance into "Team Performance" and "Individual Performance." Team performance relies on game tactics and is heavily influenced by the coaching strategy and the organized interaction of team members, and so it will not be discussed further. The following discussion of basketball performance will focus on individual performance, as defined by Figure 1.

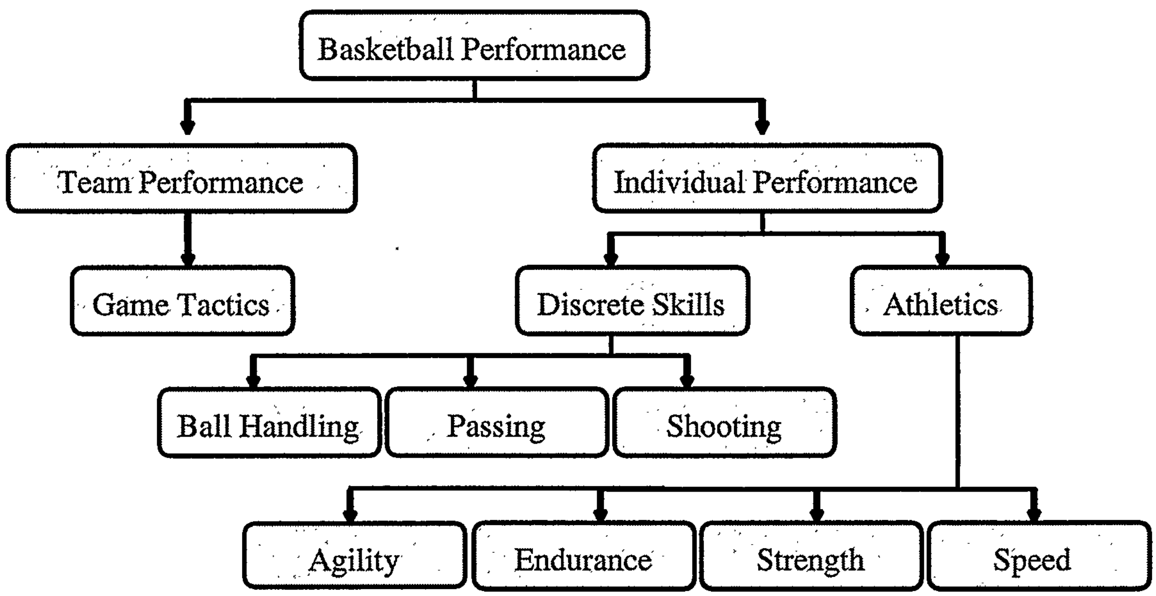

Figure 1. Schematic breakdown of basketball performance

Individual performance is a combination of discrete skills and athleticism. Discrete skills include the fundamental components of the sport, and for basketball these are dribbling the ball, passing the ball and putting the ball through the net (scoring). These discrete skills require hand-eye coordination, accuracy, and timing. If basketball was a competition of discrete skills alone, without the need to out wit and out manoeuvre opponents, performance in this sport could be graded based on the execution of these skills. However, like most team sports, these skills must be completed while opponents try to prevent their successful execution. As a result, athleticism (specifically, endurance, strength and speed) plays a role.

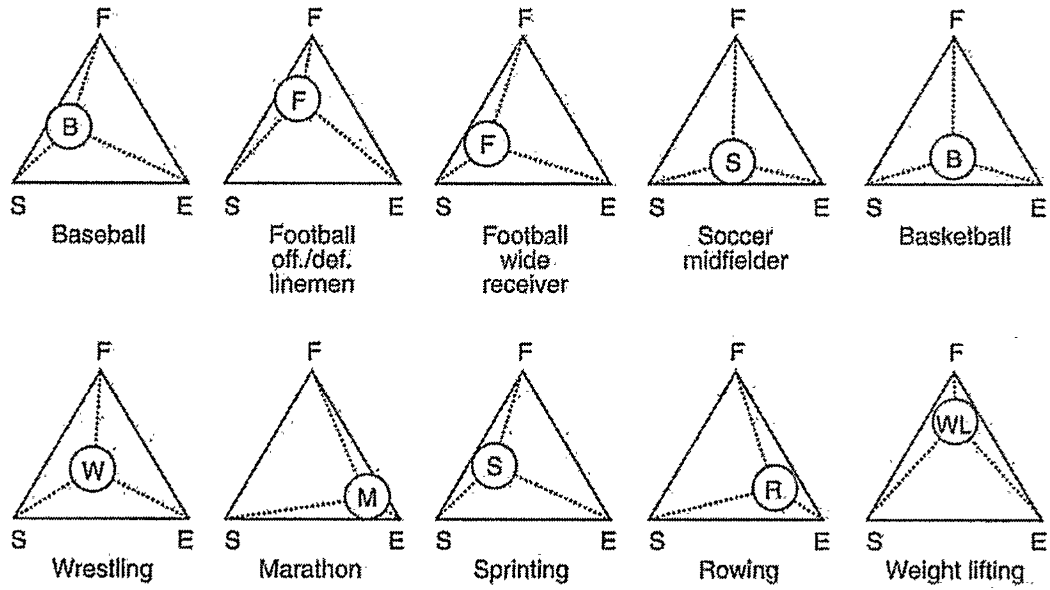

Figure 2. **Dominant composition among the biomotor abilities for various sports, (from Bompa, 1996). F = strength, S = speed, E = endurance.**

Other researchers have categorized basketball and other sports based on the relative importance of various athletic components (Bompa, 1996; Figure 2). Although the interdependence of the various athletic requirements of a sport are quite complex, most sports can be described by the various contribution of strength, speed and endurance, described as biomotor abilities (Bompa, 1996, Figure 2). According to Bompa (1996), basketball is dominated by speed and endurance, with less emphasis on strength. In addition, agility, which the author defines as a combination of speed, flexibility, coordination and power, is an important attribute of basketball and other team based sports.

In basketball, these factors of athleticism span a variety of different movements including running, stopping, jumping, and cutting (McClay et al., 1994a; McInnes et al., 1995; Abdelkrim et al., 2007; Zhang & Clowers, 2006). It has been reported that during a basketball game, players run, on average 2.1 miles during a game at an average pace of nine miles per hour, and complete over 1000 walking and shuffling steps. In addition, these athletes jump on average 70 times per game, varying based on player position (McClay et al., 1994b).

Both the breakdown of performance based on biomotor abilities, and individual versus team components highlight the complexity of defining and quantifying the performance of basketball players. Provided these complexities, many researchers have attempted to quantify performance in team based sports and measure the effect of equipment and training regimes on this performance.

2.1.2.1 Performance Evaluation

Agility tests are commonly used for testing the skill of basketball players (Simenz et al., 2005) or in laboratory settings to test "performance" (Farrow et al., 2005). These tests combine a series of common basketball movements into one drill in an attempt to elicit a "game-like" execution of movements. Agility tests have been used in a variety of sports, including soccer (Bangsbo and Thorso, 1991), netball (Farrow et al., 2005) and field hockey (Boddington et al., 2001). Agility tests are used to measure the athlete's ability to rapidly change directions and positions of the body in the horizontal plane (Farrow et al., 2005). In addition to measuring kinematic and kinetic variables during the drill, these tests can provide information about the time to complete the task. The variables measured and evaluated during agility tests may provide important information about that athlete's fitness and ease of transition between different movements, both of which seem to be important in the game of basketball.

To gain a better understanding of basketball performance, Barfield et al. (2007) developed and evaluated a performance index to quantify the performance of basketball players. This index was made up of a variety of performance measures including jump height, core strength, lane box drill and a shuttle run. The lane box drill and shuttle run were scored solely based on the time to complete each movement. In another study, (Brisuela et al., 1997) the effect of altering basketball shoe ankle support on performance in running and jumping was examined. Again, performance was assessed by the time to complete an agility test which contained a series of forward runs, backwards runs and cuts of 45 and 90 degrees, based on a previous protocol by Robinson, Frederick, and Cooper (1986). Because quantifying performance using time or speed does not provide any information about why an athlete may have been faster or slower, it is important to identify movements that not only discriminate performance based on time, but other biomechanical factors as well.

Grehainge et al., (1997) used two methods to evaluate the performance of basketball athletes: the efficiency index and volume of play. Although this method was designed for use by students and physical education teachers, the authors raised valid discussion points on the evaluation of performance in basketball and other team sports. The fundamental difficulties of evaluating the performance of an individual or team during competition in team-based sports (the multivariate nature of sport, i.e., the execution of movements at a high level of expertise; strategy; tactical efficiency; and perceptual and motor skills) were discussed in detail. The authors proposed a four-fold approach to performance assessment which included technique, product, tactics and process. Biomechanical analysis, although not discussed directly by the authors, would fit into the category of process.

In general, assessing detailed performance attributes in basketball is difficult. As a result many researchers have relied on time or speed as the primary determinant of performance. Although the tasks used by different researchers to evaluate performance are quite varied, the common denominator of most performance tests is the time it takes an athlete to complete the given task. The quicker a basketball player is, the higher the performance rating. As methods become more refined, and product modifications become more geared towards performance, manufacturers of equipment will need more detailed explanations of why a given condition is better or worse. Detailed and reliable biomechanical data during basketball movements may satisfy this need.

2.1.3 Basketball Injuries

The second and equally important function of sport equipment is the reduction of injuries.

Injuries cannot be reduced without knowledge of the types of injuries experienced by basketball athletes and their potential causes or risk factors. Most often, injuries in high school basketball athletes occur at the ankle (39.7%) and knee (14.7%) (Borowski et al., 2008). Injuries in basketball can be both chronic and acute and the type of injury incurred often depends on interactions with other players on the court. The most prevalent injuries in basketball have been reported as fracture of the fifth metatarsal, anterior cruciate ligament (ACL) rupture, and lateral ankle sprains, specifically, the tibio-calcaneal and the tibial-talus ligament, based on information from the NCAA injury surveillance data (Dick et al., 2007). It is an impossible task to predict and prevent all injuries occurring in a dynamic sport, however, understanding key details of movements within a sport can aid in innovations of equipment that can potentially reduce the prevalence of injury.

Most knee injuries occur during the landing phase of a jump, reported as up to 58% of all injuries (Gray et al., 1985). Possible mechanisms of ACL rupture as cited in literature include an imbalance in the muscle activity of the hamstrings and quadriceps (Kirkendall and Garrett, 2000), or decreased hip flexion angles and moments in female athletes during cutting manoeuvres (Landry et al., 2007). Movements that have been attributed to fracture of the fifth metatarsal include those that cause high peak pressures on the foot (lateral) such as a side cut or v-cut (Yu et al., 2007), and high center of pressure on the forefoot. The third most common injury in basketball, the lateral ankle sprain, is primarily caused by high ankle inversion moments (Gross & Lui, 2003).

2.2 Effects of varying shoe characteristics on basketball biomechanics

Many research inquiries over the years have aimed to develop footwear designs with the potential to increase the performance of basketball players. Understanding how footwear and other forms of product affect the kinematic and kinetic components of each movement may help in understanding the global effect of footwear on performance. It has been suggested that a shoe should: (1) limit the impact forces during landing; (2) support the foot during stance phase; and (3) guide the foot during the final phase of ground contact (Nigg and Segesser, 1982). The effects of certain footwear modifications on movement patterns have been previously studied. These modifications have included changes in shoe midsole, upper construction, torsional stiffness, and shoe-surface interface. The dependent variable of interest in these studies investigating the effect of footwear modifications varies, but can generally be summarized into kinematics and kinetics (Luethi et al., 1986), impact attenuation (Zang and Clowers, 2005), and performance (Valiant and Eden, 1992; Brizuela et al, 1997).

2.2.1 Validation of tests to measure the effect of footwear on basketball biomechanics

Basketball-specific movements are often used to measure changes in movement patterns based on a specific intervention, such as a change in footwear construction. Although basketball is made up of a variety of movements, a series of generic cutting, stopping and landing movements are used often in basketball research. However, it is not known which movements are reliably reproduced in a lab environment, or which are sensitive to changes in shoe construction.

To evaluate a wide range of basketball-specific movements to measure changes in footwear, a validation study was completed on a series of basketball movements and agility drills (Davis, Landry, and Nigg, 2008). Thirteen movements were chosen based on video analysis of the National Basketball Association 2007 playoffs, along with discussions with athletes and coaches. The isolated movements included in this study were

- cutting,
- lateral stops,
- pivots,
- clockwise and counterclockwise curvilinear running,
- defensive shuffling,
- lateral jab, and
- breaking and take off step of a lay-up.

Three agility movements were also analyzed, including

- zig-zag drill,
- lane drill, and
- NBA box drill (transition between shuffling and back-pedaling, and between a forward run and a side shuffle were analyzed).

The goal of this study was to determine which basketball movements were repeatable, and, therefore, good tests for use in quantifying the effect of footwear. Basketball athletes completed the series of movements in a laboratory environment. Intra-class correlation coefficients were used to quantify reliability within a single testing session, between sessions completed on the same day, and between sessions completed on different days. Repeatability scores were calculated from the kinematic and kinetic variables measured during each movement. In addition, for the three agility drills, muscle activation and foot pressure data were included and used for a secondary analysis of reliability.

This study provided a means to select a test for comparing basketball shoes that is, overall, very repeatable based on the number of high intraclass correlation coefficients (ICC) across all variables measured. It also allowed for the selection of a test for very specific footwear questions. For example, if one had a protocol that was completed across multiple days using multiple shoes, a test having high repeatability within one session and between sessions on different days should be chosen. In addition, the test allowed for the selection of movements based on the amount of rotation or torque at a specific joint. For example, if one wanted to evaluate a shoe for its ability to reduce inversion at the ankle, a movement that creates the largest rotation at the ankle could be chosen. From this study, it was determined that the shuffle and side cut, lateral jab, lay-up and modified v-cut are very reliable isolated movements and the Lane (Shuttle) drill and Zig-Zag are highly reliable agility drills.

2.2.2 Effect of modifying midsole construction

The midsole of a shoe is the portion of material between the outsole and the upper, most noted for its role in cushioning. It is most often made of ethylene vinyl acetate (EVA) foam or a similar thermoplastic-type material and can vary in hardness for the desired cushioning and flexibility properties. Modifications of the midsole material, shape, and thickness can, therefore, change the flexibility (bending and torsion), energy properties, and cushioning of an athletic shoe. Studies that examine the effects of modifying the midsole of court shoes often assess the influences on shock absorption capabilities and how modifying the flexibility, either at the metatarsal-phalangeal line or rotation around the long axis of the foot/shoe (torsion) influences movement patterns.

Often court sports are grouped together and conclusions from one sport are generalized to other sports that consist of lateral movements. In this case, in a study of tennis players performing lateral movements, Luethi, Frederick, Hawes and Nigg (1986) studied the kinematics of the lower limb and the internal forces during lateral movements in soft, flexible shoes compared to stiff, hard shoes. The soft shoe group produced greater average maximum forces, corresponding to greater lateral velocities at touchdown. The soft shoe group also had greater maximum ankle inversion than the group in hard shoes. The hard shoe group displayed more inversion between toe contact and heel contact, whereas the soft shoe group showed more inversion after heel contact. The authors surmised that soft shoes allow more rotation in the joints of the foot and, therefore, improved absorption of forces. This study showed that kinematics, during lateral movements in tennis, are highly dependent on shoe properties and a player's ability to adapt to different shoes.

Modifying midsole properties has been shown to affect the overall stability of court shoes (Valiant and Himmelsbach, 1992). To compare shoes with different midsoles, a series of drills were used to simulate basketball performance, including a dribble, change of direction, stop, shooting, lay-up, run, shuffle and a cut completed at maximal speed. Subjects wore a "stable," "unstable" and "wickedly unstable" version of the same shoe. The unstable was identical to the stable shoe, except it was made torsionally flexible by removing the middle portion of the midsole-outsole, and the wickedly unstable was the same as the unstable, only the heel counter was removed. Due to the differences in the unstable and wickedly unstable shoes compared to the control shoe condition, the reduction in performance times were 5% and 9%, respectively.

Although the authors suggest that removing the heel counter changed a shoe from being "unstable" to "wickedly unstable," the magnitude of this change in stability is difficult to quantify. It is not known if removing a heel counter makes a shoe more unstable, and by how much, compared to a shoe with an intact heel counter. Stability is a construct that is difficult to measure, especially stability in a dynamic sense. There are many components that can influence "stability" which are often based on perception and preconceived notions about what it means to be stable. This draws attention to the difficulty in quantifying the difference in stability as a result of modifications in footwear.

Removed from the laboratory setting, Curtis et al. (2008) examined shoe design and ankle sprain rates in a prospective study using National Collegiate Athletic Association (NCAA) basketball athletes who sustained a lateral ankle sprain. Information on both the ankle sprain and the type of shoe worn by the athlete was collected. Shoes were categorized based on cushioning, into a "cushioning" and "no cushioning" group. No significant differences were found between the groups in the rate of ankle injuries. Based on the proposed mechanisms of ankle injuries, it is not surprising that cushioning was not a significant factor in predicting ankle injuries. A more revealing investigation may have been related to the rates of ankle injuries as a result of upper height and construction.

Shoes with varying midsole stiffness have been compared for relative shock absorption capacities in a variety of studies (Kaelin, Stacoff, Denoth, and Stussi, 1988; Zang and Clowers., 2005). The first study showed that softer shoes attenuated the ground reaction force peak corresponding to forefoot contact by 3.3% and the heel by 18% as compared to the stiff shoes. The second study used a series of three footwear conditions worn by five subjects, all performing "step-off" landings from three different heights. It was found that athletes wearing shoes with a soft midsole had a significantly lower ground reaction force peak than those wearing shoes with a normal and hard midsole, confirming the results of the earlier study. It was also noted that kinematic variables and energy absorption did not change significantly across different midsole conditions.

Gross and Nelson (1988) measured the shock attenuation capability of the ankle joint and surface condition by having subjects land on different surfaces. Skin-mounted accelerometers were used to quantify shock attenuation. The three surfaces were 13 mm thick foam, 9 mm rubber, and cast aluminium. The authors found that landing strategy played a larger role in shock attenuation than surface properties. The vertical ground reaction force of subjects who landed on their forefoot was similar to that of subjects who touched down with their heel after landing on their forefoot-heel; however, the "forefoot only" strategy reduced the maximum force by 22%. Landing surfaces did not significantly affect the force transmission measured at the calcaneous and heel. The authors suggested that the materials may have "bottomed out" and were then close to the underlying surface of the force plate, therefore, no significant differences in shock attenuation resulted. This suggestion seems plausible, as landing from a jump can result in forces of 4-6 BW (McClay et al., 1994a) which would easily compress 13mm of foam with stiffness values presumably between 300-500N/mm.

A less-studied modification to the midsole of a basketball shoe is the addition of custom insoles and orthotics. It is now very common for athletes to wear orthotics in place of, or in addition to, stock sock liners provided inside athletic shoes. In fact, it is becoming more common for college teams to have their own, in-house Orthopedist prescribe custom orthotics to every player on the team. It is for this reason that the effect of orthotics should be understood as it becomes a supplementary layer of the midsole construction. To the author's knowledge a study investigating the effect of custom orthotics on basketball movements has not yet been published, therefore, the example of running provides a starting point for discussion. Mundermann et al. (2003) showed that posting and molding of orthotics have different effects and that, when combined, molding is responsible for the predominant effects. It is not known which orthotic modification is more beneficial in runners for reducing injury. It is also not known how different types of orthotics influence the execution of lateral movements in the basketball population. More research is needed on the effect of orthotics on either movement biomechanics or shock attenuation properties during basketball-specific movements.

Table 2 summarizes the literature investigating the effects of midsole variations on biomechanical variables during basketball type movements. As this list is quite short, it indicates that more basic research related to the effect of midsole modification on basketball movements is needed. In addition to biomechanical studies, the influence of footwear modification on athlete's perception of comfort, stability and performance is needed.

Table 2. Summary of literature investigating effects of variations in shoe midsole characteristics

First Author	Year	Independent Variable	Dependent Variable
Luethi	1986	Midsole flexibility	External forces, kinematics
Gross	1988	Landing surface	Shock attenuation
Kaelin	1988	Midsole hardness	Impact attenuation
Valiant	1992	Torsional flexibility	Performance
Mundermann	2003	Orthotics	Injury risk
Zang	2005	Midsole hardness	External forces, kinematics
Curtis	2008	Cushioning	Ankle injuries

2.2.3 Upper Construction

The upper construction of a basketball shoe can be modified in many ways, for instance, to enhance "stability." These modifications can include the type of material such as stretchable synthetic or a stiff woven cloth, the addition of reinforcements such as thermo-formable plastics or high tear strength materials, additional straps and closures, or simply the height of the upper. High-top basketball shoes have been thought to work in a similar way to ankle braces. In theory, these devices help prevent ankle injuries through two mechanisms: reducing the effective range of motion of the ankle joint complex and increasing propreoception. Shoe upper height can also have the potential to influence performance, as high tops restrict the ankle joint and reduce the possible range of motion. It is for these two reasons that research related to the effect of upper construction is of interest to the performance and injury risk of basketball athletes.

There have been several investigations into the effectiveness of high-top basketball shoes as well as changes to shoe uppers to reduce ankle injuries. Some studies have attempted a systematic approach to understanding "lateral stability" (Robinson et al., 1986) while others relied on injury data to find correlations (Curtis et al., 2008). Some studies have focused on the effect of upper modifications on performance (Brizuela et al., 1997), while others endeavoured to measure the effect on kinematics and kinetics during different sport-specific movements (Stüssi et al., 1989). Independent of methodology, the underlying goal of this research was to determine whether modifications in upper construction influence the movement patterns of basketball athletes (as measured through kinematics and kinetics), and, if so, to determine whether these changes related to performance or injury risk.

One of the difficulties in assessing the effect of stable and unstable uppers is quantifying the difference between test conditions. For this reason, a Stability Index has been developed (Lafortune, 1997). The execution of a lateral side-stepping task was compared in two types of footwear using a combination of pressure sensors and high-speed video.

The authors found differences of up to 90% in lateral pressure between the two shoe conditions. The stability index consisted of a ratio between the magnitude of pressure on the lateral side of the upper and the amount of rotation measured during the cutting movements. This approach provided a method to determine the relative stability of different footwear executions.

Robinson, et al., (1986) took a different approach to making the analysis of lateral stability more systematic by analyzing the effect of a reinforced upper by inserting stiff struts in the shank of the shoe, parallel to the tibia. The study showed significant decreases in ankle inversion, between the stiffest and the least stiff shoes, as well as the most plantarflexion in the least stiff shoe. In addition, subjects were significantly faster in the least stiff condition, indicating a link between performance and inversion ankle restriction. The use of inserting struts to modify stiffness of the upper helps reduce the number of factors that contribute to the measured changes. This study showed that modification in upper construction did change the movement biomechanics of athletes and that the changes induced also influence the performance of the athletes.

This notable contradiction between a product that aims to enhance performance and a product that aims to reduce the risk of injury (Robinson et al., 1986) was re-examined ten years later (Brizuela et al., 1997). The effect of increased ankle support on shock attenuation properties (related to injury) and basketball performance (specifically, jump height and sprint time) was quantified. Two shoes varying in ankle support were used to test the effect of increased ankle support on shock attenuation during landing from a jump. The first shoe had a high level of ankle support, including a high-cut upper, heel counter, and rear foot lacing system. The second shoe was built to be less supportive by reducing the collar height to a low top and removing the heel counter. The shoe with more support resulted in higher impact forces and higher shock transmission to the head. In addition, high-support shoes resulted in a lower range of eversion and higher inversion at the ankle during landing. In a performance test, the high-support shoes reduced jump height and increased the time to complete a running course.

Tik-Pui Fong et al. (2007) compared cloth sport shoes, running shoes, basketball shoes, and cross training shoes with a barefoot condition to assess the protective functions of cloth sport shoes. This study used a very young sample, with the average age of the subjects being 12.7 years. Ankle inversion and eversion angles were measured during a lateral cutting movement as an indication of lateral stability. The overall range of ankle rotation was small (3.6 to 4.9 degrees) as compared to a standard adult male population and, as a result, no significant differences between shoe conditions was found. As more research in the kinematics of young children and teenagers is needed, this study provides information pertaining to the kinematic differences of children and adults, as well as the effectiveness of product on kinematics at a young age.

Stüssi, Stacoff and Tiegrermann (1989) studied the effect of collar height on supination during rapid lateral breaking movements. Rearfoot Achilles tendon angle (ankle prono-supination) was used as a measure for rearfoot lateral stability for each of the shoe conditions. Significant differences between the low and the high-top and the low and the very high-top were found. No additional significant difference was found between the high-top and the very high-top, indicating that there are no additional benefits from increasing shaft height from high to very high.

A similar study was completed in which basketball shoes with different collar heights were tested to determine if increased shoe height changes the maximum inversion and eversion moment that can be actively resisted by the ankle of basketball players (Ottaviani et al., 1995). Testing of functional ankle strength under weight bearing conditions at different flexion angles was completed by 20 males in a low-cut and a three-quarter-cut basketball shoe. The results showed that shoe height did not affect the ability to actively resist an eversion moment when the foot was plantarflexed. In the two test conditions, when the foot was flat and flexed to 16 degrees of plantarflexion, the three quarters height shoe increased the active resistance to inversion by 29.4% and 20.4%, respectively. This shows that collar height may be an effective intervention in preventing excessive inversion.

Table 3 summarizes literature pertaining to the effect of variations in shoe upper construction on multiple biomechanical variables. Similar to changes in the midosle of shoes, more research is needed in this area to draw conclusions of the effectiveness of upper modification on the performance and injury risk of basketball athletes.

