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Trunk Kinematics During Cutting Maneuver

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By

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Abstract

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Cutting performance proficiency has been suggested as a highly critical athletic skill among athletes who participate in field and court sports which require frequent change of direction maneuvers. Obtaining cutting performance proficiency is a key to be successful when it comes to participation in sports requiring frequent direction changes. It has been proposed that athletes who participate in those types of sports tend to be more proficient in their dominant side cutting performance compared to their non-dominant side cutting performance. It has also been suggested that athletes who participate in field and court sports should be proficient in dominant and non-dominant side cutting performance to be successful in their sports.

It has been indicated that individuals tend to achieve faster cutting time during dominant side cutting performance compared to non-dominant side cutting performance. Also, it has been suggested that individuals obtain smaller lateral movement during their dominant side cutting performance compared to their non-dominant side cutting performance. Trunk kinematics (i.e. trunk angles and displacement) have been suggested to be correlated to cutting performance proficiency and key factors to achieve cutting performance proficiency. Therefore, it was hypothesized that subjects would exhibit smaller trunk angles and displacement during their dominant side cutting performance compared to their non-dominant side cutting performance. Trunk kinematic variables such as forward and lateral trunk angles and displacements were obtained and compared between dominant and non-dominant sides cutting performance among subjects. The results in the current study indicate that the subjects obtained less cutting time during dominant side cutting performance compared to non-dominant side cutting performance, and therefore the subjects are more proficient in dominant side cutting performance than non-dominant side cutting performance. The results also indicate that the subjects exhibited smaller lateral trunk angle and displacement during their dominant cutting performance compared to their non-dominant cutting performance. It can be concluded that lateral trunk kinematics are related to cutting performance proficiency, and therefore lateral trunk movement could be the key factor of cutting performance proficiency. Athletes should minimize lateral trunk angle and displacement to enhance their relatively less proficient non-dominant cutting performance to further enhance their cutting and overall sports performance.

Introduction

Agility and Change of Direction Performance (Cutting Performance)

Agility is considered to be an important athletic skill for individuals who participate in various field and court sports. Athletes who participate in these types of sports (e.g. soccer, handball, and basketball) engage in change of direction performance, also termed cutting performance, frequently during games (Sasaki, Nagano, Kaneko, Sakurai, & Fukubayashi, 2011; Sheppard & Young, 2006; Young, James, & Montgomery, 2002). For instance, soccer players engage in cutting performance an average of 50 times per game (Withers, Maricic, Wasilewski, & Kelli, 1982). Considering the fact that athletes tend to engage in cutting performance frequently during various field and court sports, cutting performance proficiency may be an integral element of overall performance (Sheppard &Young; Brughelli, Cronin, Levin, & Chaouachi, 2008).

The terms agility and change of direction performance have been used interchangeably in the past literature (Sheppard & Young, 2006). However, agility and change of direction performance are two distinctive athletic skills (Sheppard & Young, 2006). In fact, change of direction performance is considered to be one of the components of agility (Sheppard & Young, 2006; Young et al., 2002). Agility can be divided into two main components, perceptual/decision making and change of direction components (Sheppard & Young, 2006; Young et al., 2002). The perceptual and decision making component can be divided into visual scanning, knowledge of situations, pattern recognition, and anticipation aspects (Sheppard & Young, 2006; Young et al., 2002). The change of direction component can be divided into technical, physical (straight sprinting speed, leg muscle strength/power, and reactive strength), and anthropometric measurements aspects (Sheppard & Young, 2006; Young et al., 2002). Athletes should be expected to satisfy the perception and decision making and change of direction components of agility in a well-balanced manner to achieve cutting and overall sports performance proficiency.

Several past studies have utilized correlational analyses or longitudinal training studies between sprint speed and cutting performance (Draper & Lancaster, 1985; Little & Williams, 2005; Young, McDowell, & Scarlett, 2001; Vescovi & McGuigan, 2008), and leg muscle strength/power and cutting performance (Davis, Barnette, Kiger, Mirasola, & Young, 2004; Hoffman, Ratamess, Klatt, Faigenbaum, & Kang, 2007; Markovic, Jukic, Milanovic, & Metikos, 2007; Markovic, 2007; McBride, Triplett-McBride, Davine, & Newton. 2002; Young et al., 2002; Spiteri, Chocrane, Hart, Haff, & Nimphius, 2013). Those past studies mainly emphasize the correlations between lower body strength/power and cutting performance, and between straight sprinting and cutting performance. The findings of the past studies are considered to be inconsistent. For instance, Young et al. (2002); Markovic (2007) indicate that the correlations between strength/power and cutting performance are low. Additionally, the correlation between straight sprinting and cutting performance are also suggested to be low (Baker, 1999; Buttifant, Graham, & Cross, 1999; Clark, Martin, Lee, Fornasiero, & Quinn, 1998; Tisitskarsis, Theoharopoulus, & Garefis, 2003; Young, Hawken, & McDonald, 1996).

The low and inconsistent correlation between cutting performance and straight sprinting based on different past studies may be due to the fact that movements that involve direction changes require complex motor control and coordination of various muscle groups in multiple directions (e.g. forward, backward, and lateral directions), and often times require rotations of the whole body (Markovic, 2007). On the other hand, a unidirectional movement like straight sprinting relies more on a simple motor skill (Markovic, 2007). Additionally, straight sprinting (i.e. track and field sprinting) tends to require a greater distance to accelerate and reach the top speed in general, whereas cutting performance, involving sprinting and direction changes, requires a significantly shorter distance than straight sprinting (Sheppard & Young, 2006). Cutting performance does not allow for a long distance for acceleration to reach the maximum speed (Sheppard & Young, 2006). In fact, individuals are required to change directions within a relatively short distance before they accelerate and reach the maximum speed (Sheppard & Young, 2006). Overall, straight sprinting and cutting performance (i.e. sprinting with direction changes) may be considered to be two distinctive sports skills.

Past studies like Young et al. (2002), Markovic (2007), and Sheppard and Young (2006) indicate that the strength/power and straight sprinting components are not considered to be the only determining factors of cutting performance; therefore other determining factors of cutting performance like change of direction techniques should be taken into consideration. As Hewit et al. (2012), Sasaki et al., (2011), and Marshall et al., (2014) suggest, it is critical to analyze and determine the key factors of change of direction techniques to achieve cutting performance proficiency (i.e. faster cutting time). Body lean and posture (i.e. trunk kinematics) are proposed to be part of the technical aspects of cutting performance (Sheppard & Young, 2006, Young et al., 2002).

Technical aspects of change of direction performance can further be divided into foot placement, adjustment of strides to accelerate and decelerate, and body lean and posture (Sheppard & Young, 2006; Young et al., 2002). Particularly, body lean and posture during the stance phase of change of direction has been suggested to be a significant determining factor of cutting performance (Sheppard & Young, 2006; Sasaki et al., 2011; Marshall et al., 2014). Cutting performance contains three distinctive phases (Sheppard & Young, 2006). The deceleration phase is a period while individuals decelerate from sprinting and anticipate direction changes (Sheppard & Young, 2006). The stance phase is defined as a period while the plant foot is in contact with the ground (Sasaki et al., 2011). The re-acceleration phase is a period while individuals complete direction changes and start re-accelerating toward a targeted direction of change (Sheppard & Young, 2006).

Past studies like Sheppard and Young (2006), Young et al. (2002), and Markovic (2007) indicate that a possible correlation between straight sprinting and cutting performance, and a possible correlation between strength/power and cutting performance are inconsistent based on different findings of the different studies, as mentioned. Although straight sprinting and strength/power are considered to be important aspects of cutting performance, other aspects of cutting performance such as technique should be taken into consideration (Shepard & Young, 2006; Young et al., 2002). Therefore, straight sprinting ability and strength/power alone may not be considered to be the predominant determining factors of cutting performance. As Hewit, Cronin, and Hume (2012), Sasaki et al. (2011), and Marshall et al. (2014) suggest, technical aspects of change of direction performance are also key factors for athletes to achieve cutting performance proficiency (i.e. faster cutting time). Sheppard and Young. (2006) and Young et al. (2002) proposed that trunk movement (i.e. body lean and posture) is also a determining factor of cutting performance proficiency along with physical aspects of cutting performance (i.e. straight sprinting and strength/power).

Trunk Kinematics and Cutting Performance Proficiency

Sasaki et al. (2011) propose that several trunk kinematic variables during the stance phase, such as trunk forward and lateral angles at three distinctive time periods, at the moment of the plant foot contact, maximum trunk inclination, and foot off, and forward and lateral trunk displacement between foot contact and maximum trunk inclination and between maximum trunk inclination and foot off, may be correlated with cutting time. Moreover, Sasaki et al. (2011) suggest when individuals obtain smaller trunk angles and displacement, maintaining the trunk segment more stable during direction changes, they tend to achieve faster cutting time.

Mechanism of Trunk Kinematics for The Enhancement of Cutting Performance

Optimal trunk kinematics have been suggested to be possible key factors of change of direction techniques to achieve faster cutting time (i.e. cutting performance proficiency) (Sheppard & Young, 2006; Sasaki et al., 2011; Marshall et al., 2014). Markovic (2007) indicates that the body balance controlled by the trunk movement during direction changes may be critical to achieve faster cutting time. Houck. (2003) and Patla, Adkin and Ballard (1999) suggest that individuals control center of mass by adjusting their posture through trunk displacement during direction changes to enhance cutting performance. Several explanations regarding possible contributions of the trunk segment stabilization to enhance cutting performance have been provided. Kibler, Press, and Sciascia (2006) indicate that core stability can maximize the functions of upper and lower extremity kinetic chains which can enhance athletic performance. Core stability can be defined as the ability to control the position and the motion of the trunk over the pelvis and legs, which enables optimum production, transfer and control of force and motion of terminal segments in integrated kinetic chain activities (Kibler et al., 2006). Additionally, the kinetic chain, defined as the coordinated and sequenced activation of the body segments, enables locating the distal segments in optimum positions, velocity, and timing to enhance athletic tasks (Kibler et al., 2006). Muscle activations regarding the kinetic chain functions are based on pre-programmed patterns of muscle activations that are task oriented for specific athletic activities (Kibler et al., 2006). Two types of muscle activation patterns of the kinetic chain functions, length-dependent and force-dependent patterns, are suggested to enhance extremity segment functions (Kibler et al., 2006).

Optimal length-dependent muscle activation patterns of the kinetic chain functions can enable reciprocal inhibition. When individuals obtain optimal length of muscle fibers, they may be able to enhance the ability of reciprocal inhibition. Reciprocal inhibition can maximize agonist muscle activations and minimize antagonist muscle activations during athletic performance (Kibler et al., 2006). Enhanced reciprocal inhibition can enable the stretch-reflex capacity of muscle fibers to further enhance the ability of the stretch-shortening cycle (Kibler et al., 2006). The stretch- shortening cycle can enhance reactive strength, which is suggested to be one of the key factors to enhance cutting performance (Young et al., 2002). As individuals possess greater reactive strength, they can decrease ground contact time, and as a result they can decrease overall cutting time as well (Sasaki et al., 2011; Young et al., 2002). Ground contact time of the plant foot has been indicated to be proportional to overall cutting time (Sasaki et al., 2011; Marshall et al., 2014; Green, Blake, & Caulfield, 2011). When individuals obtain shorter ground contact time of the plant foot, they tend to be able to achieve faster cutting time (Sasaki et al., 2011; Marshall et al., 2014; Green et al., 2011). When individuals keep the trunk segment stable, they may be able to utilize the length-dependent muscle activation patterns of the kinetic chain functions, and as a consequence they may be able to utilize the advantage of reciprocal inhibition which can enhance the capacity of the stretch reflex and the stretch shortening cycle (Kibler et al., 2006). As a result, individuals may be able to enhance the capacity of reactive strength in the lower extremity muscles (Kibler et al., 2006). As a consequence of increased reactive strength via the stretch shortening cycle, individuals may be able to decrease ground contact time and achieve faster cutting time (Young et al., 2002).

Force-dependent muscle activation patterns of the kinetic chain functions integrate activations of multiple muscles to move several joints and develop force (Kibler et al., 2006). Force-dependent muscle activation patterns can aid muscle activations in the extremity segments, which enhance the capacity to support and move the extremity segments effectively (Kibler et al., 2006). For instance, maximum gastrocnemius plantar flexor power is influenced by the activation and the recruitment of hip muscles (Kibler et al., 2006). As individuals keep the trunk segment stable, they may be able to utilize the advantage of force dependent muscle activation patterns of the kinetic chain functions (Kibler et al., 2006). As individuals maintain the trunk segment more stable, they tend to generate greater power in the lower extremity, and as a consequence they may be able to achieve faster cutting time.

Additionally, the pre-programed muscle activation, which can also be achieved by the trunk segment stabilization, may further lead to several biomechanical effects that enable efficient local and distal segment functions (Kibler et al., 2006). The pre-programmed muscle activation can enhance anticipatory postural adjustment (Kibler et al., 2006). Anticipatory postural adjustment can allow the body to counteract perturbations created by the external forces during sports related tasks like kicking, throwing, and running (Kibler et al., 2006). Anticipatory postural adjustment can set up the proximal stability for the distal mobility to enhance sports related performance (Kibler et al., 2006). Anticipatory postural adjustment may allow individuals to balance themselves during direction changes by counteracting external forces, and further enhance overall cutting performance.

