A Kinematic Comparison of the Running A and B Drills with Sprinting

By

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TABLE OF CONTENTS

ABSTRACT

The A and B drills are two drills which are commonly used by sprinters as part of training. There is no scientific literature describing the biomechanics of these drills, nor are there any studies comparing these drills to sprinting technique. The purpose of this study was to compare the biomechanics of the A and B drills to sprinting. Eight university level sprinters were recruited to participate in the study. The participants completed the A and B drills as fast and as technically perfectly as possible, followed by two 60 metre runs at maximum speed. While performing the drills and sprinting, the participants were videotaped from the frontal and sagittal views. These videotapes were then used for a kinematic comparison of the drills and sprinting, based on select variables associated with sprint performance. One-way ANOVA was used to determine if significant differences existed among the three skills, with post-hoc tests determining where the differences were seen. There were significant differences in vertical displacement, vertical velocity, step frequency, support time, non-support time, shoulder range of motion (ROM), elbow flexion angular velocity (AV), trunk flexion, trunk rotation, pelvic rotation, hip flexion, hip extension AV, knee extension AV, ankle ROM, plantarflexion AV, and dorsiflexion AV. There were no significant differences in shoulder extension AV, elbow ROM, elbow extension AV, hip flexion AV, knee ROM, and knee flexion AV. Differences among the three skills were seen in the timing of peak angular velocity at the shoulder, hip, and knee. Differences among the three skills were also seen in the angle at which peak angular velocity occurred in the shoulder and ankle joint range of motion. From the results of this study, it was concluded that the kinematics in the A and B drills were not the same as sprinting. Coaches should be aware of these differences when incorporating the drills in training.

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LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Overview of Topic

There has been a fascination with running fast. It is a seemingly simple and straightforward action--move one foot in front of the other as fast as possible. Yet what is often overlooked is the high levels of neuromuscular co-ordination, the harmonious contraction and relaxation of specific muscle groups which enable the athlete to reach speeds of more than 12 metres per second (Gambetta, 1991) and produce the highest rate of striding and the fastest angular speed of leg movement of any running event. Sprinting, perhaps more than any other activity, is a demonstration of the achievement of the highest level of mechanical power output that the human body can achieve.

Running speed is important not only in athletics, but numerous other sports, such as soccer, baseball, and football. It is often the athlete who has the greatest speed who is the most successful. As a result, coaches, athletes, and sport scientists are all interested in developing techniques to improve peak running speed.

There has been extensive debate by coaches and athletes regarding the "nature versus nurture" aspect of sprinting, whether sprinting ability is something one "has," or if it is something one can develop. According to Radford (1984), sprinters are born *and* made. This means to achieve elite levels, athletes must be genetically endowed with the proper muscle fibre type and somatotype to be successful. They must also train tremendously hard for many years with the proper combination of coaching, scientific knowledge, and training methods to achieve top performance. Coaches must have knowledge and experience in periodization, the ability to train to achieve peak performance at a specific time. They must also understand their athletes, and know their strengths, weaknesses, and performance potential. Scientific coaching involves developing the proper balance of biomechanics, physiology, and psychology to exploit the potential of the "human machine." In order to achieve an "optimal" balance of the above factors, sophisticated training methods are needed.

Although sprint training programs for every coach may be slightly different, based on each individual's past experiences and personal philosophies, it is thought that there are certain key characteristics which make up a successful sprint training program. Hoskisson (1989) feels there are three important training factors which have a major effect on sprint performance. The first factor is speed training. Simply stated, a sprinter without speed will not be successful. Here the athlete performs short runs (20 to 60 metres) at maximum speed. The second factor is speed endurance in which the athlete must develop the ability to fight off or delay deceleration towards the end of a race. All things being equal, the sprinter who slows down the least will usually succeed. Speed endurance training involves the athlete running at near maximum speed for distances longer than they would perform in a race. For example, a 100 metre sprinter will run at near maximum speed for 150 to 300 metres. The third key characteristic is strength training. Without strength, neither speed or speed endurance can be developed to their fullest. Therefore, sprinters regularly perform strength training exercises such as squats, bench press, shoulder press, chin-ups, calf raises, cleans, plyometrics, and medicine ball exercises.

Although sprint training incorporates these three important factors, none of these work on the aspects of technique that make a good sprinter. These include staying on the balls of the feet, bringing the heel to the buttocks during recovery, driving the knee to parallel with the ground, driving the arms forcefully, relaxing the face and neck, and leaning slightly forward at the trunk (Carr, 1991). Therefore, sprinters regularly perform drills as a major component of their training. According to McFarlane (1994a), skill development involves performing specific drills which are designed to isolate and combine joints to rehearse a series of sensations that establish the exact motor pathways. Bell (1995), stated that drills create patterns of movement, and if performed numerous times correctly, will lead to more efficient neuromuscular patterns. This in turn will lead to better and more consistent performances.

As stated by McFarlane (1994b), there are drills that the sprinter performs which exhibit a high degree of specificity and meet the neuromuscular recruitment patterns of the sprinting, and are called the Basic Technical Model. Two of the drills of the Basic Technical Model which sprinters regularly perform are called the A drill and the B drill. The running A drill can be described basically as a rapid high knee lift or a march. The sprinter forcefully flexes the hip and lifts the thigh to horizontal, at the same time flexing the knee and bringing the heel to the buttocks. The hip and knee are then forcefully extended, and the foot is brought straight back to the ground under the body. The running B drill can be described as a rapid high knee lift, with knee extension prior to touchdown. The initial action is similar to the A drill, with hip flexion bringing the thigh to horizontal and knee flexion bringing the foot to the buttocks. But instead of bringing the foot straight back down to the ground (as in the running A drill), the knee extends prior to rapid hip extension, resulting in the foot following a circular path back to the ground. These drills are also known as the "Mach Drills" named after the developer of the drills, Gerard Mach. These drills provide the basis for the Mach system of sprint training (Mach 1980), which was developed by Mach as a result of over thirty years of track and field experience, both as a coach and as an athlete.

