Spring 2013

Kinematic and Spatiotemporal Analysis Between Sprint Drills and Maximal Sprinting

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KINEMATIC AND SPATIOTEMPORAL ANALYSIS BETWEEN SPRINT DRILLS AND MAXIMAL SPRINTING

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A Thesis Submitted to the Thomas More Honors Program

In Partial Fulfillment of the Requirements of the Degree

In

Department of Physical Therapy and Human Movement Science

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Fairfield, CT

Spring 2013

Abstract

Purpose: To determine if any kinematic differences exist between two common sprint drills (A- and B-drills) and maximal sprinting. **Methods**: 12 collegiate sprinters (19.17±1.11 y/o) granted informed consent were filmed performing two 40-meter sprints, A-skips, and B-skips. Three-dimensional motion analysis tracked the coordinates of 24 reflective markers and resulting joint kinematics were computed. **Results**: Statistical analysis revealed that sprinting yielded a significantly lower maximum hip flexion (p=0.015) but a significantly higher minimum ankle angular velocity (p=0.012) and step rate (p=0.000) value than A-drills. When compared to B-drills, sprinting values were significantly lower in maximum hip flexion (p=0.047), minimum knee flexion (p=0.043), and maximum hip angular velocity (p=0.006), but significantly higher in minimum ankle angular velocity (p=0.018) and step rate (p=0.000). Experienced sprinters had a significantly greater maximum plantar-flexion in sprinting (p=0.031) and minimum knee flexion in A-drills (p=0.030) than inexperienced sprinters. Inexperienced sprinters had a significantly greater plantar-flexion in A-drills (p=0.026) and B-drills (p=0.046), B-drill maximum knee flexion (p=0.016), maximum ankle angular velocity (p=0.024), and minimum knee angular velocity (p=0.048) than experienced sprinters. **Conclusion**: Since several kinematic differences exist between two common sprint drills as compared to maximal sprinting, efficacy of their uses is questioned.

Key Words

Key words: A-drill, acceleration, B-drill, drills, kinematics, sprinting, stride length, stride rate.

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Introduction

In the sport of track and field, athletes that compete in running events are considered either sprinters or distance runners. Sprinters, whose events are based on power, differ greatly from more economical distance runners in both physical appearance and running biomechanics[1]. Sprinting is characterized by any event that emphasizes speed and power[1,2]. Modern sprinting events include the short sprints, which range from 60 to 200 meters, and the primary long sprint event of 400 meters. Coaches design individualized training programs to maximize the performance of a track and field athlete in his or her respective event area. Sprint drills are often utilized in the training programs of high level sprinters, which help to develop the biomechanics necessary to maximize sprint speed and power[3,4,5]. In order to understand the purpose of these sprint drills and how to apply them to training, one must be able to identify the characteristics required for biomechanical proficiency in sprinting and assign the drills necessary to improve these qualities during performance.

1.1 Phases of Running

A complete gait cycle in running has four phases: stance one, flight one, stance two, and flight two[6,7]. Stance phase is where the foot is in contact with the ground and the flight phase, also known as swing phase, is where the foot is not in contact with the ground[6,7,8]. The two main phases of running are often further divided into sub-phases. The stance phase can be divided into a braking phase and propulsion phase[6,7,8]. The braking phase begins at initial foot strike and ends during midsupport by the stance leg, which is when the stance leg hip is in a close to neutral angle with the trunk[6,7,8]. The propulsion phase starts at midsupport and ends with toe-off of the stance leg[6,7,8]. As horizontal velocity increases, time spent in stance phase decreases. The average sprinter spends 30% of the gait cycle in stance phase, but elite level sprinters have been observed spending as little as 22% of the gait cycle in stance[6,7].

The swing phase can be divided into three distinct phases: initial swing, midswing, and terminal swing[6,7,8]. Initial swing begins at toe-off and becomes midswing when the hip is close to neutral with the trunk[6,7,8]. Midswing lasts from neutral hip position until the hip reaches peak flexion[6,7,8]. Terminal swing phase begins once the hip transitions from flexion to extension and it ends at initial foot contact to end a single running cycle[6,7,8]. During early initial and terminal swing phase, the contralateral limb is also not in contact with the ground, so these phases are sometimes known as flight one and flight two respectively[6,7,8]. Sprinters spend the majority of the gait cycle in swing phase because spending as little time as possible in contact with the ground helps maximize force development to increase horizontal velocity[6,7,8]. The ranges of motion for the joints of the lower limb generally are much larger in running than in walking.

1.2 Sprint Running Mechanics

Sprinting events are divided into three main phases: acceleration, top speed, and deceleration[2,8]. The acceleration phase is characterized by aggressive, powerful running form used to build the momentum needed to overcome inertia and achieve maximum velocity[1,2,8,9,10]. In acceleration, quickness does not translate to speed. The most efficient sprinters may not take the highest number of steps, but have the longest stride length corresponding to a higher degree of extension in all areas of the body and thus greater force production[2,8,10]. The main focus of an accelerating sprinter is to maximize the amount of extension in order to generate high forces while also maintaining this force for a relatively long time[2,8,10]. The hip, knee, and ankle must perform the fullest range of extension possible during toe off to push aggressively off of the ground to yield a powerful momentum to increase velocity (Figure 1)[1,2,6,9]. This must be balanced with keeping foot contact time to a minimum, decreasing the time between steps as velocity increases[1,2,10]. This prevents the athlete from wasting critical time on the ground during stance phase and more time bringing the swing leg forward into the next stride.

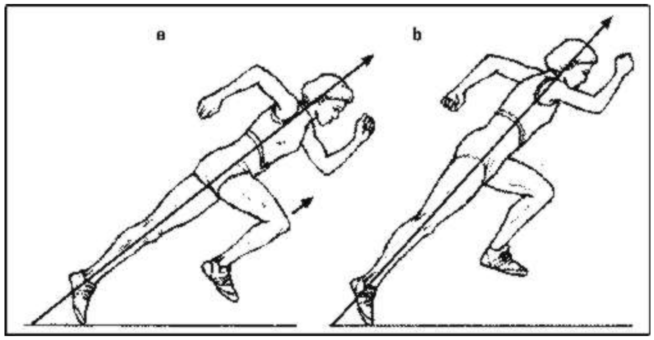

Figure 1. Part A demonstrates the proper biomechanics upon exit from the starting blocks in order to set the sprinter up for a higher top end speed during transition and peak velocity. Part B demonstrates how the athlete should look when transitioning out of acceleration into top end speed after 20-30 meters in elite sprinters.

Once the athlete has transitioned from acceleration, even the most well-trained athlete can only maintain their maximum speed for about two seconds. In order to maximize this top speed later in the race and maintain close to that speed for as long as possible, the athlete must utilize the proper biomechanics in acceleration to ensure that the speed they reach is their actual top speed[1,2,13,14,15]. With an efficient start, the athlete can set up the best timing of that top speed to ensure that he/she does not begin decelerating too early and lose valuable seconds in the shorter sprint events. Longer sprint events are not as dependent on the start, but rather it is necessary to establish a pace that will prevent the athlete from fatiguing too much at the end of the race.

The best way to set up for maximum top speed is to allow the body to naturally unfold from acceleration into transition phase running form[2,7,10,11]. In acceleration, running form is more focused on linear propulsion and requires that the body maintain close to a 45° angle upon block exit[2,7,10,11]. From there, the body is to remain at this angle designed for maximum extension until the body comes up out of the drive on its own, which is after roughly 30 meters in advanced sprinters[2,7,10,11]. Heel recovery, or distance from the ground to the base of the calcaneus, is generally lower during early phase acceleration and increases as the body stands taller as it approaches top speed.

In transition into top speed, running form is more erect and focuses on getting higher hip and knee flexion and having higher heel recovery where the foot clears the knee during swing phase. In elite sprinters, hip flexion is easily 90° and allows for the most range of motion for the leg to drive downwards into extension to create the most powerful ground contact force by reducing braking force[1,2]. The swing leg hip should flex so that the thigh is parallel to the ground, and knee flexion should be large enough to touch the heel to the buttocks[1,2,3]. The leg should cycle over the stance leg knee rather than coming up like a piston in acceleration[1,2,3]. The knee flexes beyond 90° to bring the heel up to the hamstrings, which accentuates hip flexion and reduces the moment of inertia as it progresses through swing phase[1,2]. Knee extension during toe-off in top speed is not maximal, unlike hip and ankle extension, because having a smaller knee angle increases force production and turnover of the swing leg following toe-off[1,2]. Stride length increases as knee flexion increases due to the leg's position further forward relative to the body[1,2]. The ankle remains in dorsiflexion throughout swing phase, allowing the athlete to achieve midfoot strike during ground contact[1,2,3].

Deceleration is the inevitable phase of sprinting where the athlete comes off of top speed and slows down as the race comes to an end. Running form in deceleration is most similar to that of top speed. The athlete's goal at this point in the race is to best maintain the same degree of high hip and knee flexion during swing and full extension during toe-off that allows for high speed and force production[1,2]. Since fatigue is a factor, sprinters competing in the longer sprint events must be trained to keep their form efficient despite feelings of heaviness related to lactic acid buildup[12,13]. Sprinting is highly anaerobic, so during longer duration sprint events, lactic acid resulting from anaerobic glycolysis builds up in skeletal muscles and produces feelings of intense fatigue, discomfort, and potential cramping[12,13]. This makes maintaining good form difficult for some athletes and can greatly increase their rate of deceleration. The fastest sprinters are not necessarily the fastest at top speed, but are simply better at holding off deceleration until the last possible moments of the race or can fight through the discomfort of muscle fatigue[2,3,12,13].

1.3 Anatomical Characteristics of Sprinters

From a biomechanical perspective, sprinters are built to generate large forces and high velocities. Anatomically, sprinters achieve this due to the comparatively high percentage of anaerobic type IIb fast twitch muscle fibers compared to endurance athletes and increased hypertrophy of the leg muscles[1,6,12]. Type IIb muscle fibers have fewer mitochondria, the organelle responsible for ATP production, and thus are not resistant to fatigue[6,12]. However, these muscle fibers are very large and when properly trained, can generate large forces necessary for speed and power development[6,12]. As a result, sprinters often have larger leg muscles than endurance athletes[6,12,14,15]. Recent research of animals built for speed as compared to human sprinters shows signs of anatomical differences extending beyond muscle fiber composition that could explain why some individuals are better sprinters than others[14]. Muscles with large moment arms increase the mechanical advantage of the joints they act on[6,14,15]. As mechanical advantage increases, greater torques (rotational forces) can be generated about the joint axis and increase the athlete's capacity to accelerate[6,14,15].

In order to maximize power output, sprinters must train their bodies to apply large amounts of force onto the ground while at the same time getting full extension of the entire lower limb. Without this full extension of the ankle, knee, hip, and spine during toe-off, force application is insufficient and thus will compromise impulse and forward velocity[9,10,15]. Triple extension of the entire lower kinetic chain requires coordinated eccentric contraction of the hamstring and calf muscles and concentric contraction of the quadriceps immediately following foot strike so that the sprinter can utilize as much power as possible[2,6,9,10]. This power development is largely due to quick turnover of the lower limb following foot strike, where the foot spends a very short amount of time on the ground in order to maximize the benefits of the stretch-shorten cycle (SSC)[2,9,12]. SSC is when a quick eccentric muscle contraction precedes a concentric muscle contraction in order to create a more forceful concentric movement[6,12]. During foot strike, the knee flexes slightly to cushion the impact of body weight on the lower limb, which causes the extensor muscles to eccentrically contract[6,9,10,12]. The subsequent concentric contraction needed to cause triple extension of the lower limb is thus more forceful due to the activation of the stretch reflex by the Golgi tendon organ and greater motor unit recruitment following the eccentric contraction[6,12].

1.4 Stride Rate and Stride Length

The two parameters necessary for optimizing running performance at any speed are stride length (SL) and stride rate (SR). A stride is the interval from one event on one limb to the same event on the same limb[6,16,17]. A step is the interval from one event on one limb to the same event on the contralateral limb[6,16,17]. In the case of running, a stride is normally defined as two consecutive foot strikes on the same foot[6,16,17]. SL is the measured value of that interval between ipsilateral foot contacts and SR is the number of strides in a minute[6,16,17]. The relationship between SR and SL directly influence running speed in a directly proportional fashion. This relationship is defined as:

Running speed = stride length x stride rate

Running velocity can be increased by increasing SL, SR, or both[6,16,17]. At higher speeds, SL can only increase so much due to anatomical limitations, but SR can continue to increase as the athlete learns to run more efficiently and makes greater gains in strength, power, and flexibilty[6].

There is much debate as to whether sprinters derive more benefits from an increased SL or SR. In a comprehensive study, Hunter et al. used 3D motion analysis to investigate whether an increase in SL or SR would produce higher running velocities[16]. As a group, SL was more related to running velocity than SR, but on an individual basis SR had a greater influence on velocity[16,17]. It was reported that there is a negative interaction between SL and SR, which may be the result of leg length, height of takeoff, and vertical velocity of takeoff during the flight phase of sprinting[16]. Athletes with longer limbs tended to have more difficulty increasing SR due to the increased moment of inertia of a longer limb[16]. According to this study, in order to maximize SL and SR, sprinters must have a high horizontal and low vertical velocity upon takeoff and have a long SL with a very high rate of turnover[16,17].

Salo et al. expanded upon this study to determine if elite level sprinters are more dependent on SL or SR[17]. The performances of each athlete were compared on an individual basis to discern whether each athlete was more SL or SR reliant, rather than a global comparison[17]. The results of this study indicated that elite level sprinters appear to have a balance between SL and SR that allow them to attain very fast velocities[17]. These results indicate that, based on the characteristics of the world's fastest sprinters, athletes must maximize their anatomical potential for SL while also training to improve overall SR in order to achieve elite status and have their most efficient performances[16,17].

1.5 Sprint Drills

Coaches commonly prescribe speed drills in order to help athletes practice sound sprint running mechanics. Sprint drills can be executed while walking, skipping, or running. The main goals behind these drills are to improve (1) coordination & technique, (2) leg power & acceleration, and (3) sprint endurance[3,4,5]. The specific traits of a good speed drill include staying on the balls of the feet, quickly bringing the heel up to the buttocks during leg recovery, driving the knee parallel to the ground by achieving high hip flexion, driving the arms forcefully, and leaning the trunk slightly forward[3,5].

One category of speed drill is the A-drill, which includes the A-march, the A-skip, and the A-run (Figure 2). It is commonly described as a rapid high knee march[3,5]. The idea behind the drill is to imitate the motion of sprinting in a more controlled setting and train the athlete to apply more force to the ground during foot strike through full extension. These drills are all divided into three main phases: support, driving, and recovery[3]. During the support phase, the stance leg should fully plantar flex the ankle during toe-off which also allows the hip and knee to fully extend. The driving phase emphasizes flexion at the hip to raise the thigh horizontal, while also reaching terminal knee flexion and bringing the dorsiflexed foot upwards to the buttocks[3,5]. At the same time as the driving phase, the support leg experiences a small aerial phase as it skips[3,5]. As the leg comes down to strike the ground during the recovery phase, the athlete has to fully and powerfully extend the hip and knee while bringing the swing leg directly back under the hips behind the body's center of mass[3].