Moreover, the pre-programmed muscle activations also create interactive moments that develop and control forces and loads at the joints (Kibler et al., 2006). Interactive moments are developed in the central body segments and are key factors for generating proper forces at the distal joints to minimize internal loads at the joints (Kibler et al., 2006). There are several examples of the proximal core activations that provide interactive moments for the purpose of efficient distal segment functions (Kibler et al., 2006). Interactive moments either provide the maximal force at the distal end of segments, which is similar to the mechanism of cracking a whip, or they provide the precision and the stability to the distal end (Kibler et al., 2006). For instance, the maximum force generated at the foot segment during kicking tasks is developed by the interactive moment produced by hip flexion (Kibler et al., 2006). Additionally, accuracy of ball throwing is correlated to the interactive moment at the wrist joint produced by shoulder movement (Kibler et al., 2006). As a consequence of the pre-programed muscle activations and the interactive moments, forces and movements are developed in a proximal to distal manner based on the summation of speed principle (Kibler et al., 2006).

As individuals take advantage of anticipatory postural adjustment as a result of the pre-programmed muscle activations, they can enhance the ability to maintain the overall body balance during cutting performance by counteracting external forces to achieve faster cutting time. Furthermore, as individuals can utilize interactive moments by keeping the trunk segment stable (i.e. the proximal segment), they may be able to increase power output in the lower extremity segment like plantar flexor power (i.e. the distal segment), and as a result they may be able to enhance cutting performance (Kibler et al., 2006; Marshall et al., 2014).

Increased intra-abdominal pressure can be an alternative contributor of core stability to enhance the extremity segment functions (Kibler et al., 2006). Abdominal muscles consist of transverse abdominus, internal and external obliques, and rectus abdominus (Kibler et al., 2006). Transverse abdominus muscle contraction can increase intra-abdominal pressure and tensions of thoracolumbar fascia (Kibler et al., 2006). Transverse abdominus muscle can be critical for the stabilization of the lumbar region of the spine (Kibler et al., 2006). Abdominal muscle contractions can enhance stiffness of the lumbar spine (Kibler et al., 2006). Additionally, thoracolumbar fascia is a structure which connects the lower limbs (via gluteus maximus) and the upper limbs (via latissimus dorsi) (Kibler et al., 2006). The thoracolumbar fascia covers deep layered muscles of the back and the trunk including multifidi (Kibler et al., 2006). The thoracolumbar fascia is also attached to internal oblique and transverse abdominus muscles, which provides three- dimensional support to the lumbar spine and aids the core stability (Kibler et al., 2006). The thoracolumbar muscles form a hoop around the abdomen, consisting of the fascia posteriorly, the abdominal fascia anteriorly, and the oblique muscles laterally, which creates a stabilizing corset effect (Kibler et al., 2006).

The effects of increased intra-abdominal pressure as a result of the trunk segment stabilization may also increase the kinetic chain functions for individuals to increase the capacity of power output and reactive strength in the lower extremity. When individuals maintain the trunk segment stable, they are able to increase abdominal pressure (Kibler et al., 2006). Additionally, activations of thoracolumbar muscles can also enhance the kinetic chain functions. As a result, individuals may be able to take advantage of the kinetic chain functions to enhance the capacity of power output and reactive strength in the lower extremity as well.

Sasaki et al. (2011) suggest when individuals maintain the trunk segment more stable, obtaining smaller trunk angles and displacement in forward and lateral directions, they tend to decrease ground contact time and achieve faster cutting time. Sasaki et al. (2011) suggest that the trunk segment stability can enhance reactive strength, and as a result ground contact time and cutting time can be decreased altogether. Moreover, the trunk segment stabilization may enhance the capacity of power output in the lower extremity as well. (Kibler et al., 2006). As individuals possess greater maximum plantar flexor power, they tend to achieve shorter ground contact time and faster cutting time (Marshall et al., 2014). Overall, as a result of increased power output and reactive strength in lower extremity muscles by keeping the trunk segment stable, individuals may be able to achieve shorter ground contact time and faster cutting time (Sasaki et al., 2001; Marshall et al., 2014; Young et al., 2002).

Definition of Leg Dominance (Right Dominant Cutting performance vs. Left Dominant Cutting Performance)

Cutting performance side is defined based on individuals' leg dominance while they engage in cutting performance, either right dominant cutting performance or left dominant cutting performance (Sasaki et al., 2011; Green et al., 2011). In case of soccer, soccer players typically kick a ball with their dominant legs, while they maintain the balance of the body with non-dominant legs (Sasaki et al. 2011). Similarly, in the case of cutting performance individuals also maintain the balance of the body with the non-dominant leg while decelerating from linear sprinting and initiate a change of direction task subsequently (Sasaki et al., 2011; Green et al., 2011). In case of right dominant cutting performance, the left leg is considered to be the plant leg (also called the cutting leg). On the contrary, in case of left dominant cutting performance the right leg is considered to be the plant leg (Sasaki et al., 2011; Green et al., 2011). (Images of descriptions of the plant leg are provided in APPENDIX)

Influence of Leg Dominance on Cutting Performance Proficiency

Hart, Spiteri, Lockie, Nimphius, and Newton (2014) propose that athletes' leg dominance can affect their cutting and overall sports performance. Additionally, Hart et al. (2014) also indicate that their subjects have tended to achieve faster cutting time during their dominant-side cutting performance compared to non-dominant side cutting performance. Furthermore, Green et al. (2011) indicate that their subjects tend to be more proficient in their dominant side cutting performance compared to their non-dominant side cutting performance regardless of their skill and competition levels.

Various field and court sports athletes engage in cutting performance frequently during their practice and games (Sasaki et al. 2011; Shepard & Young, 2006; Young et al., 2002). For examples, Australian Football is one of the examples of sports where athletes engage in cutting performance frequently (Hart et al., 2014). Australian Football League (AFL) Agility test is designed to assess Australian Football players' cutting performance proficiency based on leg dominance (Hart et al., 2014). Hart et al., (2014) collected cutting time in dominant and non-dominant side cutting performance among Australian Football players to determine cutting performance imbalance between dominant and non-dominant side cutting performance. Australian Football players achieved faster cutting time during their dominant side cutting performance compared to their non-dominant side cutting performance (Hart et al., 2014). By the same token, field and court sports athletes in general may also be more proficient in dominant side cutting performance compared to non-dominant side cutting performance due to the fact that they also engage in cutting performance, particularly dominant-side cutting performance more frequently than non-dominant side cutting performance.

When field and court sports athletes like Australian Football players are more proficient in their dominant side cutting performance, it may be detrimental for their success in Australian Football due to the fact that athletes are required to turn in multiple directions regardless of their preferred directions of change (Hart et al., 2014). Australian Football players are likely to experience a tremendous disadvantage when they are significantly more proficient in their dominant side cutting performance (Hart et al., 2014). When Australian Football players attempt to complete direction changes by engaging in non- dominant side cutting performance with a longer duration, their overall Australian Football related performance may suffer, and as a result they may not be successful in Australian Football altogether (Hart et al., 2014). Australian Football players are desired to obtain well-balanced cutting performance in dominant and non-dominant side performance, so that they are able to be fully agile and achieve the higher level of overall performance in Australian Football (Hart et al., 2014). Furthermore, other field and court sports athletes are also desired to obtain well balanced cutting performance as well.

Muscular Imbalance and Cutting Performance Proficiency

Young et al. (2002) have provided a possible explanation regarding unbalanced cutting performance proficiency between dominant and non-dominant side cutting performance among athletes. Reactive strength is one of the physical aspects of cutting performance which determines cutting performance proficiency (Shepard & Young, 2006; Young et al., 2002). Young et al. (2002) indicate that reactive strength of the lower extremity plays a key role for the purpose of achieving faster cutting time. Moreover, individuals tend to generate greater reactive strength during their dominant side cutting performance compared to their non-dominant side cutting performance (Young et al., 2002). As a consequence, individuals are able to obtain shorter ground contact time and faster cutting time when they engage in dominant side cutting performance compared to non-dominant side cutting performance (Young et al., 2002).

In addition to muscular imbalance in the lower extremity, asymmetrical musculature between dominant and non-dominant sides of the trunk segment may be an alternative cause of unbalanced cutting performance proficiency among athletes. Ranson, Burnett, O'Sullivan, Batt, and Kerslake (2008) indicate that cricket players who participated in their research project had developed unbalanced quadratus lumborum cross sectional areas between dominant and non-dominant sides of the trunk segment due to their predominant and prolonged usages of their dominant side of the trunk segment during cricket related performance. Additionally, Hides et al. (2008) indicate that Australian Football players exhibited muscular imbalance in terms of psoas and quadratus lumborum muscles due to their predominant engagement in Australian Football related performance with their dominant side of the body for a prolonged period of time. As McGill, Juker, and Droph (1996) indicate, the quadratus lumborum muscle functions as a strong side flexor of the lumbar spine, and provides a significant segmental stabilization in the frontal plane.

As Ranson et al. (2008) and Hides et al. (2008) suggest, individuals tend to develop muscular imbalance of the trunk muscles due to their predominant and prolonged commitment and involvement in dominant side oriented sports related tasks including cutting performance. As Sheppard and Young, (2006), Sasaki et al., (2011), and Marshall et al., 2014) suggest, posture control for the purpose of the trunk stabilization is highly critical to enhance cutting performance. When individuals fail to possess well-balanced trunk musculature, they may not be able to achieve trunk segment stability during cutting performance, and

as a result their cutting performance may suffer. Possibly, when individuals engage in dominant side cutting performance, they may tend to be able to obtain the trunk stability and achieve more proficient cutting performance. On the other hand, when individuals engage in their non-dominant side cutting performance, it would be expected that they may not be able to maintain their trunk segment stable, therefore they may not be able to perform cutting tasks successfully. Asymmetrical trunk musculature can be an alternative explanation why individuals typically fail to obtain well- balanced cutting performance proficiency in dominant and non-dominant side cutting performance.

Biomechanical Analysis of Cutting Performance

Only a limited number of past studies have utilized quantitative biomechanical analyses to determine the key factors of change of direction techniques based on trunk kinematics to achieve cutting performance proficiency. Only limited examples, like Sasaki et al. (2011) and Marshall et al. (2014) have utilized quantitative biomechanical analyses and attempted to determine the possible key factors of change of direction techniques to enhance cutting performance. Sasaki et al. (2011) suggest that biomechanical analysis is ideal for the detailed analysis in terms of techniques related to sports performance. Cutting performance can be considered to be a more realistic and functional skill compared to straight sprinting (i.e. track and field type of sprinting) in actual field and court sports settings, due to the fact that athletes tend to engage in sprinting with direction changes (i.e. cutting performance) more frequently than sole straight sprinting (Sheppard & Young, 2006). Therefore, biomechanical analysis of trunk kinematics during cutting performance is expected to be desirable for athletes, coaches, and strength and conditioning experts to determine the possible key factors of change of direction techniques to achieve cutting performance proficiency. As a consequence, the determined key factors of change of direction techniques may be utilized for the purpose of cutting and overall field and court sports performance enhancement among athletes.

The aim of this research study was to compare cutting performance and analyze differences in trunk kinematic variables (i.e. forward and lateral trunk angles and displacement) between dominant and non-dominant side cutting maneuvers. According to Hart et al. (2014), individuals tend to achieve faster cutting time during their dominant side cutting performance compared to their non-dominant side cutting performance. Additionally, Sasaki et al. (2011) and Marshall et al. (2014) indicate that ground contact time is proportional to cutting time, when individuals obtain shorter ground contact time, they tend to achieve faster cutting time. Therefore, it was hypothesized that the subjects who participated in the current study would be expected to achieve faster cutting time and shorter ground contact time during their dominant side cutting performance compared to their non-dominant side cutting performance. Moreover, Sasaki et al. (2011) indicate that trunk kinematic variables such as forward and lateral trunk angles and displacement are correlated to cutting time. The subjects' dominant side cutting performance would be expected to exhibit characteristics of trunk kinematics related to faster cutting time. Therefore, it was also hypothesized that the subjects would obtain smaller trunk forward and lateral angles and displacement during their dominant side cutting performance compared to their non-dominant side cutting performance.

Methods

Subjects

21 subjects (11 male subjects and 10 female subjects) were recruited from current kinesiology students who enrolled at California State University, Northridge (CSUN). Means of height and body weight of the subjects were 174.3 (8.4) cm (5’ 8” ½) and 73.1 (10.5) kg (161 lbs) respectively.

Healthy individuals who did not have any current lower extremity injuries or medical conditions that would interfere with the assigned testing procedure participated in this research project. Individuals who possessed any types of lower extremity injuries or medical conditions that would interfere with the assigned testing procedure were excluded. This research project was approved by Institutional Review Board Human Subjects Committee at California State University, Northridge. All subjects received an explanation of all experimental procedures. Prior to the data collection sessions, the subjects were required to complete PARQ (Physical Activity Readiness Questionnaire) and informed consent. PARQ is designed to assess health conditions of subjects to determine their qualifications to participate in research studies that involve physical activities.

Testing Procedure

Subjects were required to wear a tight spandex shirt and pants, and running shoes of their own choice during the data collections. The male subjects were allowed to be topless and the female subjects were allowed to wear sports bra as alternative options.