Table 3. Summary of literature investigating effects of variations in shoe upper construction

First Author	Year	Independent Variable	Dependent Variable
Robinson	1986	Upper reinforcement	Kinematics, performance (speed)
Stussi	1989	Collar height	Kinematics
Ottaviani	1995	Collar height	Kinematics, kinetics
Brizuela	1997	Ankle support	Shock attenuation, performance
Lafortune	1997	Shoe stability	In-shoe pressure, kinematics
Tik-Pui Fong	2007	Shoe type	Kinematics

2.3 Outlook

To develop basketball shoes that are adequate for typical basketball movements one requires tests that are relevant for basketball, reliable and sensitive. Good tests may provide an improved understanding of the loading situations in specific shoe and movement conditions. Studying defined, isolated movements in a laboratory setting allows for the quantification of variables such as the kinematics and kinetics of an athlete in the absence of confounding variables such as fatigue, other players and/or complex game strategy. Understanding the forces acting on an athlete during common basketball movements will aid in the development of products to enhance the playing experience of the athlete by improving performance and reducing the risk for injury.

Many studies in the past have attempted to quantify the changes in movement biomechanics and performance without knowing how sensitive the selected movement was to changes in footwear. If a change was not found, it may be that the specific modification in footwear did not cause a large change, or that the movement was not sensitive to that change. The following study attempts a classification of movement sensitivity based on three specific changes in shoe construction to aid in the selection of test movements for future studies.

Chapter Three: Methods

This study was approved by the University Of Calgary Office Of Medical Bioethics. Every effort was made to maintain the privacy and safety of the subjects participating in this study. All measurements were acquired after informed consent was obtained from all participants.

3.1 Subjects

The target population for this study was elite adult male basketball players. 17 subjects participated in this study (mass 87.5 (8.3) kg, height 1.91 (0.1) m). All subjects were adult males currently playing on college or university varsity teams and had an average of 11.3 years of experience playing basketball. The test subjects were from the University of Calgary (7), Mount Royal University (3), Southern Alberta Institute of Technology (5), and University of Lethbridge (2).

Subjects were recruited by contacting the head coach of each of the local varsity level basketball teams. Subjects were screened through a telephone questionnaire to verify inclusion criteria for participation. Criteria for inclusion were that the subjects were male, currently played a minimum level of competitive varsity basketball, were free from lower extremity injuries for two years prior to the testing sessions, were over the age of 18 and had a shoe size between 12 and 13 US (size of the available testing shoes). Subjects were excluded if they were unable to read or speak English, were currently receiving treatment for lower extremity injuries, or had surgery within the past 6 months.

The target sample size for this study was 20. Due to the restriction in playing ability and shoe size a total of 17 adult male basketball players were recruited and completed this study. This sample size provides 80% power to detect a difference of 2.5 degrees change (between shoe conditions) with an expected variability of the change of 2.5 degrees in ankle rotations during the 5 different basketball movements, with alpha set at $p=0.05$.

3.2 Movements

Based on the results of a previous study investigating the reliability of a larger set of basketball movements (Davis et al., 2008), a subset of five movements were chosen for this study, including three isolated movements and two agility drills. The five movements represented important aspects of the game including running, transition, cutting and agility. In order to maintain the validity of the reliability evaluation, movements were executed in exactly the same manor as during the reliability study. The following descriptions of the movements are taken from that study.

3.2.1 Isolated Movements

3.2.1.1 Lay-Up (LUB)

The Lay-up is a scoring or offensive movement in basketball consisting of two exaggerated steps before a one footed jump. It was chosen for analysis due to its high occurrence during a basketball game. The second step of the lay-up was analyzed in this study. This step is the "take off" step: the ground contact from which the athlete jumps towards the basket.

For this movement, subjects were asked to perform the lay-up at the speed they would in a game, which is a maximum controlled speed. Data were collected on the subject's right leg and foot as it came in contact with the force plate. This required the subject to perform a left handed lay-up to capture the second step. A basketball was not used to simulate the game like action as it would have interfered with lab equipment. However, a basketball net was set up to provide a visual cue to aid in the execution of the lay-up.

3.2.1.2 Shuffle and Side Cut (SCS)

The shuffle and side-cut is a typically defensive movement in a basketball game, used to guard an opponent. This movement was chosen due to the planting of the athlete's foot on the lateral aspect to change directions. The athlete started with his knees slightly bent, facing perpendicular to the direction of movement. The athlete stepped laterally with his front (right leg), and followed with the left leg. The subject shuffled for three meters to the force plate, planted his right foot laterally on the plate, and changed directions. They continued to side shuffle 3 meters back to the starting position. The cutting movement during the change of direction was analyzed. This movement was performed at the subject's maximum controlled speed.

3.2.1.3 Modified V-Cut (VCM)

The modified v-cut is an offensive movement used to fake the defender. It differs from a "normal V-cut" reported in literature (McClay et al., 1994) as it involves acceleration after the cut. The subjects performed a 5 meter forward run at two thirds maximum running speed up to the force plate. The subject planted his right foot on the force plate and made a 45 degree cut along a marked path for another 5 meter run at maximum speed. The change of direction on the force plate was the portion of this movement analyzed.

3.2.2 Agility Drills

3.2.2.1 Zig-Zag Drill (ZIG)

The zig-zag drill is a common agility drill used to test sports such as soccer, netball, basketball and field hockey. It involved the subject running on a marked path for 4 meters, planting his left foot and making a 90 degree cut around a pylon, running another four meters, making a second 90 degree cut by striking the force plate with the right leg, running another four meters, making the last 90 degree cut around a pylon, and running another four meters to the finish line. Photoelectric timing lights were used at the start line and finish line to record the time to complete each trial. The second 90 degree cut was analyzed for this movement. This drill was performed at the subject's maximum speed (Figure 3).

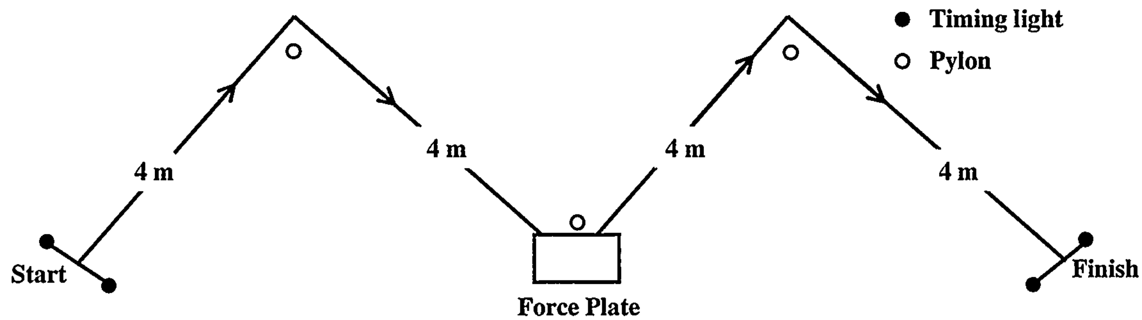

Figure 3. Schematic illustration of the Zig-Zag Drill with timing lights at the start and the finish line and a force plate aligning with the second 90 degree cut.

3.2.2.2 Shuttle Drill (SHU)

The shuttle drill is a common agility drill used by coaches for basketball. It is also referred to as the "suicide drill" and is commonly reported in literature. The subjects started 5 meters behind the force plate, ran forward and planted his right foot on the center of the force plate. The subject pushed off with his right foot, changing direction and ran back to the starting position, setting off the timing lights. Again planting with his right foot, the subject changed directions and ran 10 meters (5 meters past the force plate). Photoelectric timing lights were used at the start line and finish line to measure the time to complete each trial. The first change of directions at the force plate was analyzed for this movement. The subjects completed this drill at his maximum speed (Figure 4)..

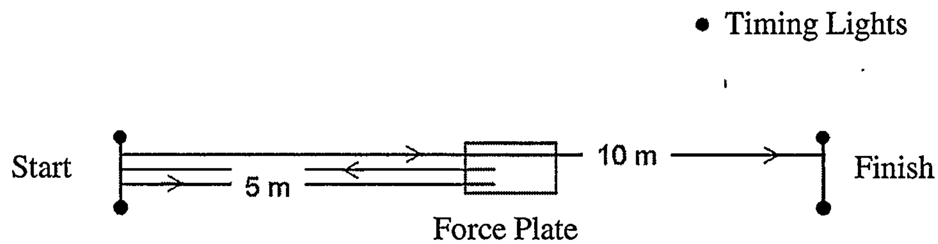

Figure 4. **Schematic illustration of the Shuttle drill with timing lights at the start and the finish line and a force plate in the middle of the test.**

3.3 Footwear

Four modified versions (2 sizes for each condition) of the adidas Young Guns shoe were used as the test shoes for this study (Figure 5). Each of the four shoe conditions was fabricated specifically for this study. The appearance of three of the test shoes was identical and therefore the subjects were blinded to the differences. One shoe varied in the upper construction and therefore the appearance of this shoe was slightly altered. Shoe 1, 3 and 4 had a 0.6mm non-woven upper reinforcement with a vamp and ankle strap and shoe 2 had a soft synthetic upper with a three stripe weld reinforcement and straps removed. The sole of shoe 3 had a TPU plate in the forefoot and a stiff stroebel board on the top of the midsole. Shoe 4 has the same properties as shoe 3, except the Torsion bar was removed and the remaining space was filled with EVA. These four shoes allowed for a comparison of three typical modifications in basketball footwear. Shoes 1 and 2 isolate changes in upper construction; one which is stiff and one which is flexible, shoes 1 and 3 isolate changes in forefoot flexibility, and shoes 3 and 4 isolate changes in midfoot bending stiffness. The changes implemented to the test shoes were not extreme and did not represent the wide range of basketball shoes available on the market, however they do represent common changes made to basketball shoes.

These shoes were subjected to a series of tests prior to the commencement of this study to determine the stiffness in the midfoot and forefoot. An Instron Machine (servo-hydraulic test device, Inston, Norwood MA, USA) was used to drive a stamp into the shoe resting on two supports 90 mm apart. The forefoot was defined as the line on the shoe corresponding to 65% of the length of the shoe on the lateral side to a point 73% of the distance on the medial side (12 degrees line to the shoe). In the midfoot test, the stamp was driven into the narrowest portion of the shoe's midfoot. Stiffness numbers were calculated using the slope of the Force-Deformation curve between 50-75% of the defined max force in the forefoot and the maximum stiffness value in the midfoot. A summary of the results can be found in table 4.

Figure 5 **The shoe model, adidas 2010 Young Guns, was used for all tests as the testing shoe. The shoe upper and bottom unit are displayed for each test shoe (Shoe 1 to 4 displayed from left to right)**

Table 4 Footwear specifications for the 8 shoes used in this study

Condition	Size [US]	Forefoot stiffness [N/mm]	Midfoot stiffness [N/mm]	Upper construction
1	12	22.8	54.0	Reinforced, forefoot and ankle strap
1	13	22.6	63.5	Reinforced, forefoot and ankle strap
2	12	21.9	50.3	Not reinforced, no straps
2	13	22.0	65.7	Not reinforced, no straps
3	12	29.6	45.6	Reinforced, forefoot and ankle strap
3	13	32.6	62.0	Reinforced, forefoot and ankle strap
4	12	30.7	20.8	Reinforced, forefoot and ankle strap
4	13	33.9	26.7	Reinforced, forefoot and ankle strap

3.4 Procedure

All five test movements were completed during one 2 hour testing session in the Human Performance Laboratory at the University of Calgary. Each movement/drill was repeated five times per session, subject and condition. Computer generated random numbers were used to randomize the order of the 5 movements and 4 shoe conditions for each subject. Randomization was employed to reduce the potential effect of fatigue or learning that may occur.

Measurements were done using an eight camera three-dimensional motion analysis system (Motion Analysis Corporation, Santa Rosa, CA, USA) and a force plate (model Z4852C, Kistler AG, Winterthur, Switzerland) for both the isolated movements and the agility drills. A rest period of up to two minutes between isolated movements and 5 minutes between agility drills was given in between trials to minimize the effect of fatigue.

Subject anthropometrics including height, mass, and age were recorded by an examiner. Twenty-six reflective markers were placed on the right leg and pelvis: three on the forefoot of the shoe, three on the rear of the shoe, two defining the lateral and medial metatarsal joints, one on the lateral malleolus, one on the medial malleolus, three on the anterior shank, two defining the Achilles tendon line on the posterior shank, three on the thigh, one on the medial and lateral epicondyle, one on the greater trochanter, one on the right and left anterior superior iliac spine, and one on the right and left superior iliac crest (Figure 6). The markers defining the joint centers (right greater trochanter, epicondyles and malleoli) were removed after the neutral trial. The movement of the reflective markers was measured using eight high speed infrared cameras at 240 Hz. Force data was collected at 2400Hz.

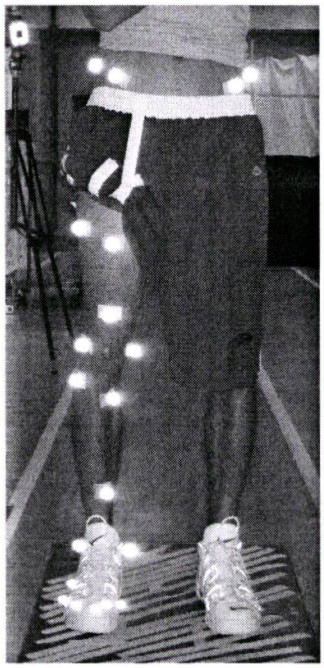

Figure 6. Anterior view of marker placement subject's right leg and foot

Each subject was allowed one practice of every drill in each shoe before data collection began. A trial was repeated for any of the three drills if (a) the subject's right foot did not strike the force plate, (b) if a reflective marker became out of place during the trial, or (c) if any other interference occurred in the testing environment.

3.5 Analysis

3.5.1 Kinematics and Kinetics

Video and force data collected during the basketball movement trials were smoothed using a fourth-order low pass Butterworth filter with a cut off frequency of 10Hz, and 100Hz respectively. The cut-off frequency of 10Hz was the highest frequency that gave smooth acceleration curves. The cut-off frequencies used are similar to those used by previous researchers in similar applications (Nigg, et al., 2009).

Analysis of data was limited to the portion of the movement corresponding to the right foot on the force plate. Data were tracked and reduced using EVaRT (Motion Analysis). Kinematic and kinetic variables were calculated using Kintrak (University of Calgary, CANADA). Kinematic and kinetic variables were calculated at the hip, knee, ankle and forefoot for each movement. At the hip and knee joints, ab/adduction, internal/external rotation, and flexion/extension angles were measured during stance phase. At the ankle and metatarsal-phalangeal joints, ab/adduction, inversion/eversion and plantar/dorsiflexion angles were measured. For each of these kinematic variables, values were analyzed at touch down and take off, the maximum and minimum value during stance. It was of interest to determine the sensitivity of movements, not just to changes at the foot and ankle level, but also at the joints more proximal to the body. The position of the body at contact with the ground, when the foot leaves the ground, as well as the maximal excursions at the joint are of interest when understanding the effect of shoe modification on the athlete.

3.5.2 Statistics

Statistical analysis was performed using SPSS (SPSS for Windows Version 16.0, SPSS Inc, Chicago, IL). Variables from all 5 trials for each subject were averaged together and used in the analysis. Separate repeated measures MANOVA tests for each of the five movements were used to determine significance across changes in footwear, where the factor was the four shoe conditions. The level of significance was set to $\alpha = 0.05$ and was corrected for multiple comparisons using a Bonferroni post hoc correction.

In order to rank the sensitivity of each movement, a Sensitivity Index was calculated for each variable and each shoe condition. For a given footwear modification, the Sensitivity Index is a ratio of the average (mean) change of a specific dependent variable across all subjects and the standard deviation of the change. It is calculated using the following equations:

$$\Delta X = X_2 - X_1$$

where,

$\Delta X =$	difference of variable X between two shoe conditions for a given subject
$X_1 =$	value of biomechanical variable is shoe 1
$X_2 =$	value of biomechanical variable is shoe 2

$$\mu_{(\Delta X)} = \frac{\sum_{i=1}^{n} \Delta X_i}{n}$$

where,

$\mu_{(\Delta X)} =$	average change of variable X across all subjects
$n =$	number of subjects
$i =$	subjects 1 through 17

$$\sigma_{(\Delta X)} = \frac{\sum_{i=1}^{n} (\Delta X_i - \mu_{(\Delta X)})^2}{n - 1}$$

where,

$\sigma_{(\Delta X)}$ = standard deviation of the change of variable X

$$SI = \frac{\mu_{(\Delta X)}}{\sigma_{(\Delta X)}}$$

where,

SI = sensitivity index of variable X

3.6 Classification of sensitivity

Sensitivity in this study was classified by the extent to which kinematic and kinetic variables change as a result of modifications in footwear during the execution of each movement. Relative sensitivity was quantified using two classifications: (1) number of statistically significant changes of biomechanical variables and (2) number of times each movement was rated with the highest sensitivity indices for a variable that changed significantly in at least one of the five movements. For a given footwear change, the movement that corresponds to the most significant changes and the highest sensitivity indices was considered to be the most sensitive.

3.7 Limitations

While the test protocol allowed for recovery time between trials, the subject may have experienced a level of fatigue that could interfere with the effect of the shoe modifications. In addition, when repeating a high number of trials (100 per collection session) at a maximal effort, the subject's enthusiasm for the project may have decreased towards the end. To compensate for these two factors, randomization of the order of the movements and shoe conditions was employed, and remuneration for the subject's efforts was granted.

The use of a laboratory environment instead of a gymnasium may have influenced the ability of the athlete to perform the movements as they would in a game situation. This decreases the ability to generalize the results from this study to a game situation. Restricting the sample of subjects to male varsity athletes increases the internal validity of the results. However, it decreases the ability to generalize to other age and gender groups.

Chapter Four: Results

All results are tabulated in the appendix A. Curves normalized to stance phase of the variables where significant differences were found are also available in appendix A.

4.1 Sensitivity Index for biomechanical variables as a result of modifying basketball shoe upper construction

Table 5. Sensitivity Index Scores and magnitude of change for all biomechanical variables that showed at least one significant change in one of the tested movements ($p<0.05$). The movements tested were Lay-up (LUB), Shuffle & side cut (SCS, Shuttle agility drill (SHU), V-cut (VCM) and Zig-zag-agility drill (ZIG). A positive change (Δx) indicates a larger value for the unstable upper, and a negative change indicates a larger value for the stable upper condition. Shaded indicates a statistically significant change. Bold font indicates the highest Sensitivity Index across all movements.

Variable	Unit	LUB		SCS		SHU		VCM		ZIG	
		ΔX	SI	ΔX	SI	ΔX	SI	ΔX	SI	ΔX	SI
Stance time	sec	0.01	0.34	-0.02	0.29	-0.02	0.23	**0.01**	**0.68**	0.00	0.02
Forefoot flexion angle (touch down)	deg	-0.19	0.26	-1.63	0.58	-0.62	0.34	-0.55	0.39	**2.52**	**0.65**
Forefoot flexion angle (take off)	deg	-2.84	0.08	**-2.20**	**0.69**	-1.37	0.32	-1.26	0.30	-2.10	0.50
Maximal forefoot flexion angle	deg	-1.70	0.18	**-2.36**	**0.47**	-0.15	0.23	-2.87	0.11	-2.93	0.19
Maximal forefoot extension angle	deg	1.35	0.14	**0.56**	**0.41**	-1.19	0.18	-1.41	0.18	1.53	0.11
Forefoot inversion angle (touch down)	deg	-0.03	0.26	1.16	0.30	0.96	0.38	0.21	0.21	**-0.19**	**0.41**
Forefoot inversion angle (take off)	deg	-0.10	0.08	**1.16**	**0.75**	1.78	0.52	0.79	0.43	1.59	0.63
Maximal forefoot inversion angle	deg	-0.01	0.36	2.02	0.17	**2.48**	**0.43**	0.22	0.35	1.64	0.32
Maximal ankle dorsiflexion angle	deg	1.46	0.38	**2.32**	**0.50**	2.34	0.04	2.42	0.37	2.78	0.31
Ankle inversion angle (take off)	deg	0.18	0.22	**2.15**	**0.86**	0.94	0.47	2.41	0.55	2.70	0.58
Maximal ankle inversion angle	deg	0.98	0.25	**3.89**	**1.53**	2.56	0.70	2.91	0.23	3.43	0.81
Maximal ankle abduction angle	deg	-0.40	0.26	1.16	0.29	1.67	0.04	-0.55	0.33	**1.70**	**0.31**
Knee flexion angle (take off)	deg	-1.04	0.12	0.25	0.09	0.33	0.05	-2.18	0.55	**-3.58**	**0.83**
Maximal knee extension angle	deg	-1.18	0.20	0.27	0.11	0.82	0.11	-1.80	0.41	**-3.28**	**0.76**
Maximal hip adduction angle	deg	1.13	0.29	2.39	0.39	-4.36	0.15	0.81	0.31	**0.83**	**0.55**
Ankle dorsi/plantarflexion impulse moment	BWms	0.00	0.35	0.01	0.30	0.01	0.11	**0.01**	**0.57**	0.00	0.25

11 of the 16 variables where significant differences were measured corresponded to movements with the highest Sensitivity Index (SI) for the specific variables. The Lay-up movement had only one significant (but small) change, however, with a rather low sensitivity index. The Zig-Zag movement had four variables with a high sensitivity indices, some of them with quite substantial changes in the variables (Table 5).

For the Zig-Zag movement, the measured kinematics showed nine significant changes, the highest number for any of the studied tests. The Modified V-Cut resulted in seven significant changes, the Shuttle Agility Drill had five, the Shuffle and Side Cut had four and the Lay-up had a single significant change.

The majority of changes in kinematics were between 1 and 3 degrees. Of the significant differences, the biggest kinematic changes for a softer upper were maximal forefoot flexion angle, maximal ankle inversion angle, maximal knee extension angle, and knee flexion angle at take off. The increase in forefoot flexion ranged from 0.15 to 2.93 degrees, with the largest change occurring during the Zig-Zag Agility Drill. The ankle reached a higher maximal inversion angle in all movements due to a softer upper, ranging from 0.98 to 3.89 degrees. During the Zig-Zag agility drill the knee reached a higher maximal knee extension angle (increase of 3.28 degrees), and was also more extended at take off (3.58 degrees).

4.2 Sensitivity Index for biomechanical variables as a result of modifying basketball shoe forefoot bending stiffness

Table 6. Sensitivity Index Scores and magnitude of change for all biomechanical variables that showed at least one significant change in one of the tested movements (p<0.05). (LUB = Lay-up, SCS = Shuffle and Side Cut, SHU = Shuttle Agility Drill, VCM = Modified V-Cut, ZIG = Zig-Zag Agility Drill. A positive change (Δx) indicates a larger value with the stiff forefoot, and a negative change indicates a larger value with the flexible forefoot. Shaded indicates a statistically significant change. Bold font indicates the highest Sensitivity Index across all movements.

Variable	Unit	LUB		SCS		SHU		VCM		ZIG	
		ΔX	SI	ΔX	SI	ΔX	SI	ΔX	SI	ΔX	SI
M-L negative impulse	N*s	1.74	0.22	0.00	0.19	-0.39	0.31	**6.00**	**0.74**	1.10	0.05
Maximal forefoot flexion angle	deg	-1.01	0.20	0.26	0.36	-1.07	0.33	**-1.91**	**0.42**	-0.33	0.17
Maximal knee internal rotation angle	deg	-0.30	0.32	-0.58	0.27	**-2.37**	**0.32**	-0.31	0.06	0.03	0.06
Hip abducton angle (touch down)	deg	-1.62	0.19	-4.31	0.16	2.56	0.10	-4.79	0.10	**-0.07**	**0.39**
Knee Int/external rotation impulse moment	BW*m*s	0.01	0.23	0.00	0.05	0.00	0.03	**0.01**	**0.59**	-0.01	0.16
Knee ad/abduction impulse moment	BW*m*s	0.01	0.34	-0.01	0.42	**-0.01**	**0.59**	0.00	0.06	0.01	0.24
Knee flexion/exension impulse moment	BW*m*s	**0.00**	**0.78**	0.00	0.29	-0.01	0.61	0.00	0.06	-0.01	0.29

Five of the seven significant differences measured corresponded to movements with the highest Sensitivity Index (SI) for the specific variables. The Zig-Zag Agility Drill had no significant changes, and did not have the highest sensitivity index for any change resulting from increasing forefoot bending stiffness. The Lay-up did not result in any significant changes, but did have the highest sensitivity index for 2 of the 7 variables. The Shuffle and Side Cut resulted in only one significant change, which was also the highest sensitivity index for that variable. The Shuttle Agility Drill and Modified V-Cut both had three statistically significant changes resulting from modifying forefoot flexibility.

Three of the significant changes were kinetic variables at the knee joint, three were kinematic variables at the forefoot, knee and hip, and one external force variable. There were no significant changes at the ankle joint (Table 6).

4.3 Sensitivity Index for biomechanical variables as a result of modifying basketball shoe midfoot bending stiffness

Table 7. Sensitivity Index Scores and magnitude of change for all biomechanical variables that showed at least one significant change in one of the tested movements ($p<0.05$). (LUB = Lay-up, SCS = Shuffle and Side Cut, SHU = Shuttle Agility Drill, VCM = Modified V-Cut, ZIG = Zig-Zag Agility Drill. A positive change (Δx) indicates a larger value in the stiff midfoot, and a negative change indicates a larger value in the flexible midfoot. Shaded indicates a statistically significant change. Bold font indicates the highest Sensitivity Index across all movements.