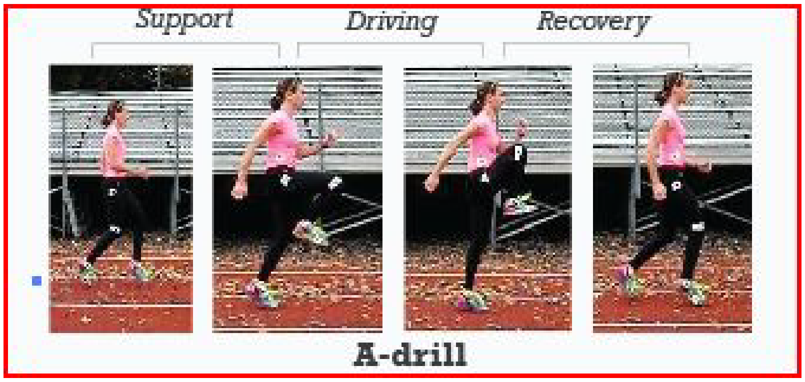

Figure 2. A sagittal plane phase analysis of A-drills.

B-drills, which also follow the march, skip, and run progression, are similar to the A-drills (Figure 3). There are the same three phases as found in the A-drills, but with a few major differences. During the driving phase, the thigh is still brought up horizontally through hip and terminal knee flexion. However, rather than extending the hip followed by the knee before driving the foot into the ground, the knee extends rapidly right before hip extension begins[3,5]. The foot moves in a more circular motion than the piston style movement of the A-drill, resulting in the foot striking slightly ahead of the body's center of mass[3]. During support phase, the body must be pulled ahead of the support leg[3]. If done correctly, the athlete should feel as though he/she is prancing. In both types of drills, the upper body must also be a focus so as to train the athlete to drive the arms aggressively to match the stride pattern, but remain controlled by keeping the elbow flexed at 90° and motion at the shoulders staying loose and fluid[3].

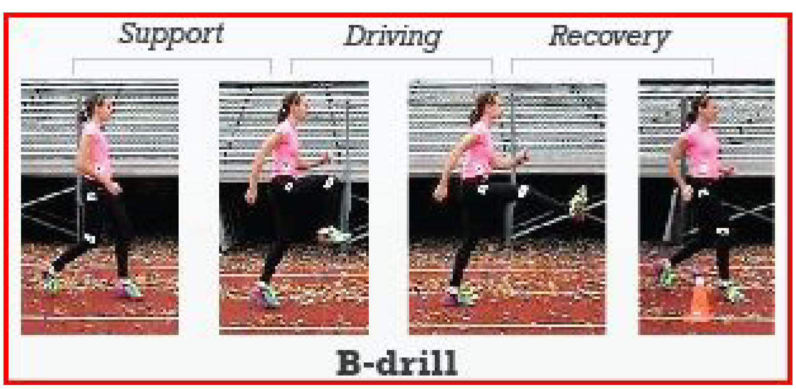

Figure 3. A sagittal plane phase analysis of B-drills.

Sprint drills like these are often incorporated into sprint training programs to help teach athletes key motions of efficient sprint form. While they are a common characteristic of many sprinting programs, there is limited research examining these drills and how they actually influence and reflect actual sprint biomechanics. One study by Kivi & Alexander found that there were two key differences between sprinting and sprint drills: angular velocity and joint range of motion[3]. Angular velocities in all measured joints decreased during execution of the drills as compared to sprinting[3]. Hip flexion, knee flexion/extension, and elbow flexion/extension all increased during the drills, but shoulder flexion/extension, ankle plantar flexion/dorsiflexion, and pelvic rotation all decreased as compared to sprinting[3]. Vertical displacement, vertical velocity, and time spent in stance and swing phase were also decreased in both sprint drills when compared to sprinting[3]. The researchers noted that there are enough differences in the kinematic variables and timing of events in the stride cycle between A- and B-drills and maximal sprinting to question their merit as a sprint biomechanics training drill[3].

There is debate in the literature regarding the use of A- and B-drills as a sprint mechanics drill or as a part of a dynamic warm-up. It is understood that these sprint drills mimic the basic characteristics of proper sprint biomechanics[3,4,5]. As a result, many coaches choose to have athletes perform these drills on days where sprint technique is the focus[3,4,5]. However, it is the coach's discretion on how the drills should be performed. Some feel that having the drills be shorter distance and a part of the warm-up is best, while others feel that they are better for use as part of the actual workout as a sprint mechanics drill[3,5]. The most notable difference between the most common A- and B-drills, the A- and B-drill, and maximal sprinting is the addition of another small aerial phase between each step. This third aerial phase takes place between what in sprinting is known as stance phase two and flight phase two.

Kivi & Alexander interviewed a number of sprint coaches in the United States and Canada for their rationale behind the use of A- and B-drills[3]. Responses varied between coaches, with some reasons including to develop sprint mechanics, to improve muscle strength and endurance by designing workouts based on the drills, to increase joint stability and muscle force production, and to refine neuromuscular pathways to improve sequencing of muscle contractions[3]. Coaches also differ regarding how the drills should be performed[3]. Some coaches felt that athletes should not exceed five meters, while others ask their athletes to complete repeated cycles of the drill as they would complete interval running workouts[3]. More recently, Triplett et al. suggested that A- and B-drills appear as a running mechanics drill after a dynamic warm-up but before the athlete's track workout[4]. The findings of the present study could provide some guidance for coaches regarding the utilization of A- and B-drills in their sprint training program as a means to develop proper sprint biomechanics.

1.6 Conclusion

The purpose of this study was to investigate any kinematic relationship between a proficiency in sprint drills and sprint performance. There were two hypotheses within the present study. The first was that both type of sprint drill would have kinematic differences from sprinting that would impact their efficacy as sprint biomechanics training tools. The second, relating to level of experience, was that sprinters that have more years of experience would be more proficient in both sprint drills and sprinting than their less experienced counterparts. This hypothesis does not support the coaching philosophy that A- and B-drills are acceptable sprint mechanics drills rather than simply a component of the dynamic warm-up. There is little previous data in the literature on the correlation between sprint drills and actual improvements in sprint performance. While anecdotal evidence among coaches exists regarding opinions about the use of sprint drills, the kinematic relationship they share with sprinting has not been researched in depth. The data obtained in this study could be used by coaches to aid in the creation of effective sprint training programs through the utilization of the proper sprint drills for biomechanical development.

Methods

In this study, seven male (19.38±1.13 yo) and five female (18.60±0.98 yo) athletes from the Sacred Heart University division I track and field program volunteered (see Table 1). Each athlete had at least four years (5.42±1.08 yrs) of experience in track and field as a sprinter and was capable of performing both A- and B-drills. Eight of the subjects were classified as long sprinters and four were classified as short sprinters. Five of the subjects were considered inexperienced (junior varsity or under four years experience) and seven were considered experienced (at least five years of varsity experience). The males (11.33±0.58 s) and females (13.08±0.16 s) were asked to provide their lifetime 100 meter personal best. An informed consent form and health history form were provided to each subject on the day of testing to assess whether they were healthy enough on the day of testing to participate. In order to participate, subjects could not have any current injuries that prevented them from practicing and had to be properly hydrated according to ACSM standards[18]. The current ACSM position stand on hydration recommends drinking 5-7 milliliters of water per kilogram of body weight at least four hours prior to exercise[18].

Testing Protocol

All testing was done on September 22, 2012 during the pre-season phase of the track and field macrocycle at the William H. Pitt Center at the Sacred Heart University campus. One hour time slots were assigned to each subject. Upon arrival, the subjects were measured for height, weight, and leg length before beginning a predetermined dynamic warm-up based on their warm-up provided by the Sacred Heart University track and field program (Table 2). Following the dynamic warm-up, 24 reflective markers (Table 3) were placed on the subject using adhesive wig tape. The subject was allowed to stride up to three times on the runway to get acclimated to the markers. Each subject was asked to perform two 40-meter sprints, two A-skips, and two B-skips. The sprint trials were performed from a standing start at the start of the runway and the drill trials were performed in a 15-meter space beginning at camera one. One trial of each drill would be at a self-selected pace while the other would be at a cadence. The cadence trials were not used for statistical analysis due to an inability of the subjects to perform either drill at the set cadence. The trials were performed in a random order established by the testing staff prior to the subjects' arrival.

Data Collection and Analysis

Nine Qualysis 3D motion capture OQUS 100 cameras (manufacturer; Sweden) were used to capture each movement. The infrared cameras recorded the location of 24 reflective markers placed on specific bony landmarks on the right side of the body. The cameras were set at a frame rate of 240 Hertz (Hz) and the volume of interest was calibrated within 1.03±0.59 mm. Tripods for each camera were placed 2.66±1.39 m from the 40-meter long runway to create a visual field at the end of the runway of 10 m in which to capture movement. Each trial was filmed for ten seconds and saved to Qualysis Track Manager software (QTM) for later analysis. 2D video was captured using a 75 Hz webcam connected to QTM software.

Event marker labels were established using visual analysis of both two and three dimensional video collected by the three dimensional Qualysis cameras and a webcam. Velocity data for the base of the fifth metatarsal body marker was compared to the visual data for a more accurate determination of the actual event marker. The events within the stride cycle of the sprint trials that were labeled were the first right foot strike (RFS), left foot toe-off (LFO), left foot strike (LFS), right foot toe-off (RFO), and the second RFS. The events labeled for the stride cycle of each drill were the same as the sprint trials. For the drill trials, it was indicated on the footstrike (FS) event markers whether there was single leg stance (SLS) or double foot stance (DFS).

The velocity data was characterized by large and small peaks, which represented right leg swing and right leg skipping respectively, and valleys, which represented right foot contact times during left leg swing and skipping. Using the velocity curve, RFS occurred when the first spike along the curve appeared during deceleration of right leg swing peaks (Figure 4). RFO occurred at the end of the small plateau in the upward acceleration of right leg swing. LFS and LFO were determined using primarily visual analysis of 2D video, but the trend between subjects indicated that the point of deceleration in the middle of right foot contact time during left leg swing phase was the best marker of LFO and the turning point from acceleration to deceleration of right foot contact during left foot skipping was the best marker of LFS.

For the purposes of this thesis, the following joint angles were analyzed based on the normative angles determined by each subject's anatomical position: ankle dorsiflexion and plantar flexion, knee flexion and extension, and hip flexion and extension. All joint positions at the maximum and minimum points along the range of motion (ROM) angle graphs were noted. Joint angular velocities were determined at the point along the joint angle plots when the slope was steepest between the maximum and minimum joint angle values. Differences in step rate (in steps/minute) were also analyzed. Step rate was calculated using the following equation:

Number of frames per stride x (1/ 240 Hz) = strides in 1 second

Inverse of strides in 1 second = strides/second

Strides/second x 2 = steps per second

All of these measurements were compared between the sprints and drills to determine if there were any notable similarities between one or both of the sprint drills and sprinting itself.

A repeated measures ANOVA was used to compare the kinematic and spatiotemporal values of sprinting, A-drills, and B-drills. For comparison of experienced and inexperienced sprinters in each trial type, independent t-tests were used.

Results

All 12 subjects were used for the spatiotemporal analysis, but for the purposes of kinematic analysis only data from five subjects was used. Subjects 5, 7, 10, 11, and 12 were chosen for the kinematic analysis because they had the most complete marker sets and completed a full right foot strike stride cycle within the area captured by the 3D cameras. The remaining seven subjects were not used because of markers lost during collection. All comparisons were made between the most complete sprint trial and self-selected A-drill and B-drill trials. The mean range of motion (ROM) and angular velocity values were taken for the five subjects in the kinematic analysis (Tables 4-7). The same five subjects used for kinematic analysis were used for the comparison of experienced ($n = 4$) and inexperienced ($n = 1$) sprinters. All 12 subjects were used for the spatiotemporal analysis of experienced ($n = 7$) and inexperienced ($n = 5$) sprinters (Table 8).

Hip Kinematics

There was a significant difference in maximum hip flexion between all three trial types [$F(2,8) = 18.0$, $p = 0.001$]. Maximum hip flexion was significantly greater in A-drills (77.4±4.5°; $p = 0.015$) and B-drills (78.0±5.2°; $p = 0.047$) when compared to maximal sprinting (58.0±9.8°) (Figure 5). There was no significant difference between the two sprint drills ($p > 0.05$). Values for maximum hip extension were significantly different between the three trial types as well [$F(2,8) = 5.4$, $p = 0.033$] (Figure 6). When compared amongst each trial condition, maximum hip extension in sprinting (-3.6±2.3°) was slightly higher, but not significantly higher, than A-drills (-3.801±2.500°; $p > 0.05$) or B-drills (-3.851±2.510°; $p > 0.05$).

There is also a significant difference between peak maximum hip flexion angular velocity values [$F(2,8) =14.181$, $p = 0.02$] (Figure 7). In sprinting, maximum hip flexion angular velocity (754.9±111.1 deg·s^{-1}) was much faster than A-drills (487.1±152.8 deg·s^{-1}; $p > 0.05$) and B-drills (463.7±100.1 deg·s^{-1}; $p = 0.006$). There was no significant difference between maximum hip extension angular velocity values in the three conditions [$F(2,8) = 0.2$, $p > 0.05$]. Hip extension angular velocity was fastest in B-drills (-567.7±124.0 deg·s^{-1}), which more closely matched sprinting (-576.9±72.4 deg·s^{-1}; $p > 0.05$) than A-drills (-643.4±311.2 deg·s^{-1}; $p > 0.05$) (Figure 8).

In the comparison of experienced and inexperienced sprinters, maximum hip flexion and extension was higher in the experienced sprinters than the inexperienced sprinter (Figure 9). During maximal sprinting, peak maximum hip flexion [$t(3) = -2.5$, $p > 0.05$] was larger in experienced sprinters (61.6±6.5°) compared to inexperienced sprinters (43.663°). Maximum hip extension [$t(3) = 1.9$, $p > 0.05$] was also larger in experienced (-4.3±1.8°) versus inexperienced (-0.480°) in sprinting (Figure 10). In A-drills, values for maximum hip flexion [$t(3) = -1.1$, $p >$

0.05] was higher in the experienced (78.5±4.4°) than inexperienced (73.215°). Likewise, maximum hip extension [t(3) = 1.8, p > 0.05] was lower in the experienced sprinters (-4.6±2.0°) than the inexperienced sprinter (-0.6°). B-drills were the only trial type that provided a different result. Maximum hip flexion [t(3) = 1.0, p > 0.05] in B-drills was higher in the inexperienced sprinter (82.6°) than the experienced sprinters (76.8±5.2°). Maximum hip extension [t(3) = 1.8, p > 0.05] was lower in the experienced sprinters (-4.7±2.0°) than the inexperienced (-0.6°).

The speed of movement at the hip also differed between the different levels of experience. Maximum hip flexion angular velocity during sprinting [t(3) = -1.5, p > 0.05] was faster in the experienced sprinters (787.1±97.5 deg·s^{-1}) compared to the inexperienced (625.9 deg·s^{-1}) (Figure 11). In contrast, maximum hip extension angular velocity [t(3) = 1.2, p > 0.05] was slower in the experienced (-595.2±68.9 deg·s^{-1}) versus the inexperienced (-503.5 deg·s^{-1}). In A-drills, maximum hip flexion angular velocity [t(3) = -0.5, p > 0.05] was faster in experienced sprinters (505.6±169.8 deg·s^{-1}) compared to inexperienced (412.9 deg·s^{-1}). Minimum hip flexion angular velocity [t(3) = 0.6, p > 0.05] was not a significantly lower value in the experienced (-690.0±338.7 deg·s^{-1}) versus the inexperienced (-457.4 deg·s^{-1}) (Figure 12). Maximum hip angular velocity [t(3) = -0.1, p > 0.05] in B-drills was not significantly faster in experienced (466.5±115.4 deg·s^{-1}) than inexperienced (452.5 deg·s^{-1}). Likewise, minimum hip flexion angular velocity [t(3) = -0.2, p > 0.05] was higher in the experienced group (-561.4±142.3 deg·s^{-1}) than the inexperienced (-592.8 deg·s^{-1}).