To measure cutting performance proficiency, the modified 505 test was performed by the subjects. The 505 test (Figure 1) is designed to assess subjects' cutting performance proficiency (Draper & Lancaster, 1985). The 505 test requires subjects to sprint 10 meters straight, turn 180 degrees at a pre-determined turning point, and re-accelerate toward the starting position (Draper & Lancaster, 1985). In this research project, a modified version of the 505 test was assigned to the subjects due to the spatial limitation in the biomechanics lab where data collection sessions took place. The sprinting distance prior to the direction change was modified and shortened to 5 meters (16.4 feet) instead of 10 meters (An image of the modified 505 test is provided in APPENDIX). The modified 505 test which was utilized in this research project was designed based on a version of Sasaki et al. (2011). In this particular research project, the subjects were required to sprint 5 meters straight, plant both of their feet on force plates in a way that they were able to place themselves in a perpendicular position to the targeted direction of change (i.e. the starting position), and re-accelerate toward the starting position as fast as possible. The 505 test has been suggested as a valid and reliable testing procedure to determine subjects' cutting proficiency (Draper & Lancaster, 1985; Sheppard & Young, 2006; Sasaki et al., 2011).

The subjects were provided with the time for warm- up prior to the data collections. The subjects were allowed to practice the modified 505 test prior to the data collections so that they were able to be familiar with technique of the particular procedure. The subjects were required to perform the modified 505 test for both dominant and non-dominant side performance. The subjects were assigned to perform three dominant and three non-dominant trials each, resulting in a total of six trials. The subjects were allowed to take up to two minutes break between trials. The researcher monitored and kept track of the time during breaks between trials. Failed attempts were excluded and discarded, when the subjects slipped or were unable to plant their feet on force plates.

Data Collection

Twelve Cortex Motion Analysis Raptor E cameras (Motion Analysis Co., Santa Rosa, CA) were utilized to collect the trunk kinematic data of the subjects. Cortex Motion Analysis Raptor E cameras are designed to collect biomechanical data of subjects based on reflective markers attached to segments and landmarks of subjects' body. Reflective markers are designed to be recognized by motion analysis cameras. Reflective markers are attached to subjects to create a desired model so that the motion analysis cameras are able to recognize and capture motions of subjects and collect biomechanical data such as kinematic and kinetic data. Two types of markers, anatomical and tracking markers, are used to create a desired model for the purpose of data collections and analyses. Anatomical markers are placed at palpable bony landmarks near segment end points (Cappozzo, Cappello, Della Croce, and Pensalfini, 1997). Tracking markers are placed at convenient locations for tracking segments (Cappozzo et al., 1997).

The marker set used to create the trunk segment in the current study is designed based on the trunk segment of the marker set utilized by Sasaki et al., (2011). 37 reflective markers, 11 mm in diameter, were attached to the following segments and landmarks of the subjects; the manubrium of the sternum, a spinous process of the second thoracic vertebra, right and left mid points of the clavicles, acromion processes, iliac crests, anterior superior iliac spines, greater trochanters, posterior superior iliac spines, sacrum, right and left thighs (four cluster markers on each thigh), medial and lateral knees, shanks (four cluster markers on each shank), medial and lateral ankles, second and fifth metatarsals of the feet. (Images of marker set are provided in APPENDIX.)

Two Kistler force plates (Kistler Co., Germany) were configured with Cortex Motion Analysis computer software (Motion Analysis Co., Santa Rosa, CA) for the purpose of the ground reaction force measurement. The trunk kinematic data was collected at 200 Hz and the ground reaction force data was collected at 2400 Hz respectively.

Data Analysis

Visual3D software (C-Motion, Germantown, MD) was utilized to calculate the subjects' cutting time, ground contact time and trunk kinematics (i.e. forward and lateral trunk angles and displacement) during the stance phase. The overall marker set was created based on a cluster marker concept to satisfy requirements of Visual3D software so as to calculate and analyze trunk kinematics of the subjects.

The trunk kinematic data was filtered by utilizing Low Pass filtering, and cut off frequency was set at 15 Hz to eliminate the unnecessary noise. Visual3D software is designed to calculate and provide biomechanical data for the purpose of motion analysis (Palmireli-Smith, McLean, Ashton-Miller, and Wojtys, 2009). Visual3D software provides kinematic data in X, Y, and Z coordinate system. Trunk forward angles and displacement were obtained in X axis. Trunk lateral angles and displacement were obtained in Y axis.

Trunk kinematics variables were determined and obtained based on the lab coordinate system (i.e. the X, Y, and Z coordinate system). In this case, the upright trunk segment in the anatomical position is considered to be a reference position. The trunk segment was created based on the marker set to calculate trunk angles and displacement. Forward trunk angles and displacement were determined as of the trunk segment angles about the X axis, and lateral trunk angles and displacement were determined based on rotation of the trunk segment about the Y axis.

The subjects' cutting time during the modified 505 test was determined based on the time period between two steps before and after the direction change (i.e. two steps before and after the subjects planted the cutting foot on a force plate during the stance phase). This was due to unavailability of timing gates in the biomechanics lab where the data collection took place. Additionally, the 505 and other types of agility testing protocols contain aspects of deceleration and acceleration abilities, which may be more attributed to sprinting ability. Obtaining cutting time during the time period between two steps before and after the direction change can emphasize the ability to change directions compared to overall cutting time measurement during the entire sequence of the modified 505 test. Ground contact time was measured based on the vertical ground reaction force while the plant foot was in contact with a force plate. Ground contact time was determined based on the time period while the subjects' plant foot was in contact with a force plate. Sasaki et al. (2011) obtained ground contact time by utilizing the same method.

Trunk forward and lateral angles at three distinctive points, at the moment of the plant foot contact, maximum trunk inclination, and the moment of the plant foot off were obtained. Additionally, forward and lateral trunk displacement were determined based on differences between the maximum and minimum trunk inclination angles occurring during two periods, between the plant foot contact and maximum trunk inclination, and between maximum trunk inclination and the plant foot off. To calculate and determine forward and lateral trunk displacement, minimum trunk forward and lateral angles (i.e. the smallest angles) were also obtained during two periods, between foot contact and maximum trunk inclination, and between maximum trunk inclination and foot off. Sasaki et al. (2011) obtained the same trunk kinematic variables.

For maximum forward trunk angle, the greatest angle from the upright trunk segment in the anatomical position was considered to be maximum forward trunk inclination angle. For minimum forward trunk angle, the smallest forward trunk inclination angle from the upright trunk segment was considered to be minimum forward trunk angle. For lateral trunk angles, lateral trunk inclination angle (i.e. lateral trunk inclination angle from the upright trunk segment) leaning against the targeted direction of change (i.e. the starting position) was considered to be the negative angle, whereas lateral trunk inclination angle leaning towards the targeted direction of change was considered to be the positive angle. Maximum lateral trunk angle was determined as the greatest negative lateral trunk angle when the subjects yielded negative lateral trunk angles. When the subjects failed to exhibit negative lateral trunk angles, the smallest positive lateral trunk angle was considered to be maximum lateral trunk angle. Minimum lateral trunk angle was determined as the greatest positive angle learning towards the targeted direction of change to further determine lateral trunk displacement.

Statistical Analysis

Mean values of dependent variables such as cutting time, ground contact time, forward and lateral trunk angles, and forward and lateral trunk displacement were compared between dominant and non-dominant side cutting performance. Cutting time and ground contact time were utilized to determine whether the subjects achieved faster cutting time and shorter ground contact time and were actually more proficient in their dominant side cutting performance compared to their non-dominant side cutting performance. Additionally, forward and lateral trunk angles, and forward and lateral trunk displacement were compared between dominant and non-dominant side cutting performance to determine the possible key factors of change of direction techniques to enhance cutting performance.

All variables in the data are described as means and standard deviations. Statistically significant differences in terms of cutting performance proficiency and trunk kinematics were compared and determined between dominant side cutting performance and non-dominant side cutting using one tailed paired t-tests. Statistical analysis was performed by using SPSS (version 22.0 for Windows), and the statistical significance was set at $p<0.05$.

Results

Overall, trunk forward inclination angle gradually increased during the first approximately 50 % of the stance phase and decreased subsequently in the second half of the stance phase in dominant and non-dominant trials (Figure 2). Lateral trunk angle stayed in the positive direction in the first approximately 60 % of the stance phase, and increased the positive angle towards the end of the stance phase in dominant and non-dominant trials (Figure 3). Overall, both forward and lateral trunk angles during the stance phase tended to exhibit similar characteristics and tendencies in dominant and non-dominant side performance.

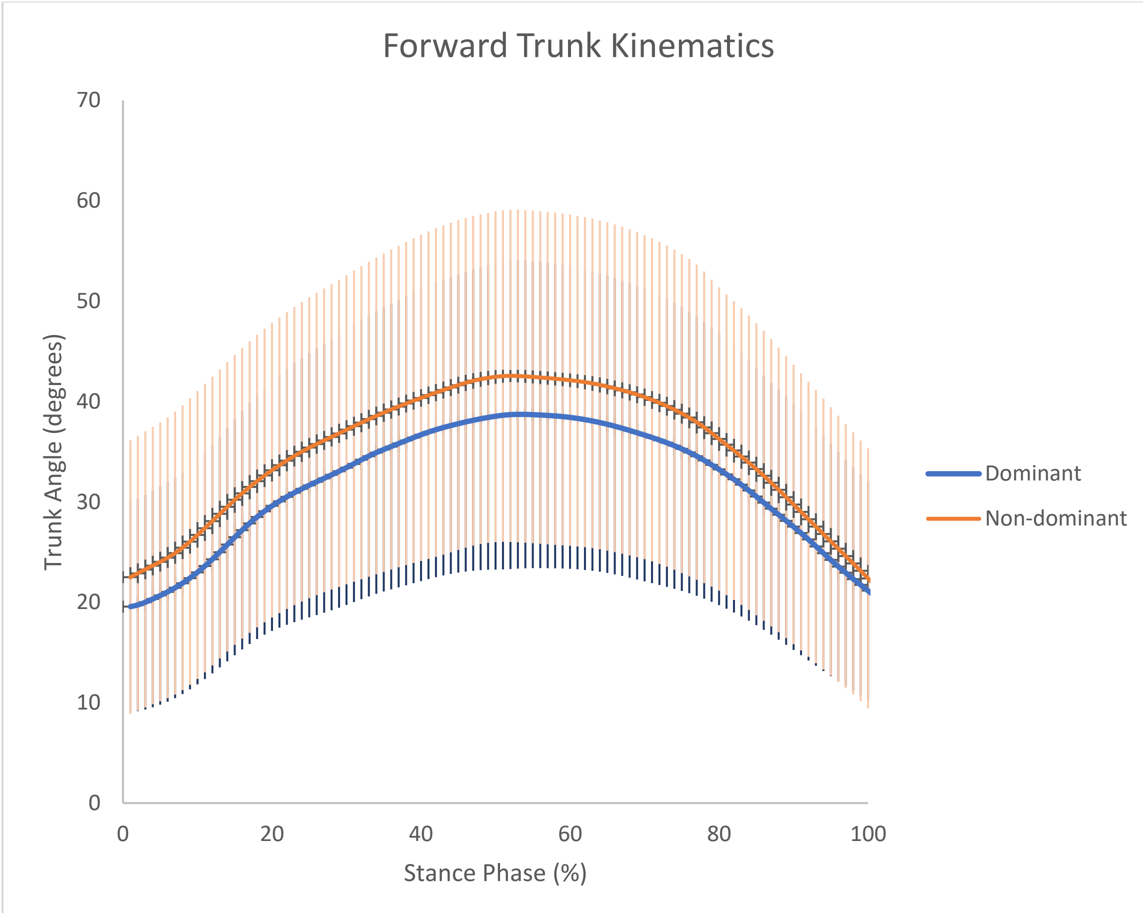

Figure 2. Forward trunk kinematics

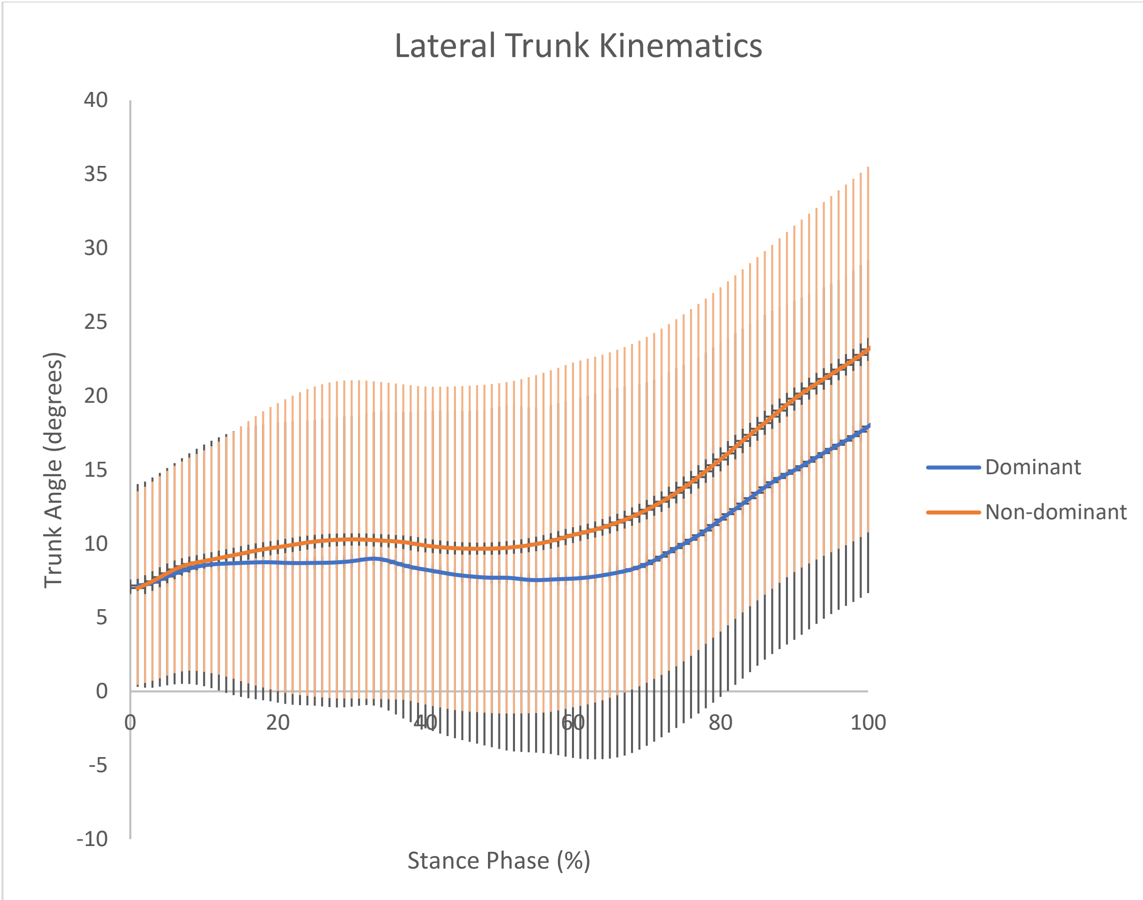

Figure 3. Lateral trunk kinematics

Table 1. Cutting performance characteristics

	Dominant	Non-dominant	t-score	p-value
Cutting time (seconds)	1.80 ± (0.21)	1.86 ± (0.21)	t=1.963	p=0.032
Ground contact time (seconds)	0.66 ± (0.10)	0.66 ± (0.13)	t=0.045	p=0.4825