The A and B drills are frequently used by coaches and athletes as part of a sprint training program (McInnis, 1997; Gardiner, 1997; Bruce, 1996). They are frequently taught in a progression, beginning with A and B march, followed by A and B skip and A and B run. There are different ways in which the drills are used in the workout, based on the type of training being performed on that particular day. Varying the time of the workout at which the drills are performed, the intensity of the drill, and the distance covered during the drill will develop the different factors affecting sprint performance.

Various track and field articles (McFarlane, 1994a; McFarlane, 1994b; Lopez, 1995) and books (Carr, 1991; Bowerman & Freeman, 1991; Gambetta, 1991; Mach, 1980) advocate the use of the running A and B drills in sprint training. These books and articles describe the technical aspects of the drills from a coaches perspective, including coaching tips and drill variations. There is no scientific documentation describing or analyzing the biomechanics of these drills, nor is there any comparison of the biomechanics of these drills as compared to the biomechanics of sprinting.

Statement of the Problem

The purpose of this study was to examine the kinematics of the running A and B training drills, and to compare them to the kinematics of sprinting. This was performed by a kinematic analysis of select variables associated with both the running A and B drills and with sprinting. This study was intended to help determine the degree of specificity of these drills to sprinting.

Hypotheses

Because these drills are used extensively in sprint training, the hypotheses for this study are that no differences in the majority of the kinematic variables will exist between the running A drill and sprinting. Similarly, no differences in the majority of the kinematic variables will exist between the running B drill and sprinting.

Limitations

1. The subjects were not elite level sprinters.

2. There were limitations in the testing apparatus. The video cameras used record at a frame rate of 60 Hz, and did not allowed for accurate measurement of the high speed movements which occurred throughout the sprint stride.

3. To allow for examination of more than one step during sprinting, the initial and final portions of the run were analyzed outside the area calibrated by the calibration tree. Therefore, errors may be present in the data calculated from these areas.

4. Human errors may have occurred in the digitizing process in which joint centres may not have been accurately recorded, or systematic errors may have been introduced.

Delimitations

1. Only selected kinematic parameters of sprinting were considered in this biomechanical study.

2. Only university level track and field athletes who exhibited good technique as visually assessed by the author in performing the running A and B drills were selected as subjects.

3. Only the running versions of the A and B drills were analyzed.

Definition of Terms

ANGLE-ANGLE DIAGRAM - is a graph which plots one joint angle as a function of another joint angle at equal intervals of time.

ANGULAR IMPULSE - is the product of the torque and the time over which the torque acts, and is expressed in newton metres per second (Nm/s) (Hall, 1995).

ANGULAR MOMENTUM - is the quantity of angular motion possessed by a body that is equal to the product of the moment of inertia and the angular velocity, and is expressed in kilogram metres squared per second (kg m^2/s) (Hall, 1995).

BALLISTIC - movements which are performed with maximal velocity and acceleration (Zehr and Sale, 1994).

BASIC TECHNICAL MODEL - consists of exercises which exhibit a high degree of specificity and meet the motor demands of sprinting (McFarlane, 1994b).

CENTRE OF MASS - is the point about which the mass of an object is equally distributed. The centre of mass is not a fixed point, but is dependent on the arrangement of the segments and their relative masses.

DIGITIZING - is the process of converting the location of a specific object recorded on video tape to a cartesian or rectangular coordinate

DIRECT LINEAR TRANSFORMATION - a three dimensional reconstruction of two or more planar camera views with the use of a three dimensional calibration structure (Wood & Marshall, 1986).

IMPULSE - is the product of force and the time over which the force acts, and is expressed in Newton seconds (Ns) (Hall, 1995).

KINEMATICS - is the branch of biomechanics that is concerned with the description of how a body moves in space. It does involve the explanations of the causes behind the observed motion (Robertson & Sprigings, 1987).

KINETICS - is the branch of biomechanics which refers to the forces causing motion.

MOMENT (or TORQUE) - is defined as the product of the force and the perpendicular distance from the line of action of the force to the axis of rotation, and is expressed in Newton metres (Nm) (Gagnon, Robertson, & Norman, 1987).

MOMENT ARM - is the perpendicular distance from the line of action of the force to the axis of rotation.

MOMENT OF INERTIA - is a body or object's resistance to angular motion (Hay, 1993). It is the product of the mass and the radius of gyration squared, and is expressed in kilogram metres squared (kg m^2).

MOMENTUM - the quantity of linear motion that a body or object possesses. It is the product of the mass and the velocity, and is expressed in kilogram metres per second (kg m/s) (Hay, 1993).

NOISE - "Error present in data collected that is unrelated to the process being studied. Some noise is almost always present in data collected in biomechanics and most other fields. Some typical examples are noise caused by human error in digitizing film, electrical interference in EMG, or mechanical vibration in a force platform. Noise may be random or systematic, and different techniques must be used to eliminate different kinds of noise" (Rodgers & Cavanagh, 1984, p. 1893).

NON-SUPPORT or FLIGHT PHASE - is the phase of the sprint stride when either foot is not in contact with the ground.