Knee Kinematics

Peak knee flexion values were not significantly different between the three trial types [F(2,8) = 1.2, p > 0.05]. Specifically, peak knee flexion was greatest in sprinting (107.3±12.5°) when compared to B-drills (102.1±13.5°; p > 0.05) and A-drills (98.4±10.°; p > 0.05) (Figure

13). Knee extension values were significantly different between the trial types, however [$F(2,8) = 5.0$, $p = 0.040$]. Knee extension, also known as minimum knee flexion, was positive in sprinting (3.3±5.6°), but negative in A-drills (-5.5±11.0°; $p > 0.05$) and B-drills (-7.6±6.1°; $p = 0.043$) (Figure 14).

Maximum knee flexion angular velocity values were not significantly different between the trial types [$F(2,8) = 0.2$, $p > 0.05$]. Values were most similar between sprinting (961.6±206.5 $deg \cdot s^{-1}$) and A-drills (995.1±554.1 $deg \cdot s^{-1}$; $p > 0.05$). This angular velocity in sprinting was much greater than in B-drills, but was not significantly different (850.0±231.6 $deg \cdot s^{-1}$; $p > 0.05$) (Figure 15). There were also no significant differences in knee extension angular velocity between the three conditions [$F(2,8) = 0.4$, $p > 0.05$]. Minimum knee flexion angular velocity was fastest in B-drills (-833.9±87.9 $deg \cdot s^{-1}$) and was not significantly different than either sprinting (-1085.7±205.0 $deg \cdot s^{-1}$; $p > 0.05$) or A-drills (-1147.9±952.5 $deg \cdot s^{-1}$; $p > 0.05$) (Figure 16).

Knee ROM and angular velocity values compared between experienced and inexperienced sprinters provided interesting results. In maximal sprinting, values for maximum knee flexion [$t(3) = 1.2$, $p > 0.05$] were higher in the inexperienced sprinter (119.9°) compared to the mean experienced group (104.2±11.9°) (Figure 17). Maximum knee extension [$t(3) = 0.0$, $p > 0.05$] was slightly higher in the inexperienced (3.5°) than the experienced (3.2±6.4°) (Figure 18). A-drill values for maximum knee flexion [$t(3) = 2.1$, $p > 0.05$] were higher in the inexperienced sprinter (112.1°) versus the experienced sprinters (94.9±7.5°). Maximum knee extension values [$t(3) = 3.9$, $p = 0.030$] were significantly lower in experienced (-10.0±5.2°) versus inexperienced (12.4°) sprinters in A-drills. In B-drills, maximum knee flexion [$t(3) = 4.9$, $p = 0.016$] was significantly higher in inexperienced sprinters (124.954°) than experienced

(96.4±5.2°), but maximum knee extension [$t(3) = 1.1$, $p > 0.05$] was not significant despite inexperienced sprinters (-1.8°) yielding higher values than experienced (-9.0±6.0°).

In sprinting, maximum knee flexion angular velocity [$t(3) = 0.2$, $p > 0.05$] was higher in the inexperienced (999.1 $deg \cdot s^{-1}$) than the experienced sprinters (952.2±237.2 $deg \cdot s^{-1}$) (Figure 19). Minimum knee flexion angular velocity [$t(3) = 0.2$, $p > 0.05$] was also faster in the inexperienced (-1052.3 $deg \cdot s^{-1}$) versus the experienced (-1094.0±235.7 $deg \cdot s^{-1}$). A-drill maximum knee flexion angular velocity [$t(3) = -0.7$, $p > 0.05$] is faster in the experienced (1086.8±594.3 $deg \cdot s^{-1}$) versus the inexperienced sprinters (627.9 $deg \cdot s^{-1}$). Minimum knee flexion angular velocity [$t(3) = 0.7$, $p > 0.05$] was faster, but not significantly so, in the inexperienced (-501.0 $deg \cdot s^{-1}$) versus the experienced (-1309.6±1017.5 $deg \cdot s^{-1}$) (Figure 20). B-drill maximum knee flexion angular velocity [$t(3) = 0.3$, $p > 0.05$] was faster in the inexperienced (927.2 $deg \cdot s^{-1}$) sprinter than the experienced (830.7±262.7 $deg \cdot s^{-1}$) group. In contrast, minimum knee flexion angular velocity [$t(3) = -3.2$, $p = 0.048$] was significantly faster in the experienced (-799.3±47.9 $deg \cdot s^{-1}$) compared to inexperienced sprinters (-972.6 $deg \cdot s^{-1}$).

Ankle Kinematics

There was not a significant difference in mean ankle dorsiflexion values between the three conditions [$F(2,8) = 0.3$, $p > 0.05$]. Ankle dorsiflexion was reduced in sprinting (12.7±6.4°), but there was no significant difference when compared to A-drills (18.8±28.7°; $p > 0.05$) and B-drills (19.9±31.5°; $p > 0.05$) (Figure 21). There was also not a significant difference in mean plantar-flexion values [$F(2,8) = 0.6$, $p > 0.05$]. The mean plantar flexion values during sprinting (-45.8±8.5°), A-drills (-36.3±14.6°), and B-drills (-42.0±17.9°) were very similar (Figure 22). No significant differences were noted between any trial conditions ($p > 0.05$).

The values for mean maximum ankle dorsiflexion were not significantly different between the three trial types [F(2,8) = 0.4, p > 0.05]. Dorsiflexion angular velocity was highest in B-drills (1528.3±775.9 deg·s^{-1}), but had no significant differences when compared to sprinting (1278.4±368.5 deg·s^{-1}; p > 0.05) and A-drills (1262.8±231.8 deg·s^{-1}; p > 0.05) (Figure 23). However, there was a significant difference between the three conditions for mean maximum ankle plantar-flexion angular velocity [F(2,8) = 20.8, p = 0.001]. Plantar flexion angular velocity values in sprinting (-1326.8±201.9 deg·s^{-1}) were much higher than in A-drills (-642.1±336.2 deg·s^{-1}; p = 0.012) and B-drills (-707.9±186.7 deg·s^{-1}; p = 0.018) (Figure 24). There was no significant difference between A-drills and B-drills (p > 0.05).

Maximum ankle dorsiflexion [t(3) = 0.4, p > 0.05] in maximal sprinting was higher in the inexperienced sprinter (15.2°) compared to the experienced sprinters (12.0±7.2°) (Figure 25). Maximum plantar flexion values [t(3) = 3.8, p = 0.031] were significantly higher in maximal sprinting in inexperienced (-32.0°) compared to experienced (-49.3±4.0°) sprinters. During A-drill trials, maximum dorsiflexion [t(3) = -0.7, p > 0.05] was higher in the experienced sprinters (23.8±30.3°) versus the inexperienced sprinter (-1.3°). Maximum plantar flexion [t(3) = -4.1, p = 0.026] was significantly higher in the inexperienced (-60.3°) than the experienced (-30.3±6.6°) (Figure 26). In B-drills, maximum dorsiflexion [t(3) = -0.9, p > 0.05] was higher in the experienced sprinters (26.2±32.6°) compared to the inexperienced (-5.1°). Maximum plantar flexion [t(3) = -3.3, p = 0.046] was significantly lower in the experienced (-34.9±9.6°) compared to the inexperienced (-70.3°) sprinters.

In maximal sprinting, both maximum ankle dorsiflexion angular velocity [t(3) = -0.9, p > 0.05] and maximum ankle plantar flexion angular velocity [t(3) = 0.6, p > 0.05] had no significant differences (Figures 27 and 28). Maximal ankle dorsiflexion angular velocity was faster in the experienced (1357.0±374.0 deg·s^{-1}) than the inexperienced (964.0 deg·s^{-1}). The opposite was true for maximum plantar flexion angular velocity, where the inexperienced (-1238.1 deg·s^{-1}) was faster than the experienced sprinters (-1393.9±218.7 deg·s^{-1}). Neither maximum dorsiflexion [t(3) = 0.5, p > 0.05] nor maximum plantar flexion [t(3) = 1.8, p > 0.05] ankle angular velocity values were significantly different in A-drills. The inexperienced sprinter (1385.5 deg·s^{-1}) had a faster maximum dorsiflexion angular velocity than the experienced sprinters (1232.2±255.7 deg·s^{-1}). Maximum plantar flexion angular velocity was higher in the inexperienced (-212.0 deg·s^{-1}) than the experienced (-749.6±271.3 deg·s^{-1}). In B-drills, maximum ankle dorsiflexion angular velocity values [t(3) = 4.3, p = 0.024] were significantly different while maximum ankle plantar flexion angular velocity values [t(3) = 1.7, p > 0.05] were not. Maximum dorsiflexion and plantar flexion angular velocities were highest in the inexperienced (2814.2 deg·s^{-1} and -476.1 deg·s^{-1} respectively) compared to the experienced (1206.9±337.2 deg·s^{-1} and -765.8±155.2 deg·s^{-1} respectively).

Step Rate

There was a significant difference between step rate in all three trial conditions [F(1.055, 11.609) = 777.037, p = 0.000]. The mean step rate values for sprinting (253.9±23.2 steps·min^{-1}) were higher than the values for A-drills (94.8±6.9 steps·min^{-1}; p = 0.000) and B-drills (92.1±7.7 steps·min^{-1}; p = 0.000) (Figure 29). There was no significant difference between A-drills and B-drills (p > 0.05). Mean step rate for each sprint drill type was found by averaging the self-selected trial with the cadence trial. In comparing experienced and inexperienced sprinters, there was not a significant difference in step rate during the sprint trials [t(10) = -0.2, p > 0.05], A-drill trials [t(10) = 0.2, p > 0.05], or B-drill trials [t(10) = -0.4, p > 0.05]. In maximal sprinting, the experienced sprinters had a higher average step rate (255.1±28.7 steps·min^{-1}) than the inexperienced sprinters (252.7±18.9 steps·min^{-1}) (Figure 30). A-drills were slightly faster in the inexperienced (95.2±6.9 steps·min^{-1}) than the experienced (94.3±7.5 steps·min^{-1}) sprinters (Figure 31). The experienced sprinters (93.0±9.9 steps·min^{-1}) were able to perform faster B-drills than the inexperienced sprinters (91.2±5.6 steps·min^{-1}) (Figure 32).

Discussion

The primary objective of this study was to determine whether coaches should use A- and B-drills as a sprint mechanics training tool or as a component of a dynamic warm-up. The original hypotheses of the present study were that (1) both type of sprint drills would have significant differences in lower extremity joint (ankle, knee, hip) angular ROM and joint angular velocities as compared to maximal sprinting, and that (2) more experienced sprinters would significant increases in joint angular ROM and joint angular velocities during both sprint drills and maximal sprinting. The primary goal of sprint drills is to encourage improvements in one or more of the following characteristics of sprint biomechanics: (1) coordination & technique, (2) leg power & acceleration, and (3) sprint endurance[3,4,5]. In order to be an effective sprint drill, A- and B-drills would need to aid in the development of efficient sprint biomechanics, primarily sprint coordination and technique.

Kivi & Alexander investigated the kinematic differences between A- and B-drills and maximal sprinting using 2-dimensional video analysis[3]. The researchers noted significant differences between A- and B-drills and maximal sprinting similar to those seen in the present study. At the hip, mean hip flexion ROM values for A- and B-drills (83° and 82° respectively) were significantly higher than maximal sprinting (57°)[3]. In the present study, hip flexion ROM was also significantly higher in A- and B-drills (77.4±4.5° and 78.0±5.2° respectively) than maximal sprinting (58.0±9.8°).

At the knee, both Kivi & Alexander and the present study found no significant differences in knee flexion ROM values between A- and B-drills and maximal sprinting[3]. Values found by Kivi & Alexander were greater than those found in the present study, with peak flexion values in sprinting (122° and 107.3±12.5° respectively) being the highest, followed by B-drills (125° and 102.1±13.5° respectively), and lastly A-drills (114° and 98.4±10.0° respectively)[3].

Ankle ROM values observed by Kivi & Alexander were significantly different between all three conditions, with sprinting yielding the highest value (49°), followed by B-drills (37°), and finally A-drills (27°)[3]. In contrast, there were no significant differences between the three conditions in the present study. This may be a result of the decision to compare maximum mean dorsiflexion and plantar flexion values rather than the difference in peak maximum and minimum ankle ROM as Kivi & Alexander did[3]. Peak dorsiflexion values in the present study were lowest in maximal sprinting (12.7±6.4°) when compared to A-drills (18.8±28.7°) and B-drills (19.912±31.506°). Peak plantar flexion values in sprinting (-45.8±8.5°), A-drills (-36.3±14.6°), and B-drills (-42.0±17.9°) in the present study were not significantly different.

Kivi & Alexander also analyzed joint angular velocity to determine the speed of movement during the three trial conditions[3]. Hip flexion angular velocity was found to be highest in sprinting (681 $deg \cdot s^{-1}$) when compared to A-drills (647 $deg \cdot s^{-1}$) and B-drills (663 $deg \cdot s^{-1}$)[3]. In the present study, sprinting yielded significantly higher maximum angular velocity (754.9±111.1 $deg \cdot s^{-1}$) than A-drills (487.1±152.8 $deg \cdot s^{-1}$) and B-drills (463.7±100.1 $deg \cdot s^{-1}$). A-drill hip extension angular velocity (525 $deg \cdot s^{-1}$) was significantly lower than sprinting (652 deg·s^{-1}) and B-drills (584 deg·s^{-1})[3]. Hip extension angular velocity in the present study was lowest in B-drills (-567.7±124.0 deg·s^{-1}), which more closely matched sprinting (-576.9±72.4 deg·s^{-1}) than A-drills (-643.4±311.2 deg·s^{-1}).

Peak knee flexion angular velocities were not significantly different between sprinting (1120 deg·s^{-1}), A-drills (1017 deg·s^{-1}), and B-drills (1113 deg·s^{-1})[3]. Results of the present study also did not yield any significant differences between hip flexion angular velocity in sprinting (961.6±206.5 deg·s^{-1}), A-drills (995.1±554.1 deg·s^{-1}), and B-drills (850.0±231.6 deg·s^{-1}). However, Kivi & Alexander noted that knee extension angular velocities were significantly slower in both A-drills (760 deg·s^{-1}) and B-drills (865 deg·s^{-1}) compared to maximal sprinting (1090 deg·s^{-1})[3]. In the present study, knee extension angular velocity was lowest in B-drills (-833.9±87.9 deg·s^{-1}) when compared to sprinting (-1085.7±205.0 deg·s^{-1}) and A-drills (-1147.9±952.5 deg·s^{-1}), but none yielded significantly different values.