Table 2. Forward trunk kinematics

	Dominant	Non-dominant	t-score	p-value
Angle at foot contact (degrees)	21.25 ± 11.8	21.93 ± 13.64	t=-0.757	p=0.229
Maximum inclination angle (degrees)	41.13 ± 14.89	41.61 ± 14.93	t=-0.261	p=0.3985
Angle at foot off (degrees)	21.05 ± 10.42	20.53 ± 12.53	t=0.268	p=0.396
Displacement between foot contact and maximum inclination (degrees)	20.08 ± 7.76	20.97± 9.51	t=-0.505	p=0.3095
Displacement between maximum inclination and foot off (degrees)	20.81 ± 9.85	22.33 ± 10.72	t=-0.974	p=0.171

Table 3. Lateral trunk kinematics

	Dominant	Non-dominant	t-score	p-value
Angle at foot contact (degrees)	7.04 ± 5.90	7.54 ± 5.31	t=-0.366	p=0.154
Maximum inclination angle (degrees)	2.47 ± 6.82	4.13 ± 6.43	t=-1.046	p=0.154
Angle at foot off (degrees)	19.20 ± 10.08	23.40 ± 12.02	t=-2.478	p=0.011
Displacement between foot contact and maximum inclination (degrees)	5.80 ± 4.77	4.53 ± 4.20	t=1.335	p=0.0685
Displacement between maximum inclination and foot off (degrees)	17.49 ± 10.61	20.15 ± 10.89	t=-1.869	p=0.038

The mean values of cutting time, lateral trunk angle at foot off, and lateral trunk displacement during the period between maximum lateral trunk inclination and foot off yielded statistically significant differences between dominant and non-dominant trials. Cutting time was shorter for dominant side performance (1.80 ± 0.21 seconds) than for non-dominant side performance (1.86 ± 0.21 seconds). Lateral trunk angle at foot off was smaller for dominant side performance (19.20 ± 10.08 degrees) than for non-dominant side performance (23.40 ± 12.02 degrees). Lateral trunk displacement between maximum lateral trunk inclination and foot off was smaller for dominant side performance (17.49 ± 10.61 degrees) than for non-dominant side performance (20.15 ± 10.89 degrees).

On the contrary, the mean values of other dependent variables, ground contact time, forward trunk angles at foot contact, maximum forward trunk inclination, and foot off, forward trunk displacement during the period between foot contact and maximum forward trunk inclination, and the period between maximum forward trunk inclination and foot off, lateral trunk angles at foot contact and maximum lateral trunk inclination, lateral trunk displacement during the period between foot contact and maximum lateral trunk inclination failed to exhibit statistically significant differences between dominant and non-dominant trials (Tables 1,2, 3).

Discussion

Influence of Leg Dominance on Cutting Performance Proficiency

Cutting time yielded a statistically significant difference with dominant side cutting performance taking less time than non-dominant side cutting performance (Table 1). These results are consistent with those of Hart et al. (2014) which indicated that the subjects achieved faster cutting time during dominant side cutting performance compared to non-dominant side performance. Individuals tend to be more proficient in their dominant side cutting performance compared to their non-dominant side cutting performance based on the result of the current study as well. On the contrary to the results for cutting time, the obtained results for ground contact time failed to exhibit statistically significant differences between dominant and non-dominant side cutting performance. In the current study, the subjects yielded similar results in terms of ground contact time in dominant and non-dominant side cutting performance.

Previous studies indicate that ground contact time and cutting time tend to be proportional; when individuals obtain shorter ground contact time, they tend to achieve faster cutting time as well (Sasaki et al., 2011; Marshall et al., 2014; Young et al., 2002). However, the previous studies did not incorporate the idea of leg dominance in relation to ground contact time (Sasaki et al., 2011; Marshall et al., 2014; Young et al. 2002). Therefore, the result in terms of ground contact time obtained in the current study may be one of a few limited examples that determined whether ground contact time would be influenced by leg dominance. The results regarding ground contact time may indicate that leg dominance may not affect ground contact time significantly. Ground contact time is measured during the stance phase; therefore ground contact time may be predominantly correlated to cutting performance proficiency during the stance phase.

In case of overall cutting performance, techniques related to phases other than the stance phase, such as the deceleration and the re-acceleration phases may also affect overall cutting performance. Adjustment of strides to accelerate and decelerate during the deceleration and the re-acceleration phases is also one of the aspects of cutting performance (Sheppard & Young, 2006; Young et al., 2002). Leg dominance may affect some of the aspects of cutting performance, such as adjustment of strides to accelerate and decelerate during the deceleration and the re-acceleration phases. In case of cutting performance, leg dominance may have affected adjustment of strides among the subjects in the current study. When the subjects engaged in dominant side cutting performance, they may have been able to adjust strides to decelerate and re-accelerate relatively easily compared to non-dominant side cutting performance. This may be due to the fact that individuals may have adopted motor control in terms of adjusting strides to decelerate and re-accelerate for changing directions in dominant side cutting. On the contrary, individuals may have not achieved motor control for the purpose of adjusting strides at the level of dominant side cutting performance in case of non-dominant side cutting performance.

Also, the way force plates were utilized in the current study was different from the setup of Sasaki et al. (2011). Two force plates were utilized to measure ground contact time in the current study, whereas one force plate was utilized in the study of Sasaki et al. (2011). The different methodology in terms of the measurement of ground contact time may have affected the results of ground contact time. When the subjects in the current study engaged in the modified 505 test, they may have needed to be aware of planting both of their feet on two force plates at the same time. This may have affected the way the subjects planted the plant foot. In this situation, the subjects in the current study may have needed to focus on the plant foot and the alternative foot at the same time. This may have resulted in the similar results in terms of ground contact time between dominant side and non-dominant side cutting performance in the current study.

Influence of Leg Dominance on Forward Trunk Kinematics

The results of forward angles at three distinctive points, at foot contact, maximum forward trunk inclination, and foot off failed to exhibit statistically significant differences between dominant and non-dominant side cutting performance. Additionally, the results of forward trunk angular displacement between foot contact and maximum forward trunk inclination and between maximum forward trunk inclination and foot off failed to exhibit statistically significant differences between dominant and non-dominant side cutting performance either.

Sasaki et al. (2011) indicate that forward trunk kinematics are correlated to cutting time, when individuals obtain smaller forward trunk angles and displacement, they tend to achieve faster cutting time. Additionally, the result in the current study indicates that the subjects tend to achieve faster cutting time during dominant side cutting performance compared to non-dominant side cutting performance. It was hypothesized that the subjects would obtain smaller forward trunk angles and displacement during dominant side cutting performance compared to non-dominant side cutting performance. The statistically insignificant results in terms of forward trunk angles and displacement obtained in the current study may indicate that forward trunk kinematics may not be affected by leg dominance.

Certainly, not many evident past examples have been available for the purpose of comparing the obtained data of trunk kinematics in the current study to the data in the past studies. The current study may be considered to be one of a few limited studies that has incorporated the idea of leg dominance and analyzed trunk kinematic variables like trunk angles and displacement to determine the possible key factors of change of direction techniques to enhance cutting performance. Therefore, the results regarding forward trunk kinematics may indicate that trunk kinematics in forward direction may not be affected by leg dominance overall. This may be due to the fact that the subjects were required to plant their feet and place themselves in a position which was perpendicular to the targeted direction of change during the stance phase of the modified 505 test in the current study.

Influence of Leg Dominance on Lateral Trunk Kinematics

Lateral trunk angle at the moment of foot off and lateral trunk displacement between maximum lateral trunk inclination and foot off exhibited statistically significant differences between dominant and non-dominant side cutting performance (Table 3). The subjects tended to obtain smaller lateral trunk angle at the moment of foot off and less lateral trunk displacement between maximum lateral trunk inclination and foot off during more proficient dominant side cutting performance. These results may indicate that lateral trunk angle and displacement tended to be more affected by leg dominance in the current study than forward trunk kinematics.

The side of cutting performance dominance, either dominant side or non-dominant side cutting performance, was defined based on leg dominance (i.e. right leg or left leg), which leg was utilized as the plant leg (Sasaki et al., 2011; Green et al., 2011).

In the current study, the subjects planted the plant leg to place themselves in a way that lateral trunk movements took place in the frontal plane during the stance phase. According to the past studies like McGill et al. (1996), Hides et al. (2008), and Ranson et al. (2008), lateral trunk musculature and movements may tend to be affected by leg dominance due to the fact that lateral body movements take place in the frontal plane. When individuals engage in sports related performance in the frontal plane, they tend to utilize their dominant side of the trunk segment along with dominant leg. When individuals tend to utilize their dominant side of the body more frequently, they end up developing unbalanced musculature between the dominant side and non-dominant side of the body. Therefore, due to the fact that angles and displacement were measured and obtained in the frontal plane, lateral trunk angles and displacement may have been affected by leg dominance in the current study.

Overall Characteristics of Trunk Kinematics in Relations to Cutting Performance Proficiency

Overall, lateral trunk kinematics in the frontal plane tended to be more affected by leg dominance compared to forward trunk kinematics in the sagittal plane. In the current study, the subjects were required to plant both of their feet on force plates during the stance phase of the modified 505 test, as a result they placed their bodies in a perpendicular position to the targeted direction of change (i.e. the starting position). In this situation, the subjects' lateral trunk movement took place in the frontal plane, and the quadratus lumborum muscle was responsible for the trunk movement in the frontal plane during the stance phase of the modified 505 test. McGill et al. (1996) indicate that the quadratus lumborum muscle functions as a strong side flexor of the lumbar spine, and provides a significant segmental stabilization in the frontal plane. Therefore, a trunk muscle like quadratus lumborum may tend to be affected by leg dominance. This is because when individuals maintain the balance of the trunk segment in the frontal plane, they need to activate the quadratus lumborum muscle in either the right or the left directions. When individuals tend to activate the quadratus lumborum muscle in the dominant side of the trunk segment more frequently, they may end up possessing unbalanced quadratus lumborum cross sectional areas between the dominant side and the non-dominant side of the trunk segment (i.e. the right side and the left side).

As Hides et al. (2008) and Ranson et al. (2008) indicate, individuals tend to develop characteristics of asymmetrical trunk segment musculature due to their prolonged engagement in sports related performance by utilizing their dominant side of the body. For instance, Ranson et al. (2008) suggest that cricket players who participated in their study have developed greater quadratus lumborum cross sectional area on the dominant side of the trunk segment due to their repeated usage of their dominant side of the body for the purpose of cricket related performance. Furthermore, Hides et al. (2008) indicate that their subjects, Australian Football League players, exhibited muscular imbalance in terms of psoas and quadratus lumborum muscles due to the fact that they have engaged in Australian Football related performance in their dominant side the body more frequently than their non-dominant side of the body.

By the same token, it can be assumed that the subjects who participated in the current study may have engaged in various tasks including cutting maneuvers during their sports and exercise related movements and everyday tasks by utilizing their dominant side of the body predominantly for a prolonged period of time, based on the results exhibiting significant differences in terms of lateral trunk angle and displacement between dominant side and non-dominant side performance in the current study. For instance, there would be a possibility that the subjects who are collegiate athletes have tended to engage in their sports specific movements by utilizing their dominant side of the body predominantly for a prolonged period of time. Active individuals who have participated in some types of sports and exercise routines may have predominantly utilized their dominant side of the body with or without their awareness. Furthermore, regardless of their fitness and activity levels, the subjects may have handled their everyday tasks predominantly with their dominant side of the body. There may be a possibility that the subjects who have participated in the current study have engaged in dominant side cutting performance predominantly for a prolonged period of time with or without their awareness. Even though not all the subjects who participated in the current study were considered to be competitive athletes who frequently engage in some types of cutting maneuvers in sports related situations, individuals may have engaged in dominant side cutting performance (i.e. changing directions in their preferred ways) on a regular basis for a prolonged period of time in their daily lives. As a result, they may have developed trunk muscular imbalance, particularly asymmetrical quadratus lumborum cross sectional areas, between dominant and non-dominant sides of the trunk segment.