SCALING FACTOR - a value obtained from an object of known length that represents a ratio of the actual size to the size of the screen in pixels. This ratio is then used to convert the digitized screen units to real life units (Peak Performance Technologies, 1992).

SMOOTHING - the minimization of data scatter that arises from experimental error. This provides the researcher with the simplest representation of the data that may adequately describe the underlying process (Wood, 1982).

SPECIFICITY PRINCIPLE - training for specific movements should be performed in the exact manner and position in which the movements will be performed (Anshel, Freedson, Hamill, Haywood, Horvat, & Plowman, 1991).

SPRINTER - is a track and field athlete who competes in distances of 400 metres or less (Carr, 1991).

SPRINTING - is running at or accelerating to maximum or near maximum speed; maximum speed approaches 12 metres/second in elite male and 11 metres/second in elite female sprinting (Gambetta, 1991).

STEP - is that part of the running action which commences at the moment when either foot terminates contact with the ground and continues until the opposite foot contacts the surface (Adrian & Cooper, 1989).

STRIDE - is identified by the termination of contact of a foot with the ground through the next contact of this same foot. One stride consists of two steps (Adrian & Cooper, 1989).

STEP FREQUENCY - is the number of steps per second.

SUPPORT PHASE - is the phase of the sprint stride when the foot is in contact with the ground.

CHAPTER II

REVIEW OF LITERATURE

Overview

There has been a great deal of literature published in the area of sprinting, particularly on the kinematics. Sprint training consists of various key components, including energy system development through running, strength training, and technical development through drills.

Phases of the Sprint Stride

As described by Schmolinski (1992) and Hay (1993), the sprint stride may be divided into a number of phases, according to their function and timing. In this study, these phases will facilitate discussion of the biomechanics of sprinting. The two main phases are when the runner is in contact with the ground (support phase), and when the runner is not in contact with the ground (non-support or flight phase). These phases are cyclic, repeating with each step.

The first phase, support, can be further divided into three sub-phases. The first is the resistive phase, when the foot contacts the ground in front of the centre of mass (see Figure 2-1, photo 1). Initial foot contact is on the outer edge of the sole high on the ball, and moves towards the inside as the whole ball of the foot makes contact under the weight of the body. The initial horizontal ground reaction force is a braking force, acting to slow down the sprinter. In sprinting, this phase is undesirable, as the whole purpose is to run fast, not to slow down. In most elite sprinters, this phase is very short in duration, and the foot lands in a position very close to the line of the centre of mass.

The second phase is the support phase, in which the centre of mass passes over the base of support (see Figure 2-1, photo 8). It is during this phase that the centre of mass is at its lowest. Support flexion occurs at the hip, knee, and ankle, resulting in an eccentric contraction of the extensor muscles at these joints. These actions produce the forces which cause the downward velocity to return to zero and cushion the force of the impact, based on the impulse-momentum relationship. They also put the extensor muscles on a stretch, which will trigger the stretch reflex, and will enable them to contract more forcefully in propulsion. All of the weight of the sprinter is balanced on the ball of the foot; the heel does not touch the ground. The distance between the ground and heel varies in individuals from a few millimetres to 3 or 4 centimetres (Schmolinski, 1992). This action decreases the vertical displacement of the centre of mass of the sprinter, enabling it to move faster in the support phase and the propulsive phase can be started earlier.

The third phase of support is the propulsive phase, where the body has passed over the centre of mass, and the powerful hip extensor and ankle plantarflexor muscles act to propel the runner forwards and upwards (see Figure 2-1, photo 3). According to Schmolinski (1992), this is the most important phase of the sprint stride. The velocity of propulsion depends mainly on the intensity and direction of the push-off force. Earlier studies (Bunn, 1978; Dillman, 1975) have indicated that "good" runners fully and rapidly extend the thigh about the hip joint before the foot leaves the ground, that "poor" runners do not obtain full extension of the knee until after the foot has left the ground. More recent studies (Mann, 1985; Mann & Herman, 1985; Tupa, Dzhalilov, & Shuvalov, 1991) have refuted this idea, stating that better sprinters tend to minimize knee extension at takeoff, thus minimizing ground contact time and increasing stride rate.

The non-support or flight phase follows support, and is characterized by the parabolic arc of the centre of mass while the athlete is airborne (see Figure 2-1, photo 4). The centre of mass reaches its highest point midway through this phase. Here, the recovery leg moves from behind the body to a position in front of the body in preparation for the next support phase. This is best accomplished by full flexion of the knee and dorsiflexion of the ankle, which act to decrease the moment of inertia of the leg and enable it to swing forward faster (see Figure 2-1, photo 8). The muscles of the recovery leg should be completely relaxed, to prevent unwanted resistance. According to Schmolinski (1992), the smallest angle between the lower leg and the thigh should take place at the moment when the knee points vertically downward. This will enable the thigh to be thrust forward and upward at maximum speed. As the thigh approaches the maximum angle of hip flexion possible for the individual, eccentric contraction of the hip extensor muscles slows this forward rotation and the lower leg swings forward in a relaxed movement (see Figure 2-1, photo 10).