Variable	Unit	LUB		SCS		SHU		VCM		ZIG	
		ΔX	SI	ΔX	SI	ΔX	SI	ΔX	SI	ΔX	SI
M-L positive impulse	Ns	-0.21	0.25	-4.89	0.18	**-14.8**	**0.62**	-0.03	0.13	0.06	0.47
Forefoot flexion angle (touch down)	deg	-1.06	0.11	-1.15	0.33	-0.49	0.11	-0.08	0.20	**-1.83**	**0.87**
Maximal ankle inversion angle	deg	-0.04	0.18	**-2.65**	**0.54**	-0.72	0.15	-0.84	0.26	-0.24	0.29
Knee flexion angle (take off)	deg	-1.62	0.35	-2.49	0.16	**3.64**	**0.59**	0.80	0.14	-1.14	0.06
Knee internal rotation angle (touch down)	deg	0.00	0.08	-0.40	0.05	0.08	0.02	-2.43	0.40	**1.37**	**0.64**
Knee abduction angle (touch down)	deg	-0.82	0.12	0.20	0.11	0.08	0.02	**1.91**	**0.56**	2.13	0.46
Maximal knee adduction angle	deg	**0.52**	**0.23**	1.24	0.09	-0.62	0.14	3.56	0.12	1.57	0.02
Hip flexion angle (touch down)	deg	-3.00	0.04	-3.36	0.46	**-4.21**	**0.58**	-2.72	0.50	-0.69	0.09
Maximal hip flexion angle	deg	-0.07	0.12	-2.28	0.24	**-5.30**	**0.57**	-2.81	0.51	0.80	0.16
Hip internal rotatoin angle (touchdown)	deg	0.32	0.08	1.72	0.25	2.15	0.06	**-2.05**	**0.43**	0.82	0.27
Hip internal rotation angle (take off)	deg	-0.17	0.12	-1.03	0.08	-2.94	0.28	**-1.75**	**0.28**	0.64	0.23

7 of the 11 significant differences measured corresponded to movements with the highest Sensitivity Index (SI) for the specific variables. The Lay-up did not result in any significant changes, but did have the highest sensitivity index for 1 of the 11 variables. The Shuffle and Side Cut resulted in only one significant change, which was also the highest sensitivity index for that variable (Table 7).

The Shuttle Agility Drill resulted in the highest number of significant kinematic changes due to modifications in midfoot bending stiffness. Out of the five significant changes, 4 were also the highest sensitivity index score.

Similar to the changes in upper stability, the majority of changes in kinematics were between 1 and 3 degrees. The largest changes occurred at the hip joint during the Shuttle Agility Drill. The hip was more flexed by approximately 10 degrees at touch down, and also reached a higher maximal flexion angle of a similar magnitude.

4.4 General Comments

In general, there was a good agreement between significant changes and high sensitivity scores: 11/16 for upper changes, 5/7 for forefoot flexibility changes, and 7/11 for midfoot stiffness changes.

The Lay-up test resulted in the fewest number of significant changes and fewest high SI scores for all of the shoe comparisons.

Although the Zig-Zag had the most significant changes due to changes in upper construction, it was not "sensitive" to changes in forefoot flexibility or midfoot bending stiffness.

The Shuttle Agility Drill and Modified V-Cut were "sensitive" to changes in the midsole of basketball shoes.

Chapter Five: Discussion

The goal of this research was to create a guide to identify repeatable, sensitive and appropriate tests that can be performed in a laboratory setting for the purpose of testing basketball shoes. Basketball is a sport characterized by diverse movements performed in a dynamic environment. The experimental tests were performed for key basketball movements to determine the level of sensitivity with which the results of changes in footwear could be measured.

In addition to determining the sensitivity of the test movements, it was of interest to identify and categorize the biomechanical variables that changed as a result of modifying a discrete property of each test shoe. In the past 20 years, there have been only a few published and peer reviewed papers which looked into the effect of basketball footwear modification on basketball biomechanics (Brizuela et al., 1997; Curtis et al., 2008; Ottaviani et al., 1995; Robinson et al., 1986; Tik-Pui Fong et al., 2007; Valiant et al., 1992; Zang et al., 2005), and therefore the addition of this information to the current body of knowledge seems timely.

5.1 Changes in Upper Construction

The results indicated that modifications to upper construction resulted in the highest number of statistically significant changes in the biomechanical execution of the five movements. Some of the changes were intuitive: for instance the result that a decrease of the restriction around the ankle joint resulted in an increase in the range of motion at the ankle in the frontal and sagittal planes. Other changes were not as intuitive: for instance, the result that flexion and extension of the knee was significantly affected in two of the five movements due to changes in upper construction. The effectiveness of high top basketball shoes in preventing ankle injuries has been questioned in the past (Brizuela et al., 1997), and although these results do not provide insight into the change in risk of injury, it can be stated that basketball shoes with a stiffer upper construction *change* the biomechanics of basketball players, and therefore have the possibility to influence injury and/or performance.

For all movements an unstable upper resulted in lower peak forefoot flexion values and correspondingly higher ankle flexion. On average, the athletes used the increased range of motion at the ankle joint with the less stiff upper construction during each movement, and also did not flex their forefoot as much in this shoe condition. This result was not consistent in each individual, indicating that not every subject "took advantage" of the increased range of motion available at the ankle.

There was a systematic increase in the maximum ankle inversion angle during the stance phase of four of the five movements tested as a result of decreased upper support. Since lateral ligamentous injuries of the ankle are one of the most common injuries incurred by a basketball athlete (Dick et al, 2007), increasing the excursion of the ankle joint in the frontal plane is not a desirable characteristic of a basketball shoe. The only movement that did not result in a significant increase in ankle inversion was the lay-up. This movement in general does not load the ankle into inversion, with peak angles 30-50% of the magnitude of the other test movements. This is an indication that the lay-up would not be a good movement to test the upper construction of basketball shoes aimed at decreasing the range of motion of the ankle.

The majority of measured changes in biomechanical variables due to changes in upper construction occurred at the metatarsal-phalengeal (MTP) and ankle joint level. In two of the five movements tested, forefoot inversion (torsional movement of the foot) increased with an "unstable upper." It can be expected that the upper contributes to the torsional stiffness properties of the entire shoe. Therefore the resultant change in foot-shoe torsion is expected.

In general, the significant changes occurred in the frontal and sagittal plane as a result of modifying basketball shoe upper construction. The Modified V-Cut and the Zig-Zag Agility Drill resulted in the highest number of statistically significant changes and the most amount of high sensitivity indices, indicating these movements are the most sensitive to changes in upper construction.

A difficulty in using shoe upper modifications as the independent variable, is quantifying the difference between the two conditions. The difference between these two samples was not quantified, and therefore the magnitude of difference between the shoes was not known. Robinson et al., (1986) attempted to address this difficulty by systematically adding struts of different stiffness into the upper of basketball shoes, and therefore could quantify the difference between each condition. This increases the internal validity of their study, but decreases the external validity of their results to regular shoes. Upper stiffness is not normally increased through the addition of struts, but rather changes in the overall materials used.

Without any additional rating of the "stability" of each sample, the test conditions can only be interpreted as "stable" and "less stable." It is not known where on the spectrum of basketball shoe upper stability that these shoes are, or how far apart they are. This study could be looking at a very limited range in the possible spectrum of basketball shoes available.

The changes in ankle inversion were quite systematic across the four "lateral" movements. There is the potential that this result is due to the soft upper deforming more under a lateral load, and, therefore, the position of the markers defining the rearfoot segment could have also been skewed. In an attempt to minimize this deformation, markers were placed on "rigid" points on the shoe including the heel counter and midsole, instead of on the flexible synthetic upper. In addition, temporary markers were used to define the ankle joint, and removed for the dynamic trials in order to minimize movement artifact of markers on locations prone to movement.

The comparison of biomechanical shoe variables for changes in upper construction (stiffness) showed that the test movement "Zig-Zag Agility Drill" was the most sensitive to these changes. Specifically, the variables forefoot flexion angle, forefoot inversion angle, ankle inversion and knee flexion and extension are proposed to be used for assessment of stiffness changes though the upper construction.

5.2 Changes in shoe forefoot bending stiffness

The intuitive (or expected) effect of increasing the shoe's forefoot stiffness, would be a respective decrease in the forefoot flexion angle during the test movements. This was the case for the Modified V-Cut, with a statistically significant decrease in maximum forefoot flexion angle in the shoes with a stiff forefoot. This same trend was seen in three other movements, however, not at the level of significance. Although not significant, there was an increase in ankle flexion corresponding to the decrease in forefoot flexion in four of the five tested movements. This was similar to the coupled ankle and MTP changes due to modified upper construction, and showed a trend of kinematic compensation across multiple joints. When a rotation is restricted at one joint, another joint (either distal or proximal) typically makes up for the difference by either increasing or decreasing the rotation respectively.

It is interesting to note that changes in shoe forefoot bending stiffness resulted in no significant changes in forefoot inversion. Although changes to the midsole were aimed at altering only one shoe parameter, in this case forefoot bending stiffness, it is not known if that modification altered other shoe characteristics, such as torsionability. Similar to the modifications in upper construction, it is almost impossible to isolate a single shoe variable and not cause a change in other shoe properties. Increasing shoe forefoot bending stiffness was achieved through adding a stiff plate in the forefoot. There is the possibility that this also altered the cushioning properties. Any change observed can then not be attributed to a single shoe variable, such as forefoot bending stiffness, but rather a more general statement, such as the effect of adding a stiff plate to the forefoot of a basketball shoe.

Both the Modified V-Cut and Shuttle Agility Drill resulted in three statistically significant biomechanical changes due to modification in shoe forefoot bending stiffness, and twice rated with the highest sensitivity indices, making these two movements the most sensitive movements to changes in forefoot bending stiffness based on statistical significance. If trends are also considered (p-value between 0.1 and 0.05), the Shuffle and Side Cut is also deemed a sensitive movement to changes in shoe forefoot flexibility.

The comparison of biomechanical shoe variables for changes in forefoot bending stiffness showed that the test movements "Shuttle Agility Drill" and the "Modified V-Cut" were the most sensitive to these changes. Specifically, knee moments, and forefoot flexion angles are proposed to be used for assessment of changes in the stiffness of the forefoot region of the midsole.

5.3 Changes in shoe midfoot bending stiffness

Shoe midfoot bending stiffness is thought to be an important property of basketball shoes based on the need to support the arch of the foot and prevent excessive strain of the plantar fascia. This footwear modification is intended to have a long term effect on chronic injuries, but it was not known, nor documented if this footwear modification affected the movements of basketball athletes, or had any other acute effects.

There were no statistically significant changes in any biomechanical variable during the Shuffle and Side Cut or the Lay-up as a result of the modification of the midfoot bending stiffness. Unlike changes to shoe upper construction and forefoot bending stiffness, the majority of significant changes due to midfoot bending stiffness occurred at the knee and hip for the remaining three movements. In four of the five tested movements, athletes' hips and knees were more flexed in the shoe with a weak midfoot construction, which resulted in an overall more crouched position during stance phase. The effects of modifying midfoot stiffness were not systematic, and difficult to group into functional adaptations. However, the results of this study did show that modifying midfoot bending stiffness does have an acute effect on the execution of basketball movements, and therefore should be investigated in more detail.

The comparison of biomechanical shoe variables for changes in midfoot bending stiffness showed that the test movement "Shuttle Agility Drill" was the most sensitive to these changes. Specifically, the medio-lateral ground reaction force impulse, knee flexion angle and hip flexion angle are proposed to be used for assessment of changes in the stiffness of the midfoot region of the midsole.

5.4 Sensitivity Classification

Sensitivity Index scores were used to represent the sensitivity of each movement. This allowed for comparison of the sensitivity between all movements and variables tested, as each variable is represented by a single value. The general sensitivity of a movement was evaluated based on the number of statistically significant changes, as well as the number of highest SI scores across all movements. In general, there was a good agreement between statistically significant changes and high Sensitivity Indices (SI).

The relative movement sensitivity was dependent on both the footwear modification introduced, and the dependent variable of interest. Based on changes in shoe upper construction, the Lay-up was the least sensitive movement as it resulted in only one statistically significant change and was never rated with the highest SI score. The Zig-Zag Agility Drill was the most sensitive. In general, the Zig-Zag movement also resulted in the largest changes across all variables. These attributes make ***the Zig-Zag movement the best test for changes in basketball shoe upper construction***.

Although the Zig-Zag Agility Drill was determined to be one of the most sensitive movements to changes in shoe upper construction, it is one of the least sensitive movements to midsole construction based on changes in kinematic and kinetic variables. This finding illustrates the need to select appropriate tests based on the specific footwear modification tested. In addition, it suggests the need for shoe changes to be large enough to illicit a response by the athlete that is measurable. The relatively small changes in shoe forefoot flexibility resulted in small and non significant changes to the athlete. The Zig-

Zag movement, Lay-Up and Shuffle and Side Cut are not sensitive movements for changes in shoe forefoot flexibility. ***The Shuttle Agility Drill and the Modified V-Cut were the most sensitive movements to changes in forefoot bending stiffness***

The sensitivity Index scores as results of changes in shoe midfoot bending stiffness also varied based on the joint and variable of interest. In general, ***the Shuttle Agility Drill was the most sensitive movement to changes in midfoot bending stiffness***, and the Lay-Up and Shuffle and Side Cut were the least sensitive. The observed variability in sensitivity points out the need to be able to select specific movements based on a variable of interest, making the detailed tables (Appendix A) an important component of the study.

The sensitivity index used in this study gave an indication of the average effect of a specific footwear modification and the variability of this effect. This method is useful when considering the global effect of a specific footwear modification, but tends to mask effects (sensitivity) when the direction of change is variable and subject specific. For example, if half of the athletes increased the peak external forces while wearing one shoe compared to another, and the other half decreased the peak external forces, the mean change would be low, and the standard deviation of the change quite high. This causes an exaggeratedly low SI, even though the absolute value of the change across all subjects was high. As a result most sensitivity indices were below 1.0 in this study. In the study by Eiser (2003), sensitivity index scores of up to 1.6 were calculated, however the task being measured was walking and therefore the expected variability in kinematic and kinetic variables is lower than complex basketball tasks

An alternative method of calculating a sensitivity index could be to calculate the index with the absolute value of the change for each individual and ignore the direction of the change. This would allow for a classification of sensitivity based on magnitude of effect of a certain intervention, and the result would not be skewed by assuming a uni-directional change when in fact it is not the case. This method has relevance to this study as there were many subject specific adjustments to different footwear conditions across all movements.

The study compared shoes with well defined specific differences. Thus, the results do not provide an understanding for the available difference in basketball shoes but rather a comparison of specific differences. The decision to compare the selected shoes is most likely the reason for the small differences in sensitivity. The changes in forefoot stiffness illustrate the limitation of this study. The "stiff" forefoot shoe measured during a three point bend test was 29.6 – 32.6N/mm, and the "flexible" shoe measured 22.6 - 22.8 N/mm, a difference of less than 30%. Because the difference between each footwear condition was quite small, the effect of these changes was also quite small. This was evident by the sensitivity analysis resulting in scores less than 1, which indicates that the standard deviation of the changes across all subjects was larger than the magnitude of the change itself.

There are two possible solutions to this limitation for consideration in future investigations. The first is to select shoes that are significantly different across many footwear properties, not just one as in this study. The resulting sensitivity scores would presumably be higher, and the ability to discriminate relative sensitivity between different movements greater. The disadvantage becomes the interpretation of the changes, which was not the primary goal of this study. The second option would be to make the difference in each selected condition greater. For example, increasing the forefoot stiffness by 300% instead of 30% should enhance the differences resulting from the different footwear conditions. However, this solution is difficult to manufacture and out of the range with which basketball shoes are developed for production.

In addition to the relatively small differences between footwear conditions, footwear properties change with wear as a shoe becomes "broken in." It can be hypothesized that the shoe properties experienced by tester 1 were different than tester 17, and therefore the effect of that same shoe could be quite different. A post-measurement 3-point bend test of the test shoes should be completed to determine the effect of approximately 40 hours of wear on midsole bending properties.

In spite of the recommended improvements in the selection of footwear modifications, it has been previously reported that the kinematics of the lower extremity change little in response to modification in footwear. In addition, these changes are often subject specific, small and inconsistent (Nigg, 2010). A new concept, described by Nigg (2010) as "the preferred movement path" provides a new way of interpreting the effect of footwear modifications on the skeleton which shifts the emphasis from aligning the skeleton to maintaining a preferred path of minimal resistance. If this is the case, identifying the control mechanism which maintain the preferred movement path would guide the selection of dependent variables used to calculate relative sensitivity.

The task of analyzing basketball biomechanics is constrained by many factors. First, movements within the sport are often reactions to the environment at a given time period, which can consist of a team-mate, opponent, location of the ball and position on the court. In a laboratory, for purposes of data collection, the movements are pre-planned, structured, and repeated multiple times. Although set to a maximum speed, the drills are not exact replications of the movements performed in a game. A second constraint is the basketball surface the athlete plays on. This affects the amount of traction the athlete has when making cuts and turns, therefore the replication of the movement may be changed in the lab situation due to the different surface condition. Thirdly, the movements are complex and consist of a series of angular running, cutting, landing and jumping tasks. This allows for a large degree of individual specific executions of the movements in the real game situation. However, in the test situation one does not want this variability.

5.5 Does reliability imply sensitivity?

The first step in the evaluation of basketball movements for use as tests in a laboratory was determining the reliability of each movement for various experimental set-ups, specifically within one test session, within one day and between days (Davis et al., 2008). As a general rule of thumb, the more consistently a movement was performed, the more reliable it was. Good reliability helps minimize the variability in movement execution, which makes detecting differences easier. For this reason, reliability in some sense should be a good predictor of sensitivity. However, this is only true if what makes a movement reliable does not make it impervious to external influence, such as modification in footwear.

On average, the movements selected for the quantification of sensitivity were highly reliable; however within the sub-set of five movements, the relative reliability was different for different variables. Through looking qualitatively at the agreement between reliability and sensitivity of variables that changed significantly to a modification in footwear, it can be determined if selecting the most reliable movement would have resulted in high sensitivity to changes in footwear.

Table 8 includes the intraclass correlation coefficients (ICC) for maximal ankle inversion angle from Davis et al. (2008), along with the corresponding Sensitivity Index from the current study as a result of two modifications in footwear.

Table 8. Movement Sensitivity Index based on changes in ankle inversion as a result of modifications in shoe upper stability and midfoot bending stiffness and the corresponding Intraclass Correlation Coefficient (ICC) for the maximal ankle inversion angle. The ICCs are from the previous study (Davis et al., 2008).

Movement	ICC	Sensitivity Index	
		Upper Stability	Midfoot Stiffness
Lay-up	0.379	0.247	0.179
Shuffle and Side Cut	**0.823**	**1.527**	**0.542**
Shuttle Agility Drill	0.766	0.698	0.146
Modified V-Cut	0.770	0.231	0.258
Zig-Zag Agility Drill	0.817	0.811	0.292

For maximal ankle inversion angle, the highest sensitivity indices corresponded to the highest ICC for both changes in upper stability and midfoot bending stiffness. The general trend of reliability and sensitivity rank for the remaining movements was fairly consistent (Table 8).

Table 9. Movement Sensitivity Index based on changes in knee flexion angle at touch down as a result of modifications in shoe upper stability and midfoot bending stiffness and corresponding Intraclass Correlation Coefficient (ICC) for the knee flexion angle at take off. The ICCs are from the previous study (Davis et al., 2008).

Movement	ICC	Sensitivity Index	
		Upper Stability	Midfoot Stiffness
Lay-up	0.380	0.117	0.354
Shuffle and Side Cut	0.688	0.091	0.159
Shuttle Agility Drill	0.502	0.050	0.590
Modified V-Cut	0.815	0.549	0.136
Zig-Zag Agility Drill	0.636	0.828	0.062

For the knee flexion angle at take off, the highest sensitivity index did not corresponded to the highest ICC, and there was no general trend of high reliability scores corresponding to high sensitivity indices for the remaining movements (Table 9).

The results indicate that for some variables there is a relationship between reliability and sensitivity, but for others the two ratings are independent. For variables in which a relationship exists, the selection of the best movement is easy. For changes in ankle inversion angle, the Shuffle and Side Cut movement has the highest reliability and the highest sensitivity for two separate changes in footwear. In addition the changes in ankle inversion angle were statistically significant for the Shuffle and Side Cut. It is straight forward to select this movement as the best test for measuring the effect of footwear on ankle inversion angle. For variables where there does not seem to be a clear relationship, such as knee flexion angle at take off, choosing the best movement is more difficult. One movement may have a high reliability, but not the highest sensitivity, or vice versa. Either the reliability rating or the sensitivity rating needs to be scaled for importance. Due to the sensitivity scores being determined from very discrete changes in footwear, it would be sensible to use the reliability as the primary rating of the test, and sensitivity the secondary rating if the change in footwear is more general than the specific modifications studied.

This connection between reliability and sensitivity to change should be considered in future work. It may be hypothesized that the most reliable movements do not make the best tests for understanding the effect of footwear modifications. If a certain control mechanism is in place to maintain the consistency in the kinematics of a certain movement, the measurable effect of footwear could be minimized. If this is the case, a researcher would need to look at relatively unreliable movements that are potentially more influenced by external perturbations. This potential research path will be difficult to pursue as measuring differences within a data set that contains high error variance would require more advanced methods, however the findings would aid in the selection of functional movement tests for footwear.

5.6 Summary

(1) The most sensitive movement to changes in upper construction was the Zig-Zag Agility Drill

(2) The most sensitive movements to changes in forefoot bending stiffness were the Shuttle Agility Drill and the Modified V-Cut

(3) The most sensitive movement to changes in midfoot bending stiffness was The Shuttle Agility Drill

(4) In general, the Lay-Up was not sensitive to any changes in footwear

(5) The Sensitivity Indices correspond to statistically significant changes fairly well. However, The most reliable movements did not always correspond to the most sensitive

Chapter Six: Conclusion

The analysis of basketball movements is an important part for the assessment of basketball shoes. Movement in basketball is complex and multifaceted. It includes running, jumping side cutting and many other elements. Therefore, it is important to know which movement can and should be used for such assessments. However, the use of complex basketball movements for evaluating the effectiveness of footwear is complicated. There are many uncontrollable variables and many sources of variability in movement analysis. Determining potential sources of error and understanding the limitations of using certain movements as tests is very important to ensure an effective analysis.

Sources of error and variability include the equipment used to collect data, the placement of markers used to define segments and joints, and the variability in the execution of the movement itself. As the total variability of a test condition increases, the mathematical ability to measure differences between conditions decreases. For this reason, the evaluation of a test for the effect of footwear on human movement must include answers to the following questions:

(1) How reliably can we measure human movement in three dimensional space?

   a. How accurate is the used equipment?
   b. How accurate are the applied methods (marker placement, tracking, etc.)

(2) How reliably can subjects repeat movements in a laboratory environment?

(3) Does footwear change the observable biomechanics of basketball athletes?

(4) Are basketball movements "sensitive" to these changes?

(5) Are some basketball movements more sensitive to certain changes than others?

The main purpose of this study was to determine the relative sensitivity of basketball movements to changes in basketball footwear. A stratification of movement sensitivity was completed by using a combination of the number of statistically significant changes measured during each movement and a comparison of calculated sensitivity indices for each dependent variable. It was determined that basketball movements are sensitive to changes in footwear, and more importantly, that some movements are more sensitive than others. In addition, movement sensitivity, like reliability, is dependent on the biomechanical variables of interest. It is therefore important to select the most appropriate test movement and variables for the question of interest.

Movement sensitivity was also dependent on the footwear modification imposed on the athletes. For changes in upper construction, the Zig-Zag agility drill was most sensitive. For change in shoe forefoot flexibility, the modified v-cut and shuttle agility drill were most sensitive. For changes in midfoot bending stiffness, the shuttle agility drill was most sensitive. These footwear dependent results highlight the need for an analysis of movement sensitivity for other common modification in basketball footwear such as the collar height, torsional stiffness and available coefficients of traction.

This study used a variety of discrete kinematic and kinetic variables to quantify the execution of basketball movements and measure the relative effect of modifications in footwear. Out of all of the biomechanical variables that are possible to measure, only a small sub-set was considered, and only a small portion of the basketball movement was analyzed (one foot contact on the ground). An expansion of the dependent variables used to quantify the effect of footwear modifications is needed in order to gain a broader view of the magnitude of effect that basketball footwear can have on athletes. This study evaluated the relative sensitivity of basketball movements without consideration of which variables are more meaningful to the basketball athlete than others. An interpretation of the relevance of biomechanical variables on basketball performance and injuries is needed in order to enhance the evaluation of footwear modifications from those that cause change to those that cause either a positive or a negative change. Understanding the relevance of the variables that change significantly with modifications in footwear properties will help to understand the control mechanisms of the human body, and better understand the effect of specific footwear changes.

Although there are many limitations in this study, the results give new information about the sensitivity of basketball specific movements to changes in footwear. Combined with the results of the reliability study, specific and meaningful tests can be selected to evaluate changes in footwear. It is not certain how these variables are related to performance and injury, however knowing the reliable and sensitive movements allows for meaningful research in basketball footwear design.

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Appendix A

The following tables contain the detailed results for the changes in kinematics, kinetics and external forces as a result of the three modifications in basketball footwear.

Each table contains the mean and standard deviation in each of the shoe conditions, along with the difference, p-value and sensitivity index score.

In addition, for the variables where significant differences between shoe conditions were found, curves normalized to stance phase are presented. The mean normalized curve for all subjects and the standard error of the mean are presented in each figure.