As McGill et al. (1996) indicate, the quadratus lumborum muscle functions as a strong side flexor of the lumbar spine, and provides a significant segmental stabilization in the frontal plane. In the current study, the subjects were likely to achieve smaller lateral trunk angle at the moment of foot off and lateral trunk displacement between maximum trunk inclination and foot off during their dominant side cutting performance compared to their non-dominant side cutting performance. The subjects may possess greater quadratus lumborum cross sectional area and the stabilization ability on the dominant side of the trunk segment, as a result they may be able to maintain the trunk segment more stable in the frontal plane when they engage in dominant side cutting performance. On the contrary, during their non- dominant side cutting performance they may not be able to maintain the trunk segment as stable as when they engage in dominant side cutting performance. Overall, the results regarding lateral trunk kinematics may indicate that individuals may be able to maintain the trunk segment more stable in the frontal plane during their dominant side cutting performance compared to their non-dominant side performance.

Unlike the results of lateral trunk angles at foot contact and maximum lateral trunk inclination obtained by Sasaki et al. (2011), the vast majority of the results among the subjects failed to exhibit negative lateral trunk angles at foot contact and maximum lateral trunk inclination on average in the current study.

The negative lateral trunk angle is defined as the lateral trunk inclination angle leaning against the targeted direction of change, and the positive lateral trunk angle is defined as the lateral trunk inclination angle leaning towards the targeted direction of change during the modified 505 test (based on the X, Y, and Z lab coordinate system). The obtained results of lateral trunk angles were -6.8 ± 7.8 degrees at foot contact and -14.4 ± 14.4 degrees at maximum lateral trunk inclination in the study of Sasaki et al. (2011). The obtained results of lateral trunk angles were 7.04 ± 5.90 degrees for dominant side cutting performance and 7.54 ± 5.31 degrees for non-dominant side cutting performance at foot off, and 2.47 ± 6.82 degrees for dominant side cutting performance and 4.13 ± 6.43 degrees for non-dominant side performance at maximum lateral trunk inclination in the current study. Overall, the subjects who participated in the current study have exhibited only positive lateral trunk angles on average. The results of Sasaki et al. (2011) indicate that their subjects tended to lean against the targeted direction of change and exhibit negative lateral trunk angles at foot contact and maximum lateral trunk inclination on average. On the contrary, the subjects in the current study did not lean against the targeted direction of change as much as the subject in the study of Sasaki et al. (2011), and as a consequence they exhibited positive lateral trunk angles on average.

These inconsistent results regarding lateral trunk angles may be due to a methodological difference in terms of the way that force plates were utilized between the research study of Sasaki et al. (2011) and the current study. In case of Sasaki et al. (2011), they used one force plate for the purpose of the measurement of ground reaction force to further determine the duration of the stance phase and ground contact time. On the other hand, two force plates were utilized for the same purposes in the current study. In the current study, two force plates were placed next to each other in the biomechanics lab that was utilized for the purpose of data collection. In this situation, it was more natural for the subjects to plant both of their feet on force plates during the stance phase. Therefore, the subjects were particularly instructed to plant both of their feet on force plates during the stance phase. In this situation, possibly the subjects needed to be aware of planting both of their feet on force plates at the same time. Due to the fact that the plant foot is the foot placed on the side of the negative direction of lateral trunk inclination angle (i.e. the direction against the targeted direction of change) and the alternative foot is the foot placed on the side of the positive direction (i.e. the direction towards the targeted direction of change), the subjects may have not been able to lean toward the negative direction much, and tended to keep the trunk segment relatively up-right since they also needed to be aware of planting the alternative foot along with the plant foot. On the contrary to the current study, when the subjects in the study of Sasaki et al. (2011) planted the plant foot on one force plate, possibly they did not need to be aware of the alternative foot, and as a result they were able to lean towards the negative direction as much as they needed.

Additionally, the methodology for obtaining trunk kinematics was inconsistent between the current study and the study of Sasaki et al. (2011). Trunk kinematics including lateral angles were obtained and determined based on the X, Y, Z lab coordinate system in the current study. On the contrary, Sasaki et al. (2011) obtained lateral trunk angles as the angles between the long axis of the principal axis of the trunk segment and the z–axis in the y–z plane. Possibly, the difference in terms of the coordinate system for obtaining the lateral trunk angles may have affected the inconsistent results of lateral trunk angles between the current study and the study of Sasaki et al. (2011).

A possible alternative cause of inconsistent results in terms of lateral trunk angles may be due to the inconsistent population demographics between the current study and the study of Sasaki et al. (2011). The subjects who have participated in the current study were college students from California State University, Northridge. The various male and female subjects, including collegiate athletes, active individuals who have engaged in some types of exercise routines, and inactive individuals, may possess various levels of fitness and physical abilities. On the contrary, the subjects who participated in the study of Sasaki et al. (2011) were all division I male soccer players who may be expected to possess higher levels of fitness and physical abilities overall. In fact, the results regarding ground contact time indicate that the subjects in the study of Sasaki et al. (2011) obtained shorter ground contact time (0.44 ±0.07 seconds) than the subjects from the current study (0.66 ±0.10 seconds for dominant side performance and 0.66 ± 0.13 seconds for non-dominant side performance), although the results in terms of cutting time cannot be compared directly due to the deviation of the method measuring cutting time. The results indicate that athletes in the study of Sasaki et al. (2011) may be more physically fit on average and be able to achieve faster ground contact time than the subjects from the current study.

The possible deviation in terms of fitness and physical abilities may have resulted in the inconsistent results of the lateral trunk angles between the current study and the study of Sasaki et al. (2011). Overall, athletes may be quicker due to their superior physical abilities in general. Therefore, due to the fact that athletes may be quicker, they need to counteract the greater velocity while they engage in cutting performance compared to individuals who belong to general population who may not be as quick as athletes. The division I male soccer players who participated in the study of Sasaki et al. (2011) may have had to counteract the greater velocity while they engaged in the modified 505 test. As a consequence, the subjects from the study of Sasaki et al. (2011) may have needed to deal with the greater momentum to maintain the balance of the body and make a complete stoppage by leaning against the targeted direction of change (in the negative direction) while they engaged in cutting performance. Still, this did not increase ground contact time among the subjects in the study of Sasaki et al. (2011) compared to that of the subjects in the current study. This may be due to the fact that division I male succor players in the study of Sasaki et al. (2011) may possess a higher level of reactive strength than the subjects in the current study. As a result, the subjects in the study of Sasaki et al. (2011) were able to achieve shorter ground contact time on average due to that fact that ground contact time is correlated to reactive strength (Young et al. 2002).

In case of the 505 test, individuals decelerate from initial sprinting, make a complete stoppage, and re-accelerate towards the starting position by turning 180 degrees. In this situation, individuals need to decelerate by counteracting and handling momentum to stop completely and re-accelerate subsequently. When individuals need to counteract the greater momentum so that they are able to stop themselves completely to prepare for re-acceleration toward the starting position by turning 180 degrees, they also need to deal with the greater velocity as well, due to the fact that momentum is proportional to velocity, when velocity is greater momentum becomes greater as well. In this situation, individuals may need to lean against the starting position (the negative direction) in the greater extent, and therefore the results of lateral trunk angles obtained by Sasaki et al. (2011) may have turned out to be negative angles on average. On the contrary to the subjects from the study of Sasaki et al. (2011), the subjects from the current study may have not needed to deal with excessive velocity and momentum as much as the division I soccer players while they engaged in the modified 505 test. As a result, they did not need to lean towards the negative direction as much as the subjects from the study of Sasaki et al. (2011). Therefore, the overall results of trunk lateral angles were on average in the positive direction.

In addition to the inconsistent results regarding lateral trunk angles at foot contact and maximum lateral trunk inclination, one of the results in terms of lateral trunk displacements also exhibited inconsistent results between the study of Sasaki et al. (2011) and the current study. The results regarding lateral trunk displacement between foot contact and maximum lateral trunk inclination exhibited similar results in both Sasaki et al. (2011) and the current study. In case of Sasaki et al. (2011), the subjects demonstrated 6.6±8.3 degrees. In the current study, the subjects demonstrated 5.80 ± 4.77 and 4.53 ± 4.20 degrees on average in dominant and non-dominant side performance respectively. On the contrary, the results in terms of lateral trunk displacement between maximum lateral trunk inclination and foot off exhibited inconsistent results. In case of Sasaki et al. (2011), the subjects demonstrated 48.1±14.5 degrees. In the current study, the subjects demosntrated 17.49 ± 10.61 and 20.15 ± 10.89 degrees on average in dominant and non-dominant side performance respectively.

Overall, the subjects in the study of Sasaki et al. (2011) demonstrated a larger displacement than the subjects in the current study. Similar to the example of deviations in terms of lateral trunk angles, this deviation may also be due to the methodological inconsistence regarding the setup of force plates. As mentioned in the explanations of inconsistent lateral trunk angles, the subjects in the study of Sasaki et al. (2011) only needed to focus on planting the plant foot on one force plate during the stance phase, therefore they were able to move the trunk segment as much as they needed. On the contrary, the subjects in the current study were required to plant both of their feet on two force plates during the stance phase, therefore they were not able to move the trunk segment as much as the subjects in the study of Sasaki et al. (2011). Additionally, the different coordinate systems to obtain trunk kinematics utilized in the study of Sasaki et al. (2011) and the current may also have affected this deviation, just like the example of lateral trunk angles.

Alternatively, due to the fact that the subjects in the study of Sasaki et al. (2011) were all division I male soccer players, they may possess higher levels of physical abilities compared to the subjects in the current study. The subjects in the study of Sasaki et al. (2011) may have needed to deal with the greater velocity and momentum to stop themselves completely to further re-accelerate subsequently compared to the subjects in the current study. Trunk displacements were determined based on differences between maximum and minimum angles. Overall, the subjects in the study of Sasaki et al. (2011) tended to lean towards the negative direction at maximum lateral trunk inclination to counteract the greater velocity and momentum to stop completely to further re-accelerate. Lateral trunk displacement between maximum lateral trunk inclination and foot off was determined based on a difference between maximum and minimum angles during this period. The subjects in the study of Sasaki et al. (2011) tended to move the trunk segment in a greater extent by shifting the trunk segment from the negative direction to the positive direction to counteract the greater velocity and momentum, and as a consequence they demonstrated a larger lateral trunk displacement between maximum lateral trunk inclination and foot off. On the contrary, the subjects in the current study tended to exhibit the positive maximum lateral trunk inclination angle. Unlike the division I male soccer players, the subjects in the current study may have not needed to deal with the excessive velocity and momentum during the direction change, and as a result they tended to move the trunk segment less within the range of the positive direction.

Practical Applications

Overall, individuals may be able to enhance cutting performance by maintaining smaller lateral trunk angles at the moment of foot off and less lateral trunk displacement between maximum lateral trunk inclination and foot off. As individuals obtain smaller lateral trunk angle and displacement and maintain the trunk segment more stable in the frontal plane (i.e. smaller lateral trunk movement), they may be able to take advantage of anticipatory postural adjustment (Kibler et al., 2006). As a result of the enhanced anticipatory postural adjustment, individuals may be able to achieve faster cutting time by counteracting external forces and balancing themselves effectively. Additionally, as individuals utilize the enhanced kinetic chain functions via the increased capacity of the stretch shortening cycle and interactive moments by keeping the trunk segment more stable in the frontal plane (i.e. obtaining smaller lateral trunk angle and displacement), they may be able to increase the capacity of reactive strength and power output in the lower extremity (Kibler et al., 2006). As a consequence of the increased capacity of reactive strength and power output in the lower extremity muscles, individuals may be able to enhance cutting performance as well (Marshall et al., 2014; Young et al., 2002).

To enhance less proficient non-dominant cutting performance, individuals may need to maintain smaller lateral trunk movement during the stance phase of cutting performance. Furthermore, individuals may need to pay closer attention to lateral trunk movement at two critical points, at the moment of foot off and between maximum lateral trunk inclination and foot off, particularly when they engage in less proficient non-dominant side cutting performance. Coaches and strength and conditioning specialists may be recommended to take a closer look at athletes' lateral trunk movement during the stance phase of cutting performance, particularly while athletes engage in non-dominant side cutting performance. Moreover, coaches and strength and conditioning specialists may also need to encourage athletes to keep their lateral trunk movement minimum particularly at the moment of foot off and between maximum lateral trunk inclination and foot off, when they practice non-dominant side cutting performance. Individuals may be able to obtain well- balanced cutting performance by enhancing less proficient non-dominant side cutting performance based on the findings of this particular study. As a consequence, individuals may also be able to enhance overall sports performance requiring frequent direction changes (Hart et al., 2014). Hart et al. (2014) suggest that strength and conditioning routines to enhance lower extremity muscular strength may also be critical to achieve cutting performance proficiency. Strength and conditioning routines to strengthen related muscular strength to cutting performance (i.e. lower extremity muscular strength) may also be taken into account along with cutting performance practice routine to enhance techniques of cutting performance (Hart et al., 2014). Addition to lower extremity strength, muscular strength of the trunk segment may also be critical for individuals to enhance cutting performance along with cutting performance practice routines incorporating technical aspects. Particularly, strengthening the trunk muscles, such as the quadratus lumborum muscle, may enhance the ability to maintain the trunk segment more stable to further enhance lower extremity functions. As a consequence, individuals may be able to enhance cutting performance.