The hip then begins to extend, due to powerful concentric contraction of the hip extensor muscles (see Figure 2-1, photo 13). With this action, the athlete attempts to achieve a backwards horizontal velocity of the foot at the instant of ground contact which is greater than the forward horizontal velocity of the centre of mass. This would result in a negative velocity of the foot relative to the centre of mass, and would produce a propulsive force on contact (Hay, 1993). According to Mann (1985), no sprinter has been

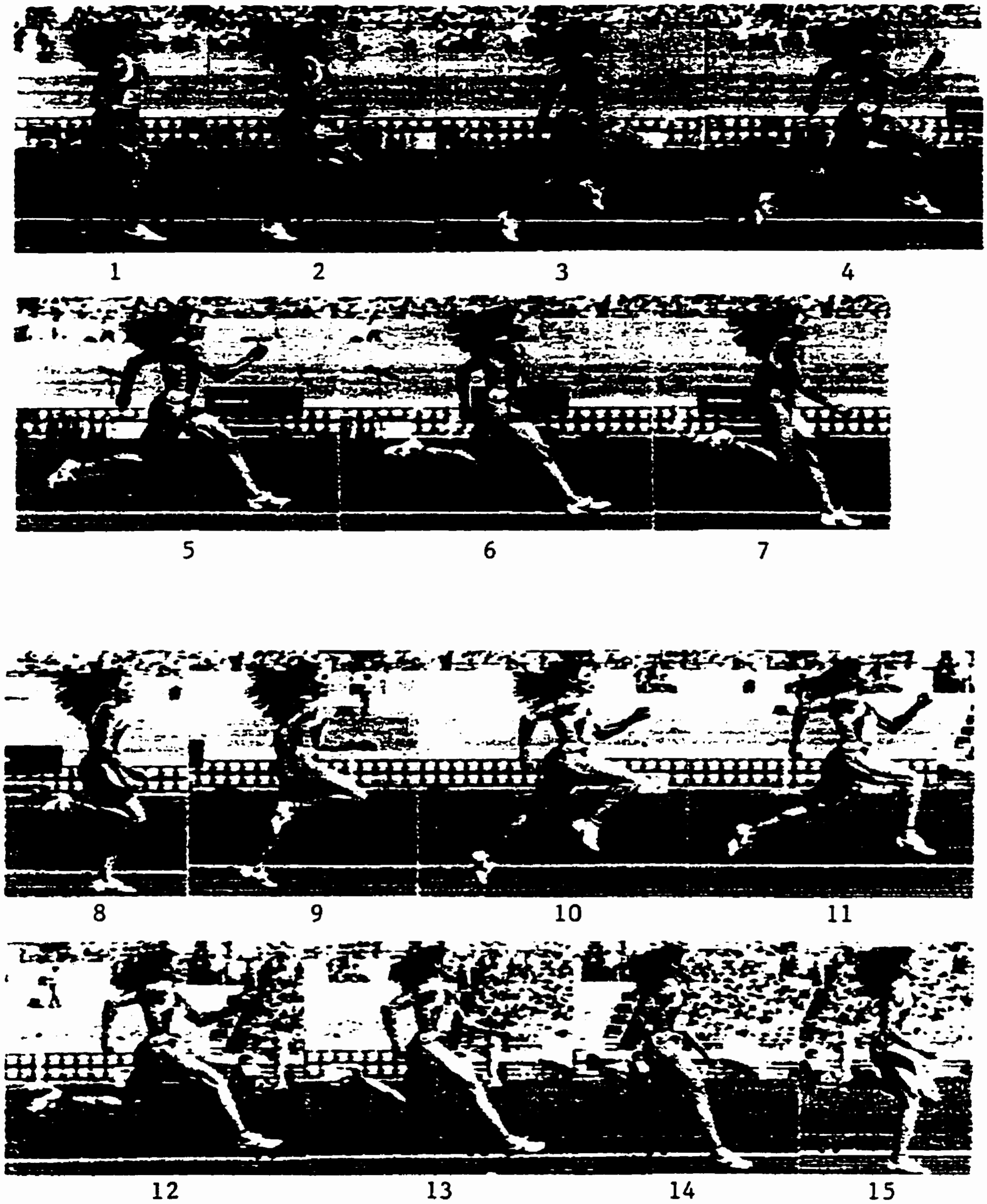


Figure 2-1. Photosequence of elite sprint technique (Hommel, 1991, pp. 74-75).

able to produce this negative foot velocity, which indicates that ground contact produces braking forces which act to slow the sprinter down.

Muscle Activity in Sprinting

Sprinters are noted for having muscular physiques, as sprinting is an action which involves powerful contractions of all the major muscles groups of the body. These muscles function in such a way that the resulting movements are smooth, precise, and fast.

Muscle Fibre Type

According to McArdle, Katch, and Katch, (1991), there are two distinct types of muscle fibres, based on their contractile and metabolic characteristics. The first are slow-twitch fibres, which are red in colour due to high levels of mitochondria and myoglobin, They are characterized by low speeds of contraction, and do not have well developed glycolytic capacity, which is required energy production in short term, high intensity exercise. Slow twitch fibres (type I) are fatigue resistant and are well suited for prolonged aerobic exercise. The second muscle fibre type are the fast-twitch fibres (type II). These fibres are white in colour due to their low levels of mitochondria and myoglobin. Fast-twitch fibres are capable of generating energy rapidly for quick, forceful muscle contractions. The intrinsic speed of contraction and tension in these fibres is two to three times as fast as that of slow twitch fibres (McArdle, Katch, & Katch, 1991). These fibres rely on having a well developed, short-term glycolytic system for energy transfer. Fast-twitch fibres are generally activated in short-term, sprint activities as well as other forceful muscular contractions that depend almost entirely on anaerobic metabolism for energy (McArdle, Katch, & Katch, 1991). A study by Mero, Jaakkola, and Komi (1991) found that young male athletes who participate in "fast" activities (sprinting, weightlifting, tennis) had 59 percent type II muscle fibres. They found significant relationships among muscle fibre type, reaction time, and rate of force production. The greater the percentage of type II muscle fibre, the faster the reaction time. Similarly, the greater the percentage of type II muscle fibre, the greater the rate of force production. Mero and Komi (1987) found that a group of trained male sprinters with personal best 100 metre times averaging 10.62 seconds had 64.3% fast twitch muscle fibre, while a second group of trained male sprinters with personal best 100 metre times averaging 10.96 seconds had 54.0% fast twitch muscle fibre. These results may have important implications for sprinting. Sprinting requires fast reaction time for starts, and high rates of muscle force production for rapid acceleration and for the development of a high peak horizontal velocity. Therefore, sprinters who possess a greater percentage of fast twitch (type II) muscle fibres may possess the attributes which may result in superior performance.