Table 10. Summary of Changes in biomechanical variables due to changes in shoe upper stability during the Lay-Up

	Variable	n	Stable Upper		Unstable Upper		Diff	P	SI
			Mean	SD	Mean	SD		Value	
External Forces	Vertical impulse	17	469.58	56.27	476.14	47.65	6.56	0.48	0.10
	A-P positive impulse	17	92.45	19.14	93.39	19.82	0.93	0.67	0.01
	A-P negative impulse	17	-1.32	0.75	-1.29	0.78	-0.03	0.74	0.32
	M-L positive impulse	17	3.11	2.48	2.28	1.11	-0.83	0.30	0.01
	M-L negative impulse	17	-89.55	28.94	-92.86	20.84	3.31	0.86	0.10
	Stance time	17	0.24	0.03	0.25	0.03	0.01	0.17	0.34
Forefoot Kinematics	TD Flexion angle	17	4.25	2.69	4.05	2.26	-0.19	0.79	0.26
	TO Flexion angle	17	5.38	3.36	2.54	3.85	-2.84	0.07	0.08
	Max Flexion angle	17	9.32	4.26	7.62	2.97	-1.70	0.16	0.18
	Max Extension angle	17	-3.61	2.12	-4.96	2.00	1.35	0.12	0.14
	TD Inversion angle	17	0.30	1.66	0.27	1.26	-0.03	0.72	0.26
	TO Inversion angle	17	0.18	1.69	0.09	1.07	-0.10	0.95	0.08
	Max Eversion angle	17	1.12	1.54	1.21	1.11	0.09	0.55	0.36
	Max Inversion angle	17	-1.51	1.27	-1.50	1.21	-0.01	0.58	0.36
Ankle Kinematics	TD Flexion angle	17	6.14	6.89	9.47	5.12	3.33	0.11	0.12
	TO Flexion angle	17	-20.83	4.30	-21.39	5.59	0.57	0.42	0.27
	Max Dorsiflexion angle	17	9.18	3.70	10.65	3.90	1.46	0.18	0.38
	Max Plantarflexion angle	17	-20.96	4.05	-21.61	5.34	0.66	0.44	0.21
	TD Inversion angle	17	-6.13	4.66	-6.32	4.76	0.19	0.91	0.32
	TO Inversion angle	17	-6.54	3.72	-6.72	3.90	0.18	0.78	0.22
	Max Eversion angle	17	8.84	3.46	8.73	2.81	-0.11	0.50	0.18
	Max Inversion angle	17	-8.30	2.93	-9.28	3.42	0.98	0.37	0.25
	TD abduction angle	17	-1.02	4.08	-0.54	4.10	-0.48	0.35	0.18
	TO abduction angle	17	-7.87	3.84	-8.41	2.92	0.54	0.34	0.35
	Max abduction angle	17	4.31	4.16	3.91	4.29	-0.40	0.41	0.26
	Max adduction angle	17	-8.00	3.85	-8.99	2.70	1.00	0.45	0.21
Knee Kinematics	TD Flexion angle	17	-25.93	6.66	-25.05	4.77	-0.88	0.95	0.42
	TO Flexion angle	17	-10.46	4.81	-9.42	3.79	-1.04	0.47	0.12
	Max Flexion angle	17	-53.70	6.85	-52.43	6.14	-1.26	0.17	0.31
	Max Extension angle	17	-10.46	4.81	-9.28	3.88	-1.18	0.30	0.20
	TD Internal Rotation angle	17	-5.98	4.43	-6.87	3.33	0.89	0.11	0.07
	TO Internal Rotation angle	17	2.66	2.30	2.81	2.16	0.15	0.67	0.14
	Max External Rotation angle	17	-6.66	4.45	-7.34	3.34	0.68	0.18	0.31
	Max Internal Rotation angle	17	5.03	4.01	5.04	3.57	0.01	0.93	0.58
	TD abduction angle	17	1.49	4.59	2.55	3.56	1.06	0.26	0.32
	TO abduction angle	17	-0.79	3.71	-0.41	4.23	-0.37	0.77	0.12
	Max abduction angle	17	2.85	3.65	4.38	3.10	1.52	0.08	0.02
	Max adduction angle	17	-14.87	3.65	-15.24	4.09	0.36	0.60	0.33
Hip Kinematics	TD Flexion angle	17	44.29	6.56	44.42	5.17	0.13	0.19	0.11
	TO Flexion angle	17	7.99	5.61	8.36	5.01	0.38	0.90	0.18
	Max Flexion angle	17	45.18	6.20	45.07	5.27	-0.12	0.30	0.42
	Max Extension angle	17	7.71	5.50	8.02	5.17	0.31	0.92	0.18
	TD Internal Rotation angle	17	3.97	5.01	3.52	4.97	-0.45	0.80	0.50
	TO Internal Rotation angle	17	16.23	4.18	16.40	4.37	0.17	0.92	0.21
	Max External Rotation angle	17	16.75	3.08	17.05	4.33	0.30	0.81	0.05
	Max Internal Rotation angle	17	-8.23	3.71	-8.83	4.48	0.61	0.60	0.40
	TD abduction angle	17	-2.01	4.74	-2.60	5.36	0.59	0.25	0.08
	TO abduction angle	17	1.65	4.76	0.94	4.26	-0.72	0.32	0.15
	Max abduction angle	17	5.92	4.68	5.08	3.95	-0.84	0.70	0.17
	Max adduction angle	17	-5.29	3.45	-6.43	3.45	1.13	0.05	0.29
Ankle Moment	Ad/abduction	17	0.03	0.09	0.02	0.08	-0.01	0.28	0.35
	In/eversion	17	0.02	0.04	0.01	0.08	-0.02	0.20	0.42
	dorsi/plantarflexion	17	0.00	0.03	0.01	0.03	0.00	0.27	0.35
Knee Moment	Int/external rotation	17	-0.01	0.08	-0.01	0.06	0.00	0.51	0.20
	Ad/abduction	17	-0.04	0.05	-0.06	0.07	0.01	0.10	0.55
	flexion/exension	17	0.01	0.03	0.01	0.03	0.00	0.25	0.37
Hip Moment	Int/external rotation	17	0.03	0.02	0.02	0.03	-0.01	0.33	0.31
	Ad/abduction	17	-0.01	0.08	-0.03	0.11	0.01	0.24	0.37
	flexion/exension	17	0.01	0.02	0.01	0.02	0.00	0.14	0.48

Table 11. Summary of Changes in biomechanical variables due to changes in shoe upper stability during the Shuffle and Side Cut

	Variable	n	Stable Upper Mean	Stable Upper SD	Unstable Upper Mean	Unstable Upper SD	Diff	P Value	SI
External Forces	Vertical impulse	17	509.64	85.45	495.79	100.56	-13.85	0.33	0.25
	A-P positive impulse	17	20.60	8.34	19.32	8.19	-1.28	0.49	0.22
	A-P negative impulse	17	-16.73	7.02	-15.34	5.52	-1.39	0.29	0.03
	M-L positive impulse	17	353.86	47.77	331.96	104.85	-21.90	0.33	0.26
	M-L negative impulse	17	-0.07	0.11	19.74	76.81	19.67	0.33	0.22
	Stance time	17	0.50	0.09	0.48	0.10	-0.02	0.25	0.29
Forefoot Kinematics	TD Flexion angle	17	1.97	2.86	0.34	2.94	-1.63	0.18	0.58
	TO Flexion angle	17	4.91	3.56	2.71	3.66	-2.20	0.03	0.69
	Max Flexion angle	17	11.95	4.85	9.59	5.18	-2.36	0.06	0.47
	Max Extension angle	17	0.90	2.38	-1.46	2.52	0.56	0.12	0.41
	TD Inversion angle	17	-0.75	1.67	-1.90	3.32	1.16	0.28	0.30
	TO Inversion angle	17	-1.69	1.86	-2.85	1.49	1.16	0.03	0.75
	Max Eversion angle	17	-0.29	1.69	-0.67	1.00	0.37	0.41	0.23
	Max Inversion angle	17	-6.11	2.48	-8.13	2.98	2.02	0.08	0.17
Ankle Kinematics	TD Flexion angle	17	-7.07	8.74	-8.12	8.96	1.04	0.43	0.21
	TO Flexion angle	17	-14.54	6.47	-13.61	7.72	-0.93	0.47	0.19
	Max Dorsiflexion angle	17	20.13	5.52	22.45	5.36	2.32	0.07	0.50
	Max Plantarflexion angle	17	-15.38	6.27	-15.38	6.90	0.00	0.98	0.01
	TD Inversion angle	17	-8.00	5.76	-8.10	5.87	0.10	0.89	0.04
	TO Inversion angle	17	-19.04	3.63	-21.20	3.43	2.15	0.01	0.86
	Max Eversion angle	17	-6.69	3.27	-7.27	4.21	0.58	0.36	0.24
	Max Inversion angle	17	-22.73	2.48	-26.61	2.77	3.89	0.00	1.53
	TD abduction angle	17	1.76	5.14	2.55	3.35	0.79	0.50	0.18
	TO abduction angle	17	-2.33	5.00	-0.11	5.72	-2.21	0.07	0.50
	Max abduction angle	17	4.70	4.25	5.86	3.27	1.16	0.27	0.29
	Max adduction angle	17	-7.02	3.67	-6.17	4.86	-0.85	0.59	0.14
Knee Kinematics	TD Flexion angle	17	-45.41	12.82	-43.43	11.99	-1.98	0.21	0.31
	TO Flexion angle	17	-22.62	7.17	-22.87	8.08	0.25	0.86	0.09
	Max Flexion angle	17	-76.74	9.69	-74.86	10.45	-1.88	0.21	0.30
	Max Extension angle	17	-21.44	6.32	-21.71	6.78	0.27	0.83	0.11
	TD Internal Rotation angle	17	-3.27	6.25	-3.18	5.19	-0.09	0.91	0.00
	TO Internal Rotation angle	17	0.07	4.16	0.14	4.32	0.06	0.93	0.06
	Max External Rotation angle	17	-5.56	6.10	-5.63	5.54	0.07	0.93	0.02
	Max Internal Rotation angle	17	7.13	7.78	7.48	7.07	0.35	0.74	0.15
	TD abduction angle	17	0.90	4.70	0.71	4.64	-0.19	0.83	0.05
	TO abduction angle	17	8.18	6.84	8.30	6.89	0.12	0.92	0.02
	Max abduction angle	17	8.72	6.58	9.21	6.29	0.49	0.67	0.07
	Max adduction angle	17	-14.19	6.63	-14.39	5.66	0.20	0.81	0.01
Hip Kinematics	TD Flexion angle	17	44.51	9.65	44.92	9.93	0.41	0.75	0.04
	TO Flexion angle	17	19.48	9.45	21.43	10.65	1.95	0.16	0.47
	Max Flexion angle	17	63.24	16.78	59.03	12.06	-4.20	0.28	0.23
	Max Extension angle	17	17.03	8.40	19.72	9.39	2.69	0.19	0.40
	TD Internal Rotation angle	17	28.52	5.49	28.84	5.77	0.32	0.57	0.18
	TO Internal Rotation angle	17	30.75	10.42	32.78	5.02	2.03	0.60	0.39
	Max External Rotation angle	17	37.83	7.67	37.68	7.51	-0.15	0.82	0.31
	Max Internal Rotation angle	17	21.37	9.51	23.98	6.48	2.61	0.40	0.19
	TD abduction angle	17	-3.26	12.35	-5.60	7.12	2.34	0.80	0.22
	TO abduction angle	17	9.00	8.27	6.00	5.83	-3.01	0.14	0.09
	Max abduction angle	17	11.98	8.80	9.12	5.64	-2.86	0.21	0.03
	Max adduction angle	17	-13.48	12.51	-15.87	7.78	2.39	0.82	0.39
Ankle Moment	Ad/abduction	17	-0.01	0.05	-0.01	0.07	0.00	0.55	0.13
	In/eversion	17	-0.05	0.03	-0.06	0.05	0.01	0.35	0.31
	dorsi/plantarflexion	17	0.03	0.03	0.04	0.04	0.01	0.36	0.30
Knee Moment	Int/external rotation	17	-0.01	0.07	-0.01	0.05	0.00	0.85	0.14
	Ad/abduction	17	0.04	0.05	0.03	0.08	-0.01	0.17	0.43
	flexion/exension	17	-0.03	0.04	-0.02	0.06	-0.01	0.15	0.45
Hip Moment	Int/external rotation	17	0.02	0.13	0.02	0.12	0.00	0.96	0.03
	Ad/abduction	17	-0.04	0.06	-0.04	0.05	0.01	0.39	0.18
	flexion/exension	17	0.02	0.04	0.03	0.03	0.00	0.46	0.15

Table 12. Summary of Changes in biomechanical variables due to changes in shoe upper stability during the Shuttle Agility Drill

	Variable	n	Stable Upper Mean	Stable Upper SD	Unstable Upper Mean	Unstable Upper SD	Diff	P Value	SI
External Forces	Vertical impulse	17	478.03	125.92	457.69	79.28	-20.34	0.33	0.31
	A-P positive impulse	17	40.91	82.76	18.74	7.49	-22.16	0.31	0.28
	A-P negative impulse	17	-14.23	9.33	-15.77	8.84	1.53	0.41	0.15
	M-L positive impulse	17	332.32	111.08	321.81	98.64	-10.51	0.76	0.02
	M-L negative impulse	17	-0.51	1.27	18.92	73.83	18.41	0.32	0.30
	Stance time	17	0.50	0.09	0.48	0.07	-0.02	0.34	0.23
Forefoot Kinematics	TD Flexion angle	17	2.68	3.13	2.06	2.85	-0.62	0.28	0.34
	TO Flexion angle	17	9.73	5.94	8.36	7.77	-1.37	0.62	0.32
	Max Flexion angle	17	18.20	7.11	18.05	10.63	-0.15	0.87	0.23
	Max Extension angle	17	2.08	3.20	0.89	2.97	-1.19	0.13	0.18
	TD Inversion angle	17	-0.22	1.33	-1.18	1.73	0.96	0.05	0.38
	TO Inversion angle	17	-0.92	2.10	-2.70	2.34	1.78	0.03	0.52
	Max Eversion angle	17	0.67	2.03	-0.35	1.85	-0.32	0.08	0.12
	Max Inversion angle	17	-4.76	2.54	-7.24	2.34	2.48	0.00	0.43
Ankle Kinematics	TD Flexion angle	17	-8.71	6.40	-8.17	6.93	-0.54	0.76	0.22
	TO Flexion angle	17	-15.40	8.68	-12.77	9.50	-2.63	0.15	0.03
	Max Dorsiflexion angle	17	22.30	6.69	24.64	8.79	2.34	0.05	0.04
	Max Plantarflexion angle	17	-16.91	6.83	-15.70	7.64	-1.21	0.26	0.36
	TD Inversion angle	17	-6.84	4.55	-8.31	6.20	1.47	0.86	0.23
	TO Inversion angle	17	-18.23	4.17	-19.17	5.06	0.94	0.17	0.47
	Max Eversion angle	17	-5.58	4.35	-7.03	4.61	1.44	0.32	0.38
	Max Inversion angle	17	-22.00	5.24	-24.56	4.82	2.56	0.02	0.70
	TD abduction angle	17	1.23	4.53	2.13	3.38	0.90	0.53	0.17
	TO abduction angle	17	-0.57	6.45	1.34	4.39	0.77	0.31	0.06
	Max abduction angle	17	5.88	4.99	7.55	3.68	1.67	0.39	0.04
	Max adduction angle	17	-5.28	6.02	-3.79	3.69	-1.49	0.53	0.08
Knee Kinematics	TD Flexion angle	17	-34.79	9.70	-36.75	7.95	1.96	0.64	0.36
	TO Flexion angle	17	-24.88	8.26	-25.21	10.34	0.33	0.88	0.05
	Max Flexion angle	17	-67.78	9.06	-68.65	8.01	0.87	0.57	0.18
	Max Extension angle	17	-20.37	4.78	-21.19	7.54	0.82	0.70	0.11
	TD Internal Rotation angle	17	1.29	7.26	0.98	5.96	-0.31	0.74	0.07
	TO Internal Rotation angle	17	-0.73	4.49	0.13	3.78	-0.60	0.20	0.27
	Max External Rotation angle	17	-4.55	4.52	-4.28	4.53	-0.27	0.68	0.32
	Max Internal Rotation angle	17	9.57	7.92	8.46	6.79	-1.11	0.27	0.29
	TD abduction angle	17	1.77	15.09	-2.11	6.40	0.35	0.31	0.03
	TO abduction angle	17	9.53	6.16	7.90	7.53	-1.63	0.27	0.30
	Max abduction angle	17	13.76	13.73	9.66	7.09	-4.11	0.27	0.23
	Max adduction angle	17	-12.38	6.17	-11.40	6.08	-0.98	0.32	0.10
Hip Kinematics	TD Flexion angle	17	37.43	12.46	39.46	8.81	2.03	0.48	0.27
	TO Flexion angle	17	14.67	9.94	13.27	10.86	-1.39	0.60	0.10
	Max Flexion angle	17	51.18	10.88	49.87	11.87	-1.31	0.61	0.08
	Max Extension angle	17	10.09	11.20	10.12	8.50	0.03	0.99	0.05
	TD Internal Rotation angle	17	21.40	6.99	21.69	5.77	0.29	0.88	0.37
	TO Internal Rotation angle	17	22.94	8.00	23.24	5.96	0.30	0.87	0.23
	Max External Rotation angle	17	32.49	7.41	32.32	5.35	-0.16	0.94	0.24
	Max Internal Rotation angle	17	16.85	6.68	17.87	4.74	1.02	0.59	0.35
	TD abduction angle	17	-12.75	15.33	-8.69	7.17	-4.06	0.22	0.04
	TO abduction angle	17	4.94	14.43	6.94	8.22	2.00	0.51	0.12
	Max abduction angle	17	9.17	11.98	11.28	6.52	2.12	0.45	0.02
	Max adduction angle	17	-19.92	14.89	-15.56	6.36	-4.36	0.22	0.15
Ankle Moment	Ad/abduction	17	0.02	0.04	0.03	0.05	0.01	0.24	0.40
	In/eversion	17	-0.01	0.02	0.00	0.04	0.00	0.85	0.03
	dorsi/plantarflexion	17	0.01	0.02	0.02	0.02	0.01	0.04	0.11
Knee Moment	Int/external rotation	17	-0.04	0.04	-0.04	0.06	-0.01	0.44	0.55
	Ad/abduction	17	-0.01	0.05	-0.01	0.07	0.00	0.65	0.22
	flexion/exension	17	-0.02	0.03	-0.01	0.04	-0.01	0.23	0.35
Hip Moment	Int/external rotation	17	0.00	0.04	0.02	0.09	0.01	0.42	0.35
	Ad/abduction	17	-0.02	0.06	-0.01	0.09	-0.01	0.33	0.04
	flexion/exension	17	0.00	0.02	0.01	0.05	0.01	0.30	0.23

Table 13. Summary of Changes in biomechanical variables due to changes in shoe upper stability during the modified V-Cut

	Variable	n	Stable Upper Mean	Stable Upper SD	Unstable Upper Mean	Unstable Upper SD	Diff	P Value	SI
External Forces	Vertical impulse	17	331.04	57.92	341.38	54.65	10.34	0.08	0.50
	A-P positive impulse	17	53.29	13.66	53.32	20.12	0.04	0.99	0.20
	A-P negative impulse	17	-13.54	4.61	-20.05	18.93	6.52	0.20	0.33
	M-L positive impulse	17	0.46	0.45	0.79	1.32	0.33	0.35	0.35
	M-L negative impulse	17	-159.18	24.39	-165.71	25.31	6.52	0.08	0.26
	Stance time	17	0.26	0.05	0.27	0.05	0.01	0.02	0.68
Forefoot Kinematics	TD Flexion angle	17	2.81	2.07	2.26	2.54	-0.55	0.27	0.39
	TO Flexion angle	17	16.32	5.67	15.06	6.13	-1.26	0.30	0.30
	Max Flexion angle	17	26.97	5.23	24.10	7.11	-2.87	0.03	0.11
	Max Extension angle	17	1.77	2.03	0.36	3.16	-1.41	0.03	0.18
	TD Inversion angle	17	0.05	0.87	0.26	1.25	0.21	0.52	0.21
	TO Inversion angle	17	-1.48	1.62	-2.27	2.35	0.79	0.26	0.43
	Max Eversion angle	17	0.49	1.23	0.44	1.38	-0.05	0.98	0.34
	Max Inversion angle	17	-4.56	1.57	-4.78	1.22	0.22	0.86	0.35
Ankle Kinematics	TD Flexion angle	17	-2.58	6.71	-2.72	7.18	0.14	0.91	0.03
	TO Flexion angle	17	-13.90	5.79	-13.68	5.41	-0.22	0.79	0.07
	Max Dorsiflexion angle	17	22.35	5.42	24.77	6.20	2.42	0.21	0.37
	Max Plantarflexion angle	17	-14.54	5.38	-14.19	5.11	-0.36	0.54	0.27
	TD Inversion angle	17	-6.33	4.87	-7.28	5.05	0.96	0.28	0.11
	TO Inversion angle	17	-15.23	5.80	-17.64	4.83	2.41	0.05	0.55
	Max Eversion angle	17	-3.74	4.70	-4.81	4.23	1.07	0.26	0.09
	Max Inversion angle	17	-16.73	5.38	-19.64	4.57	2.91	0.00	0.23
	TD abduction angle	17	1.70	7.99	1.20	4.17	-0.49	0.25	0.31
	TO abduction angle	17	-3.14	9.06	-3.85	5.35	0.70	0.58	0.15
	Max abduction angle	17	4.33	8.51	3.78	3.58	-0.55	0.20	0.33
	Max adduction angle	17	-6.37	7.61	-6.94	4.23	0.57	0.42	0.30
Knee Kinematics	TD Flexion angle	17	-45.70	11.78	-45.66	11.12	-0.04	0.13	0.01
	TO Flexion angle	17	-25.41	7.82	-23.23	5.75	-2.18	0.04	0.55
	Max Flexion angle	17	-66.80	8.40	-67.19	8.28	0.38	0.62	0.13
	Max Extension angle	17	-24.19	6.79	-22.39	5.42	-1.80	0.12	0.41
	TD Internal Rotation angle	17	-0.96	6.56	-1.90	6.76	0.94	0.43	0.17
	TO Internal Rotation angle	17	4.39	4.33	3.63	4.52	-0.77	0.36	0.17
	Max External Rotation angle	17	-2.89	6.01	-3.84	5.97	0.95	0.40	0.21
	Max Internal Rotation angle	17	8.91	6.09	8.45	5.72	-0.46	0.65	0.07
	TD abduction angle	17	-4.44	5.89	-5.58	6.16	1.14	0.50	0.20
	TO abduction angle	17	-0.60	5.63	0.36	5.48	-0.24	0.50	0.24
	Max abduction angle	17	1.76	5.02	1.33	5.44	-0.42	0.77	0.12
	Max adduction angle	17	-14.01	6.22	-14.90	5.49	0.89	0.42	0.22
Hip Kinematics	TD Flexion angle	17	43.55	6.30	45.18	4.22	1.63	0.25	0.39
	TO Flexion angle	17	-4.27	3.52	-4.40	4.61	0.12	0.92	0.07
	Max Flexion angle	17	44.91	5.35	46.27	4.45	1.36	0.27	0.18
	Max Extension angle	17	-4.49	3.66	-4.61	4.60	0.12	0.92	0.12
	TD Internal Rotation angle	17	9.07	5.53	10.62	5.33	1.54	0.12	0.20
	TO Internal Rotation angle	17	20.87	5.91	21.42	5.99	0.55	0.47	0.01
	Max External Rotation angle	17	26.25	6.63	26.85	6.06	0.60	0.45	0.07
	Max Internal Rotation angle	17	7.44	5.15	8.24	5.38	0.80	0.35	0.07
	TD abduction angle	17	-7.43	5.72	-8.61	6.51	1.18	0.38	0.51
	TO abduction angle	17	9.57	5.77	9.51	5.36	-0.06	0.96	0.27
	Max abduction angle	17	11.01	5.32	11.07	5.49	0.06	0.96	0.30
	Max adduction angle	17	-12.09	4.71	-12.89	4.71	0.81	0.48	0.31
Ankle Moment	Ad/abduction	17	0.02	0.04	0.03	0.05	0.01	0.24	0.22
	In/eversion	17	-0.01	0.02	0.00	0.04	0.00	0.85	0.00
	dorsi/plantarflexion	17	0.01	0.02	0.02	0.02	0.01	0.04	0.57
Knee Moment	Int/external rotation	17	-0.04	0.04	-0.04	0.06	-0.01	0.44	0.15
	Ad/abduction	17	-0.01	0.05	-0.01	0.07	0.00	0.65	0.13
	flexion/exension	17	-0.02	0.03	-0.01	0.04	-0.01	0.23	0.32
Hip Moment	Int/external rotation	17	0.00	0.04	0.02	0.09	0.01	0.42	0.20
	Ad/abduction	17	-0.02	0.06	-0.01	0.09	-0.01	0.33	0.24
	flexion/exension	17	0.00	0.02	0.01	0.05	0.01	0.30	0.27

Table 14. Summary of Changes in biomechanical variables due to changes in shoe upper stability during the Zig-Zag Drill