There are several critical findings based on the outcomes in the current study. Possibly, smaller lateral trunk movement in the frontal plane may be a key factor of change of direction techniques to enhance cutting performance among athletes and active individuals. Furthermore, the findings and the methodologies of the current study may provide a reference point for similar research studies focusing on technical aspects of cutting performance to further determine additional key factors of change of direction techniques to enhance cutting performance in the future, due to the limited availability of similar past research studies which are focused on technical aspects of cutting performance.

Limitations and Potential Future Research Topics

There may be several limitations in the current study. Along with the findings and the methodologies of the current study, limitations may provide possible research topics for similar research studies focusing on technical aspects of cutting performance to further determine additional key factors of change of direction techniques to enhance cutting performance in the future.

Sample size in the current study may be considered to be small since only 21 subjects participated in the data collection.

Demographics of the subjects who participated in the current study were inconsistent with populations in the similar past research studies like Sasaki et al. (2011), Marshall et al. (2014), and Green et al. (2011). In the current study, all the subjects who participated in the data collections were Kinesiology students enrolled at California State University, Northridge. Various types of male and female subjects, collegiate athletes, active individuals who have participated in some types of exercise routines on a regular basis, and inactive individuals, participated in the data collection sessions in the current study. On the contrary to the subjects who participated in the current study, all the subjects from the similar past research projects, such as Sasaki et al. (2011), Marshall et al. (2014), and Green et al. (2011), were competitive athletes. Generally, athletes are expected to possess overall higher levels of athletic abilities, therefore cutting performance proficiency and the characteristics of trunk kinematics may be inconsistent between the subjects who participated in the current study and subjects who belong to athlete population.

The 505 test is a cutting performance proficiency assessment protocol focused on a 180-degree direction change. In the current study, the modified 505 test, was assigned to the subjects for the purpose of the data collection. In real court and field sports and different types of agility testing protocols, angles of direction changes vary. Therefore, cutting performance proficiency and characteristics of trunk kinematics may be affected by various change of direction angles that are required in different types of agility testing protocols and actual sports related situations. For the similar future research studies, various change of direction angles other than 180 degrees may be utilized as well. Various types of agility testing procedures with several different change of direction angles may also be utilized to determine the additional key factors of change of direction techniques.

The aim of the current study was to identify the possible key factors of change of direction techniques to enhance cutting performance among athletes and athletic individuals. As Shepard and Young (2006) Young et al. (2002), and Hewit et al. (2012) suggest, several technical aspects of cutting performance are considered to be highly critical for individuals to enhance cutting performance. Several technical aspects of cutting performance, such as foot placement, adjustment of strides to accelerate and decelerate, and body lean and posture, have been proposed to be related to cutting performance proficiency (Shepard & Young 2006; Young et al., 2002; Hewit et al., 2012). In the current study, variables solely focused on trunk kinematics (i.e. body lean and posture) were obtained and analyzed to determine the key factors of change of direction techniques to enhance cutting performance. Other technical aspects of cutting performance, such as foot placement and adjustment of strides to accelerate and decelerate, should also be taken into account to further determine possible additional key factors of change of direction techniques. Possibly, variables such as foot placement and adjustment of strides to accelerate and decelerate may be examined to further determine the additional key factors of change of direction techniques for the similar future research studies.

The current study focused on the change of direction component of agility. As Shepard & Young (2006) and Young et al. (2002) indicate, agility can be divided into the perceptual and decision making and the change of direction components. The change of direction component does not contain the perceptual and decision making component of agility. The modified 505 test which was utilized for the purpose of the data collection in the current study is focused on the change of direction component of agility, and the modified 505 test is considered to be a closed skill, based on the fact that it does not require any aspects of the perceptual and decision making component. In actual sports related situations, the perceptual and decision making component can be highly critical since individuals are required to react to existing external stimulus such as movement of opponents and balls. Overall, agility is considered to be an open skill. Visual scanning, anticipation, pattern recognition, and knowledge of situations aspects belong to the perceptual and decision making component (Shepard & Young, 2006; Young et al., 2002). To fully enhance agility and overall sports related performance, not only the change of direction component but also the perceptual and decision making component should be enhanced. Possibly, the influence of external stimulus related to aspects like visual scanning, anticipation, pattern recognition, and knowledge of situations may affect variables like cutting time, ground contact time, and trunk kinematics. For future research studies, the perceptual and decision- making component may also be added as possible variables to further examine technical aspects of cutting performance and determine the possibly key factors of change of direction techniques to enhance cutting performance. Some types of external stimulus such as opponents and /or balls may be incorporated in testing conditions to examine trunk kinematics and other technical aspects of cutting performance.

Additionally, anthropometric aspects of the change of direction component may be taken into account. Anthropometric measurements have been suggested to be a factor which could impact cutting performance proficiency (Shepard & Young, 2006; Young et al., 2002). Sheppard and Young (2006) suggest that shorter individuals who have the lower center of gravity may be able to change directions more rapidly compared to taller individuals with the higher center of gravity. Possibly, subjects' anthropometric measurements (i.e. height and limb length) may also be taken into account and obtained to determine if there would be possible correlations to cutting performance proficiency and technical aspects of cutting performance for future research projects.

Conclusion

The current study may be considered to be one of a few limited examples of research studies that have attempted to analyze technical aspects of cutting performance and determine the possible key factors of change of direction techniques to enhance cutting performance by incorporating the idea of leg dominance. As mentioned, only a few studies have attempted to determine key factors of change of direction techniques to enhance cutting performance (Sasaki et al., 2011; Marshall et al., 2014). Therefore, only limited evidence is available in the literature at this moment, and it might be difficult to compare the obtained results in the current study directly to the results provided by limited similar past research studies. Nevertheless, the obtained results in the current study may be able to propose possible characteristics of the key factors of change of direction techniques to enhance cutting performance among athletes and athletic individuals.

Additionally, this may be the first research study which has integrated the idea of leg dominance to further determine the key factors of change of direction techniques to enhance cutting performance. Hart et al. (2014) indicate that leg dominance significantly affects cutting performance among athletes, and athletes tend to be more proficient in dominant side cutting performance compared to non-dominant side cutting performance. Additionally, Hart et al. (2014) emphasize that it is highly desirable for athletes to obtain well-balanced cutting performance in dominant and non-dominant side cutting performance. However, Hart et al. (2014) did not attempt to determine how individuals may be able to find solutions to obtain well-balanced cutting performance based on biomechanical analysis. As several past research studies like Sasaki et al. (2011), Hart et al. (2014), Marshall et al. (2014), Green et al. (2011), Hewit et al. (2012) and Sheppard and Young (2006) indicate, it is highly critical for athletes to enhance cutting performance to be successful in sports that require frequent direction changes. Moreover, Sasaki et al. (2011), Marshall et al. (2014), and Hewit et al. (2012) suggest that determining the key factors of change of direction techniques would be highly critical for athletes to further enhance their cutting and overall sports performance. Sasaki et al. (2011) and Marshall et al. (2014) have found out and indicated the limited possible key factors of change of direction techniques to enhance cutting performance based on their findings. However, Sasaki et al. (2011) and Marshall et al. (2014) failed to incorporate the idea of leg dominance to analyze and determine the key factors of change of direction techniques.

The obtained results in the current study indicated that forward trunk kinematics were not significantly affected by leg dominance. Therefore, forward trunk kinematics may not be considered to be a key factor of change of direction techniques to enhance cutting performance. Furthermore, the results in the current study also indicated that lateral trunk kinematics were more affected by leg dominance. The results in terms of lateral trunk kinematics in the current study may provide the possible key factors of change of direction techniques for the purpose of the enhancement of cutting performance. To enhance cutting performance, it is highly crucial for athletes to possess well- balanced cutting performance between dominant and non-dominant side cutting performance (Hart et al., 2014). To enhance relatively less proficient non-dominant side cutting performance, possibly individuals may be able to utilize the characteristics of lateral trunk kinematics based on more proficient dominant side cutting performance.

As the obtained result in terms of cutting time indicates, the subjects who participated in the current study tended to be more proficient in their dominant side cutting performance compared to their non-dominant side cutting performance. Furthermore, the subjects obtained smaller lateral trunk angle at foot off and lateral trunk displacement between maximum lateral trunk inclination and foot off on average during dominant side cutting performance. When individual maintain smaller trunk angle and displacement, they may be able to keep the trunk segment more stable, and as a result they tend to achieve faster cutting time. Based on the results in the current study, it can be concluded that smaller lateral trunk angle at foot off and lateral trunk displacement between maximum lateral trunk inclination and foot off are considered to be the key factors of change of direction techniques to enhance cutting performance. Based on the findings of the current study, individuals may enhance cutting performance by maintaining smaller lateral trunk movement. When individuals obtain smaller lateral trunk angles and displacements, they can keep the trunk segment more stable. As a result, individuals may be able to enhance extremity segment functions and further achieve faster cutting time.