Muscular Activity of the Lower Body in Sprinting

Figure 2-2 outlines the electromyographic activity of various muscles of the trunk and legs during sprinting, as expressed as percent of the sprint stride cycle. The cycle starts at ground contact in the resistive phase, continues through the support and propulsive phases, and proceeds through the swing phase.

The iliacus muscle becomes active immediately after toe-off and remains active for approximately 150 milliseconds (Mann, Moran, and Dogherty, 1986), and is involved in initiating hip flexion. According to Mann et al. (1986), the iliopsoas, is the prime flexor of the hip joint, assisted by the rectus femoris and the tensor fascia latae via the iliotibial band. With increases in running speed, it is the activity of this muscle group that brings about the greatest change in the angular movement of the lower extremity. This may suggest that further increases in maximal running speed are facilitated by increased activity of the hip flexors (Mann et al., 1986).

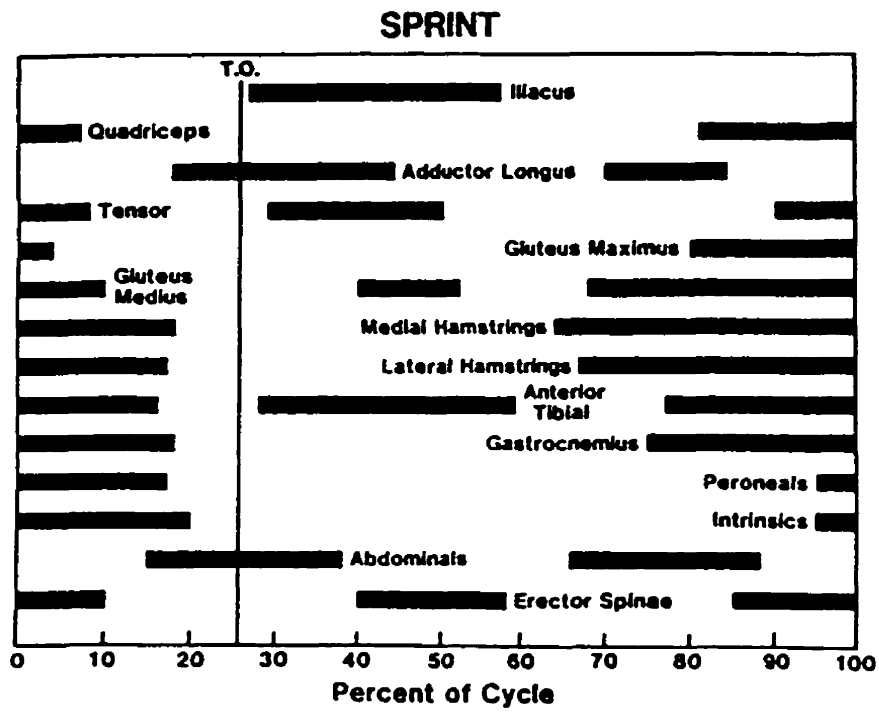


Figure 2-2. Lower body EMG during sprinting expressed as percent of cycle (Mann, Moran, & Dougherty, 1986, p. 509)

Three of the four quadriceps muscles (vastus medialis, vastus lateralis, and vastus intermedius) contract concentrically during the latter stages of the swing phase, when there is knee extension as the leg prepares for ground contact. Knee extension is initiated about 100 milliseconds prior to maximum hip flexion, and is secondary to the angular momentum developed by the rapid hip flexion. This extension occurs without any electrical activity in the quadriceps. The quadriceps muscle becomes active about 50 milliseconds after maximum hip flexion has been achieved (Mann et al., 1986). Knee extension is linked with hip flexion to produce forward movement of the lower extremity. Following foot contact and early midsupport, the quadriceps undergo an eccentric contraction. This eccentric contraction stabilizes the knee joint as support flexion occurs which helps to absorb the impact of foot contact (Mann et al., 1986), and prevents the lowering of the centre of mass during the support phase (Wiemann & Tidow, 1995). The knee extension which occurs during the propulsive phase is the result of the forward movement of the body over the fixed foot.

The fourth quadricep muscle (rectus femoris) shows activity which is unique from the other three quadricep muscles. This is due to the fact that it is a two-jointed muscle, crossing both the hip and knee joints. According to Mero and Komi (1987), the rectus femoris becomes active after ground contact and contracts eccentrically due to extension at the hip and flexion at the knee. During forward swing of the thigh during recovery, the rectus femoris contracts concentrically to assist in hip flexion. It is not very active, though, in extending the knee in preparation for ground contact. Mero and Komi (1987) concluded that the rectus femoris was more important as a hip flexor than as a knee extensor.