	Variable	n	Stable Upper Mean	Stable Upper SD	Unstable Upper Mean	Unstable Upper SD	Diff	P Value	SI
External Forces	Vertical impulse	17	381.31	72.30	391.38	68.75	10.07	0.59	0.09
	A-P positive impulse	17	31.14	10.49	33.11	6.37	1.96	0.44	0.25
	A-P negative impulse	17	-30.33	12.65	-31.06	12.44	0.73	0.96	0.11
	M-L positive impulse	17	0.25	0.52	0.26	0.50	0.01	0.95	0.11
	M-L negative impulse	17	-248.99	33.61	-254.03	30.32	5.04	0.56	0.04
	Stance time	17	0.31	0.06	0.31	0.11	0.00	0.92	0.02
Forefoot Kinematics	TD Flexion angle	17	1.94	3.01	-0.58	4.38	2.52	0.04	0.65
	TO Flexion angle	17	14.06	6.42	11.96	5.76	-2.10	0.17	0.50
	Max Flexion angle	17	25.04	7.58	22.11	5.62	-2.93	0.28	0.19
	Max Extension angle	17	0.91	3.30	-2.45	3.82	1.53	0.01	0.11
	TD Inversion angle	17	0.21	1.44	0.02	1.48	-0.19	0.31	0.41
	TO Inversion angle	17	-1.44	2.44	-3.03	1.17	1.59	0.02	0.63
	Max Eversion angle	17	0.72	2.15	0.10	1.46	-0.61	0.09	0.35
	Max Inversion angle	17	-5.68	2.88	-7.31	2.07	1.64	0.02	0.32
Ankle Kinematics	TD Flexion angle	17	-9.38	8.96	-9.59	8.34	0.20	0.31	0.28
	TO Flexion angle	17	-15.71	7.20	-16.09	8.09	0.37	0.82	0.27
	Max Dorsiflexion angle	17	20.80	8.03	23.57	8.97	2.78	0.15	0.31
	Max Plantarflexion angle	17	-16.91	6.82	-17.16	7.61	0.25	0.68	0.24
	TD Inversion angle	17	-7.33	5.24	-7.58	6.07	0.25	0.72	0.20
	TO Inversion angle	17	-16.90	5.34	-19.60	5.07	2.70	0.05	0.58
	Max Eversion angle	17	-6.06	4.42	-6.62	4.82	0.55	0.41	0.19
	Max Inversion angle	17	-20.58	5.27	-24.01	2.99	3.43	0.03	0.81
	TD abduction angle	17	1.75	4.23	1.44	3.58	-0.31	0.97	0.01
	TO abduction angle	17	-4.29	5.60	-2.24	6.07	-2.05	0.19	0.37
	Max abduction angle	17	4.19	3.70	5.90	3.68	1.70	0.04	0.31
	Max adduction angle	17	-6.74	5.39	-6.18	4.80	-0.56	0.60	0.28
Knee Kinematics	TD Flexion angle	17	-35.62	9.29	-32.74	8.07	-2.88	0.17	0.38
	TO Flexion angle	17	-27.31	7.68	-23.73	6.17	-3.58	0.01	0.83
	Max Flexion angle	17	-65.66	4.23	-64.81	6.92	-0.85	0.71	0.10
	Max Extension angle	17	-24.82	6.18	-21.54	6.09	-3.28	0.01	0.76
	TD Internal Rotation angle	17	0.90	5.73	-0.36	4.82	-0.53	0.39	0.06
	TO Internal Rotation angle	17	3.32	3.72	3.42	3.26	0.10	0.91	0.14
	Max External Rotation angle	17	-2.78	5.24	-3.23	5.38	0.44	0.78	0.08
	Max Internal Rotation angle	17	9.25	5.75	9.02	5.73	-0.23	0.89	0.12
	TD abduction angle	17	-2.63	6.00	-1.64	5.90	-0.98	0.83	0.23
	TO abduction angle	17	2.23	4.75	3.21	5.63	0.98	0.59	0.03
	Max abduction angle	17	3.99	4.27	4.93	5.50	0.95	0.64	0.04
	Max adduction angle	17	-14.60	4.67	-14.34	5.47	-0.26	0.75	0.07
Hip Kinematics	TD Flexion angle	17	39.74	8.35	40.21	5.38	0.47	0.59	0.20
	TO Flexion angle	17	-0.41	7.71	-1.34	4.84	0.93	0.43	0.10
	Max Flexion angle	17	41.30	9.81	43.09	8.30	1.80	0.16	0.42
	Max Extension angle	17	-1.91	7.88	-2.80	5.25	0.89	0.50	0.09
	TD Internal Rotation angle	17	22.84	5.60	23.55	5.93	0.70	0.34	0.07
	TO Internal Rotation angle	17	16.16	4.63	18.80	5.71	2.64	0.22	0.12
	Max External Rotation angle	17	29.47	4.35	31.13	6.39	1.67	0.24	0.07
	Max Internal Rotation angle	17	13.95	4.61	15.47	3.96	1.52	0.08	0.11
	TD abduction angle	17	-13.99	8.94	-14.49	9.52	0.50	0.64	0.34
	TO abduction angle	17	8.00	6.70	7.87	5.50	-0.12	0.93	0.72
	Max abduction angle	17	12.75	6.63	11.56	5.54	-1.20	0.61	0.35
	Max adduction angle	17	-17.43	7.16	-18.26	7.83	0.83	0.56	0.55
Ankle Moment	Ad/abduction	17	0.02	0.05	0.03	0.05	0.01	0.30	0.21
	In/eversion	17	0.00	0.01	0.00	0.02	0.00	0.88	0.02
	dorsi/plantarflexion	17	0.02	0.04	0.02	0.04	0.00	0.24	0.25
Knee Moment	Int/external rotation	17	-0.06	0.05	-0.05	0.05	0.00	0.43	0.06
	Ad/abduction	17	-0.02	0.06	-0.02	0.07	0.01	0.91	0.03
	flexion/exension	17	-0.04	0.04	-0.03	0.04	-0.01	0.22	0.22
Hip Moment	Int/external rotation	17	-0.01	0.06	0.00	0.05	-0.01	0.19	0.25
	Ad/abduction	17	-0.01	0.11	-0.01	0.13	0.00	0.99	0.01
	flexion/exension	17	-0.01	0.04	0.00	0.04	-0.01	0.12	0.36

Table 15. Summary of Changes in biomechanical variables due to changes in shoe forefoot bending stiffness during the Lay-Up

	Variable	n	Flexible Forefoot Mean	Flexible Forefoot SD	Stiff Forefoot Mean	Stiff Forefoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	469.58	56.27	471.58	53.40	2.01	0.69	0.34
	A-P positive impulse	17	92.45	19.14	97.83	18.98	5.37	0.14	0.33
	A-P negative impulse	17	-1.32	0.75	-1.10	0.55	-0.22	0.16	0.19
	M-L positive impulse	17	3.11	2.48	2.82	2.15	-0.30	0.09	0.31
	M-L negative impulse	17	-89.55	28.94	-91.29	29.27	1.74	0.63	0.22
	Stance time	17	0.24	0.03	0.25	0.03	0.00	0.51	0.03
Forefoot Kinematics	TD Flexion angle	17	4.25	2.69	3.73	1.69	-0.52	0.44	0.02
	TO Flexion angle	17	5.38	3.36	4.00	3.61	-1.38	0.10	0.05
	Max Flexion angle	17	9.32	4.26	8.31	3.67	-1.01	0.15	0.20
	Max Extension angle	17	-3.61	2.12	-3.17	2.23	-0.44	0.38	0.27
	TD Inversion angle	17	0.30	1.66	0.33	1.25	0.03	0.91	0.24
	TO Inversion angle	17	0.18	1.69	-0.03	1.30	-0.15	0.50	0.18
	Max Eversion angle	17	1.12	1.54	0.96	1.04	-0.16	0.48	0.25
	Max Inversion angle	17	-1.51	1.27	-1.60	1.21	0.09	0.76	0.23
Ankle Kinematics	TD Flexion angle	17	6.14	6.89	5.86	8.26	-0.28	0.99	0.11
	TO Flexion angle	17	-20.83	4.30	-21.32	5.87	0.49	0.80	0.32
	Max Dorsiflexion angle	17	9.18	3.70	9.37	4.88	0.19	0.76	0.19
	Max Plantarflexion angle	17	-20.96	4.05	-21.65	5.62	0.69	0.67	0.26
	TD Inversion angle	17	-6.13	4.66	-6.51	3.79	0.38	0.45	0.22
	TO Inversion angle	17	-6.54	3.72	-6.92	4.69	0.38	0.52	0.21
	Max Eversion angle	17	8.84	3.46	9.06	3.56	0.22	0.69	0.19
	Max Inversion angle	17	-8.30	2.93	-8.97	3.49	0.68	0.25	0.21
	TD abduction angle	17	-1.02	4.08	-0.39	3.84	-0.63	0.68	0.18
	TO abduction angle	17	-7.87	3.84	-7.00	2.99	-0.87	0.19	0.21
	Max abduction angle	17	4.31	4.16	4.24	4.24	-0.08	0.76	0.22
	Max adduction angle	17	-8.00	3.85	-7.20	3.11	-0.80	0.23	0.32
Knee Kinematics	TD Flexion angle	17	-25.93	6.66	-26.31	5.94	0.38	0.74	0.33
	TO Flexion angle	17	-10.46	4.81	-8.90	4.68	-1.56	0.16	0.37
	Max Flexion angle	17	-53.70	6.85	-53.23	5.55	-0.46	0.62	0.13
	Max Extension angle	17	-10.46	4.81	-8.86	4.74	-1.60	0.15	0.38
	TD Internal Rotation angle	17	-5.98	4.43	-7.28	4.32	1.30	0.21	0.08
	TO Internal Rotation angle	17	2.66	2.30	2.43	2.54	-0.23	0.65	0.23
	Max External Rotation angle	17	-6.66	4.45	-8.17	4.41	1.51	0.12	0.13
	Max Internal Rotation angle	17	5.03	4.01	4.73	4.03	-0.30	0.66	0.32
	TD abduction angle	17	1.49	4.59	2.27	5.80	0.78	0.41	0.18
	TO abduction angle	17	-0.79	3.71	1.04	9.08	0.25	0.37	0.12
	Max abduction angle	17	2.85	3.65	5.35	8.90	2.50	0.22	0.11
	Max adduction angle	17	-14.87	3.65	-15.43	5.08	0.56	0.40	0.41
Hip Kinematics	TD Flexion angle	17	44.29	6.56	44.34	6.81	0.05	0.97	0.38
	TO Flexion angle	17	7.99	5.61	7.01	7.02	-0.98	0.38	0.01
	Max Flexion angle	17	45.18	6.20	44.90	6.75	-0.28	0.85	0.09
	Max Extension angle	17	7.71	5.50	6.82	7.21	-0.90	0.41	0.01
	TD Internal Rotation angle	17	3.97	5.01	4.95	5.59	0.99	0.29	0.13
	TO Internal Rotation angle	17	16.23	4.18	16.34	4.94	0.11	0.88	0.21
	Max External Rotation angle	17	16.75	3.08	16.83	4.26	0.08	0.91	0.01
	Max Internal Rotation angle	17	-8.23	3.71	-7.52	4.90	-0.71	0.52	0.39
	TD abduction angle	17	-2.01	4.74	-2.56	6.29	0.55	0.63	0.28
	TO abduction angle	17	1.65	4.76	-0.03	6.23	-1.62	0.39	0.19
	Max abduction angle	17	5.92	4.68	5.92	6.09	-0.01	1.00	0.17
	Max adduction angle	17	-5.29	3.45	-6.82	4.91	1.52	0.12	0.24
Ankle Moment	Ad/abduction	17	0.03	0.09	0.02	0.08	0.00	0.35	0.26
	In/eversion	17	0.02	0.04	0.02	0.06	0.00	0.33	0.26
	dorsi/plantarflexion	17	0.00	0.03	0.01	0.04	0.00	0.46	0.46
Knee Moment	Int/external rotation	17	-0.01	0.08	-0.02	0.06	0.01	0.15	0.23
	Ad/abduction	17	-0.04	0.05	-0.05	0.06	0.01	0.30	0.34
	flexion/exension	17	0.01	0.03	0.01	0.03	0.00	0.59	0.78
Hip Moment	Int/external rotation	17	0.03	0.02	0.02	0.03	-0.01	0.41	0.31
	Ad/abduction	17	-0.01	0.08	-0.02	0.09	0.00	0.39	0.22
	flexion/exension	17	0.01	0.02	0.01	0.02	0.00	0.47	0.00

Table 16. Summary of Changes in biomechanical variables due to changes in shoe forefoot bending stiffness during the Shuffle and Side Cut

	Variable	n	Flexible Forefoot Mean	Flexible Forefoot SD	Stiff Forefoot Mean	Stiff Forefoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	509.64	85.45	495.54	95.16	-14.09	0.26	0.46
	A-P positive impulse	17	20.60	8.34	18.92	8.48	-1.68	0.42	2.77
	A-P negative impulse	17	-16.73	7.02	-16.35	6.94	-0.39	0.72	2.86
	M-L positive impulse	17	353.86	47.77	345.96	49.24	-7.90	0.30	0.60
	M-L negative impulse	17	-0.07	0.11	-0.07	0.12	0.00	0.86	0.19
	Stance time	17	0.50	0.09	0.48	0.09	-0.02	0.10	0.31
Forefoot Kinematics	TD Flexion angle	17	1.97	2.86	0.94	2.98	-1.03	0.22	0.34
	TO Flexion angle	17	4.91	3.56	4.65	3.53	-0.26	0.70	0.20
	Max Flexion angle	17	11.95	4.85	12.21	5.13	0.26	0.84	0.36
	Max Extension angle	17	0.90	2.38	-0.02	2.57	-0.88	0.22	0.30
	TD Inversion angle	17	-0.75	1.67	-0.92	1.69	0.17	0.23	0.03
	TO Inversion angle	17	-1.69	1.86	-2.03	1.49	0.35	0.33	0.02
	Max Eversion angle	17	-0.29	1.69	-0.50	1.36	0.20	0.25	0.07
	Max Inversion angle	17	-6.11	2.48	-5.80	1.93	-0.31	0.41	0.02
Ankle Kinematics	TD Flexion angle	17	-7.07	8.74	-5.94	11.47	-1.13	0.69	0.10
	TO Flexion angle	17	-14.54	6.47	-6.33	18.28	-8.21	0.08	0.46
	Max Dorsiflexion angle	17	20.13	5.52	26.45	16.21	6.31	0.15	0.11
	Max Plantarflexion angle	17	-15.38	6.27	-16.63	12.49	1.25	0.68	0.38
	TD Inversion angle	17	-8.00	5.76	-7.68	5.25	-0.33	0.60	0.13
	TO Inversion angle	17	-19.04	3.63	-17.20	5.32	-1.85	0.07	0.48
	Max Eversion angle	17	-6.69	3.27	-5.80	4.37	-0.90	0.32	0.26
	Max Inversion angle	17	-22.73	2.48	-21.33	4.42	-1.39	0.20	0.33
	TD abduction angle	17	1.76	5.14	4.57	7.88	2.81	0.09	0.53
	TO abduction angle	17	-2.33	5.00	-0.17	11.69	-2.15	0.40	0.82
	Max abduction angle	17	4.70	4.25	7.05	7.76	2.35	0.15	0.38
	Max adduction angle	17	-7.02	3.67	-6.71	11.23	-0.31	0.91	0.03
Knee Kinematics	TD Flexion angle	17	-45.41	12.82	-43.06	10.28	-2.34	0.27	0.29
	TO Flexion angle	17	-22.62	7.17	-21.56	15.75	-1.06	0.79	0.07
	Max Flexion angle	17	-76.74	9.69	-75.60	9.27	-1.14	0.53	0.16
	Max Extension angle	17	-21.44	6.32	-19.47	17.15	-1.97	0.64	0.12
	TD Internal Rotation angle	17	-3.27	6.25	-2.63	6.35	-0.64	0.57	0.36
	TO Internal Rotation angle	17	0.07	4.16	-0.34	4.36	0.26	0.65	0.43
	Max External Rotation angle	17	-5.56	6.10	-6.52	5.77	0.96	0.37	0.27
	Max Internal Rotation angle	17	7.13	7.78	6.55	6.77	-0.58	0.62	0.27
	TD abduction angle	17	0.90	4.70	-0.24	5.34	-0.66	0.17	0.14
	TO abduction angle	17	8.18	6.84	4.88	9.81	-3.30	0.10	0.12
	Max abduction angle	17	8.72	6.58	7.68	7.15	-1.04	0.30	0.13
	Max adduction angle	17	-14.19	6.63	-15.91	6.73	1.72	0.30	0.23
Hip Kinematics	TD Flexion angle	17	44.51	9.65	44.17	9.58	-0.34	0.84	0.05
	TO Flexion angle	17	19.48	9.45	21.30	12.23	1.82	0.32	0.26
	Max Flexion angle	17	63.24	16.78	58.92	12.58	-4.32	0.34	0.25
	Max Extension angle	17	17.03	8.40	19.30	10.86	2.26	0.36	0.34
	TD Internal Rotation angle	17	28.52	5.49	30.20	6.64	1.68	0.15	0.08
	TO Internal Rotation angle	17	30.75	10.42	31.63	5.81	0.88	0.15	0.51
	Max External Rotation angle	17	37.83	7.67	38.36	7.50	0.52	0.42	0.41
	Max Internal Rotation angle	17	21.37	9.51	24.49	7.81	3.12	0.29	0.04
	TD abduction angle	17	-3.26	12.35	-5.31	7.96	2.05	0.72	0.38
	TO abduction angle	17	9.00	8.27	4.69	5.79	-4.31	0.05	0.16
	Max abduction angle	17	11.98	8.80	8.02	6.56	-3.96	0.11	0.06
	Max adduction angle	17	-13.48	12.51	-15.96	8.04	2.48	0.92	0.37
Ankle Moment	Ad/abduction	17	-0.01	0.05	-0.01	0.06	0.00	0.27	0.31
	In/eversion	17	-0.05	0.03	-0.05	0.03	0.00	0.62	0.14
	dorsi/plantarflexion	17	0.03	0.03	0.03	0.03	0.00	0.63	0.13
Knee Moment	Int/external rotation	17	-0.01	0.07	-0.01	0.05	0.00	0.86	0.05
	Ad/abduction	17	0.04	0.05	0.03	0.05	-0.01	0.14	0.42
	flexion/exension	17	-0.03	0.04	-0.02	0.04	0.00	0.30	0.29
Hip Moment	Int/external rotation	17	0.02	0.13	0.02	0.11	0.00	0.60	0.14
	Ad/abduction	17	-0.04	0.06	-0.03	0.06	0.00	0.55	0.16
	flexion/exension	17	0.02	0.04	0.02	0.05	0.00	0.29	0.29

Table 17. Summary of Changes in biomechanical variables due to changes in shoe forefoot bending stiffness during the Shuttle Agility Drill

	Variable	n	Flexible Forefoot Mean	Flexible Forefoot SD	Stiff Forefoot Mean	Stiff Forefoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	478.03	125.92	476.64	111.38	-1.39	0.91	0.16
	A-P positive impulse	17	40.91	82.76	19.91	6.95	-20.99	0.34	0.34
	A-P negative impulse	17	-14.23	9.33	-14.99	8.95	0.76	0.61	1.59
	M-L positive impulse	17	332.32	111.08	342.75	70.29	10.43	0.66	0.03
	M-L negative impulse	17	-0.51	1.27	-0.12	0.21	-0.39	0.26	0.31
	Stance time	17	0.50	0.09	0.50	0.08	-0.01	0.55	0.03
Forefoot Kinematics	TD Flexion angle	17	2.68	3.13	2.43	4.11	-0.25	0.95	0.13
	TO Flexion angle	17	9.73	5.94	8.14	6.07	-1.59	0.18	0.37
	Max Flexion angle	17	18.20	7.11	17.14	8.03	-1.07	0.25	0.33
	Max Extension angle	17	2.08	3.20	1.53	4.04	-0.56	0.98	0.02
	TD Inversion angle	17	0.90	4.38	-0.54	1.58	-0.36	0.19	0.31
	TO Inversion angle	17	0.71	6.42	-1.59	1.32	0.89	0.14	0.40
	Max Eversion angle	17	2.19	6.00	0.08	1.65	-2.11	0.78	0.37
	Max Inversion angle	17	-3.58	5.07	-4.99	1.61	1.41	0.16	0.07
Ankle Kinematics	TD Flexion angle	17	-8.71	6.40	-8.18	7.23	-0.53	0.31	0.26
	TO Flexion angle	17	-15.40	8.68	-12.59	7.30	-2.81	0.96	0.01
	Max Dorsiflexion angle	17	22.30	6.69	23.41	8.65	1.11	0.68	0.37
	Max Plantarflexion angle	17	-16.91	6.83	-15.28	5.26	-1.63	0.16	0.10
	TD Inversion angle	17	-7.08	4.50	-8.79	5.84	1.71	0.13	0.40
	TO Inversion angle	17	-17.16	5.87	-17.39	4.60	0.23	0.84	0.05
	Max Eversion angle	17	-5.10	4.63	-6.97	3.69	1.87	0.11	0.42
	Max Inversion angle	17	-21.40	5.60	-21.70	5.43	0.30	0.77	0.07
	TD abduction angle	17	2.66	7.22	2.39	4.11	-0.27	0.88	0.37
	TO abduction angle	17	0.94	8.68	0.69	6.37	-0.25	0.89	0.03
	Max abduction angle	17	7.42	7.84	7.15	5.03	-0.27	0.88	0.04
	Max adduction angle	17	-3.74	8.48	-4.74	6.35	1.00	0.62	0.13
Knee Kinematics	TD Flexion angle	17	-34.79	9.70	-35.35	9.38	0.56	0.70	0.10
	TO Flexion angle	17	-24.88	8.26	-25.64	9.53	0.76	0.66	0.11
	Max Flexion angle	17	-67.78	9.06	-69.45	7.11	1.67	0.28	0.28
	Max Extension angle	17	-20.37	4.78	-22.13	5.91	1.75	0.21	0.32
	TD Internal Rotation angle	17	1.29	7.26	1.57	6.39	0.28	0.81	0.16
	TO Internal Rotation angle	17	8.28	4.49	5.63	4.96	-2.65	0.64	0.39
	Max External Rotation angle	17	-4.55	4.52	-5.56	4.85	1.01	0.23	0.12
	Max Internal Rotation angle	17	9.57	7.92	7.20	6.72	-2.37	0.03	0.32
	TD abduction angle	17	1.77	15.09	-2.74	7.01	0.97	0.27	0.06
	TO abduction angle	17	9.53	6.16	7.22	8.47	-2.31	0.14	0.12
	Max abduction angle	17	13.76	13.73	9.08	7.23	-4.68	0.22	0.62
	Max adduction angle	17	-12.38	6.17	-12.10	7.11	-0.28	0.63	0.32
Hip Kinematics	TD Flexion angle	17	37.43	12.46	35.50	9.28	-1.94	0.39	0.14
	TO Flexion angle	17	14.67	9.94	12.45	7.78	-2.22	0.35	0.13
	Max Flexion angle	17	51.18	10.88	48.29	11.31	-2.89	0.31	0.18
	Max Extension angle	17	10.09	11.20	9.61	8.34	-0.48	0.87	0.04
	TD Internal Rotation angle	17	21.40	6.99	23.05	6.74	1.65	0.46	0.25
	TO Internal Rotation angle	17	22.94	8.00	23.01	5.25	0.07	0.97	0.21
	Max External Rotation angle	17	32.49	7.41	31.95	6.61	-0.54	0.85	0.23
	Max Internal Rotation angle	17	16.85	6.68	18.82	5.51	1.97	0.35	0.29
	TD abduction angle	17	-12.75	15.33	-8.73	7.92	-4.02	0.30	0.22
	TO abduction angle	17	4.94	14.43	7.51	7.70	2.56	0.44	0.10
	Max abduction angle	17	9.17	11.98	11.88	7.18	2.72	0.38	0.01
	Max adduction angle	17	-19.92	14.89	-15.81	8.22	-4.11	0.25	0.33
Ankle Moment	Ad/abduction	17	-0.02	0.06	-0.02	0.06	0.00	0.28	0.30
	In/eversion	17	-0.06	0.03	-0.06	0.03	0.00	0.98	0.01
	dorsi/plantarflexion	17	0.04	0.02	0.04	0.02	0.00	0.92	0.03
Knee Moment	Int/external rotation	17	0.01	0.06	0.02	0.05	0.00	0.90	0.03
	Ad/abduction	17	0.03	0.04	0.02	0.06	-0.01	0.05	0.59
	flexion/exension	17	-0.02	0.04	-0.01	0.05	-0.01	0.04	0.61
Hip Moment	Int/external rotation	17	0.02	0.12	0.01	0.12	0.00	0.47	0.20
	Ad/abduction	17	-0.04	0.05	-0.04	0.03	0.00	0.80	0.07
	flexion/exension	17	0.02	0.03	0.02	0.02	0.00	0.76	0.08

Table 18. Summary of Changes in biomechanical variables due to changes in shoe forefoot bending stiffness during the modified V-Cut