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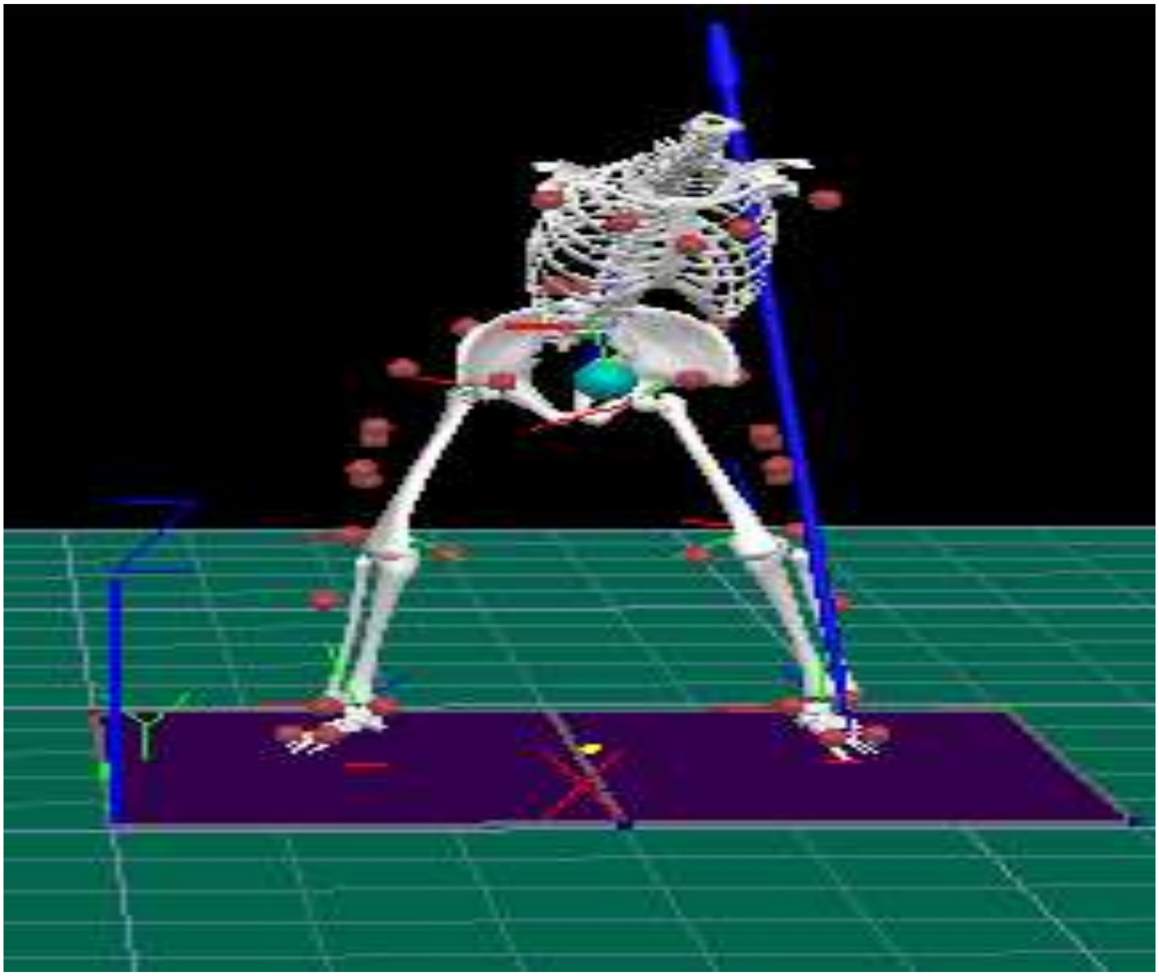
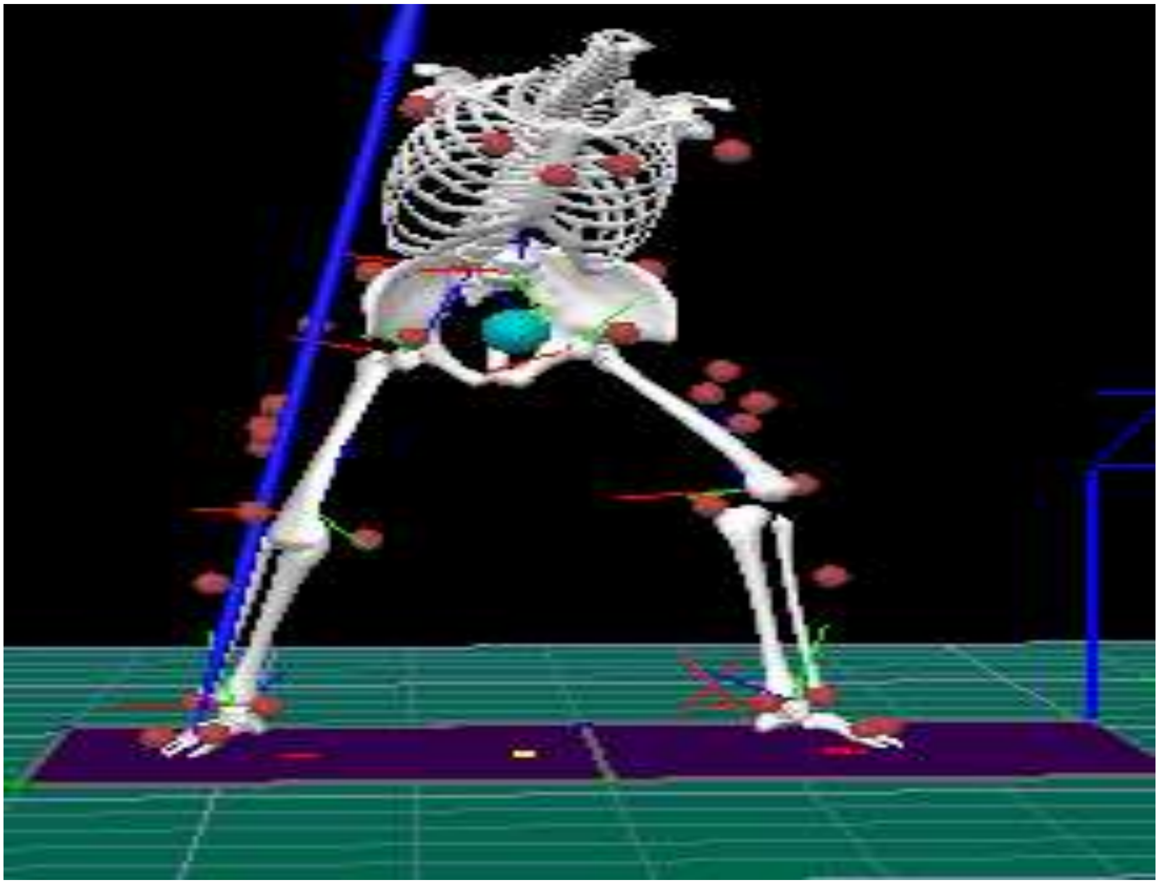
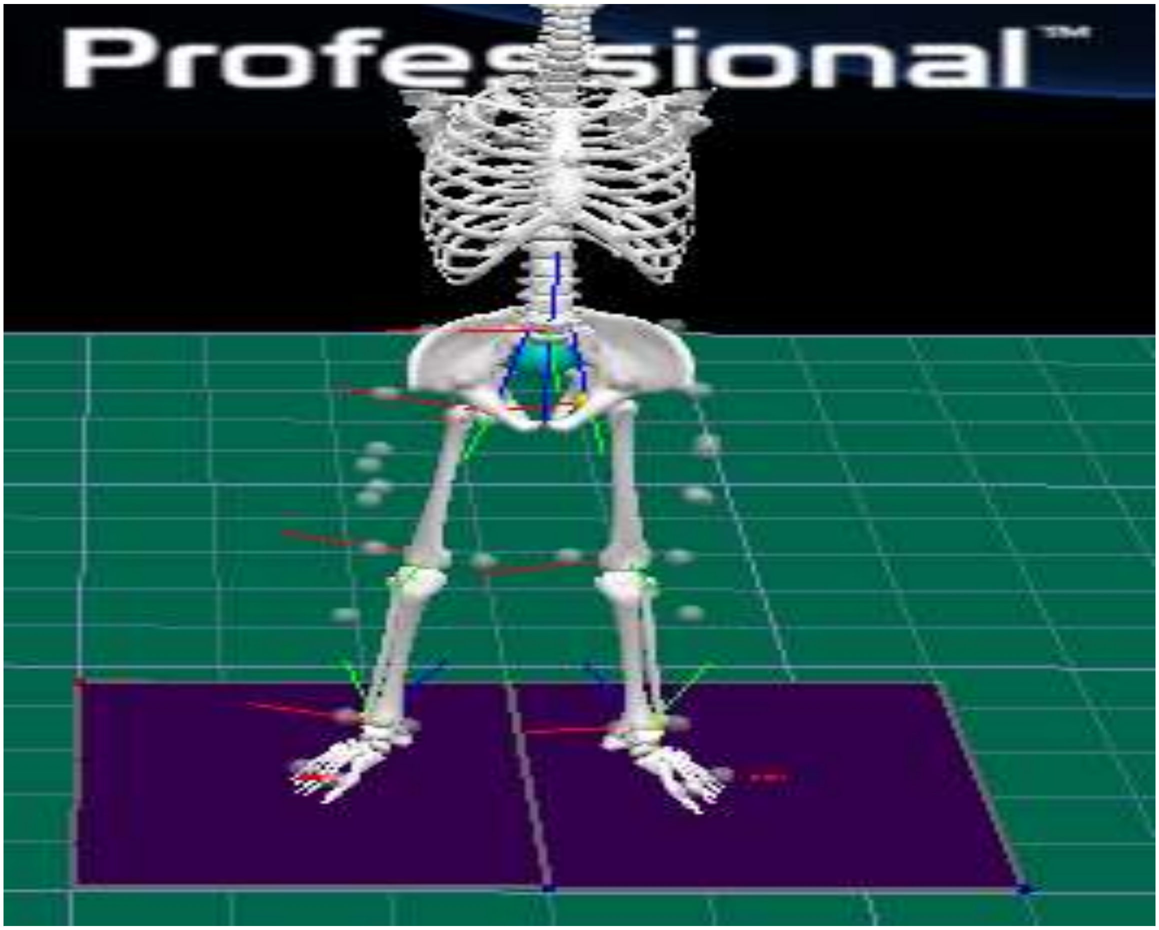
Appendix: Pictures



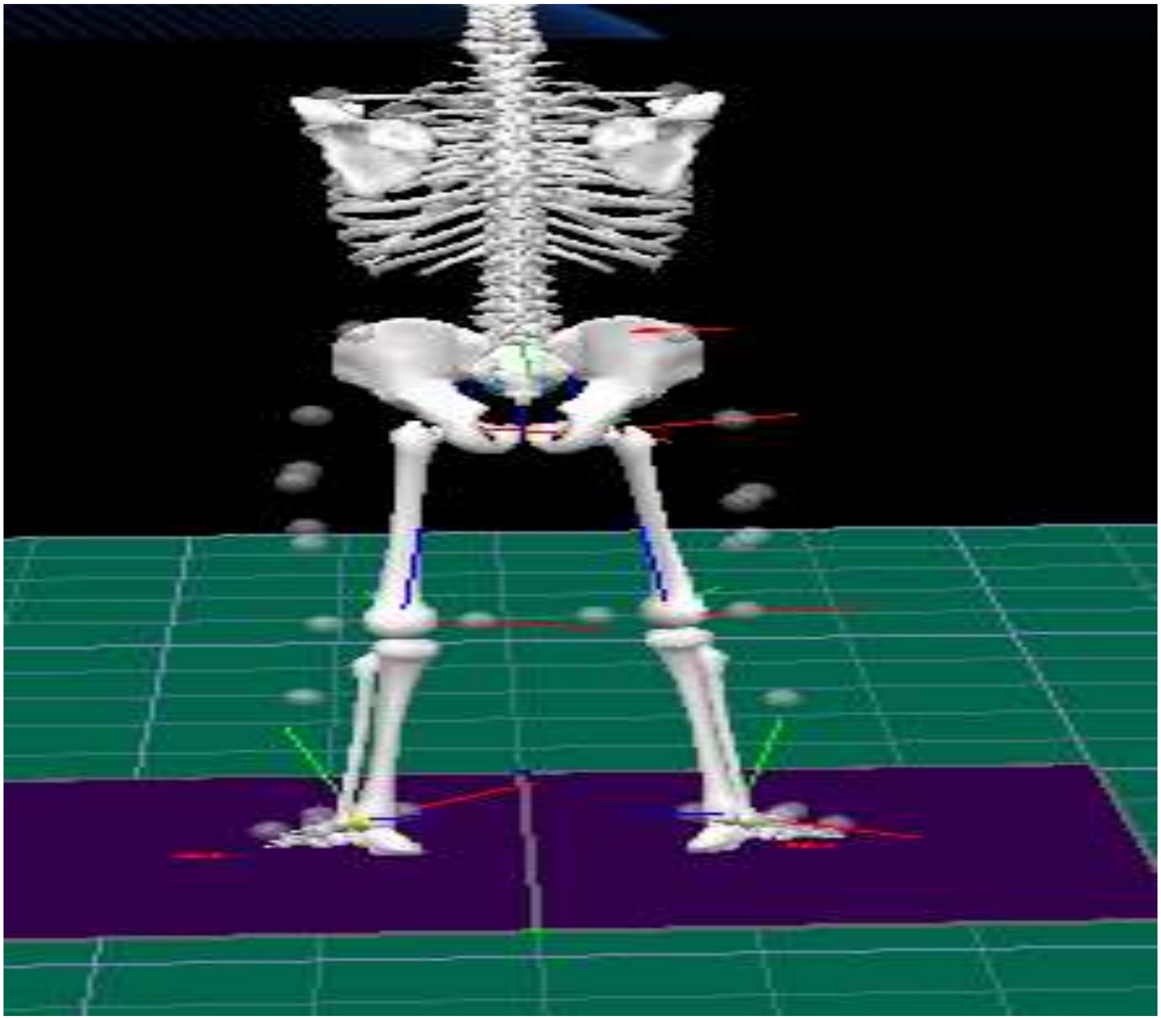
Picture 1. Description of the plant leg (the cutting leg) Right leg dominant (using LEFT leg as the plant leg) Left leg non-dominant



Picture 2. Description of the plant leg (the cutting leg) Right leg non-dominant (using RIGHT leg as the plant leg) Left