The adductor longus becomes active during toe-off, and remains active during follow-through and early forward swing. In addition, there is a short burst of activity during foot descent prior to ground contact. Exactly what role this muscle serves in sprinting is not clear, although during toe-off a lateral force is being exerted against the stance leg and abduction is occurring at the hip joint, as the contralateral hip is reaching maximum flexion. The adductor longus may be acting to stabilize the femur against the pelvis and undergoes eccentric contraction (Mann et al., 1986). Wiemann and Tidow (1995) believe it may be acting as a hip flexor, to decelerate the hip in hyperextension and initiate hip flexion The short burst of activity at the beginning of foot descent during sprinting may be to adduct the thigh to bring the foot toward the midline (Mann et al, 1986), to act as the antagonist muscle for the gluteus maximus to help stabilize the thigh during hip extension (Wiemann & Tidow, 1995), or it may act as a hip extensor.

The activities of the gluteus medius and tensor fascia latae provide abductor stability to the hip joint just prior to and after foot contact. At the time of foot contact, the femur in relation to the pelvis is adducted; therefore, these muscles undergo an eccentric contraction. Throughout the remainder of the support phase, as abduction occurs at the hip joint, they undergo concentric contraction (Mann et al., 1986).

The hamstrings (biceps femoris, semitendinosus, and semimembranosus) become active just prior to maximum hip flexion and shortly after the onset of knee extension. This muscle group, through an eccentric contraction, assists in controlling the hip as it approaches maximal hip flexion and then helps to modulate the rapid extension of the knee joint as well as contributing to extension of the hip joint. The hamstring activity continues into the support phase. The greater the speed, the longer the period of activity during the support phase, which lends further support to its activity as a hip extensor during support (Mann et al., 1986). Wiemann and Tidow (1995) reported that the activity of the hamstrings continues through the contact phase and right up to the initiation of forward swing, and feel that this prolonged muscular activity reflects the importance of these muscles in sprinting.

The gluteus maximus becomes active towards the end of the sprint cycle, where it functions in association with the hamstrings to decelerate the swinging limb in the forward direction, and initiate movement towards ground contact (Simonsen et al., 1985). Wiemann and Tidow (1995) found that the activity of the gluteus maximus continues through the resistive and support phases, and terminates late in support. These researchers feel that the role of the gluteus maximus is primarily in stabilization rather than propulsion, that the hamstrings are the muscles for propulsion in sprinting.

The muscles of the anterior compartment of the lower leg, represented by the tibialis anterior, demonstrates activity beginning after toe-off and continuing through the remainder of the swing phase and through the first half of the support phase. During sprinting, there is always an interruption in the electrical activity at the end of forward swing when plantar flexion of the ankle joint begins. During the swing phase the tibialis anterior functions to bring about dorsiflexion at the ankle joint, and following foot contact helps to stabilize the ankle joint and probably assists the dorsiflexion of the ankle joint, which occurs after foot contact until midsupport (Mann et al., 1986). It is not known if the tibialis anterior is responsible for accelerating the tibia over the support foot (Mann et al., 1986).

The gastrocnemius function, which represents the posterior calf muscles, demonstrates onset of activity during foot descent, providing stability to the ankle joint in preparation for foot contact. The activity of the gastrocnemius continues to foot contact and the midsupport phase. During this period of support, rapid dorsiflexion occurs at the ankle joint, and the gastrocnemius undergoes an eccentric contraction which controls the forward movement of the tibia over the fixed foot. It is this stabilization of the limb by the gastrocnemius, along with the forward movement of the trunk, that enables the knee to extend during toe-off. The gastrocnemius then undergoes a concentric contraction which initiates plantar flexion, which begins the propulsive phase. According to Mann et al. (1986), there is little or no push-off from the posterior calf musculature. It should be noted that during this same period of time the swinging limb, in particular the hip, is undergoing rapid flexion that reaches its peak just after plantar flexion of the ankle joint begins. It is therefore postulated that the majority of the forward propulsion during sprinting is brought about by the rapid hip flexion of the swing limb, rather than by push-off of the stance limb. This is in direct contrast to Mero and Komi (1987) who suggested that the gastrocnemius is active during the propulsive phase, indicating that they have a primary function in the propulsive phase of sprinting.

The peroneal muscles, which represent the lateral compartment muscles of the lower leg, become active late into swing phase during foot descent, and continue until shortly after foot contact. The intrinsic muscles of the foot are active during foot descent, and continue into ground contact, support, and early propulsion (Mann et al., 1986).

Muscular Activity of the Trunk and Upper Body in Sprinting

The muscle activity of the abdominals during sprinting is related to the forward and backward movement of the pelvis in the sagittal plane. The period of activity corresponds to the end of the hip extension when the pelvis is also reaching maximum extension or backward rotation. The abdominals would therefore be undergoing an eccentric contraction. The activity then continues after toe-off, through follow-through, and into early forward swing, during which time flexion of the hip is initiated. It is probable that the forward movement of the pelvis just precedes the onset of hip flexion and the pelvis movement is brought about by a concentric contraction of the abdominal muscles. The second period of activity occurs when the opposite extremity is undergoing the same movements (Mann et al., 1986).

In the upper trunk, there is a synchrony in the muscular activity of the pectoralis major, latissimus dorsi, and deltoid muscles. When forward swing of the arm at the shoulder is initiated, there is a concentric contraction of the anterior deltoid and pectoralis major. As the arm passes the body and approaches maximum forward flexion, the latissimus dorsi and posterior deltoid contract eccentrically to decelerate the arm forward, and begin contracting concentrically, accelerating it backward (Mero & Komi, 1987). Similarly, as the arm passes the body in its backwards movement, the pectoralis major and anterior deltoid begin to contract eccentrically to decelerate the limb, and begin forward flexion. According to Hinrichs (1990), EMG activity of the upper extremity approaches 60% maximum in the shoulder extensor muscles during running, which may indicate the importance of these muscles in the running stride.