At the ankle, both dorsiflexion and plantar flexion angular velocity values for A-drills (407 deg·s^{-1} and 393 deg·s^{-1} respectively) and B-drills (463 deg·s^{-1} and 445 deg·s^{-1} respectively) were significantly slower than maximal sprinting (805 deg·s^{-1} and 790 deg·s^{-1} respectively)[3]. In the present study, dorsiflexion angular velocity was highest in B-drills (1528.3±775.9 deg·s^{-1}) but was not significantly higher than sprinting (1278.4±368.5 deg·s^{-1}) and A-drills (1262.8±231.8 deg·s^{-1}). Plantar flexion angular velocity values in sprinting (-1326.752±201.855 deg·s^{-1}) were significantly higher than in A-drills (-642.1±336.2 deg·s^{-1}) and B-drills (-707.9±186.7 deg·s^{-1}).

Regarding step rate, Kivi & Alexander found the A-drill (4.83 steps·s^{-1}) to have the highest frequency, followed by sprinting (4.60 steps·s^{-1}) and B-drills (4.08 steps·s^{-1})[3]. The present study, however, found maximal sprinting (253.9±23.2 steps·min^{-1}) to have a significantly higher step rate than A-drills (94.8±6.9 steps·min^{-1}) and B-drills (92.1±7.7 steps·min^{-1}).

A simple phase analysis of A- and B-drills compared to maximal sprinting revealed that although not all discrete variables yielded significant differences between the sprint drills and maximal sprinting, the three movement patterns are different enough that their efficacy as sprint biomechanics training tools should be questioned. The movement patterns during both A- and B-drills involve an additional aerial phase portion between swing phase and stance phase of the gait cycle, a feature not seen in sprinting. This additional aerial phase alters the maximum velocity, step rate, and kinematic patterns of the exercise in a way that do not reflect the characteristics of maximal sprinting. Effective sprint drills train the neuromuscular pathways responsible for a movement in a way that makes the movement pattern more efficient.

From a neuromuscular perspective, A- and B-drills do not mimic the movement patterns seen in maximal sprinting. Improvements in neuromuscular function are thought to come from increasing motor unit recruitment, nerve conduction velocity (NCV), and rate of force development (RFD)[19,20,21]. In an ideal sprint drill, the kinematic pattern would mimic or exceed normative values in maximal sprinting. By doing so, motor units of the muscle groups associated with maximal sprinting would become acclimated to the movement pattern and the nervous system would more efficiently recruit muscles to generate high forces needed for sprinting. To maximize RFD, the ability of the body to develop muscle force quickly, the athlete must be able to produce a high RFD early in a muscle contraction[20,21,22]. The speed of the action potential along the neuronal pathway, known as NCV, improves with increased myelination of the axons of associated muscles[19]. In order to increase myelination of the muscles needed in sprinting, high volumes of intense training must be a regular occurrence within sprint training programs[19]. The combination of optimal motor unit recruitment, RFD, NCV, motor unit synchronization, and reflex potentiation of the SSC results in intramuscular coordination, which is the sum total of neural adaptations within a single muscle[19,23].

Sprint drills are meant to enhance a quality of sprinting in order to allow for a transfer of skill that results in improved sprint performance. The transfer of a skill between a drill and the desired movement pattern is a function of the gain in performance versus then gain in trained exercise[23]. The key to this transfer of skill is specificity: the adaptations that result from an exercise must be specific to the training stress of sprinting[23]. An activity that is specific to sprinting would mirror the musculoskeletal demands of sprinting, which include unilateral leg extensor muscle contractions resulting in horizontal movement[23]. In order to be proficient in sprinting, many different muscles must be activated at different times and intensities, which can only occur with proper training[23]. The transfer of skills from sprint drills to sprinting depend on the drill's ability to produce positive or negative transfer[23,24]. Ideally, a sprint drill results in a positive transfer of skill, where the drill reinforces the muscle-activation patterns necessary for success in the sport skill[23,24]. Negative transfer is an increase in coactivation of antagonist muscles in response to a drill, resulting in force production in the opposite direction of the intended movement pattern[23,24]. In the case of sprinting, a drill would need to result in intermuscular coordination of the hip, knee, and ankle flexors and extensors in a way that is most conducive to producing triple extension and maximal force[19,23,24]. However, there is no one single drill or exercise that can result in sprint skill development[23]. Instead, it is important to create a combination of general and specific exercises within a sprint program to produce the most appreciable differences in sprint performance[23].

The comparison between experienced and inexperienced sprinters produced interesting results regarding the ability to execute the drills and attain normative ROM values during maximal sprinting. While not all values analyzed produced significant differences, a phase analysis showed that the inexperienced sprinters were unable to produce as smooth of a movement pattern during both drills, particularly B-drills, and executed the drills at a slower rate than the experienced sprinters. The most likely explanation for the differences between the two levels of experience was that the more an individual practices a skill, in this case sprint drills and sprinting, the more efficient the movement patterns become. Many young athletes see sprinting as a skill that does not take much practice to become proficient, but becoming a high-level sprinter requires a balance of efficient biomechanics and muscle strength[25]. Although all of the inexperienced sprinters in this study had some experience with sprinting, not all of them had many years of experience with either A- or B-drills. The addition of another phase during the movement patterns of these drills and the knee extension in correspondence with terminal hip flexion during B-drills can cause a younger athlete to have some difficulty executing the drills with a high level of proficiency[3]. Coaches that utilize these drills during sprint training programs should recognize that a younger athlete may not fully understand the biomechanics of the drills and may need to slow their pace down even below their self-selected pace to be successful.

There were some notable limitations in this study. While the original subject pool was an adequate sample size, the number of subjects used in the kinematic analysis ended up being a smaller pool due to issues during data collection and filtering. During the data collection, the markers were affixed with wig tape, which proved to be inadequate when the subject became sweaty following the dynamic warm-up. If the subject lost an essential marker for a joint angle calculation, the trial could not be used. Some subjects' sprint trials also only included one left foot stride within the frame, which could not be used for analysis. Regarding the cadence trials, most subjects did not properly follow the cadence, so the trials could not be used for kinematic analysis. Due to time constraints related to the team's training schedule, there could not be a second day of testing to resolve these issues. In future studies, the testing staff would need to troubleshoot these issues by holding a second day of trials for subjects whose data was incomplete. The testers would also need to establish a realistic cadence if the cadence variable were to be included that could be easily understood and properly interpreted by the subjects.

Practical Applications

Both A- and B-drills are a common part of many modern-day sprint training programs. The issue that these drills present is that many athletes do not fully understand the role that A- and B-drills play in sprinting. This is likely the result of the complexity of the movement patterns during A- and B-drills. Good sprint coaches know to anticipate questions from their athletes regarding the purpose of the exercises and workouts they prescribe. In the case of A- and B-drills, coaches that are questioned about their use and efficacy should steer clear of describing them as tools for the improvement of sprint biomechanics. Instead, coaches should present the idea that A- and B-drills are dynamic movement drills that increase the athlete's capacity to sprint by preparing the body for the explosive demands of sprinting.

Calling A- and B-drills a sprint drill may be something of a misnomer. The goal of a good sprint drill is to improve some aspect of sprinting, whether it be biomechanics, speed, or muscle strength. Based on the findings of this study, success in A- and B-drills does not necessarily correlate with success in sprinting. As discussed previously, the movement patterns of these drills and maximal sprinting differ greatly as a result of the addition of an aerial skipping phase between stance and swing phase. This alone is enough to raise questions about their efficacy as a sprint biomechanics training tool. While the findings of this study do not conclusively discount these exercises as essential parts of a successful sprint program, coaches should use caution when prescribing A- and B-drills as tools for enhancing sprint biomechanics.

However, these drills do have a place in a sprint training program as part of a dynamic warm-up. While the movement patterns are not similar to sprinting, both A- and B-drills require muscle activation of the same muscles necessary for maximal sprinting. If the athlete performs A- and B-drills prior to a sprint workout, it can be assumed that the drills will provide the same benefits as other dynamic drills. A dynamic warm-up provides greater benefits than any other warm-up type because the athlete is actively moving the body through various types of ROM and prepares the body for the activity it is about to perform[26,27,28]. Among the benefits of dynamic warm-ups are increases in core temperature, prestretching of the muscles to prepare them for movement, increased circulation to the muscles, increased viscosity of joint synovial fluids, and preparation of the neuromuscular system for activity[26,27,28]. Dynamic warm-ups usually progress from simple, single joint drills to more complex movements that may be explosive in nature[4,26,27,28]. The best place for complex drills like the A- and B-drills are at the end of a dynamic warm-up when all of the associated musculature needed for success in the drills has been properly prepared through simpler drills[4].

Emerging research suggests that resisted sprinting is a more effective method of improving sprint biomechanics[29,30,31,32]. While the common sprint drills of the present study do mimic the characteristics of maximal sprinting, the additional aerial phase alters the movement pattern in a way that makes them more appropriate as a part of a dynamic warm-up. In contrast, resisted sprinting requires the athlete to over-exaggerate sprinting kinematics in order to overcome the increased load on the body[29,30,31,32]. Resisted sprinting methods include parachute resistance, bullet belts, sled towing, and weighted vests[29]. The increased ROM and force application necessary to overcome the added resistance are thought to result in neuromuscular and musculoskeletal adaptations that improve sprint performance[29,30,31,32].

Conclusions

The findings of the present study support the hypothesis that A- and B-drills have enough kinematic and spatiotemporal differences from maximal sprinting to be considered an ineffective sprint biomechanics training tool. The finding also support the secondary hypothesis that more experienced sprinters will be more proficient at performing both sprint drills and maximal sprinting than inexperienced sprinters. Coaches should use caution when using the nomenclature of sprint drills when describing A- and B-drills in their sprint programs to avoid confusion among their athletes. Instead, these drills should be incorporated into the dynamic warm-up and be used to prepare the body for the demands of sprinting.

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Tables and Figures

Figures

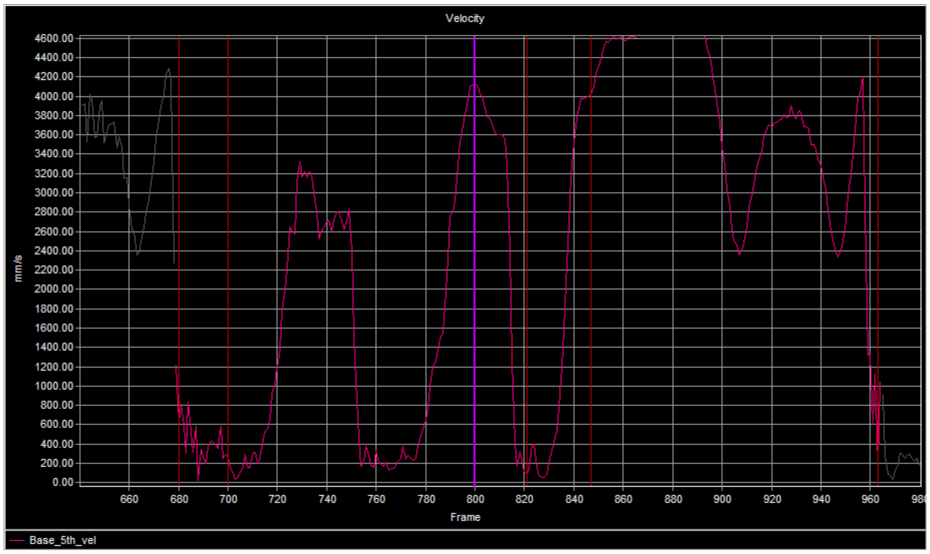

Figure 4. Velocity data for the cadence A skip trial of subject 11 plotted on a frame number (x-axis) versus velocity (y-axis) curve. The pink portion of the curve is the data for one stride cycle. The red lines indicate event markers.

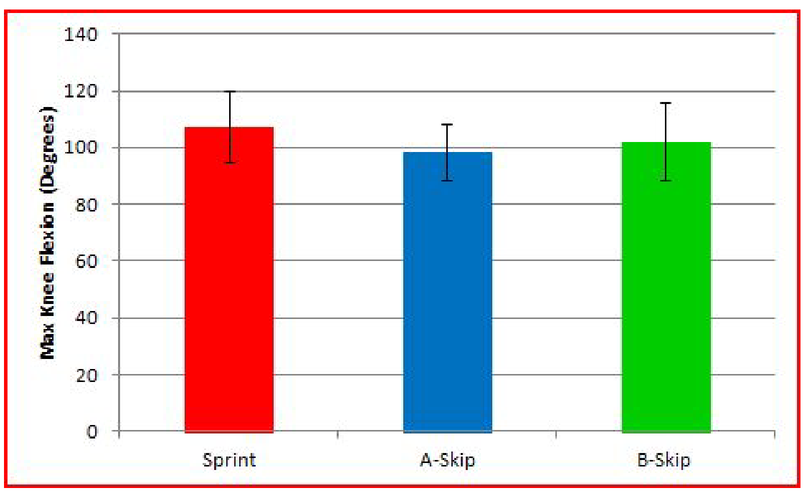

Figure 5. The kinematic comparison of sagittal plane ROM found at the hip measured in degrees. Maximum hip flexion is greater in both A- and B-drills when compared to sprinting.

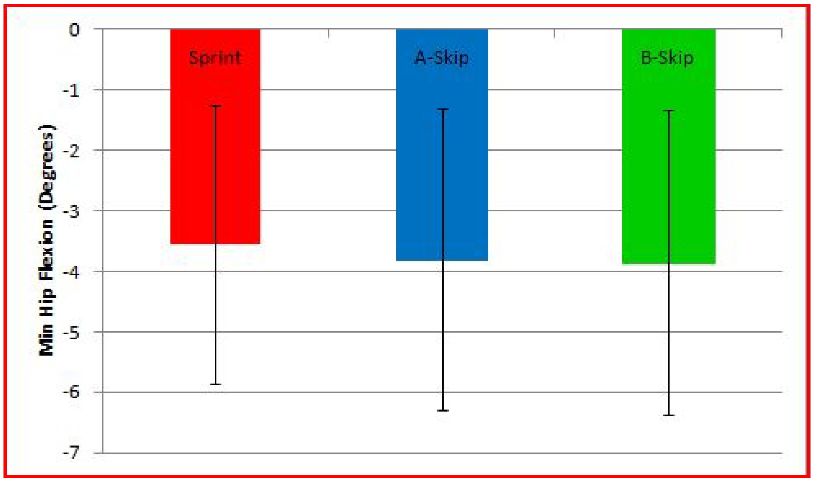

Figure 6. The kinematic comparison of sagittal plane ROM found at the hip measured in degrees. Maximum hip extension is greatest during A-drills and B-drills as compared to sprinting. This is likely the result of a marker error as 2D video analysis shows that hip extension is higher in sprinting.