Picture 3. Marker set anterior view



Picture 4. Marker set posterior view

Appendix: Figures

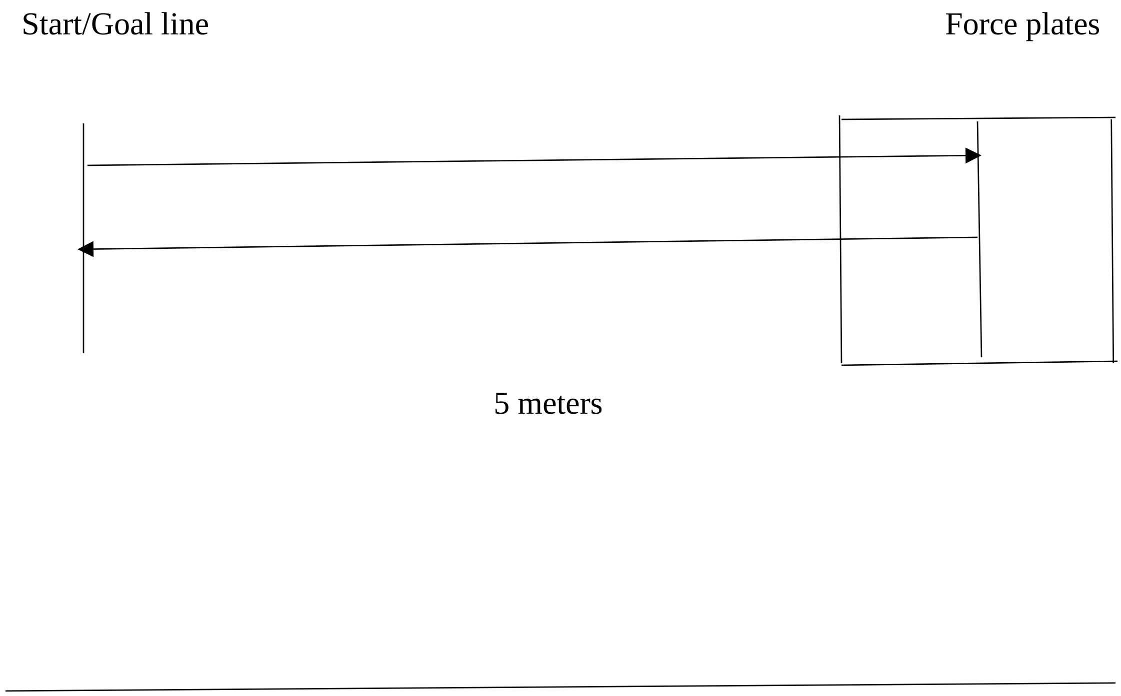


Figure 1. The modified 505 test

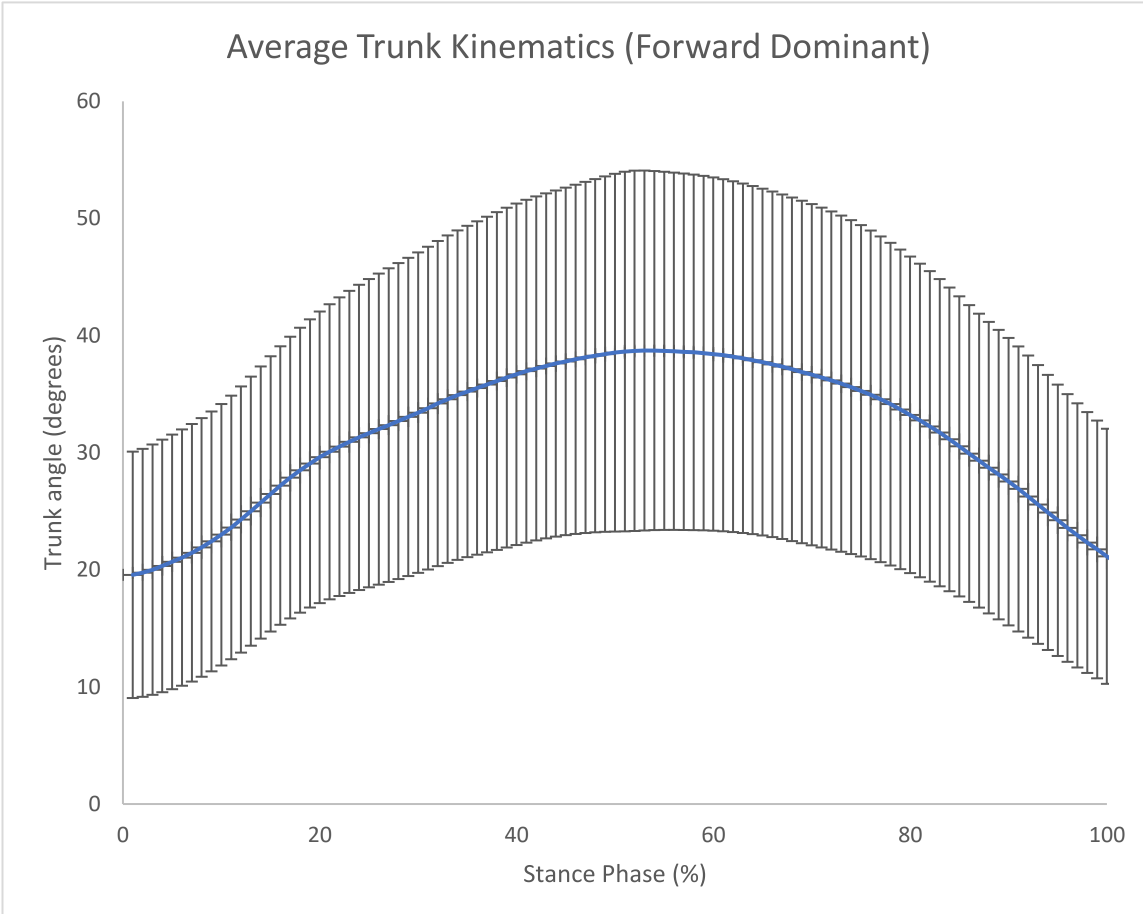


Figure 4. Forward trunk angle for dominant performance

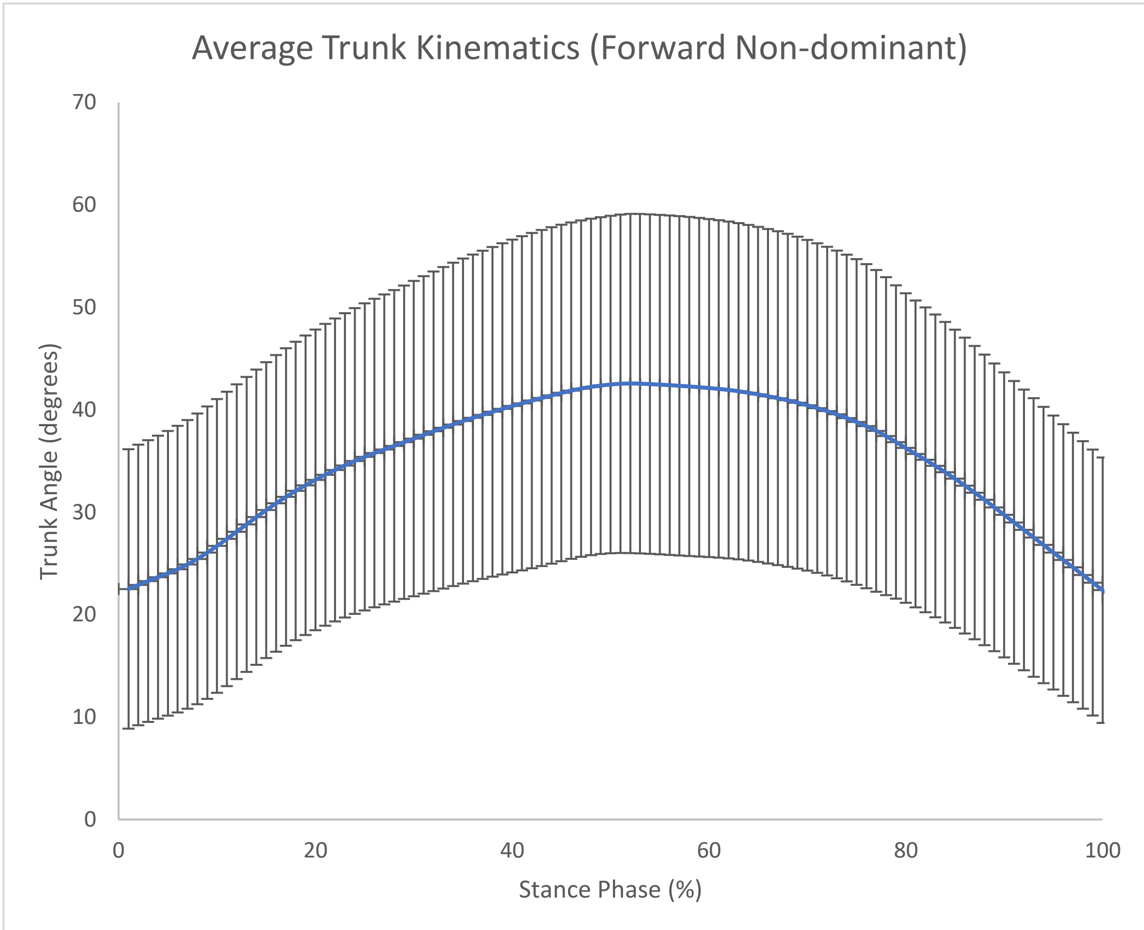


Figure 5. Forward trunk angle for non-dominant performance

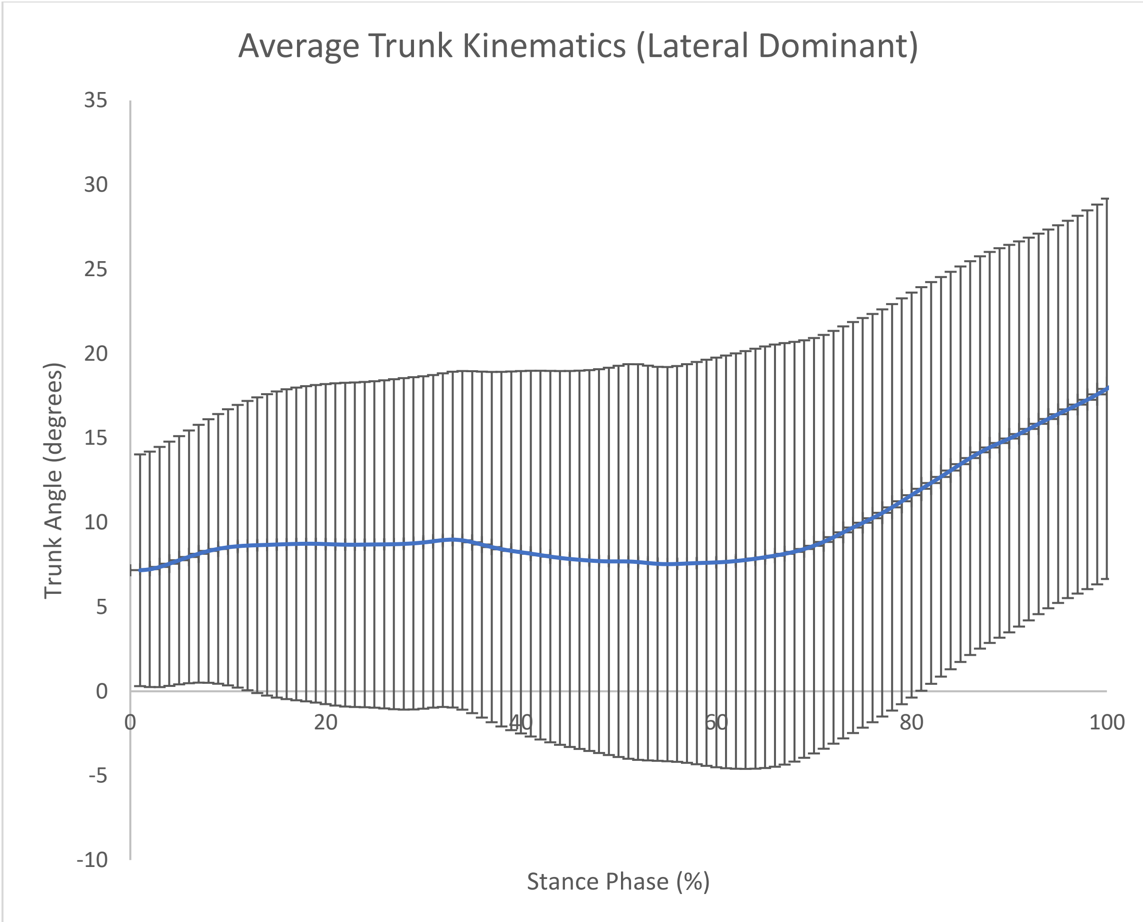


Figure 6. Lateral trunk angle for dominant performance

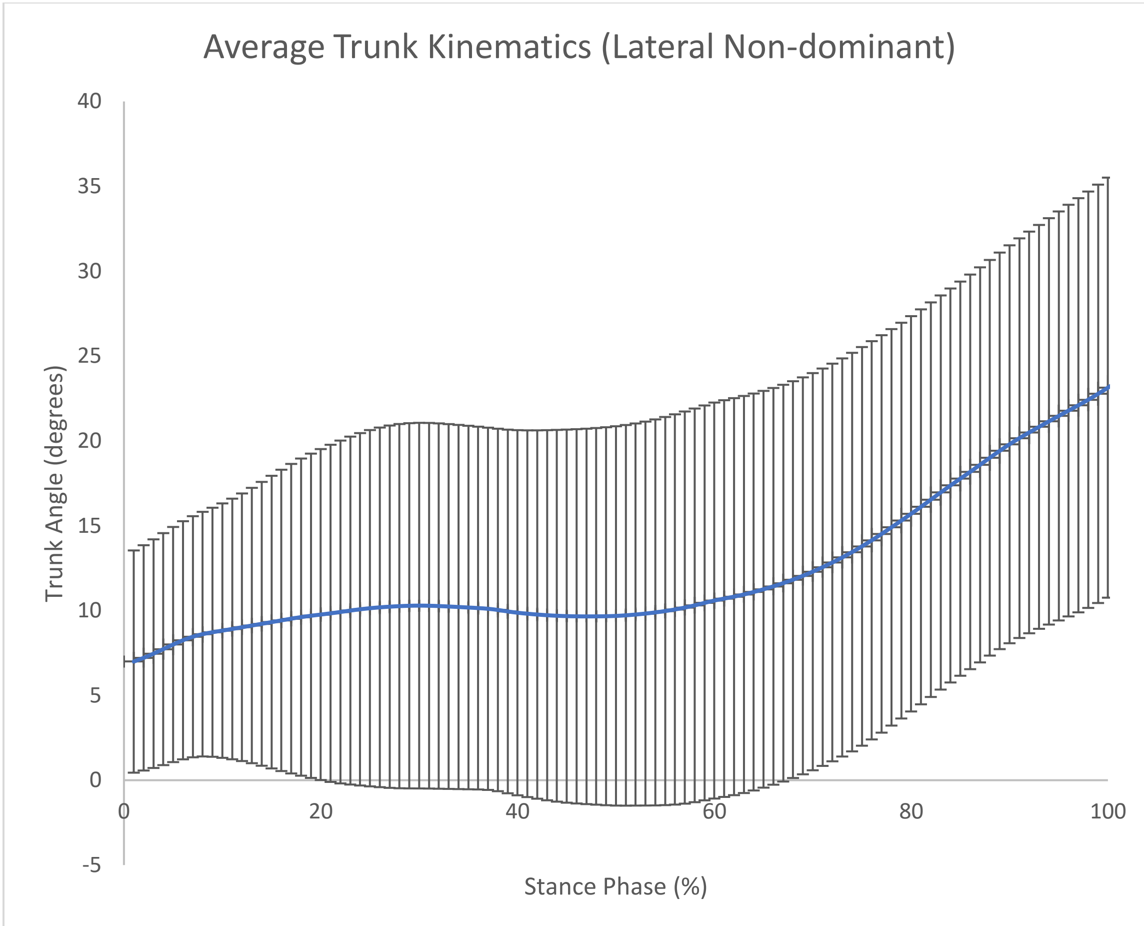


Figure 7. Lateral trunk angle for non-dominant performance