In the upper arm, the muscular activity of the biceps brachii, brachioradialis and the triceps brachii are coordinated with the muscles of the trunk to enhance arm drive in sprinting. (see Figure 2-3.). Muscular activity begins in the biceps and brachioradialis when forward swing of the arm begins, which is before and during the braking phase of

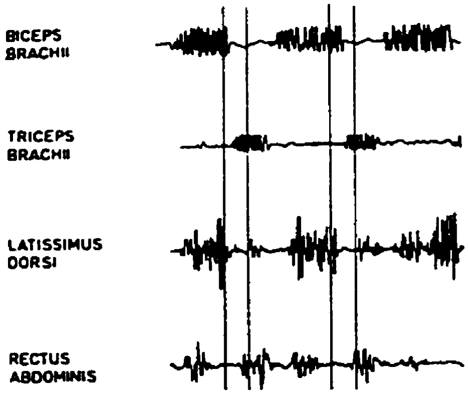


Figure 2-3. EMG activity during sprinting of the biceps brachii, triceps brachii, latissimus dorsi, and rectus abdominis. (Mero & Komi, 1987, p. 269). The first set of lines represents the period of contralateral ground contact, and the second set of lines is ipsilateral ground contact.

the ipsilateral leg. The activity continues until the arm is positioned in front of the body, where the triceps now contract to decelerate the arm forward, limit elbow flexion, and initiate backward swing. This tricep activity is approximately 100 to 120 milliseconds (Mero and Komi, 1987). As the arm swings backwards, the biceps and brachioradialis again contract, to limit the amount of extension of the elbow. This activity continues until midway through contralateral ground contact, when the triceps again briefly contract to slightly extend the elbow. As the arm approaches the end of backswing, the biceps contract to decelerate the arm (Hinrichs, 1985).

Kinematics of Sprinting

The term "kinematics" refers to the branch of biomechanics that is concerned with the description of how a body moves in space, without reference to the causes behind the observed motion (Robertson & Sprigings, 1987). It is the type of analysis that a coach would perform when watching his/her athletes train, as it is "what you see" when a skill is performed. A considerable amount of literature is available describing the kinematics of sprinting.

Horizontal Velocity

Generating a high horizontal velocity is the key to successful sprinting, as it is the athlete who can produce a high velocity and maintain it through the duration of a race who will win. Northrip, Logan, and McKinney (1974) claimed that the theoretical maximal horizontal velocity for humans during running is 12.9 m/s. Philips and Tibshirani (1997), in a summary of the 100 metres for Donovan Bailey at the 1996 Olympics, reported that during one ten metre segment of the race he achieved a horizontal velocity of 13.2 m/s. There are certain inaccuracies with this value, however. Firstly, the timing was only to a tenth of a second, so errors could be present in the accuracy of the interval times. Secondly, Swiss Timing, the official timing company of athletics at the 1996 Olympics, admitted to errors in the 70 and 80 metre interval times, where they neglected to correct for the 20 metre distance between the laser timing device and the blocks. Therefore, caution must be taken in accepting this velocity. Previous studies have reported horizontal velocities ranging from 8.85 m/s to 10.78 m/s (Armstrong, Costill, & Gehlsen, 1984; Luhtanen & Komi, 1978; Mann & Sprague, 1983; Mann & Herman, 1985), although these studies did not use elite level (world class) sprinters. A more recent study by Hoskisson and Korchemny (1991), in which elite junior sprinters were analyzed using high speed cinematography, found a maximal horizontal velocity 11.9 m/s. Similarly, in a biomechanical study of the men's 100 metre final at the World Championships in Athletics in 1991, the winner of the race, Carl Lewis, achieved a maximal horizontal velocity of 12.05 m/s (Ae, Ito, & Suzuki, 1992).

Vertical Displacement and Velocity

Vertical velocity in sprinting has been virtually ignored in academic research on sprinting, as it is the component of the resultant velocity which should be minimized. Mann (1985) found that "good" male sprinters attain a mean vertical velocity of 0.52 m/s, while "average" male sprinters reach 0.61 m/s, and "poor" male sprinters 0.69 m/s. This classification may be adequate as a general estimate of sprinting ability, but to categorize a sprinter according to their vertical velocity may not be an accurate representation of performance potential. A sprinter may have a vertical velocity larger than ideal, but still have a high horizontal velocity. Perhaps the resultant velocity may be the more important parameter to measure as it would take into consideration both the horizontal and vertical components of the velocity. Mero, Luhtanen and Komi (1986) found vertical velocities of 0.69 m/s for a group of 11 male sprinters (mean 100m time = 10.84 sec) and 0.62 m/s for 7 female sprinters (mean 100m time = 11.95 sec). According to Mann's classification, the males would be considered "poor" and the females "average" sprinters, which is hardly plausible based on each group's mean 100 metre time. These values, though, particularly the vertical velocity for the males, are higher than ideal and should be decreased to ensure that the athletes are maximizing the horizontal component of their velocity.

Although the key to top sprinting is maximizing horizontal velocity, some vertical displacement and velocity is necessary to allow for the recovery leg to swing forward in preparation for the next ground contact. The vertical displacement of the centre of mass has been reported at 5.0 cm by Mero, Luhtanen and Komi (1986). Luhtanen and Komi

(1978) reported somewhat larger vertical displacement values of 6.7 cm, but these values must be questioned as the subjects included in the study were not only sprinters, but also throwers, decathletes, and jumpers.