	Variable	n	Flexible Forefoot Mean	Flexible Forefoot SD	Stiff Forefoot Mean	Stiff Forefoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	331.04	57.92	335.43	58.21	4.38	0.40	0.10
	A-P positive impulse	17	53.29	13.66	53.61	21.71	0.32	0.94	0.10
	A-P negative impulse	17	-13.54	4.61	-13.42	5.01	-0.11	0.93	0.27
	M-L positive impulse	17	0.46	0.45	0.34	0.30	-0.12	0.14	0.44
	M-L negative impulse	17	-159.18	24.39	-165.18	25.01	6.00	0.03	0.74
	Stance time	17	0.26	0.05	0.26	0.05	0.00	0.70	0.27
Forefoot Kinematics	TD Flexion angle	17	2.81	2.07	2.41	2.17	-0.40	0.80	0.18
	TO Flexion angle	17	16.32	5.67	16.17	6.36	-0.15	0.95	0.08
	Max Flexion angle	17	26.97	5.23	25.06	5.45	-1.91	0.05	0.42
	Max Extension angle	17	1.77	2.03	1.62	2.34	-0.15	0.77	0.25
	TD Inversion angle	17	0.05	0.87	0.09	1.22	0.04	0.97	0.17
	TO Inversion angle	17	-1.48	1.62	-0.96	2.04	-0.51	0.25	0.32
	Max Eversion angle	17	0.49	1.23	0.68	1.74	0.19	0.70	0.16
	Max Inversion angle	17	-4.56	1.57	-4.11	0.97	-0.44	0.28	0.21
Ankle Kinematics	TD Flexion angle	17	-0.69	9.95	-2.61	7.26	1.92	0.50	0.17
	TO Flexion angle	17	-10.92	13.18	-11.26	5.75	0.35	0.90	0.03
	Max Dorsiflexion angle	17	24.82	11.18	23.65	5.81	-1.17	0.71	0.05
	Max Plantarflexion angle	17	-11.93	11.67	-12.53	4.76	0.60	0.84	0.10
	TD Inversion angle	17	-6.33	4.87	-7.82	4.28	1.50	0.13	0.40
	TO Inversion angle	17	-15.23	5.80	-15.77	5.15	0.54	0.64	0.12
	Max Eversion angle	17	-3.74	4.70	-4.67	3.70	0.93	0.36	0.24
	Max Inversion angle	17	-16.73	5.38	-17.80	5.32	1.07	0.30	0.27
	TD abduction angle	17	1.70	7.99	1.64	4.39	-0.05	0.98	0.54
	TO abduction angle	17	-3.14	9.06	-3.15	7.66	0.01	1.00	0.00
	Max abduction angle	17	4.33	8.51	4.13	4.38	-0.20	0.93	0.02
	Max adduction angle	17	-11.93	7.61	-6.81	5.66	-5.13	0.83	0.05
Knee Kinematics	TD Flexion angle	17	-45.70	11.78	-43.59	12.22	-2.11	0.42	0.21
	TO Flexion angle	17	-25.41	7.82	-24.56	10.25	-0.84	0.63	0.12
	Max Flexion angle	17	-66.80	8.40	-66.40	9.08	-0.41	0.75	0.08
	Max Extension angle	17	-24.19	6.79	-22.67	11.06	-1.52	0.48	0.18
	TD Internal Rotation angle	17	-0.96	6.56	0.02	7.29	-0.94	0.43	0.21
	TO Internal Rotation angle	17	4.39	4.33	2.99	5.87	-1.41	0.12	0.18
	Max External Rotation angle	17	-2.89	6.01	-3.47	7.14	0.59	0.60	0.39
	Max Internal Rotation angle	17	8.91	6.09	8.59	6.05	-0.31	0.70	0.06
	TD abduction angle	17	-4.44	5.89	-5.34	5.17	0.90	0.42	0.20
	TO abduction angle	17	-0.60	5.63	-2.72	10.44	2.12	0.48	0.42
	Max abduction angle	17	1.76	5.02	1.42	6.46	-0.33	0.82	0.10
	Max adduction angle	17	-14.01	6.22	-17.56	12.02	3.55	0.14	0.13
Hip Kinematics	TD Flexion angle	17	43.55	6.30	41.84	4.75	-1.71	0.22	0.11
	TO Flexion angle	17	-4.27	3.52	-4.37	4.81	0.09	0.94	0.14
	Max Flexion angle	17	44.91	5.35	43.27	5.22	-1.64	0.22	0.22
	Max Extension angle	17	-4.49	3.66	-4.59	4.63	0.10	0.94	0.49
	TD Internal Rotation angle	17	9.07	5.53	9.28	3.85	0.21	0.83	0.01
	TO Internal Rotation angle	17	20.87	5.91	19.60	5.39	-1.27	0.24	0.35
	Max External Rotation angle	17	26.25	6.63	25.91	6.58	-0.34	0.64	2.05
	Max Internal Rotation angle	17	7.44	5.15	7.36	5.20	-0.08	0.95	0.17
	TD abduction angle	17	-7.43	5.72	-7.27	8.92	-0.16	0.92	0.20
	TO abduction angle	17	9.57	5.77	4.77	13.35	-4.79	0.18	0.10
	Max abduction angle	17	11.01	5.32	13.10	13.44	2.09	0.54	0.12
	Max adduction angle	17	-12.09	4.71	-15.32	13.72	3.23	0.33	0.10
Ankle Moment	Ad/abduction	17	0.02	0.04	0.02	0.04	0.00	0.92	0.03
	In/eversion	17	-0.01	0.02	-0.01	0.03	0.00	0.90	0.03
	dorsi/plantarflexion	17	0.01	0.02	0.02	0.02	0.00	0.48	0.20
Knee Moment	Int/external rotation	17	-0.04	0.04	-0.05	0.05	0.01	0.04	0.59
	Ad/abduction	17	-0.01	0.05	-0.01	0.07	0.00	0.83	0.06
	flexion/exension	17	-0.02	0.03	-0.02	0.03	0.00	0.82	0.06
Hip Moment	Int/external rotation	17	0.00	0.04	-0.01	0.05	0.00	0.06	0.56
	Ad/abduction	17	-0.02	0.06	-0.02	0.08	0.00	0.84	0.05
	flexion/exension	17	0.00	0.02	0.00	0.03	0.00	0.47	0.20

Table 19. Summary of Changes in biomechanical variables due to changes in shoe forefoot bending stiffness during the Zig-Zag Drill

	Variable	n	Flexible Forefoot		Stiff Forefoot		Diff	P	SI
			Mean	SD	Mean	SD		Value	
	Vertical impulse	17	381.31	72.30	390.35	73.35	9.04	0.33	0.25
	A-P positive impulse	17	31.14	10.49	32.13	9.00	0.99	0.68	0.11
External Forces	A-P negative impulse	17	-30.33	12.65	-30.72	15.17	0.39	0.82	0.06
	M-L positive impulse	17	0.25	0.52	0.27	0.72	0.02	0.78	0.07
	M-L negative impulse	17	-248.99	33.61	-250.09	32.30	1.10	0.85	0.05
	Stance time	17	0.31	0.06	0.33	0.08	0.02	0.34	0.26
	TD Flexion angle	17	1.94	3.01	0.86	2.84	-1.08	0.13	0.45
	TO Flexion angle	17	14.06	6.42	14.44	7.69	0.38	0.99	0.05
	Max Flexion angle	17	25.04	7.58	24.70	7.41	-0.33	0.31	0.17
Forefoot Kinematics	Max Extension angle	17	0.91	3.30	0.16	2.95	-0.75	0.27	0.40
	TD Inversion angle	17	0.21	1.44	-0.04	1.07	-0.17	0.23	0.31
	TO Inversion angle	17	-1.44	2.44	-1.66	1.33	0.22	0.57	0.06
	Max Eversion angle	17	0.72	2.15	0.26	1.29	-0.45	0.14	0.23
	Max Inversion angle	17	-5.68	2.88	-5.87	1.81	0.20	0.77	0.23
	TD Flexion angle	17	-9.38	8.96	-10.08	8.13	0.70	0.48	0.23
	TO Flexion angle	17	-15.71	7.20	-14.94	8.12	-0.78	0.25	0.30
	Max Dorsiflexion angle	17	20.80	8.03	21.89	7.91	1.10	0.28	0.26
	Max Plantarflexion angle	17	-16.91	6.82	-16.43	7.63	-0.48	0.31	0.28
	TD Inversion angle	17	-7.33	5.24	-7.87	5.48	0.53	0.72	0.09
Ankle Kinematics	TO Inversion angle	17	-16.90	5.34	-17.51	4.48	0.61	0.61	0.07
	Max Eversion angle	17	-6.06	4.42	-5.94	3.41	-0.13	0.36	0.24
	Max Inversion angle	17	-20.58	5.27	-21.19	4.57	0.61	0.66	0.11
	TD abduction angle	17	1.75	4.23	2.49	4.43	0.74	0.26	0.29
	TO abduction angle	17	-4.29	5.60	0.34	16.45	-3.95	0.26	0.21
	Max abduction angle	17	4.19	3.70	8.97	14.69	4.78	0.23	0.31
	Max adduction angle	17	-6.74	5.39	-3.26	14.92	-3.47	0.38	0.23
	TD Flexion angle	17	-35.62	9.29	-35.02	11.02	-0.60	0.76	0.08
	TO Flexion angle	17	-27.31	7.68	-26.11	6.48	-1.20	0.34	.0.25
	Max Flexion angle	17	-65.66	4.23	-67.58	6.38	1.92	0.23	0.31
	Max Extension angle	17	-24.82	6.18	-24.09	5.55	-0.73	0.55	0.15
	TD Internal Rotation angle	17	0.90	5.73	1.46	5.31	0.56	0.55	0.34
Knee Kinematics	TO Internal Rotation angle	17	3.32	3.72	3.81	4.54	0.49	0.68	0.03
	Max External Rotation angle	17	-2.78	5.24	-3.02	5.93	0.23	0.78	0.18
	Max Internal Rotation angle	17	9.25	5.75	9.28	5.40	0.03	0.97	0.06
	TD abduction angle	17	-2.63	6.00	-3.90	7.48	1.27	0.19	0.15
	TO abduction angle	17	2.23	4.75	2.38	6.31	0.15	0.92	0.10
	Max abduction angle	17	3.99	4.27	4.32	5.78	0.33	0.81	0.01
	Max adduction angle	17	-14.60	4.67	-15.19	5.58	0.59	0.49	0.07
	TD Flexion angle	17	39.74	8.35	38.72	5.42	-1.02	0.47	0.01
	TO Flexion angle	17	-0.41	7.71	-2.36	7.00	1.95	0.13	0.15
	Max Flexion angle	17	41.30	9.81	42.21	8.16	0.91	0.56	0.26
	Max Extension angle	17	-1.91	7.88	-3.17	6.94	1.26	0.34	0.05
	TD Internal Rotation angle	17	22.84	5.60	23.49	5.67	0.64	0.65	0.18
Hip Kinematics	TO Internal Rotation angle	17	16.16	4.63	17.12	5.01	0.96	0.28	0.09
	Max External Rotation angle	17	29.47	4.35	30.94	7.29	1.47	0.38	0.10
	Max Internal Rotation angle	17	13.95	4.61	14.60	5.41	0.64	0.37	0.01
	TD abduction angle	17	-13.99	8.94	-12.50	11.17	-1.49	0.35	0.25
	TO abduction angle	17	8.00	6.70	7.93	6.11	-0.07	0.96	0.39
	Max abduction angle	17	12.75	6.63	13.18	7.61	0.43	0.83	0.33
	Max adduction angle	17	-17.43	7.16	-15.73	7.19	-1.70	0.79	0.35
	Ad/abduction	17	0.02	0.05	0.04	0.05	0.01	0.30	0.29
Ankle Moment	In/eversion	17	0.00	0.01	-0.01	0.04	0.00	0.52	0.12
	dorsi/plantarflexion	17	0.02	0.04	0.03	0.03	0.01	0.37	0.32
	Int/external rotation	17	-0.06	0.05	-0.05	0.07	-0.01	0.99	0.16
Knee Moment	Ad/abduction	17	-0.02	0.06	-0.03	0.10	0.01	0.27	0.24
	flexion/exension	17	-0.04	0.04	-0.03	0.05	-0.01	0.65	0.29
	Int/external rotation	17	-0.01	0.06	0.00	0.06	-0.01	0.99	0.28
Hip Moment	Ad/abduction	17	-0.01	0.11	-0.01	0.15	0.00	0.57	0.09
	flexion/exension	17	-0.01	0.04	0.00	0.04	0.00	0.69	0.40

Table 20. Summary of Changes in biomechanical variables due to changes in shoe midfoot bending stiffness during the Lay-Up

	Variable	n	Weak Midfoot Mean	Weak Midfoot SD	Stiff Midfoot Mean	Stiff Midfoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	469.55	57.41	471.58	53.40	2.03	0.63	0.14
	A-P positive impulse	17	92.56	21.78	97.83	18.98	5.27	0.06	0.19
	A-P negative impulse	17	-1.17	0.58	-1.10	0.55	-0.07	0.64	0.07
	M-L positive impulse	17	3.03	2.10	2.82	2.15	-0.21	0.38	0.25
	M-L negative impulse	17	-88.29	29.84	-91.29	29.27	3.00	0.34	0.25
	Stance time	17	0.25	0.03	0.25	0.03	0.00	0.31	0.30
Forefoot Kinematics	TD Flexion angle	17	4.79	2.99	3.73	1.69	-1.06	0.35	0.11
	TO Flexion angle	17	4.20	4.18	4.00	3.61	-0.20	0.98	0.35
	Max Flexion angle	17	8.65	4.28	8.31	3.67	-0.34	0.86	0.21
	Max Extension angle	17	-3.63	3.38	-3.17	2.23	-0.46	0.55	0.26
	TD Inversion angle	17	1.87	4.25	0.33	1.25	-1.55	0.14	0.40
	TO Inversion angle	17	1.35	4.45	-0.03	1.30	-1.32	0.25	0.22
	Max Eversion angle	17	2.19	4.16	0.96	1.04	-1.23	0.24	0.10
	Max Inversion angle	17	-1.22	4.11	-1.60	1.21	0.38	0.71	0.21
Ankle Kinematics	TD Flexion angle	17	6.97	7.32	5.86	8.26	-1.11	0.99	0.31
	TO Flexion angle	17	-20.77	4.87	-21.32	5.87	0.56	1.00	0.25
	Max Dorsiflexion angle	17	10.33	4.86	9.37	4.88	-0.97	0.65	0.21
	Max Plantarflexion angle	17	-20.91	4.67	-21.65	5.62	0.73	0.85	0.16
	TD Inversion angle	17	-6.31	5.47	-6.51	3.79	0.20	0.95	0.28
	TO Inversion angle	17	-7.36	3.50	-6.92	4.69	-0.44	0.37	0.21
	Max Eversion angle	17	8.52	3.88	9.06	3.56	0.54	0.25	0.37
	Max Inversion angle	17	-9.02	4.02	-8.97	3.49	-0.04	0.60	0.18
	TD abduction angle	17	-1.41	5.20	-0.39	3.84	-1.02	0.26	0.29
	TO abduction angle	17	-7.00	5.49	-7.00	2.99	0.00	0.69	0.21
	Max abduction angle	17	4.47	6.44	4.24	4.24	-0.24	0.84	0.22
	Max adduction angle	17	-7.42	5.78	-7.20	3.11	-0.22	0.54	0.30
Knee Kinematics	TD Flexion angle	17	-25.88	6.59	-26.31	5.94	0.42	0.45	0.07
	TO Flexion angle	17	-10.52	4.14	-8.90	4.68	-1.62	0.26	0.35
	Max Flexion angle	17	-54.08	6.87	-53.23	5.55	-0.84	0.50	0.17
	Max Extension angle	17	-10.35	4.05	-8.86	4.74	-1.49	0.32	0.23
	TD Internal Rotation angle	17	-7.28	3.04	-7.28	4.32	0.00	0.80	0.08
	TO Internal Rotation angle	17	2.53	2.90	2.43	2.54	-0.10	0.72	0.02
	Max External Rotation angle	17	-7.51	3.07	-8.17	4.41	0.65	0.34	0.17
	Max Internal Rotation angle	17	4.67	3.63	4.73	4.03	0.06	0.86	0.09
	TD abduction angle	17	3.09	3.47	2.27	5.80	-0.82	0.33	0.12
	TO abduction angle	17	0.66	4.13	1.04	9.08	0.38	0.85	0.02
	Max abduction angle	17	4.51	3.36	5.35	8.90	0.84	0.70	0.04
	Max adduction angle	17	-14.91	4.34	-15.43	5.08	0.52	0.38	0.23
Hip Kinematics	TD Flexion angle	17	47.35	13.23	44.34	6.81	-3.00	0.92	0.04
	TO Flexion angle	17	7.08	5.77	7.01	7.02	-0.08	0.62	0.11
	Max Flexion angle	17	44.97	7.38	44.90	6.75	-0.07	0.86	0.12
	Max Extension angle	17	6.86	5.86	6.82	7.21	-0.04	0.65	0.04
	TD Internal Rotation angle	17	4.63	6.86	4.95	5.59	0.32	0.44	0.08
	TO Internal Rotation angle	17	16.51	4.90	16.34	4.94	-0.17	0.86	0.12
	Max External Rotation angle	17	17.17	4.83	16.83	4.26	-0.33	0.72	0.12
	Max Internal Rotation angle	17	-8.51	4.89	-7.52	4.90	-1.00	0.11	0.15
	TD abduction angle	17	-2.79	4.16	-2.56	6.29	-0.23	0.68	0.11
	TO abduction angle	17	0.40	4.22	-0.03	6.23	-0.37	0.57	0.06
	Max abduction angle	17	4.85	3.35	5.92	6.09	1.07	0.33	0.27
	Max adduction angle	17	-6.08	2.66	-6.82	4.91	0.74	0.59	0.28
Ankle Moment	Ad/abduction	17	0.02	0.08	0.02	0.08	0.00	0.29	0.31
	In/eversion	17	0.02	0.06	0.01	0.06	0.00	0.67	0.12
	dorsi/plantarflexion	17	0.01	0.04	0.00	0.03	0.00	0.42	0.23
Knee Moment	Int/external rotation	17	-0.02	0.06	-0.02	0.06	0.00	0.21	0.36
	Ad/abduction	17	-0.05	0.06	-0.05	0.06	0.00	0.82	0.06
	flexion/exension	17	0.01	0.03	0.01	0.03	0.00	0.21	0.37
Hip Moment	Int/external rotation	17	0.02	0.03	0.02	0.03	0.00	0.71	0.11
	Ad/abduction	17	-0.02	0.09	-0.02	0.09	0.01	0.46	0.21
	flexion/exension	17	0.01	0.02	0.01	0.01	0.00	0.90	0.03

Table 21. Summary of Changes in biomechanical variables due to changes in shoe midfoot bending stiffness during the Shuffle and Side Cut

	Variable	n	Weak Midfoot Mean	Weak Midfoot SD	Stiff Midfoot Mean	Stiff Midfoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	502.71	75.50	495.54	95.16	-7.16	0.52	0.17
	A-P positive impulse	17	19.53	5.70	18.92	8.48	-0.62	0.76	2.77
	A-P negative impulse	17	-16.10	6.11	-16.35	6.94	0.24	0.83	2.79
	M-L positive impulse	17	350.85	33.15	345.96	49.24	-4.89	0.49	0.18
	M-L negative impulse	17	-0.06	0.09	-0.07	0.12	0.01	0.63	0.18
	Stance time	17	0.49	0.08	0.48	0.09	-0.01	0.49	0.18
Forefoot Kinematics	TD Flexion angle	17	2.09	2.81	0.94	2.98	-1.15	0.39	0.33
	TO Flexion angle	17	4.55	3.17	4.65	3.53	0.10	0.98	0.09
	Max Flexion angle	17	12.37	4.18	12.21	5.13	-0.16	0.95	0.10
	Max Extension angle	17	0.52	2.80	-0.02	2.57	-0.50	0.63	0.27
	TD Inversion angle	17	0.25	5.09	-0.92	1.69	0.67	0.28	0.07
	TO Inversion angle	17	-1.07	4.33	-2.03	1.49	0.96	0.35	0.22
	Max Eversion angle	17	0.88	4.84	-0.50	1.36	-0.38	0.21	0.25
	Max Inversion angle	17	-5.94	4.34	-5.80	1.93	-0.13	0.97	0.04
Ankle Kinematics	TD Flexion angle	17	-8.66	7.02	-8.20	7.33	-0.46	0.33	0.25
	TO Flexion angle	17	-14.41	6.55	-8.58	16.46	-5.83	0.16	0.44
	Max Dorsiflexion angle	17	20.21	6.69	24.22	14.00	4.01	0.29	0.05
	Max Plantarflexion angle	17	-16.04	5.69	-14.05	7.32	-1.99	0.14	0.35
	TD Inversion angle	17	-8.74	6.02	-7.68	5.25	-1.06	0.23	0.31
	TO Inversion angle	17	-19.54	4.16	-17.20	5.32	-2.34	0.07	0.48
	Max Eversion angle	17	-7.37	4.07	-5.80	4.37	-1.57	0.17	0.36
	Max Inversion angle	17	-23.99	3.28	-21.33	4.42	-2.65	0.05	0.54
	TD abduction angle	17	2.13	6.45	4.57	7.88	2.44	0.17	0.26
	TO abduction angle	17	-1.99	5.44	-0.17	11.69	-1.81	0.50	0.37
	Max abduction angle	17	5.36	4.25	7.05	7.76	1.69	0.35	0.24
	Max adduction angle	17	-7.75	4.84	-6.71	11.23	-1.03	0.70	0.10
Knee Kinematics	TD Flexion angle	17	-44.51	12.30	-43.06	10.28	-1.44	0.48	0.18
	TO Flexion angle	17	-24.05	6.82	-21.56	15.75	-2.49	0.53	0.16
	Max Flexion angle	17	-75.73	7.73	-75.60	9.27	-0.13	0.92	0.02
	Max Extension angle	17	-21.84	6.24	-19.47	17.15	-2.37	0.58	0.14
	TD Internal Rotation angle	17	-3.03	6.21	-2.63	6.35	-0.40	0.66	0.05
	TO Internal Rotation angle	17	0.05	4.00	-0.34	4.36	0.28	0.59	0.36
	Max External Rotation angle	17	-6.26	4.87	-6.52	5.77	0.26	0.74	0.22
	Max Internal Rotation angle	17	6.79	7.18	6.55	6.77	-0.24	0.79	0.11
	TD abduction angle	17	0.04	4.97	-0.24	5.34	0.20	0.83	0.11
	TO abduction angle	17	7.44	7.27	4.88	9.81	-2.56	0.17	0.14
	Max abduction angle	17	8.24	6.78	7.68	7.15	-0.57	0.66	0.07
	Max adduction angle	17	-14.67	5.70	-15.91	6.73	1.24	0.39	0.09
Hip Kinematics	TD Flexion angle	17	47.53	9.14	44.17	9.58	-3.36	0.08	0.46
	TO Flexion angle	17	22.84	11.96	21.30	12.23	-1.54	0.48	0.18
	Max Flexion angle	17	61.20	11.03	58.92	12.58	-2.28	0.35	0.24
	Max Extension angle	17	20.59	11.24	19.30	10.86	-1.29	0.58	0.14
	TD Internal Rotation angle	17	28.48	7.02	30.20	6.64	1.72	0.26	0.25
	TO Internal Rotation angle	17	32.66	5.67	31.63	5.81	-1.03	0.38	0.08
	Max External Rotation angle	17	38.49	6.99	38.36	7.50	-0.13	0.91	0.00
	Max Internal Rotation angle	17	22.78	7.08	24.49	7.81	1.71	0.18	0.21
	TD abduction angle	17	-6.92	8.58	-5.31	7.96	-1.60	0.36	0.29
	TO abduction angle	17	5.08	7.77	4.69	5.79	-0.39	0.78	0.14
	Max abduction angle	17	8.01	7.77	8.02	6.56	0.01	0.99	0.07
	Max adduction angle	17	-17.57	5.81	-15.96	8.04	-1.60	0.26	0.42
Ankle Moment	Ad/abduction	17	-0.01	0.06	-0.01	0.07	0.00	0.46	0.21
	In/eversion	17	-0.05	0.03	-0.05	0.03	0.00	0.54	0.20
	dorsi/plantarflexion	17	0.03	0.03	0.04	0.02	0.00	0.64	0.14
Knee Moment	Int/external rotation	17	-0.01	0.05	-0.01	0.05	0.00	0.88	0.03
	Ad/abduction	17	0.03	0.05	0.03	0.07	0.00	0.91	0.00
	flexion/exension	17	-0.02	0.04	-0.02	0.05	0.00	0.94	0.06
Hip Moment	Int/external rotation	17	0.02	0.11	0.03	0.10	0.01	0.22	0.30
	Ad/abduction	17	-0.03	0.06	-0.04	0.04	0.01	0.42	0.21
	flexion/exension	17	0.02	0.05	0.03	0.03	0.00	0.40	0.21

Table 22. Summary of Changes in biomechanical variables due to changes in shoe midfoot bending stiffness during the Shuttle Agility Drill