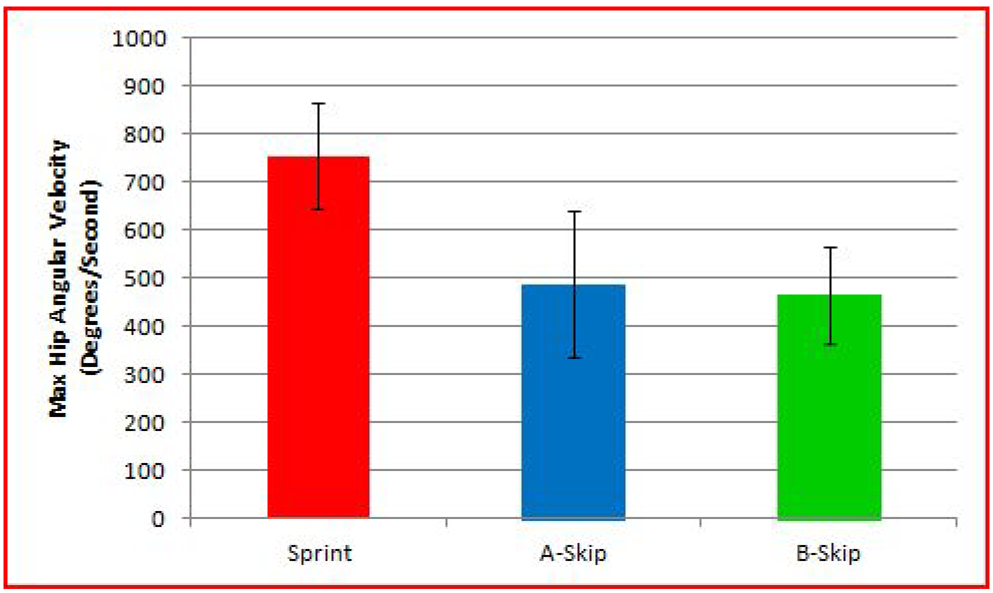

Figure 7. The kinematic comparison of angular velocity found at the hip measured in degrees/second. Hip angular velocity during sprinting is much greater than during sprint drills.

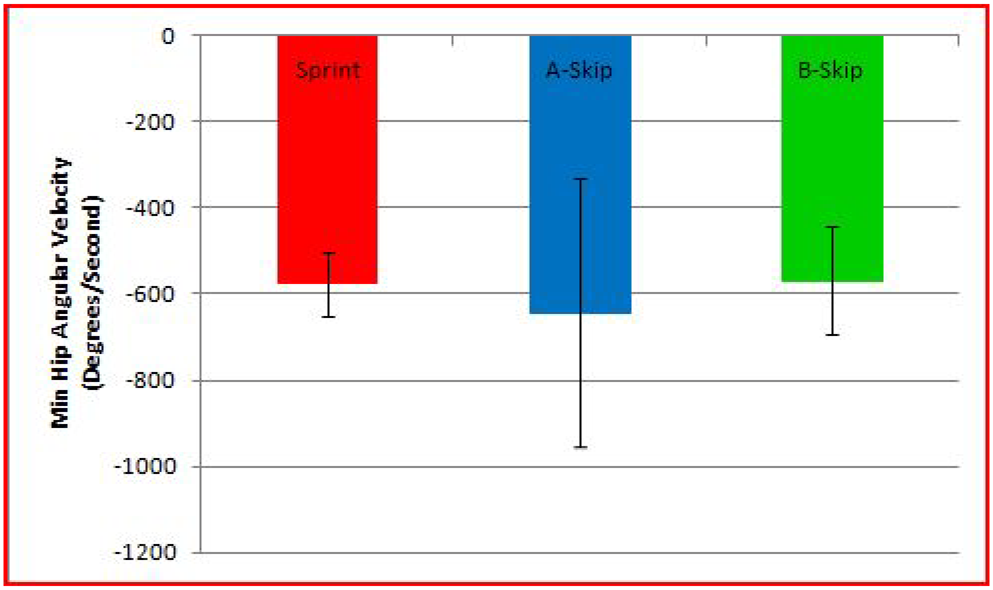

Figure 8. The kinematic comparison of angular velocity found at the hip measured in degrees/second. Peak minimum hip flexion angular velocity is lowest during A-drills compared to sprinting and B-drills.

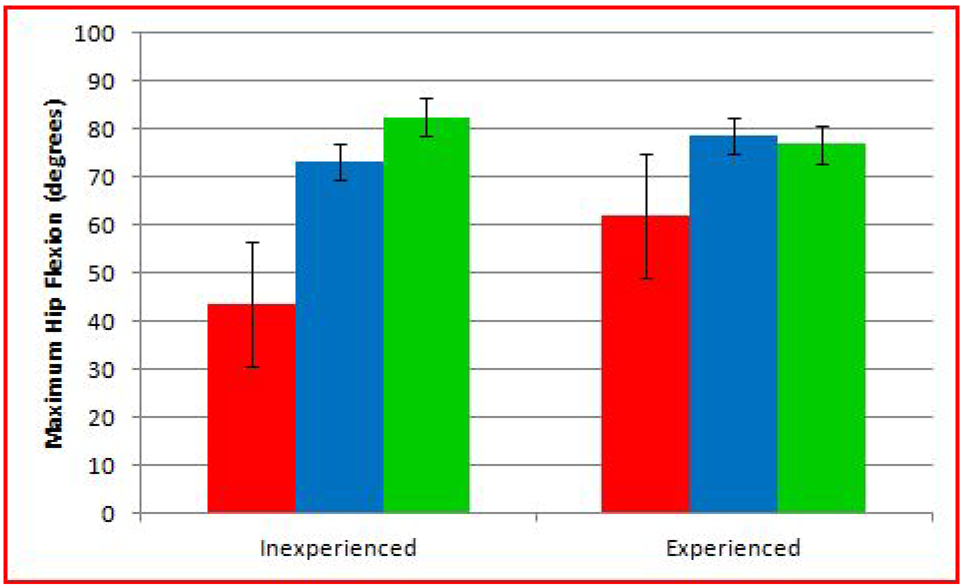

Figure 9. The kinematic comparison of sagittal plane ROM found at the hip measured in degrees. Experienced sprinters had greater average hip flexion values than the inexperienced sprinter in sprinting and A-drills, but not in B-drills.

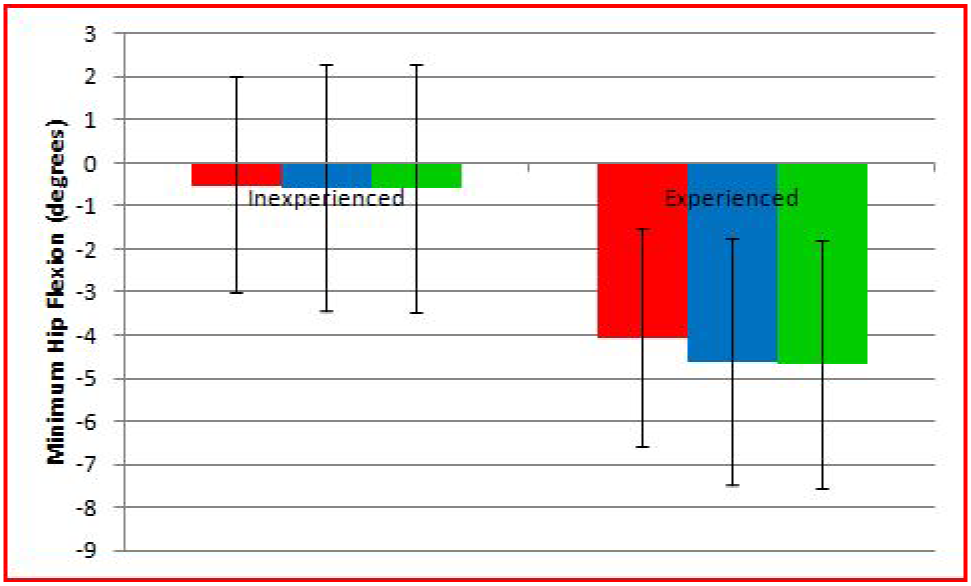

Figure 10. The kinematic comparison of sagittal plane ROM found at the hip measured in degrees. The experienced sprinters had higher hip extension values in all conditions than the inexperienced sprinter.

Figure 11. The kinematic comparison of angular velocity found at the hip measured in degrees/second. The experienced sprinters had greater hip angular velocities during all three conditions than the inexperienced sprinter.

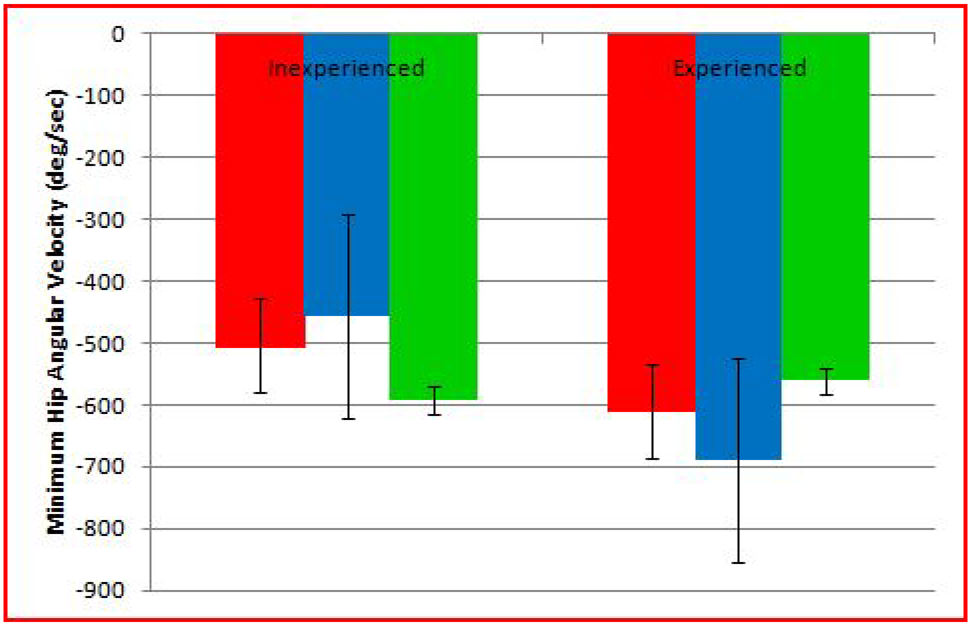

Figure 12. The kinematic comparison of angular velocity found at the hip measured in degrees/second. The experienced sprinters had lower peak minimum values in sprinting and A-drills, but not B-drills, when compared to the inexperienced sprinter.

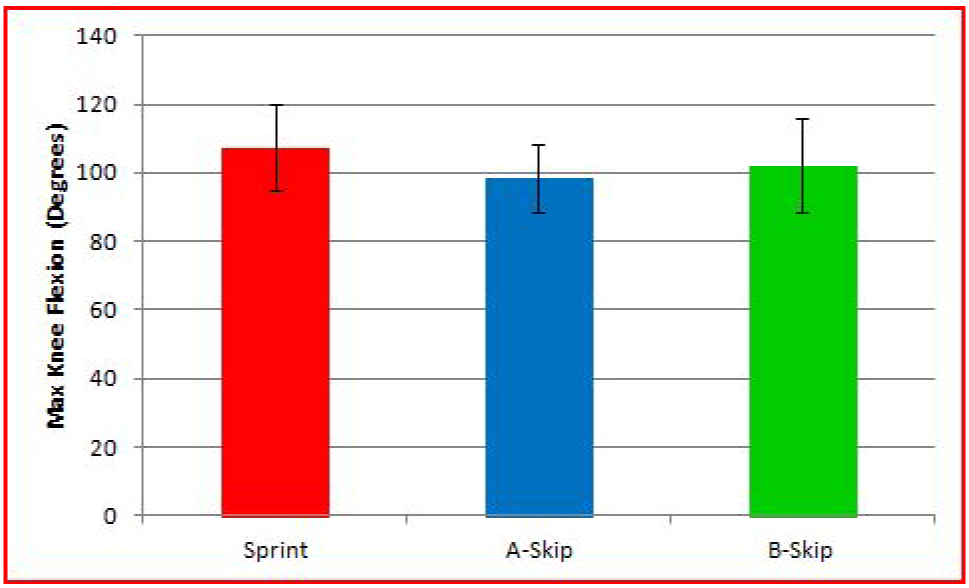

Figure 13. The kinematic comparison of sagittal plane ROM found at the knee measured in degrees. Knee flexion is greatest in sprinting when compared to sprint drills.

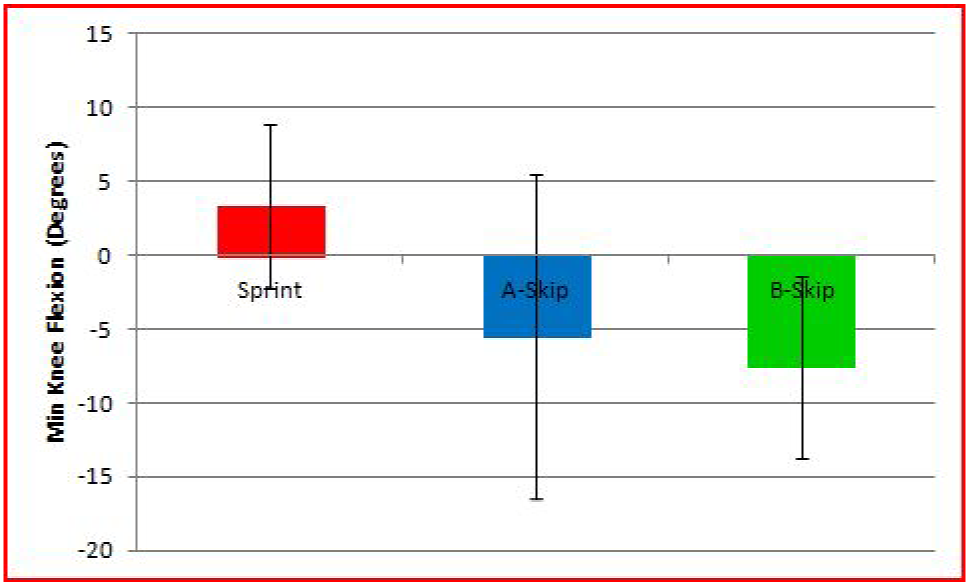

Figure 14. The kinematic comparison of sagittal plane ROM found at the knee measured in degrees. The knee does not fully extend during sprinting, but shows some indication of hyperextension during both types of sprint drills, which could be due to marker error rather than actual joint kinematics.

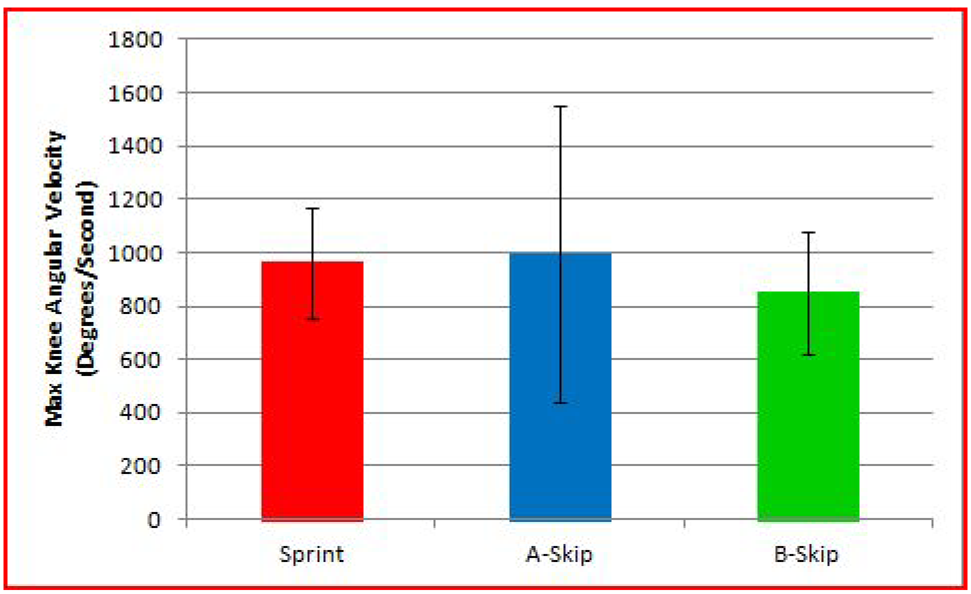

Figure 15. The kinematic comparison of angular velocity found at the knee measured in degrees/second. Sprinting and A-drills are the most similar when compared to B-drills.