	Variable	n	Weak Midfoot		Stiff Midfoot		Diff	P	SI
			Mean	SD	Mean	SD		Value	
External Forces	Vertical impulse	17	512.01	185.27	476.64	111.38	-35.37	0.17	0.37
	A-P positive impulse	17	24.04	10.28	19.91	6.95	-4.13	0.13	1.45
	A-P negative impulse	17	-13.45	10.08	-14.99	8.95	1.54	0.44	1.63
	M-L positive impulse	17	357.56	81.04	342.75	70.29	-14.81	0.03	0.62
	M-L negative impulse	17	-0.11	0.21	-0.12	0.21	0.01	0.86	0.05
	Stance time	17	0.54	0.15	0.50	0.08	-0.04	0.09	0.46
Forefoot Kinematics	TD Flexion angle	17	2.92	3.99	2.43	4.11	-0.49	0.83	0.11
	TO Flexion angle	17	7.13	4.78	8.14	6.07	1.01	0.95	0.17
	Max Flexion angle	17	17.31	6.46	17.14	8.03	-0.17	0.86	0.28
	Max Extension angle	17	0.78	3.53	1.53	4.04	0.75	1.00	0.09
	TD Inversion angle	17	0.36	4.81	-0.54	1.58	0.18	0.56	0.20
	TO Inversion angle	17	-0.58	4.07	-1.59	1.32	1.01	0.06	0.45
	Max Eversion angle	17	1.10	4.46	0.08	1.65	-1.02	0.21	0.02
	Max Inversion angle	17	-6.61	6.12	-4.99	1.61	-1.62	0.30	0.32
Ankle Kinematics	TD Flexion angle	17	-4.23	15.18	-8.18	7.23	3.96	0.24	0.20
	TO Flexion angle	17	-13.26	11.41	-12.59	7.30	-0.67	0.81	0.06
	Max Dorsiflexion angle	17	25.83	12.47	23.41	8.65	-2.42	0.52	0.13
	Max Plantarflexion angle	17	-13.50	13.85	-15.28	5.26	1.78	0.61	0.16
	TD Inversion angle	17	-7.78	6.65	-8.79	5.84	1.01	0.28	0.28
	TO Inversion angle	17	-18.83	5.85	-17.39	4.60	-1.43	0.19	0.35
	Max Eversion angle	17	-6.20	6.09	-6.97	3.69	0.76	0.48	0.18
	Max Inversion angle	17	-22.42	6.01	-21.70	5.43	-0.72	0.57	0.15
	TD abduction angle	17	3.50	10.92	2.39	4.11	-1.11	0.64	0.26
	TO abduction angle	17	0.23	8.69	0.69	6.37	0.46	0.86	0.52
	Max abduction angle	17	8.71	11.13	7.15	5.03	-1.56	0.59	0.14
	Max adduction angle	17	-3.44	10.37	-4.74	6.35	1.29	0.65	0.12
Knee Kinematics	TD Flexion angle	17	-37.06	5.86	-35.35	9.38	-1.70	0.42	0.21
	TO Flexion angle	17	-22.00	7.40	-25.64	9.53	3.64	0.03	0.59
	Max Flexion angle	17	-70.74	7.32	-69.45	7.11	-1.28	0.49	0.18
	Max Extension angle	17	-18.78	6.80	-22.13	5.91	3.35	0.08	0.48
	TD Internal Rotation angle	17	1.49	5.89	1.57	6.39	0.08	0.95	0.02
	TO Internal Rotation angle	17	-0.04	3.96	-0.39	4.96	0.35	0.60	0.24
	Max External Rotation angle	17	-5.09	4.23	-5.56	4.85	0.47	0.58	0.19
	Max Internal Rotation angle	17	8.20	6.27	7.20	6.72	-1.00	0.24	0.11
	TD abduction angle	17	-2.66	5.26	-2.74	7.01	0.08	0.94	0.02
	TO abduction angle	17	8.77	5.87	7.22	8.47	-1.55	0.34	0.13
	Max abduction angle	17	9.54	5.91	9.08	7.23	-0.46	0.67	0.30
	Max adduction angle	17	-12.72	6.39	-12.10	7.11	-0.62	0.46	0.14
Hip Kinematics	TD Flexion angle	17	39.71	9.87	35.50	9.28	-4.21	0.02	0.58
	TO Flexion angle	17	11.47	8.58	12.45	7.78	0.99	0.57	0.22
	Max Flexion angle	17	53.59	12.76	48.29	11.31	-5.30	0.03	0.57
	Max Extension angle	17	9.16	8.87	9.61	8.34	0.45	0.82	0.11
	TD Internal Rotation angle	17	20.90	7.34	23.05	6.74	2.15	0.08	0.06
	TO Internal Rotation angle	17	25.96	5.59	23.01	5.25	-2.94	0.03	0.28
	Max External Rotation angle	17	33.43	6.26	31.95	6.61	-1.48	0.31	0.03
	Max Internal Rotation angle	17	17.31	6.91	18.82	5.51	1.51	0.19	0.35
	TD abduction angle	17	-9.20	8.29	-8.73	7.92	-0.46	0.83	0.52
	TO abduction angle	17	9.12	8.15	7.51	7.70	-1.61	0.28	0.39
	Max abduction angle	17	12.05	6.82	11.88	7.18	-0.16	0.90	0.21
	Max adduction angle	17	-17.97	7.08	-15.81	8.22	-2.16	0.19	0.43
Ankle Moment	Ad/abduction	17	-0.02	0.06	-0.02	0.06	0.00	0.82	0.13
	In/eversion	17	-0.06	0.03	-0.07	0.04	0.01	0.12	0.45
	dorsi/plantarflexion	17	0.04	0.02	0.05	0.03	0.01	0.16	0.41
Knee Moment	Int/external rotation	17	0.02	0.05	0.01	0.05	-0.01	0.28	0.30
	Ad/abduction	17	0.02	0.06	0.03	0.06	0.01	0.16	0.34
	flexion/exension	17	-0.01	0.05	-0.02	0.05	0.00	0.36	0.14
Hip Moment	Int/external rotation	17	0.01	0.12	0.01	0.11	0.00	0.86	0.03
	Ad/abduction	17	-0.04	0.03	-0.05	0.04	0.01	0.17	0.35
	flexion/exension	17	0.02	0.02	0.03	0.03	0.01	0.12	0.40

Table 23. Summary of Changes in biomechanical variables due to changes in shoe midfoot bending stiffness during the modified V-Cut

	Variable	n	Weak Midfoot		Stiff Midfoot		Diff	P	SI
			Mean	SD	Mean	SD		Value	
External Forces	Vertical impulse	17	338.87	57.39	335.43	58.21	-3.45	0.59	0.10
	A-P positive impulse	17	52.90	23.38	53.61	21.71	0.71	0.84	0.27
	A-P negative impulse	17	-15.02	5.52	-13.42	5.01	-1.60	0.17	0.75
	M-L positive impulse	17	0.37	0.40	0.34	0.30	-0.03	0.68	0.13
	M-L negative impulse	17	-162.05	21.62	-165.18	25.01	3.13	0.41	0.23
	Stance time	17	0.27	0.05	0.26	0.05	0.00	0.30	0.28
Forefoot Kinematics	TD Flexion angle	17	2.50	3.07	2.41	2.17	-0.08	0.96	0.20
	TO Flexion angle	17	14.57	4.95	16.17	6.36	1.60	0.47	0.22
	Max Flexion angle	17	24.95	4.62	25.06	5.45	0.11	0.85	0.03
	Max Extension angle	17	1.58	2.76	1.62	2.34	0.04	0.59	0.02
	TD Inversion angle	17	1.22	4.14	0.09	1.22	-1.14	0.21	0.18
	TO Inversion angle	17	0.45	3.87	-0.96	2.04	0.51	0.15	0.28
	Max Eversion angle	17	1.96	4.09	0.68	1.74	-1.28	0.15	0.24
	Max Inversion angle	17	-4.16	4.34	-4.11	0.97	-0.04	0.97	0.11
Ankle Kinematics	TD Flexion angle	17	-2.28	5.88	-2.61	7.26	0.33	0.81	0.06
	TO Flexion angle	17	-12.69	5.55	-11.26	5.75	-1.43	0.24	0.30
	Max Dorsiflexion angle	17	23.35	5.83	23.65	5.81	0.30	0.81	0.24
	Max Plantarflexion angle	17	-13.50	5.13	-12.53	4.76	-0.97	0.34	0.06
	TD Inversion angle	17	-7.95	4.84	-7.82	4.28	-0.13	0.88	0.04
	TO Inversion angle	17	-16.63	3.76	-15.77	5.15	-0.86	0.39	0.22
	Max Eversion angle	17	-5.51	3.84	-4.67	3.70	-0.84	0.20	0.34
	Max Inversion angle	17	-18.65	4.23	-17.80	5.32	-0.84	0.32	0.26
	TD abduction angle	17	0.80	5.67	1.64	4.39	0.84	0.40	0.21
	TO abduction angle	17	-4.76	5.55	-3.15	7.66	-1.61	0.16	0.37
	Max abduction angle	17	3.68	4.86	4.13	4.38	0.45	0.55	0.15
	Max adduction angle	17	-11.93	4.68	-6.81	5.66	-5.13	0.86	0.05
Knee Kinematics	TD Flexion angle	17	-44.53	13.50	-43.59	12.22	-0.94	0.69	0.10
	TO Flexion angle	17	-23.77	6.49	-24.56	10.25	0.80	0.59	0.14
	Max Flexion angle	17	-67.34	7.64	-66.40	9.08	-0.94	0.31	0.26
	Max Extension angle	17	-22.10	5.42	-22.67	11.06	0.57	0.78	0.07
	TD Internal Rotation angle	17	-2.45	6.54	0.02	7.29	-2.43	0.04	0.40
	TO Internal Rotation angle	17	3.18	3.68	2.99	5.87	-0.19	0.85	0.31
	Max External Rotation angle	17	-4.01	5.81	-3.47	7.14	-0.54	0.64	0.38
	Max Internal Rotation angle	17	7.89	5.06	8.59	6.05	0.70	0.32	0.18
	TD abduction angle	17	-3.43	6.68	-5.34	5.17	1.91	0.13	0.56
	TO abduction angle	17	0.56	3.47	-2.72	10.44	2.16	0.23	0.05
	Max abduction angle	17	2.37	4.37	1.42	6.46	-0.94	0.49	0.25
	Max adduction angle	17	-14.00	5.17	-17.56	12.02	3.56	0.14	0.12
Hip Kinematics	TD Flexion angle	17	44.56	7.66	41.84	4.75	-2.72	0.05	0.50
	TO Flexion angle	17	-3.30	4.16	-4.37	4.81	1.06	0.44	0.14
	Max Flexion angle	17	46.08	7.19	43.27	5.22	-2.81	0.04	0.51
	Max Extension angle	17	-3.65	3.69	-4.59	4.63	0.94	0.47	0.12
	TD Internal Rotation angle	17	11.33	5.81	9.28	3.85	-2.05	0.02	0.43
	TO Internal Rotation angle	17	21.35	5.76	19.60	5.39	-1.75	0.16	0.28
	Max External Rotation angle	17	26.73	7.53	25.91	6.58	-0.81	0.37	0.22
	Max Internal Rotation angle	17	8.68	6.43	7.36	5.20	-1.31	0.10	0.27
	TD abduction angle	17	-7.73	6.87	-7.27	8.92	-0.46	0.80	0.64
	TO abduction angle	17	8.42	6.95	4.77	13.35	-3.65	0.27	0.35
	Max abduction angle	17	10.24	6.19	13.10	13.44	2.86	0.41	0.15
	Max adduction angle	17	-11.89	5.42	-15.32	13.72	3.43	0.33	0.40
Ankle Moment	Ad/abduction	17	0.02	0.04	0.02	0.04	0.00	0.60	0.15
	In/eversion	17	-0.01	0.03	-0.01	0.02	0.01	0.23	0.36
	dorsi/plantarflexion	17	0.02	0.02	0.01	0.02	0.00	0.36	0.28
Knee Moment	Int/external rotation	17	-0.05	0.05	-0.05	0.04	0.00	0.79	0.06
	Ad/abduction	17	-0.01	0.07	-0.02	0.06	0.00	0.35	0.33
	flexion/exension	17	-0.02	0.03	-0.02	0.02	0.00	0.64	0.11
Hip Moment	Int/external rotation	17	-0.01	0.05	0.00	0.06	0.00	0.54	0.12
	Ad/abduction	17	-0.02	0.08	-0.02	0.08	0.00	0.51	0.27
	flexion/exension	17	0.00	0.03	0.00	0.03	0.00	0.93	0.03

Table 24. Summary of Changes in biomechanical variables due to changes in shoe midfoot bending stiffness during the Zig-Zag Drill

	Variable	n	Weak Midfoot Mean	Weak Midfoot SD	Stiff Midfoot Mean	Stiff Midfoot SD	Diff	P Value	SI
External Forces	Vertical impulse	17	380.70	70.25	390.35	73.35	9.65	0.15	0.41
	A-P positive impulse	17	30.11	10.70	32.13	9.00	2.02	0.15	0.41
	A-P negative impulse	17	-31.33	12.31	-30.72	15.17	-0.60	0.96	0.01
	M-L positive impulse	17	0.20	0.58	0.27	0.72	0.06	0.10	0.47
	M-L negative impulse	17	-241.43	30.76	-250.09	32.30	8.66	0.25	0.32
	Stance time	17	0.33	0.08	0.33	0.08	0.00	0.95	0.02
Forefoot Kinematics	TD Flexion angle	17	2.68	3.08	0.86	2.84	-1.83	0.03	0.87
	TO Flexion angle	17	11.81	3.99	14.44	7.69	2.63	0.28	0.23
	Max Flexion angle	17	23.96	4.43	24.70	7.41	0.74	1.00	0.23
	Max Extension angle	17	1.64	2.87	0.16	2.95	-1.48	0.08	0.67
	TD Inversion angle	17	-0.29	1.51	-0.04	1.07	-0.25	0.84	0.16
	TO Inversion angle	17	-1.35	2.08	-1.66	1.33	0.31	0.52	0.32
	Max Eversion angle	17	0.49	1.30	0.26	1.29	-0.23	0.30	0.20
	Max Inversion angle	17	-6.70	3.01	-5.87	1.81	-0.83	0.53	0.30
Ankle Kinematics	TD Flexion angle	17	-9.92	8.42	-10.08	8.13	0.16	0.43	0.14
	TO Flexion angle	17	-15.18	8.17	-14.94	8.12	-0.24	0.32	0.21
	Max Dorsiflexion angle	17	22.36	7.86	21.89	7.91	-0.47	0.47	0.28
	Max Plantarflexion angle	17	-17.32	7.68	-16.43	7.63	-0.88	0.29	0.19
	TD Inversion angle	17	-7.71	5.73	-7.87	5.48	0.15	0.42	0.21
	TO Inversion angle	17	-17.25	5.34	-17.51	4.48	0.26	0.50	0.03
	Max Eversion angle	17	-6.14	3.98	-5.94	3.41	-0.20	0.24	0.32
	Max Inversion angle	17	-21.44	4.95	-21.19	4.57	-0.24	0.28	0.29
	TD abduction angle	17	3.05	4.71	2.49	4.43	-0.55	0.34	0.02
	TO abduction angle	17	-5.13	7.25	0.34	16.45	-4.79	0.18	0.39
	Max abduction angle	17	5.42	3.69	8.97	14.69	3.56	0.34	0.26
	Max adduction angle	17	-7.28	6.19	-3.26	14.92	-4.02	0.29	0.29
Knee Kinematics	TD Flexion angle	17	-33.48	8.85	-35.02	11.02	1.53	0.94	0.02
	TO Flexion angle	17	-27.24	9.28	-26.11	6.48	-1.14	0.61	0.06
	Max Flexion angle	17	-67.48	4.66	-67.58	6.38	0.10	0.79	0.07
	Max Extension angle	17	-23.80	6.34	-24.09	5.55	0.29	0.81	0.06
	TD Internal Rotation angle	17	-0.09	5.41	1.46	5.31	1.37	0.10	0.64
	TO Internal Rotation angle	17	2.16	3.91	3.81	4.54	1.65	0.06	0.05
	Max External Rotation angle	17	-3.24	4.77	-3.02	5.93	-0.23	0.95	0.55
	Max Internal Rotation angle	17	8.38	4.59	9.28	5.40	0.90	0.64	0.44
	TD abduction angle	17	-1.77	5.84	-3.90	7.48	2.13	0.03	0.46
	TO abduction angle	17	2.68	6.81	2.38	6.31	-0.30	0.85	0.53
	Max abduction angle	17	5.82	5.21	4.32	5.78	-1.50	0.11	0.12
	Max adduction angle	17	-13.62	5.04	-15.19	5.58	1.57	0.05	0.02
Hip Kinematics	TD Flexion angle	17	39.42	8.45	38.72	5.42	-0.69	0.56	0.09
	TO Flexion angle	17	-2.46	5.47	-2.36	7.00	-0.10	0.82	0.01
	Max Flexion angle	17	41.41	10.30	42.21	8.16	0.80	0.68	0.16
	Max Extension angle	17	-3.82	5.43	-3.17	6.94	-0.65	0.85	0.10
	TD Internal Rotation angle	17	22.67	6.61	23.49	5.67	0.82	0.80	0.27
	TO Internal Rotation angle	17	16.49	5.76	17.12	5.01	0.64	0.45	0.23
	Max External Rotation angle	17	29.86	7.39	30.94	7.29	1.08	0.24	0.27
	Max Internal Rotation angle	17	14.14	6.11	14.60	5.41	0.45	0.74	0.05
	TD abduction angle	17	-16.24	6.86	-12.50	11.17	-3.74	0.28	0.16
	TO abduction angle	17	6.28	6.40	7.93	6.11	1.64	0.37	0.29
	Max abduction angle	17	10.86	5.83	13.18	7.61	2.32	0.31	0.42
	Max adduction angle	17	-17.95	7.20	-15.73	7.19	-2.22	0.99	0.18
Ankle Moment	Ad/abduction	17	0.04	0.05	0.02	0.05	-0.01	0.35	0.37
	In/eversion	17	-0.01	0.04	-0.01	0.03	0.00	0.66	0.06
	dorsi/plantarflexion	17	0.03	0.03	0.02	0.03	-0.01	0.21	0.46
Knee Moment	Int/external rotation	17	-0.05	0.07	-0.06	0.04	0.01	0.45	0.10
	Ad/abduction	17	-0.03	0.10	-0.03	0.09	0.00	0.54	0.10
	flexion/exension	17	-0.03	0.05	-0.04	0.03	0.01	0.34	0.16
Hip Moment	Int/external rotation	17	0.00	0.06	-0.01	0.06	0.00	0.75	0.10
	Ad/abduction	17	-0.01	0.15	-0.02	0.13	0.00	0.93	0.05
	flexion/exension	17	0.00	0.04	0.00	0.04	0.00	0.50	0.21

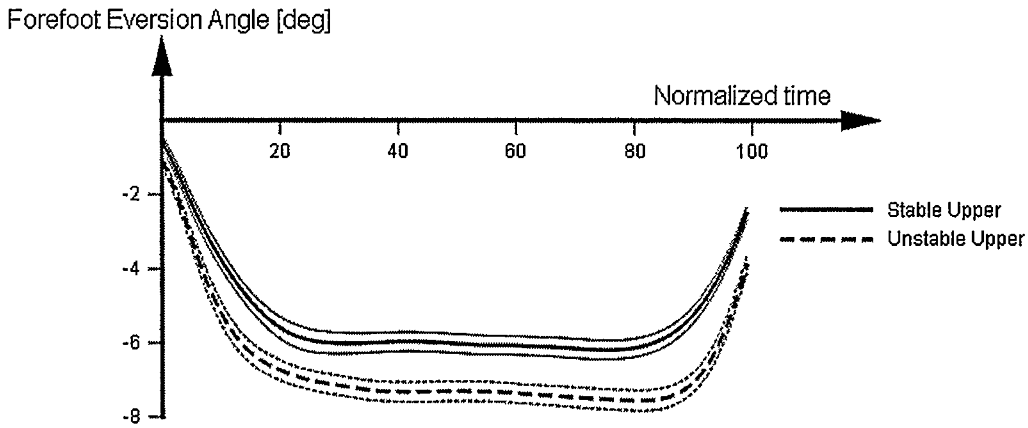

Figure 7. **Forefoot inversion angle during the Shuffle and Side Cut in shoes with a stable and unstable upper construction.**

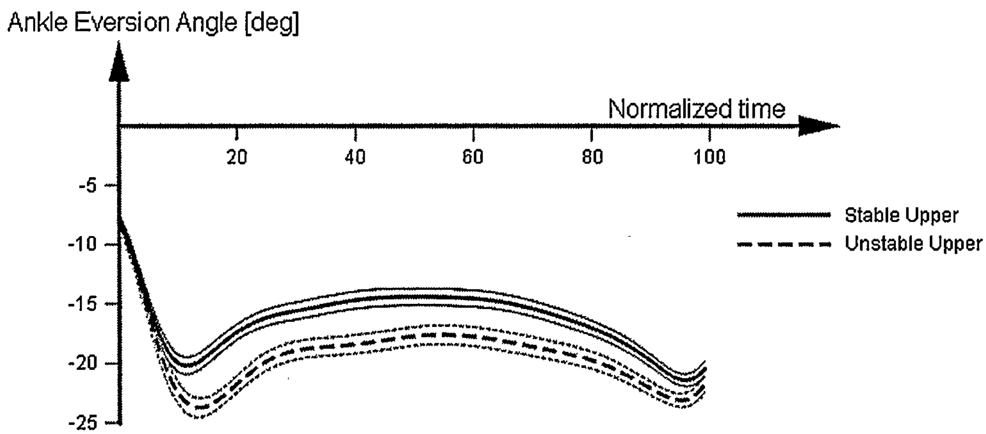

Figure 8. **Ankle inversion angle during the Shuffle and Side Cut in shoes with a stable and unstable upper construction.**

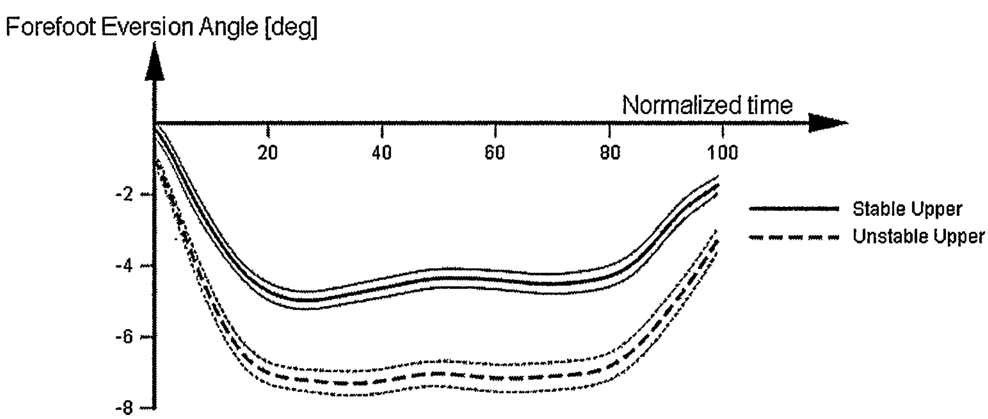

Figure 9. **Forefoot inversion angle during the Shuttle Agility Drill in shoes with a stable and unstable upper construction.**

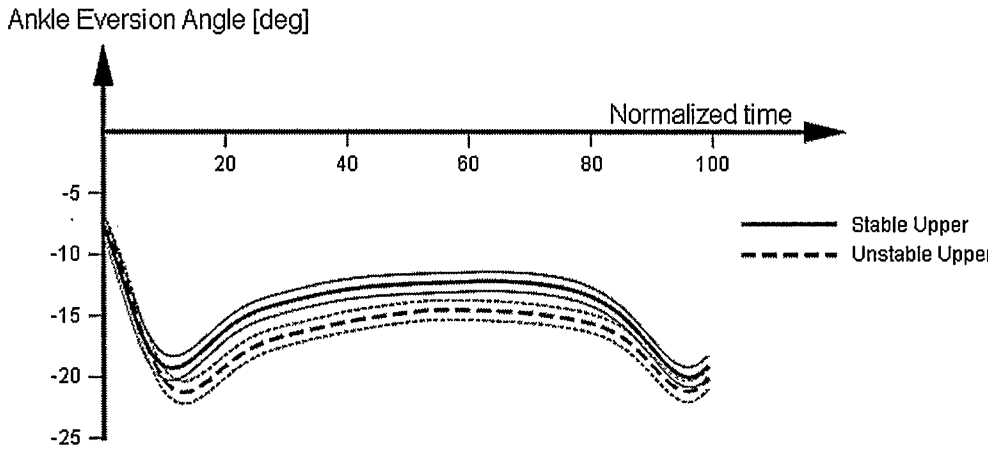

Figure 10. Ankle inversion angle during the Shuttle Agility Drill in shoes with a stable and unstable upper construction.

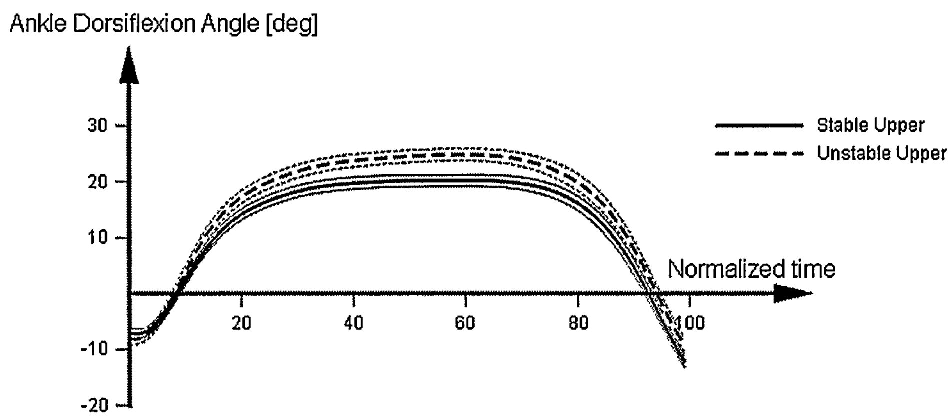

Figure 11. Ankle plantarflexion angle during the Shuttle Agility Drill in shoes with a stable and unstable upper construction.

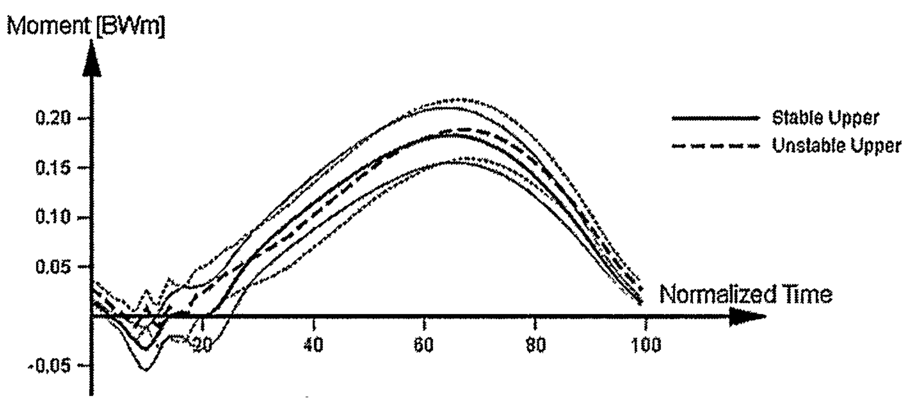

Figure 12. Ankle plantar/dorsiflexion moment during the Modified V-Cut in shoes with a stable and unstable upper construction.

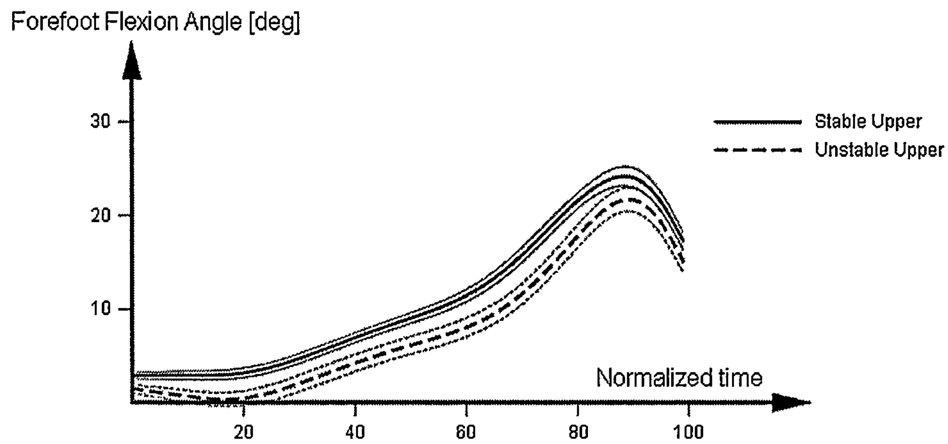

Figure 13. **Forefoot flexion angle during the Modified V-Cut in shoes with a stable and unstable upper construction.**

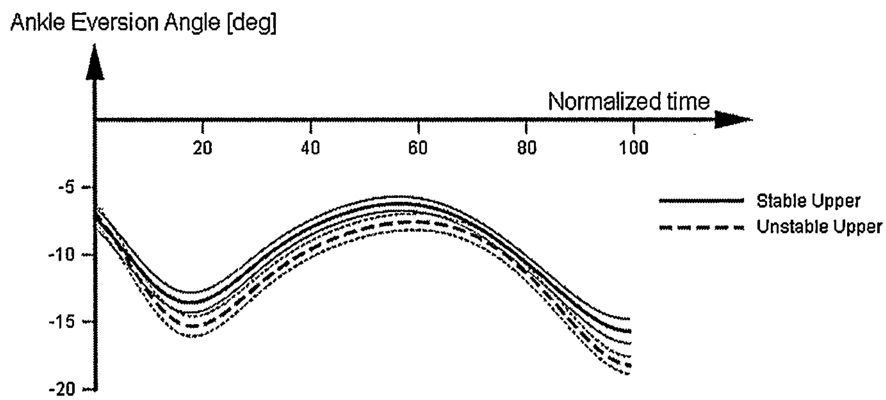

Figure 14. **Ankle inversion angle during the Modified V-Cut in shoes with a stable and unstable upper construction.**

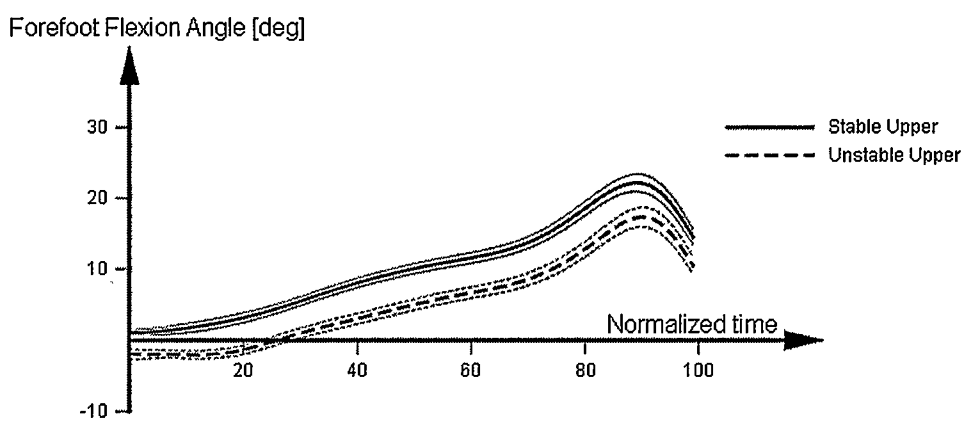

Figure 15. **Forefoot flexion angle during the Zig-Zag Agility Drill in shoes with a stable and unstable upper construction.**

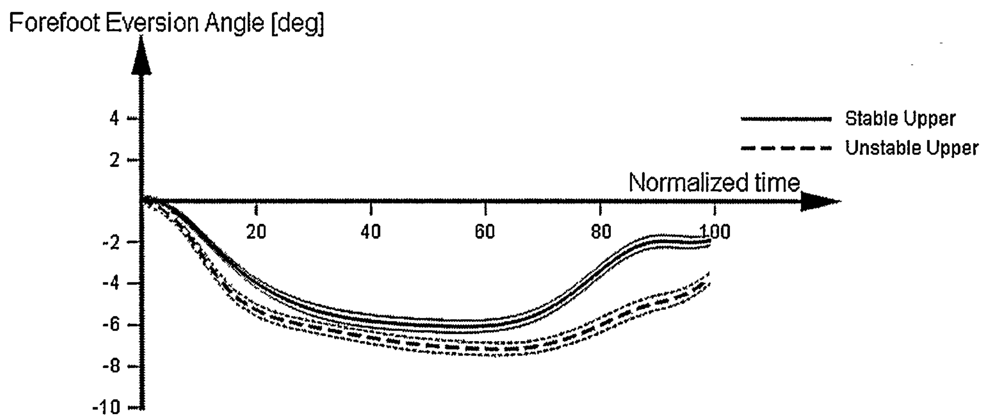

Figure 16. **Forefoot inversion angle during the Zig-Zag Agility Drill in shoes with a stable and unstable upper construction.**

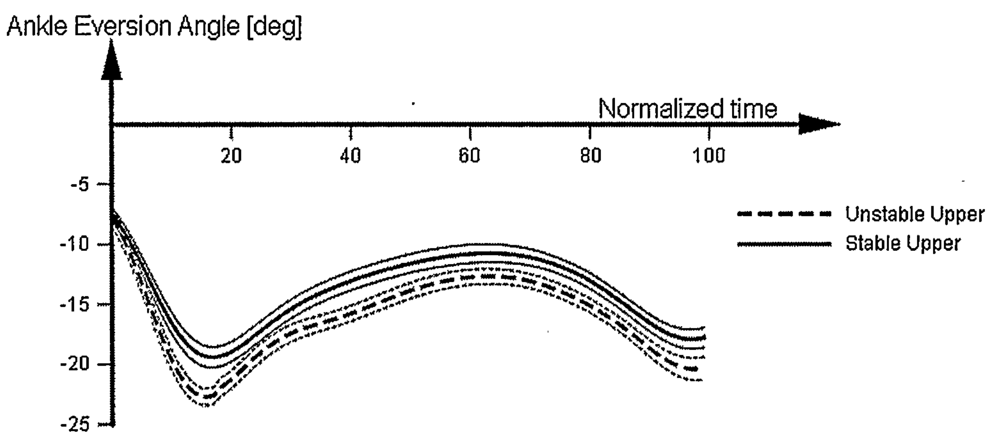

Figure 17. **Ankle inversion angle during the Zig-Zag Agility Drill in shoes with a stable and unstable upper construction.**

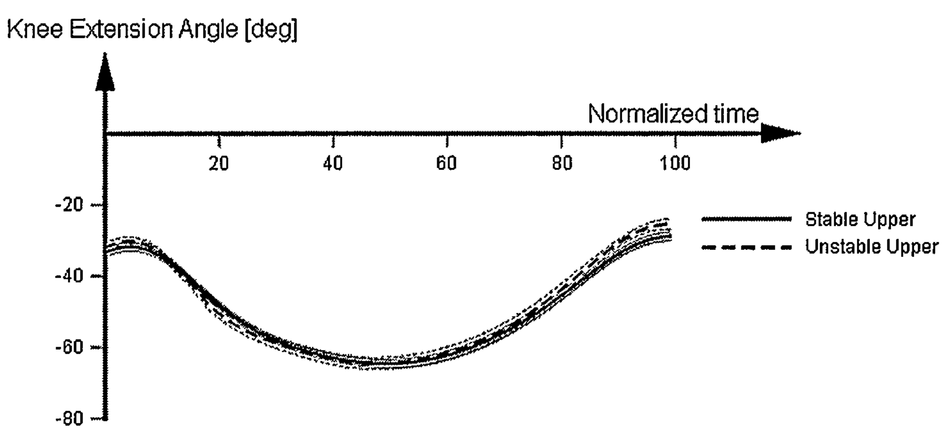

Figure 18. **Knee flexion angle during the Zig-Zag Agility Drill in shoes with a stable and unstable upper construction.**

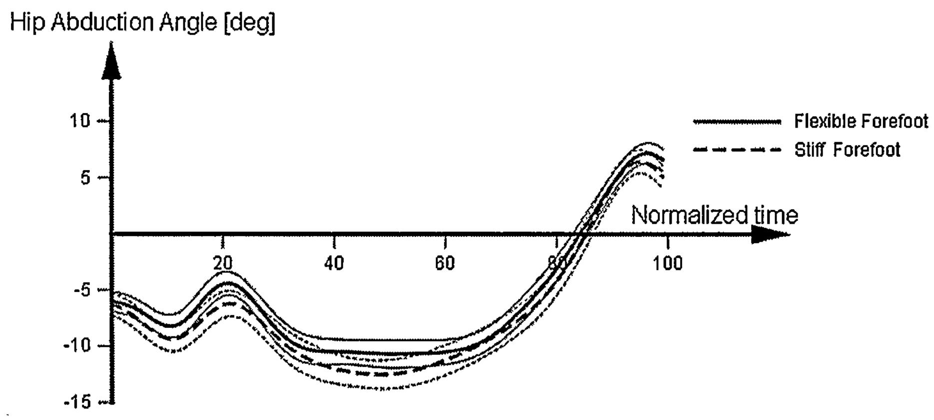

Figure 19. **Hip add/abduction angle during the Shuffle and Side Cut in shoes with a stiff and flexible forefoot.**

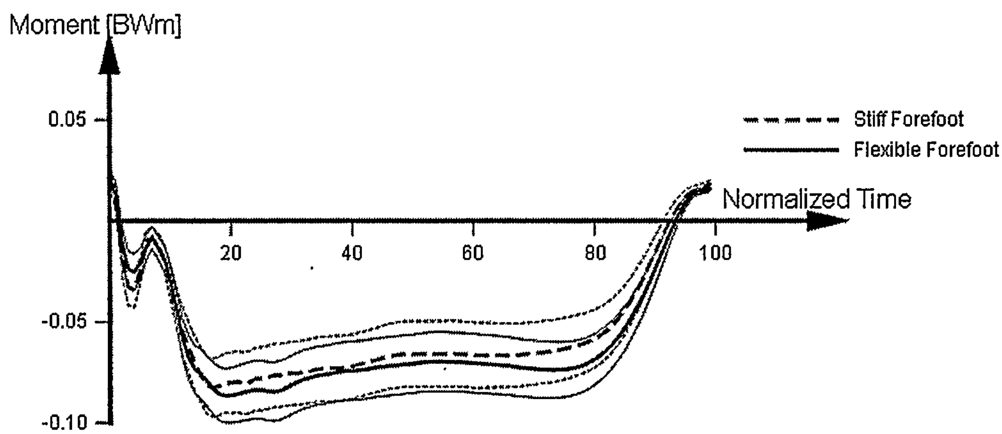

Figure 20. **Knee flexion/extension moment during the Shuttle Agility Drill in shoes with a stiff and flexible forefoot.**

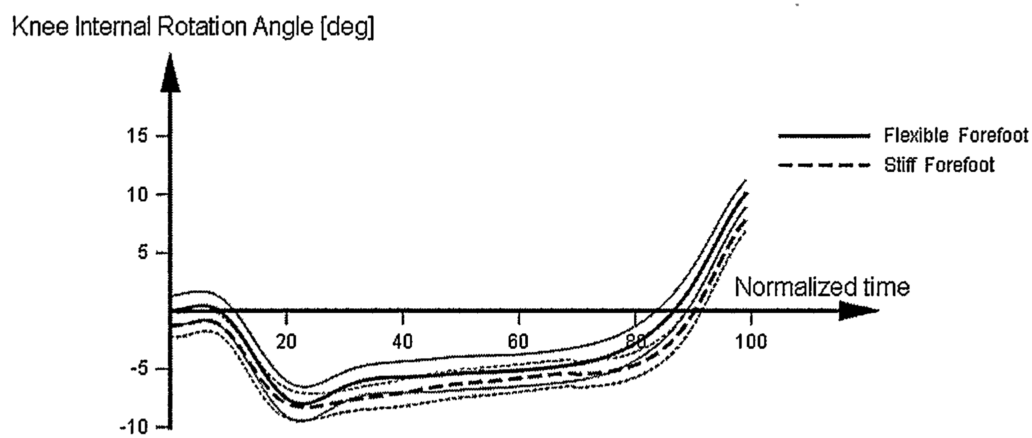

Figure 21. **Knee internal rotation angle during the Shuttle Agility Drill in shoes with a stiff and flexible forefoot.**

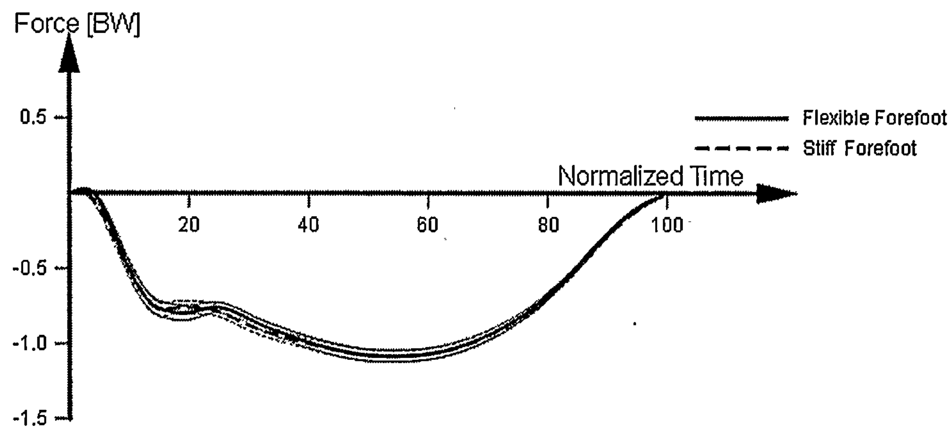

Figure 22. **Medio-lateral force during the Modified V-Cut in shoes with a stiff and flexible forefoot.**

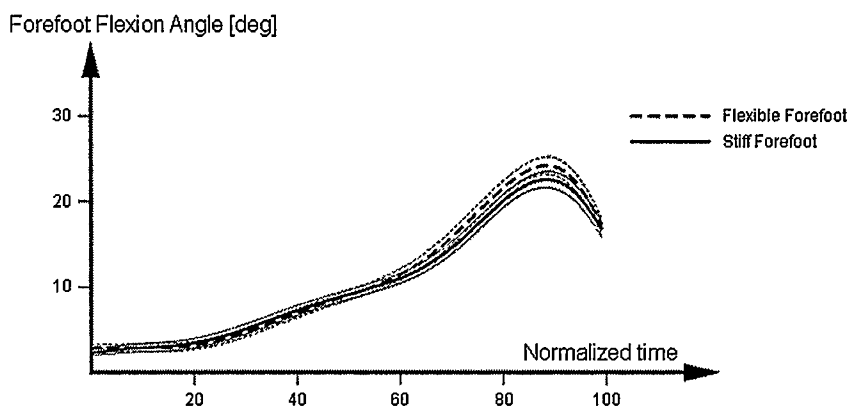

Figure 23. **Forefoot flexion angle during the Modified V-Cut in shoes with a stiff and flexible forefoot.**

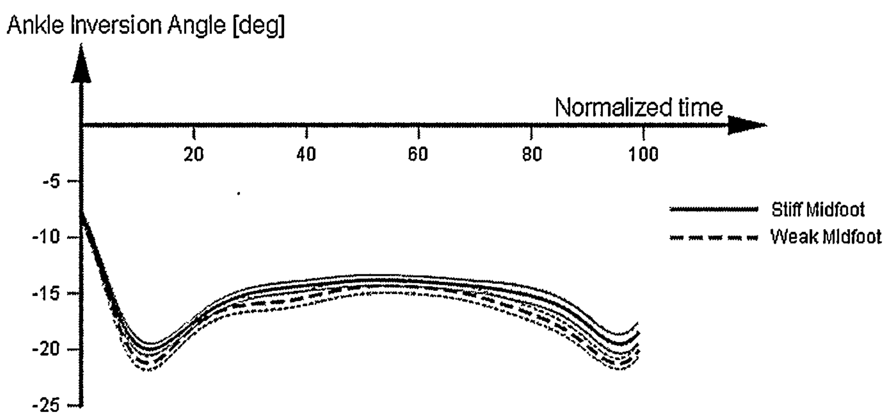

Figure 24. **Ankle inversion angle during the Shuffle and Side Cut in shoes with a stiff and weak midfoot.**

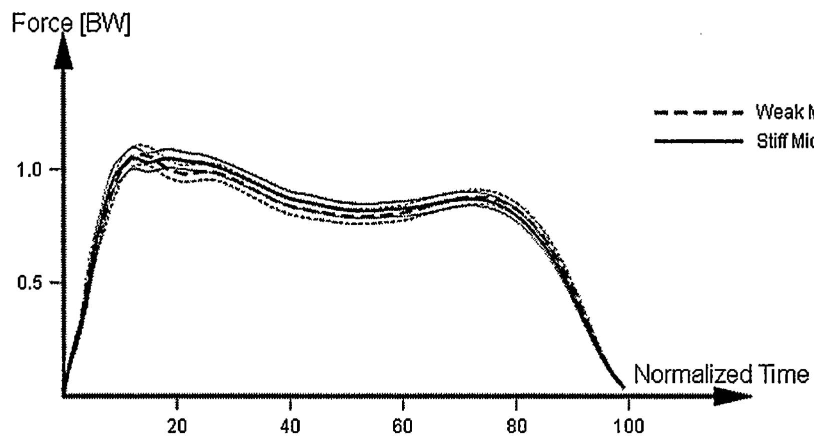

Figure 25. **Medio-lateral force during the Shuttle Agility Drill in shoes with a stiff and weak midfoot.**

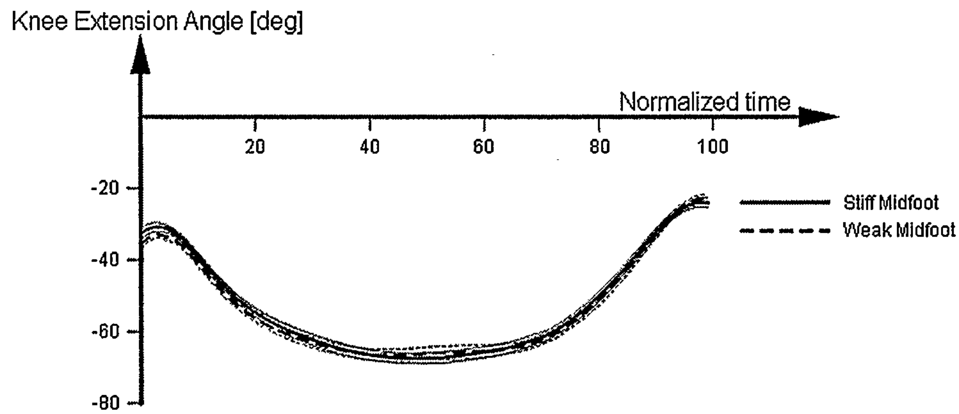

Figure 26. **Knee flexion angle during the Shuttle Agility Drill in shoes with a stiff and weak midfoot.**

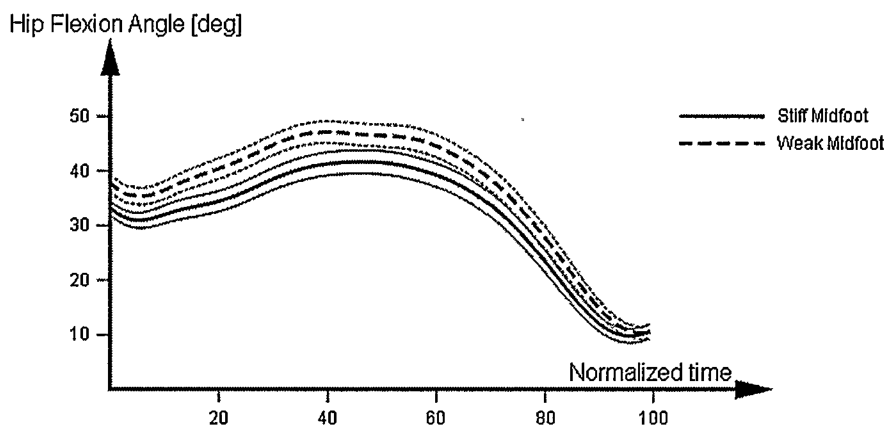

Figure 27. **Hip flexion angle during the Shuttle Agility Drill in shoes with a stiff and weak midfoot.**

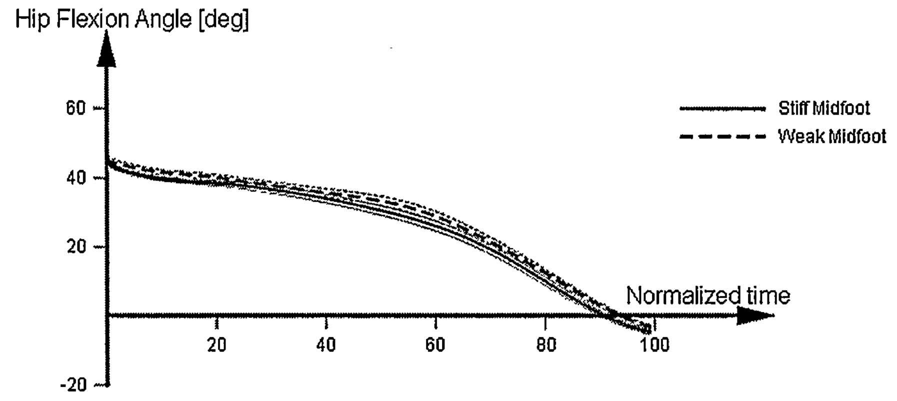

Figure 28. Hip flexion angle during the Modified V-Cut in shoes with a stiff and weak midfoot.

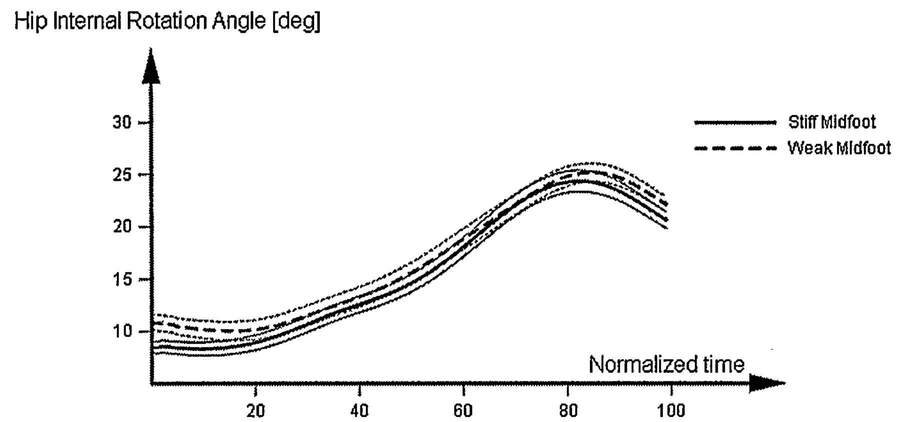

Figure 29. Hip internal rotation angle during the Modified V-Cut in shoes with a stiff and weak midfoot.

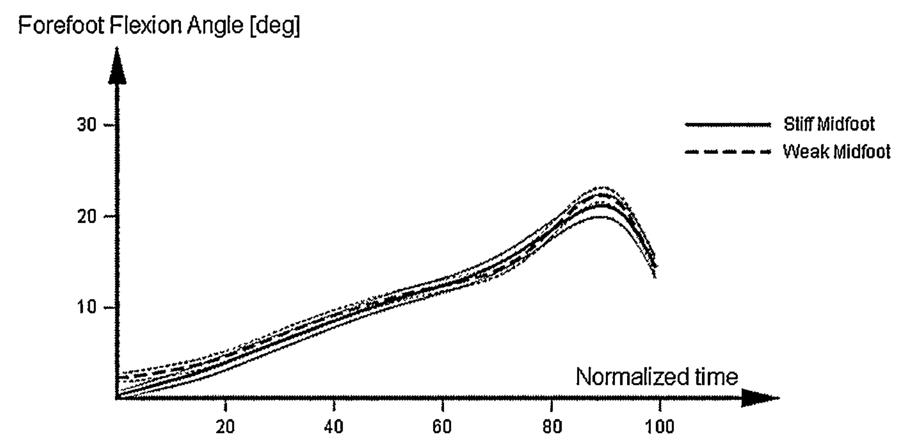

Figure 30. Forefoot flexion angle during the Zig-Zag Agility Drill in shoes with a stiff and weak midfoot.

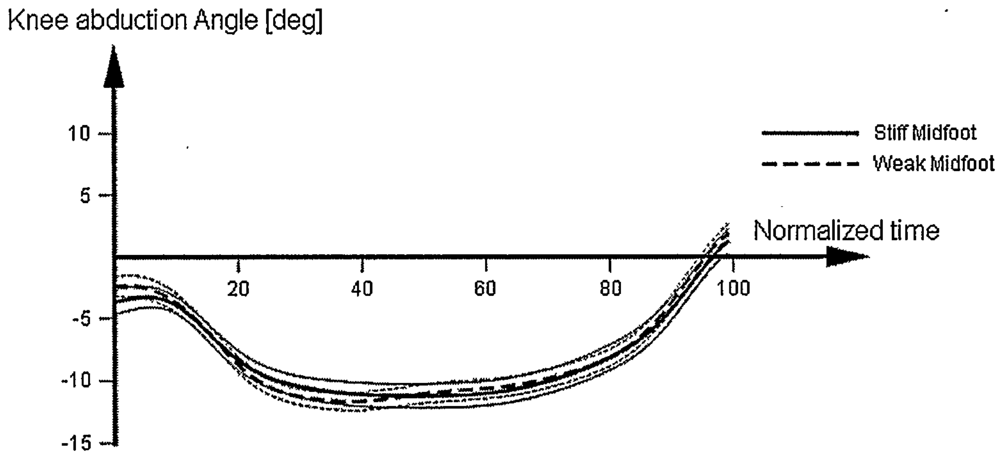

Figure 31. **Knee adduction angle during the Zig-Zag Agility Drill in shoes with a stiff and weak midfoot.**