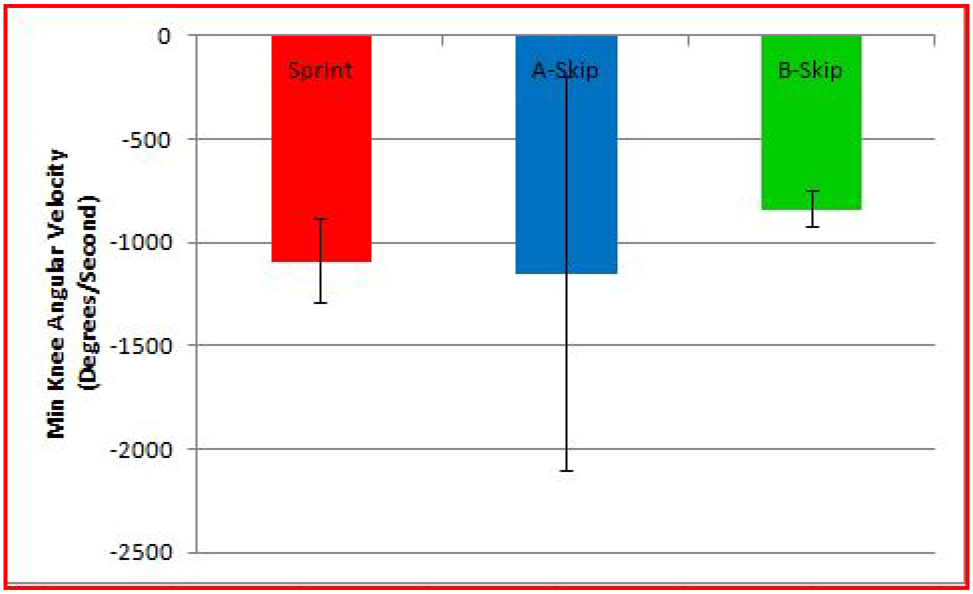

Figure 16. The kinematic comparison of angular velocity found at the knee measured in degrees/second. Sprinting and A-drills have the smallest values, which are more closely related than to B-drills.

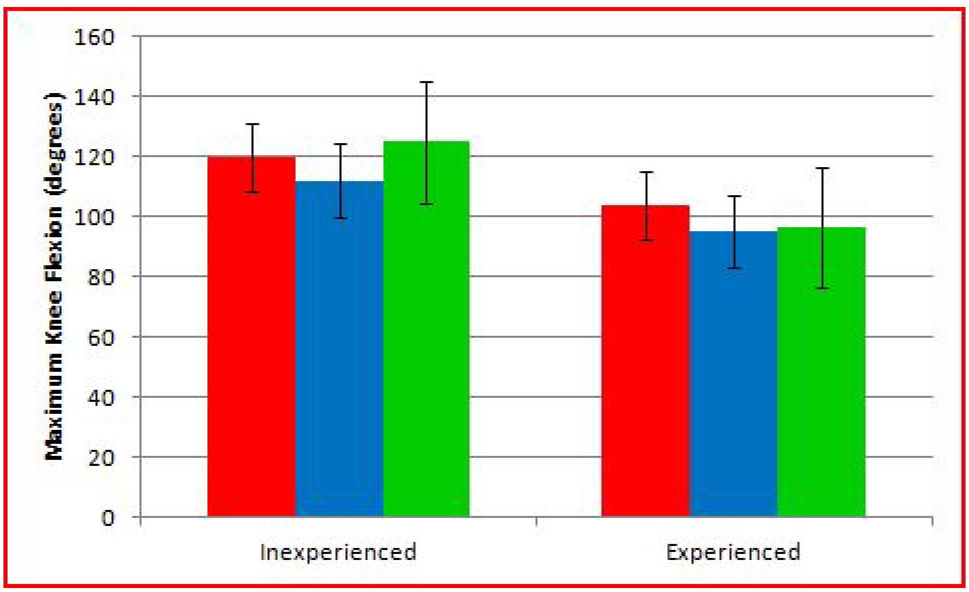

Figure 17. The kinematic comparison of sagittal plane ROM found at the knee measured in degrees. Knee flexion is highest in the inexperienced sprinter in all three trial conditions than the experienced sprinters.

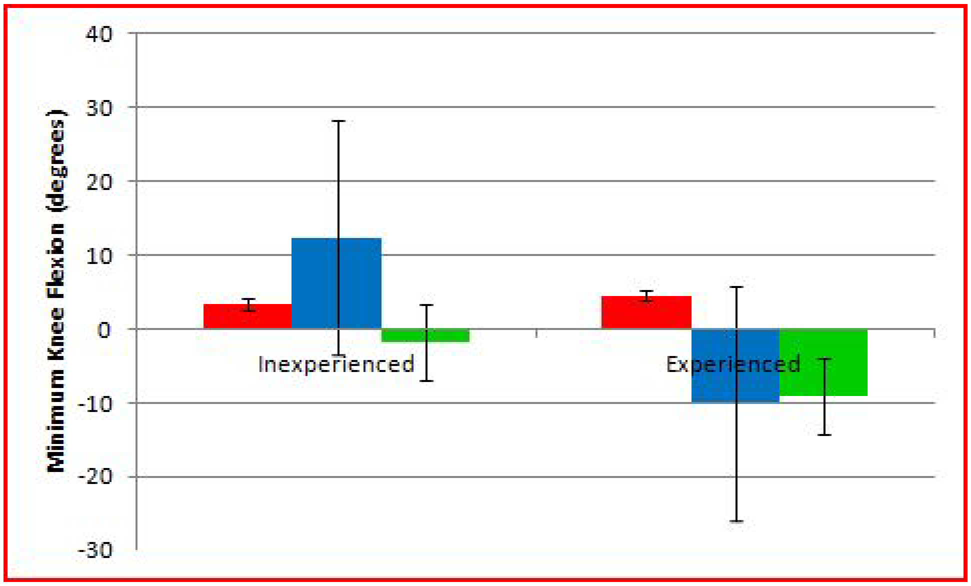

Figure 18. The kinematic comparison of sagittal plane ROM found at the knee measured in degrees. The experienced sprinters were measured with some degree of hyperextension during both sprint drills, which was not confirmed using 2D analysis. In sprinting, the experienced sprinters had a greater degree of knee flexion during stance when maximum knee extension should occur. The inexperienced sprinter had a large knee flexion value during A-drills but the knee was slightly hyperextended in B-drills.

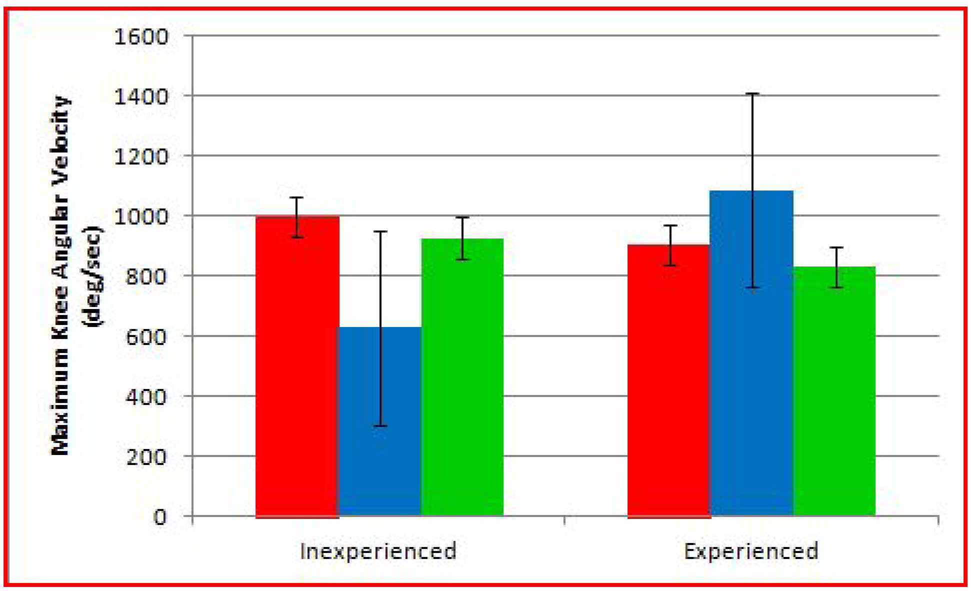

Figure 19. The kinematic comparison of angular velocity found at the knee measured in degrees/second. In sprinting and B-drills, the inexperienced sprinter had a greater maximum knee angular velocity than the experienced sprinters, but A-drill knee angular velocity was significantly higher in the experienced sprinters.

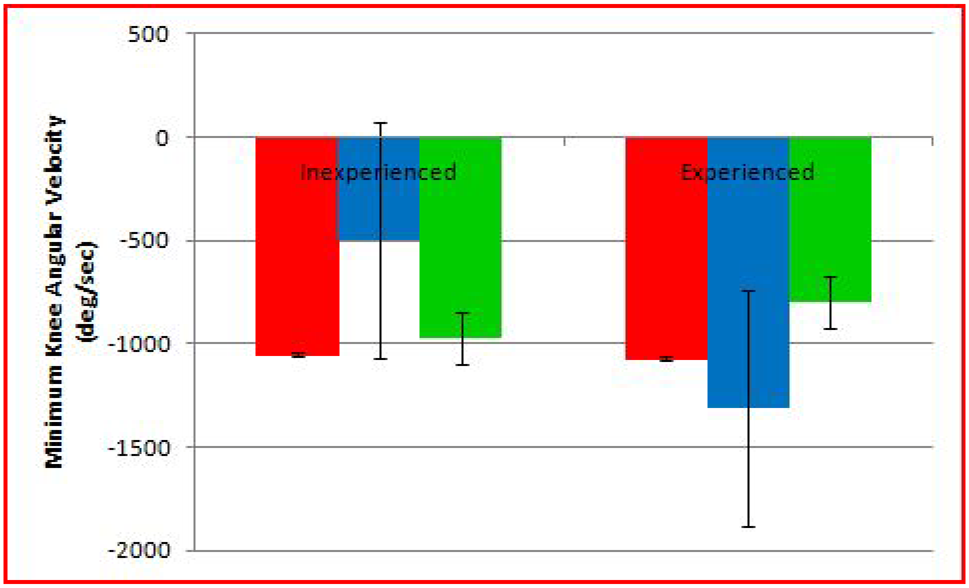

Figure 20. The kinematic comparison of angular velocity found at the knee measured in degrees/second. Peak minimum knee angular velocity was significantly lower in the experienced sprinters during A-drills when compared to the inexperienced sprinter. Sprinting and B-drill minimum knee angular velocity values were not significantly different.

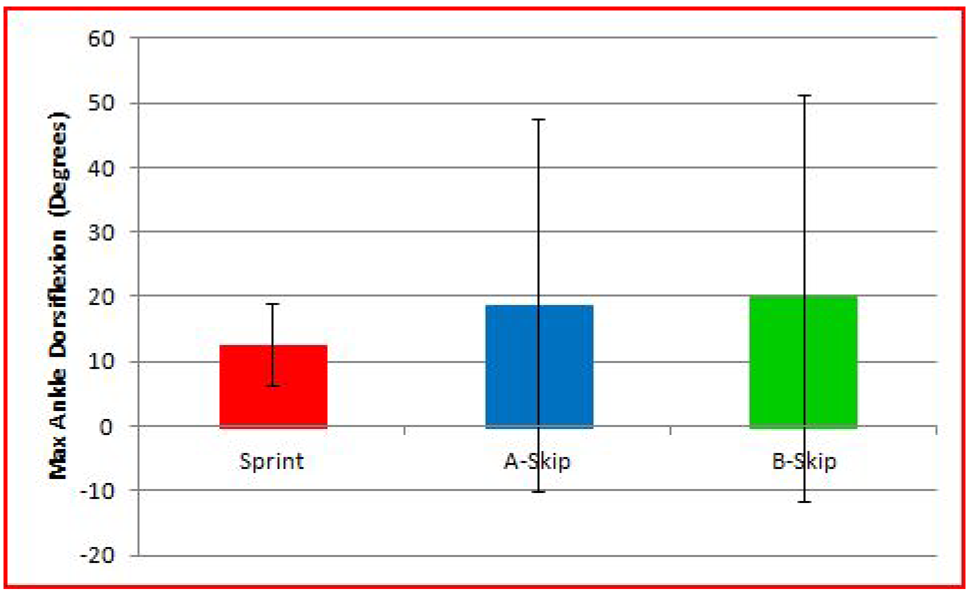

Figure 21. The kinematic comparison of sagittal plane ROM found at the ankle measured in degrees. Dorsiflexion values are highest in sprint drills compared to sprinting.

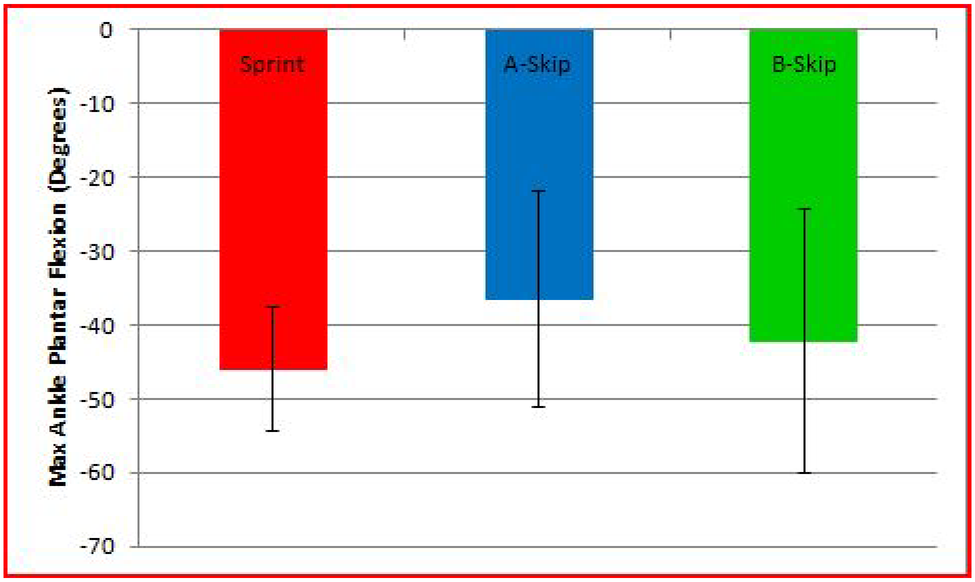

Figure 22. The kinematic comparison of sagittal plane ROM found at the ankle measured in degrees. Large internal moments by the triceps surae muscle complex during all three trial types result in large degrees of plantar flexion. Plantar flexion is highest in maximal sprinting.

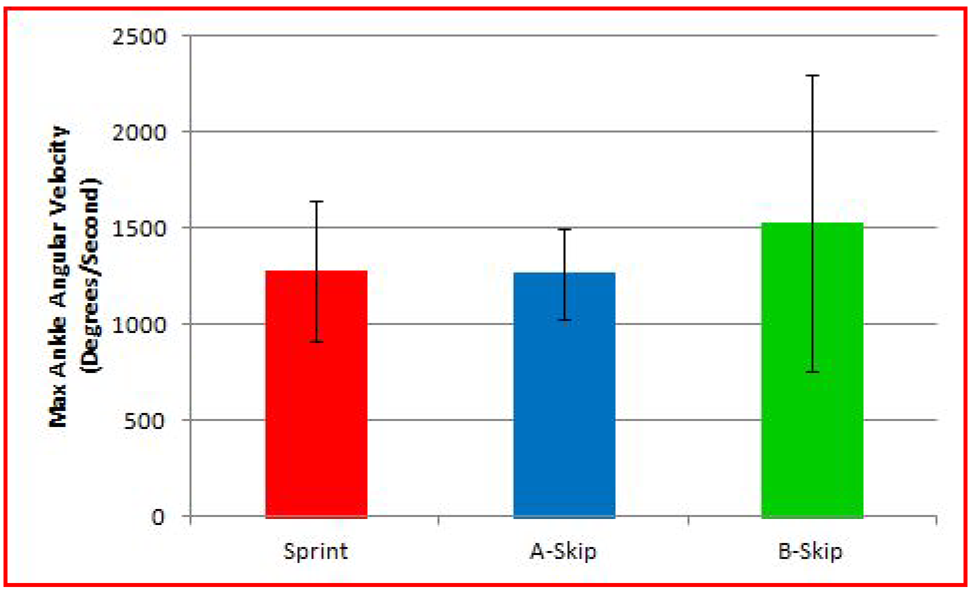

Figure 23. The kinematic comparison of angular velocity found at the ankle measured in degrees/second. The largest angular velocity value at the ankle is seen in B-drills. Values in B-drills were signficantly higher than in maximal sprinting.

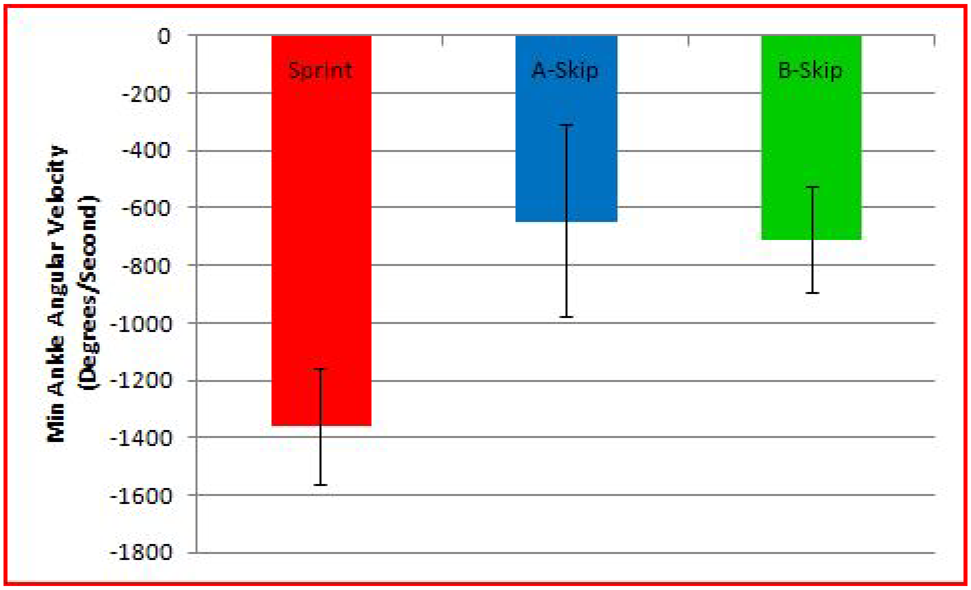

Figure 24. The kinematic comparison of angular velocity found at the ankle measured in degrees/second. The minimum angular velocity is signficantly lower in sprinting as compared to both sprint drills.

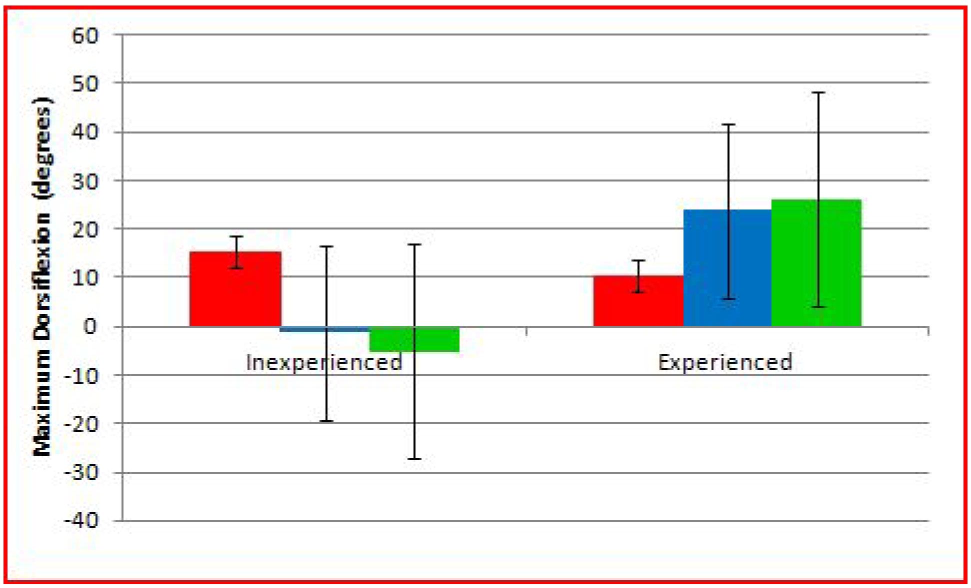

Figure 25. The kinematic comparison of sagittal plane ROM found at the ankle measured in degrees. Peak dorsiflexion values during sprint drills were signficantly higher in the experienced sprinters than the inexperienced sprinter, but no significance was found in maximal sprinting.

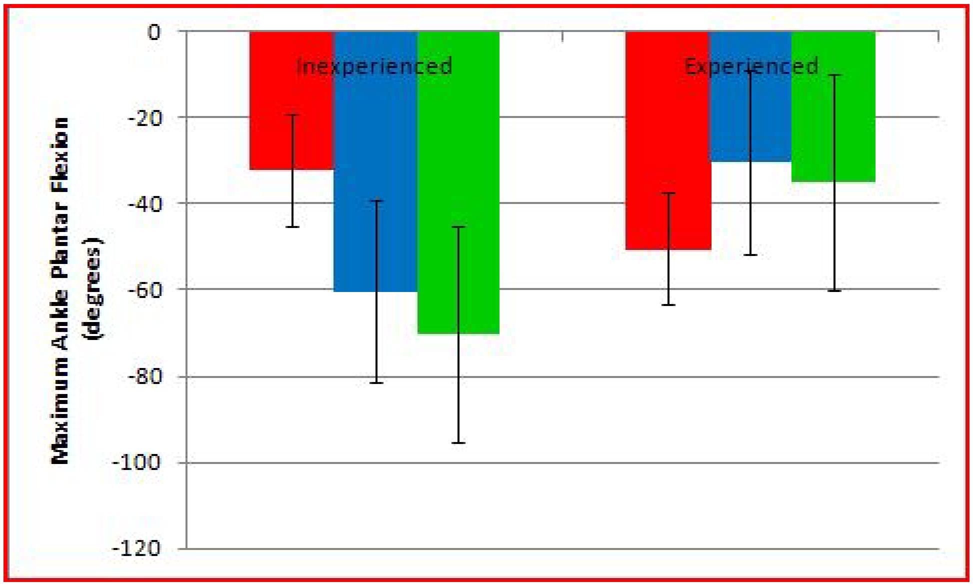

Figure 26. The kinematic comparison of sagittal plane ROM found at the ankle measured in degrees. The inexperienced sprinter had signficantly higher plantar flexion (lower dorsiflexion) values than the experienced sprinters in both sprint drills, but experienced sprinters had significantly higher values in maximal sprinting.

Figure 27. The kinematic comparison of angular velocity found at the ankle measured in degrees/second. Peak ankle angular velocity was significantly higher in the inexperienced sprinter's B-drills when compared to those of the experienced sprinters.

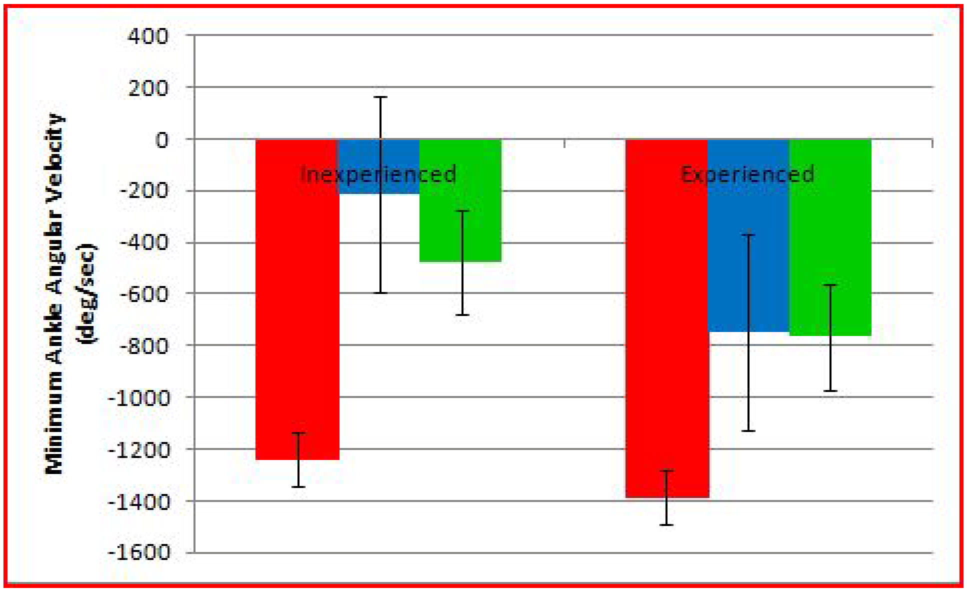

Figure 28. The kinematic comparison of angular velocity found at the ankle measured in degrees/second. Peak minimum ankle angular velocity was lowest in the experienced sprinters in all three conditions.

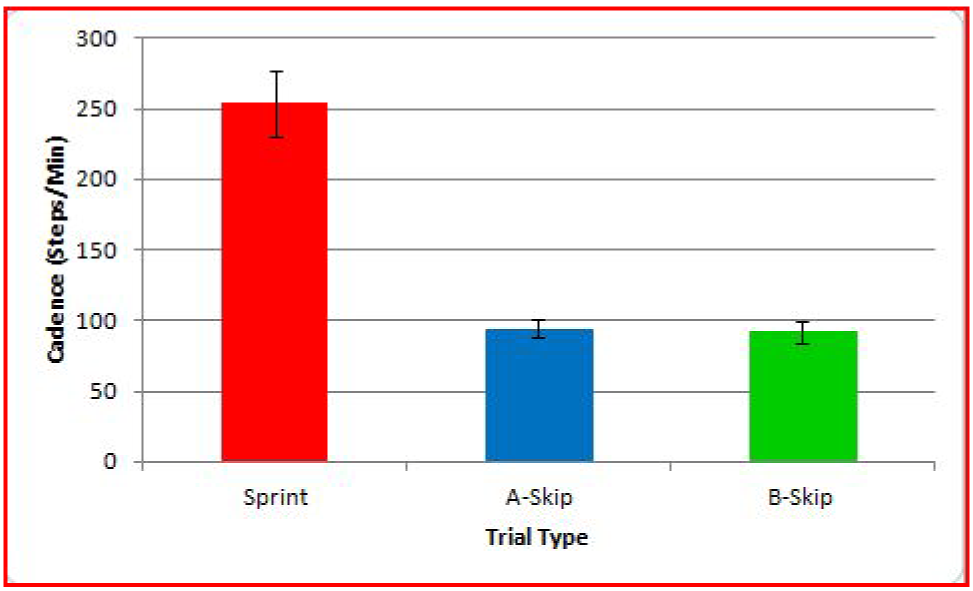

Figure 29. A bar graph depicting the cadence differences between sprinting, A-drills, and B-drills. The cadence (in steps/minute) during sprinting was significantly higher than the cadence for either A-drills or B-drills when at a self-selected pace. Had the auditory cue cadence trials been successful, a separate bar would have been made for the cadence data for each drill type. It is expected that the auditory cue trials would have yielded similar results to the sprinting trials.

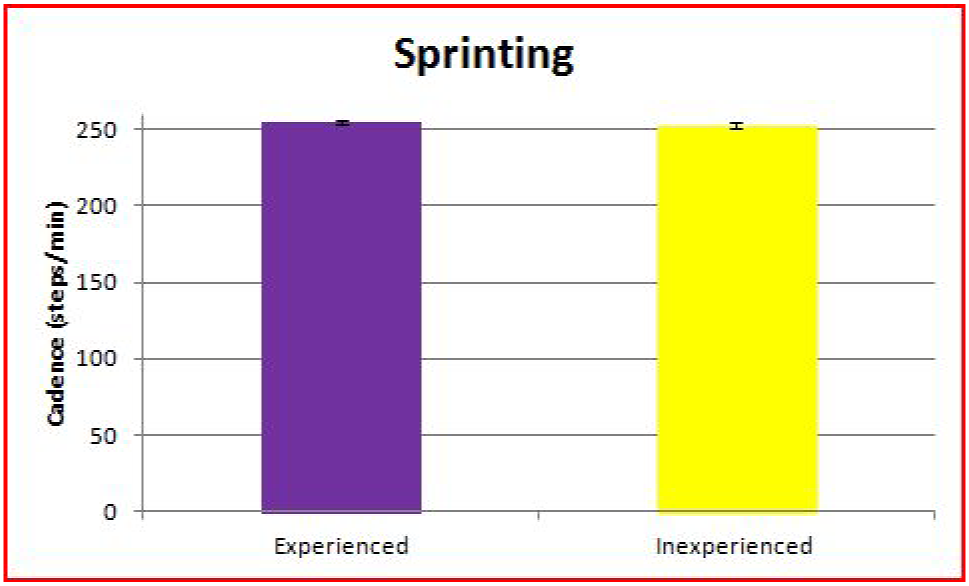

Figure 30. A comparison of the cadence differences between maximal sprinting trials in experienced and inexperienced sprinters. Experienced sprinters had only a slightly higher step rate than inexperienced sprinters in maximal sprinting.

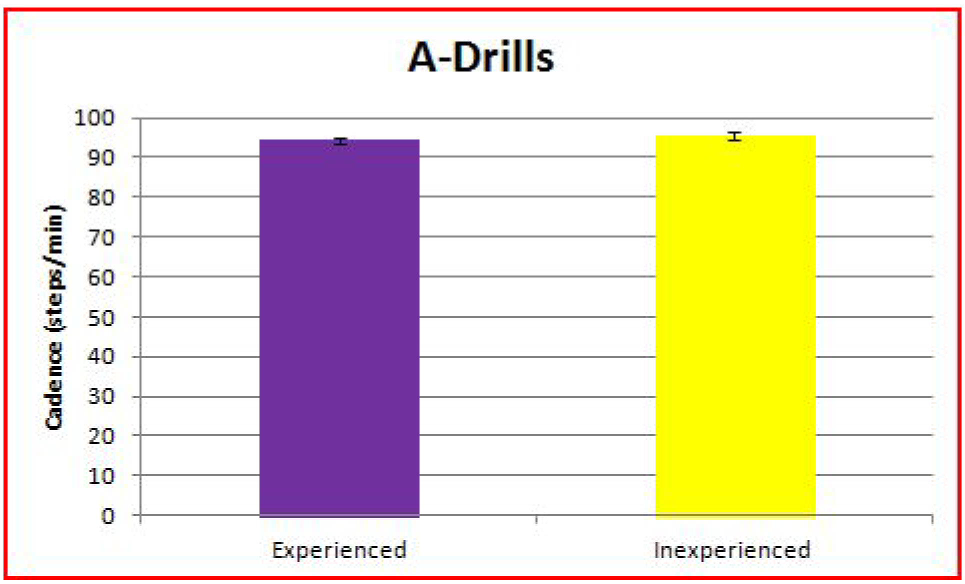

Figure 31. A comparison of the cadence differences between A-drills trials in experienced and inexperienced sprinters. Inexperienced sprinters had only a slightly higher step rate than experienced sprinters in A-drills.

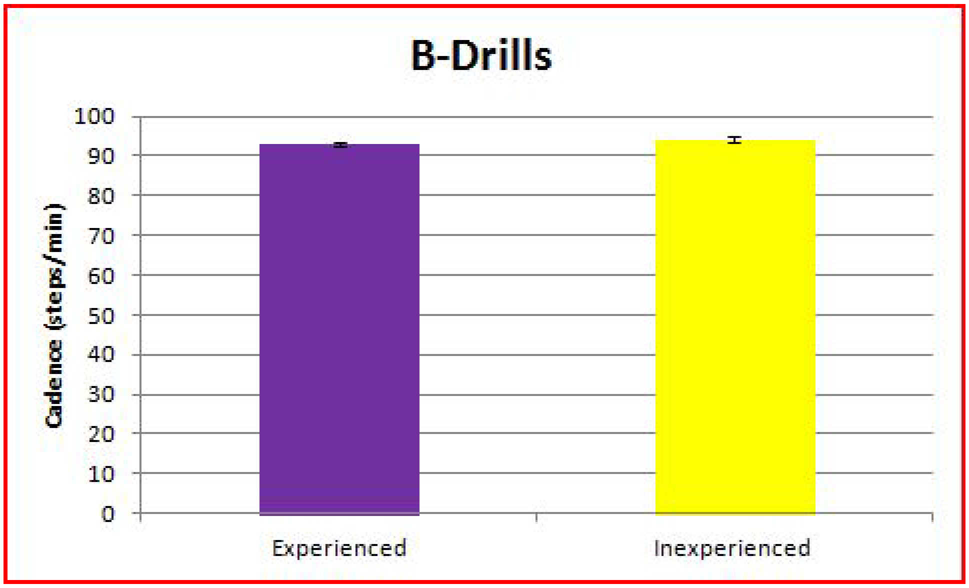

Figure 32. A comparison of the cadence differences between B-drills trials in experienced and inexperienced sprinters. Inexperienced sprinters had only a slightly higher step rate than experienced sprinters in B-drills.

Tables

Subject	Gender	Age	Height (cm)	Weight (kg)	Leg Length (cm)	100m Personal Best
1	Male	18 (I)	193.04	82.55	104.14	12.40
2	Male	21 (E)	185.42	65.32	90.17	10.92
3	Male	18 (I)	180.34	61.69	85.09	11.40
4	Female	18 (I)	167.64	55.34	82.55	13.20
5	Male	20 (E)	185.42	87.54	92.71	10.80
6	Female	18 (I)	170.18	55.34	83.82	13.20
7	Female	18 (I)	175.26	58.97	87.63	13.20
8	Female	19 (I)	172.72	69.85	88.90	12.80
9	Male	20 (E)	182.88	78.02	99.06	11.74
10	Female	20 (E)	167.64	68.04	87.63	13.00
11	Male	20 (E)	172.72	68.04	93.98	10.97
12	male	20 (E)	172.72	69.40	85.09	11.02
Average	-	19.17±1.11	177.17±8.11	68.34±10.21	90.06±6.46	12.05±1.01
Males	7	19.38±1.13	181.61±7.31	71.78±9.59	91.92±7.01	11.33±0.58
Females	5	18.60±0.98	170.69±3.21	61.51±6.79	86.11±2.54	13.08±0.16

Table 1. Individual and averaged subject information related to age, height, weight, leg length, and 100 meter personal best. (I = inexperienced, E = experienced)

1. Knee circles	33. Leg cradle
2. Glute bridge #1	34. Drop lunges
3. Glute bridge #2	35. Lateral squats
4. Glute bridge #3	36. Inchworms
5. Hip crossovers	37. Inverted hamstrings
6. 2-way calf stretch	38. Straight leg march
7. Lunge & twist	39. Straight leg hamstring stretch
8. High knee pulls	40. Leg swings
9. Forward lunge with forearm to instep	41. Lateral leg swings
10. Walking quad pulls	42. Hurdle/hip mobility (forward)
	21. Hurdle/hip mobility (reverse)

Table 2. Dynamic warm-up provided for each participant based upon dynamic warm-up assigned by the SHU sprint coach. Each was performed 12 times per leg.

Upper Body Markers	Lower Body Markers
Right anterior head	Right ASIS
Left anterior head	Left ASIS
Right posterior head	Right PSIS
Left posterior head	Left PSIS
C2 (cervical spine)	Greater trochanter of femur
Sternoclavicular joint	Anterior midpoint of thigh
Acromion process	Posterior midpoint of thigh
Lateral epicondyle of humerus	Patella
Styloid process of radius	Lateral epicondyle of femur
Mid-axillary point of thorax	Anterior midpoint of leg
T8 (thoracic spine)	Posterior midpoint of leg
	Lateral malleolus of tibia
	Base of the 5th metatarsal

Table 3. Bony landmarks indicated using reflective markers for measurement by the Qualysis 3D Motion Capture System.

Sprint	Hip Flex Max		Knee Flex Max		Ankle DF Max	
	Deg	**% GC**	**Deg**	**% GC**	**Deg**	**% GC**
Subject 5	65.11038	71.05263	106.9841	58.77193	21.23953	8.77193
Subject 7	43.66321	93.69369	119.8807	74.77477	15.20776	14.41441
Subject 10	56.15675	64.22764	89.03463	56.09756	3.639731	11.38211
Subject 11	68.97677	66.05505	117.8296	55.04587	11.3418	11.00917
Subject 12	56.12982	70.47619	102.7879	53.33333	11.90662	9.52381
MEAN	58.00739	73.10104	107.3034	59.60469	12.66709	11.02029
SD	9.791392	11.86936	12.48227	8.70686	6.398625	2.176333
A-Skip						
Subject 5	84.10987	85.81081	101.5786	73.64865	69.53891	21.95946
Subject 7	73.21463	87.5	112.0776	75	-1.31137	100
Subject 10	79.15846	83.42857	98.78366	78.28571	5.949268	5.428571
Subject 11	77.34751	84.16667	94.91239	78.61111	10.42618	3.888889
Subject 12	73.41048	73.57724	84.51409	64.63415	9.483285	10.56911
MEAN	77.44819	82.89666	98.37327	74.03592	18.81726	28.36921
SD	4.514954	5.44129	10.0288	5.66714	28.72702	40.66466
B-Skip						
Subject 5	83.37981	85.97122	96.10745	65.10791	74.93552	21.94245
Subject 7	82.61086	72.64706	124.9537	74.41176	-5.10011	100
Subject 10	72.8145	75.1462	95.55544	75.4386	6.597007	3.508772
Subject 11	78.71261	73.88889	90.75317	76.38889	12.17814	3.611111
Subject 12	72.40494	82.73092	103.3116	64.25703	10.95323	41.76707
MEAN	77.98455	78.07686	102.1363	71.12084	19.91276	34.16588
SD	5.217831	5.907451	13.52077	5.926482	31.50617	40.04614

Table 4. Maximum flexion values at the hip, knee, and ankle for each subject used for kinematic analysis. Also listed is at what percent of the gait cycle the maximum value was attained.

Sprint	Hip Flex Min		Knee Flex Min		Ankle PF Max	
	Deg	% GC	Deg	% GC	Deg	% GC
Subject 5	-4.12976	10.52632	2.870589	94.73684	-46.6027	37.7193
Subject 7	-0.48048	71.17117	3.4685	28.82883	-32.0129	30.63063
Subject 10	-4.99965	39.8374	11.25901	87.80488	-54.8127	47.96748
Subject 11	-1.96786	15.59633	3.235033	88.99083	-49.8112	25.68807
Subject 12	-6.17482	43.80952	-4.42548	89.52381	-45.9911	26.66667
MEAN	-3.55051	36.18815	3.281531	77.97704	-45.8461	33.73443
SD	2.305013	24.38118	5.550768	27.60279	8.486371	9.257289
A-Skip						
Subject 5	-4.28129	25.67568	-10.5879	94.93243	-22.7776	96.95946
Subject 7	-0.56909	51.28205	12.39426	40.0641	-60.3373	38.14103
Subject 10	-5.19264	32.28571	-4.20684	48	-27.771	97.42857
Subject 11	-2.08841	43.88889	-8.67893	93.33333	-32.4048	13.05556
Subject 12	-6.87576	24.39024	-16.6301	32.11382	-38.1547	53.25203
MEAN	-3.80144	35.50451	-5.54191	61.68874	-36.2891	59.76733
SD	2.499985	11.72308	10.97429	30.15048	14.59454	37.05995
B-Skip						
Subject 5	-4.32736	19.42446	-16.4181	91.72662	-28.1148	93.52518
Subject 7	-0.5772	32.05882	-1.78568	96.47059	-70.3084	41.17647
Subject 10	-5.51763	12.8655	-1.76665	44.73684	-48.5196	90.05848
Subject 11	-2.08917	36.38889	-8.02363	94.44444	-34.934	12.22222
Subject 12	-6.74512	42.57028	-9.8468	92.77108	-28.0361	53.41365
MEAN	-3.85129	28.66159	-7.56817	84.02992	-41.9826	58.0792
SD	2.510096	12.24281	6.140344	22.03875	17.89963	34.23968

Table 5. Minimum flexion values at the hip, knee, and ankle for each subject used for kinematic analysis. Also listed is at what percent of the gait cycle the minimum value was attained.

Sprint	Hip Flex Min		Knee Flex Min		Ankle PF Max	
	Deg	% GC	Deg	% GC	Deg	% GC
Subject 5	928.293	57.89474	1000.784	28.07018	1098.788	44.73684
Subject 7	625.8738	76.57658	999.1255	4.504505	964.0108	1.801802
Subject 10	771.2091	55.28455	619.3755	27.64228	1112.679	3.252033
Subject 11	708.3242	16.51376	1006.745	28.44037	1897.216	4.587156
Subject 12	740.7377	16.19048	1181.786	30.47619	1319.424	3.809524
MEAN	754.8876	44.49202	961.5633	23.8267	1278.423	11.63747
SD	111.0729	26.96892	206.5073	10.85604	368.5038	18.53111
A-Skip						
Subject 5	508.941	65.87838	584.2873	53.04054	1485.845	98.64865
Subject 7	412.8898	55.76923	627.9177	52.5641	1385.495	98.39744
Subject 10	378.7907	66.57143	853.475	50	1260.289	98.57143
Subject 11	390.2573	53.05556	964.0504	52.77778	1304.88	99.16667
Subject 12	744.5644	9.756098	1945.534	10.1626	877.6999	9.756098
MEAN	487.0887	50.20614	995.053	43.709	1262.842	80.90806
SD	152.792	23.39185	554.0616	18.79276	231.777	39.77619
B-Skip						
Subject 5	605.0658	85.2518	468.0669	95.68345	1243.177	1.079137
Subject 7	452.5184	60	927.1681	98.82353	2814.248	98.82353
Subject 10	365.1131	45.02924	1045.572	47.66082	1467.6	97.36842
Subject 11	378.022	51.94444	1000.672	49.16667	1395.817	98.88889
Subject 12	517.6037	60.64257	808.4519	53.81526	720.8891	35.74297
MEAN	463.6646	60.57361	849.9862	69.02995	1528.346	66.38059
SD	100.0937	15.2105	231.5732	25.88795	775.9036	45.47671

Table 6. Maximum angular velocity values at the hip, knee, and ankle for each subject used for kinematic analysis. Also listed is at what percent of the gait cycle the maximum value was attained.

Sprint	Hip Flex Min		Knee Flex Min		Ankle PF Max	
	Deg	% GC	Deg	% GC	Deg	% GC
Subject 5	-530.824	82.45614	-1142.67	76.31579	-1417.68	16.66667
Subject 7	-503.472	70.27027	-1052.27	100	-1238.05	24.32432
Subject 10	-692.617	15.44715	-750.573	75.60976	-1098.5	22.76423
Subject 11	-584.327	9.174312	-1279.4	73.3945	-1626.72	20.18349
Subject 12	-573.059	43.80952	-1203.5	77.14286	-1432.81	19.04762
MEAN	-576.86	44.23148	-1085.68	80.49258	-1362.75	20.59726
SD	72.41359	32.3916	204.9814	10.99353	201.8548	3.025265
A-Skip						
Subject 5	-652.312	90.54054	-946.767	90.54054	-530.188	39.52703
Subject 7	-457.356	94.87179	-501.004	91.02564	-212.04	11.85897
Subject 10	-449.254	88.85714	-700.292	88.85714	-534.894	55.42857
Subject 11	-478.341	89.72222	-763.63	90	-839.21	54.16667
Subject 12	-1179.91	11.38211	-2827.88	11.38211	-1094	11.38211
MEAN	-643.434	75.07476	-1147.91	74.36109	-642.067	34.47267
SD	311.2343	35.68042	952.5327	35.21557	336.1678	21.77787
B-Skip						
Subject 5	-759.407	87.76978	-785.77	83.81295	-557.658	88.48921
Subject 7	-592.768	92.05882	-972.578	89.70588	-476.117	94.70588
Subject 10	-567.413	47.36842	-864.074	86.54971	-922.689	88.59649
Subject 11	-440.905	88.88889	-797.961	88.05556	-830.017	52.22222
Subject 12	-477.817	89.55823	-749.21	1.606426	-752.973	2.008032
MEAN	-567.662	81.12883	-833.919	69.9461	-707.891	65.20437
SD	124.0323	18.93809	87.92407	38.26448	186.6646	39.12169

Table 7. Minimum angular velocity values at the hip, knee, and ankle for each subject used for kinematic analysis.

Subject	Sprint	A-Skip	B-Skip
1	277.5	106.2	99.6
2	219.6	101.1	90
3	244.5	97.5	90.9
4	249.6	89.7	88.5
5	286.8	95.4	97.8
6	255	98.1	95.7
7	266.7	92.4	88.5
8	222.9	87.3	84
9	236.1	86.7	84.6
10	234.3	86.7	87
11	269.4	91.2	87.6
12	284.1	104.7	111
MEAN	253.875	94.75	92.1
SD	23.16353423	6.864732002	7.738921701

Table 8. Stride rate data for all subjects used for spatiotemporal analysis.