According to Mann (1986), the majority of the effort in sprinting is expended vertically, not horizontally. Once a sprinter has reached maximum velocity, the energy expended in the horizontal direction is minimal to maintain this velocity. At ground contact, the ground reaction force is acting in the negative direction, or opposite to the direction of travel. Therefore, the athlete slows down slightly, resulting in a loss of momentum. This is based on the impulse-momentum relationship, which states that the impulse of a force is equal to a change in momentum (Hay, 1993), where impulse is the product of force multiplied by time and momentum is the product of mass multiplied by velocity:

$$\text{Impulse} = \text{Change in Momentum}$$

$$F\,t = mv_f - mv_i$$

When the athlete is in propulsion, there is an increase in momentum due to an increase in velocity. This is because the ground reaction force is acting in the same direction as the sprinter, propelling him/her forward. During constant speed sprinting, the momentum lost in the resistive phase balances the momentum gained in the propulsive phase, so little energy is required to maintain horizontal velocity. In the vertical direction, though, the sprinter is coming down in the parabolic pathway of the centre of mass, where force generated by eccentric contraction of the hip and knee extensor muscles results in a decrease in vertical momentum as the vertical velocity is reduced to zero. This is immediately followed by concentric contraction of the same muscles which produces force to generate vertical momentum as the athlete again becomes airborne. This rapid reversal of vertical velocity, occurring in a period of 0.10 seconds or less (Burt, 1994), is where most of the energy is expended in sprinting.

Stride Length and Stride Frequency

Average running speed is the product of step length and step frequency:

Average Running Speed (m/s) = Step Length (m) x Step Frequency (steps/s)

A step is that part of the running action which begins at the moment when one foot terminates contact with the ground and continues until the opposite foot contacts the surface (Adrian and Cooper, 1989). The term "step" is frequently used interchangeably with "stride," which is incorrect as they refer to different phases of the sprinting stride. A stride is identified by the termination of contact of a foot with the ground through the next contact with the same foot, and involves two steps (Adrian and Cooper, 1989).

Step frequency is the number of steps per second, and is calculated by measuring step time. According to Hay and Reid (1988), step time may be considered the sum of the time the athlete is in contact with the ground (the support time), and the time during which the athlete is in the air (the non-support time). Step frequency is the inverse of step time. This means if one step is completed in half a second, the step frequency is two steps per second. It is a combination of a long step length and a high step frequency which is an indication of a fast runner, all other things being equal. If a short runner wants to achieve a fast running speed, this runner will have to take more steps per unit time than a long-legged runner, whose step will usually be longer.

It has been reported that initial increases in speed by an experienced runner are a result of an increased step length. After a step of optimal length has been attained, further increases in speed become a matter of increasing step frequency (Adrian & Cooper, 1989). Luhtanen and Komi (1978) found that step length leveled off at high velocities, whereas step rate continued to increase (Figure 2-4.).

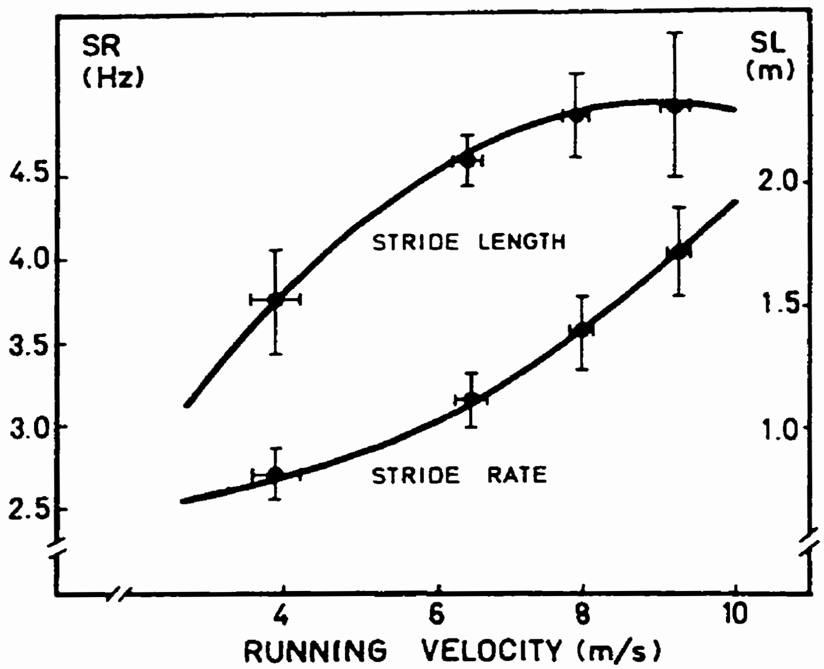


Figure 2-4. Stride length and stride frequency when measured at various running velocities (Luhtanen & Komi, 1978, p. 25.) The terms "stride length" and "stride rate" are used incorrectly on this graph, and should read "step length" "and "step rate."

According to Hay (1993), step length is the sum of three separate distances: (1) the take-off distance, which is the horizontal distance that the centre of mass is forward of the toe of the take-off foot the instant it leaves the ground, (2) the flight distance, which is the horizontal distance that the centre of mass travels while the runner is in the air, and (3) the landing distance, which is the horizontal distance the toe of the leading foot is in front of the centre of mass the instant of ground contact (Figure 2-5.).

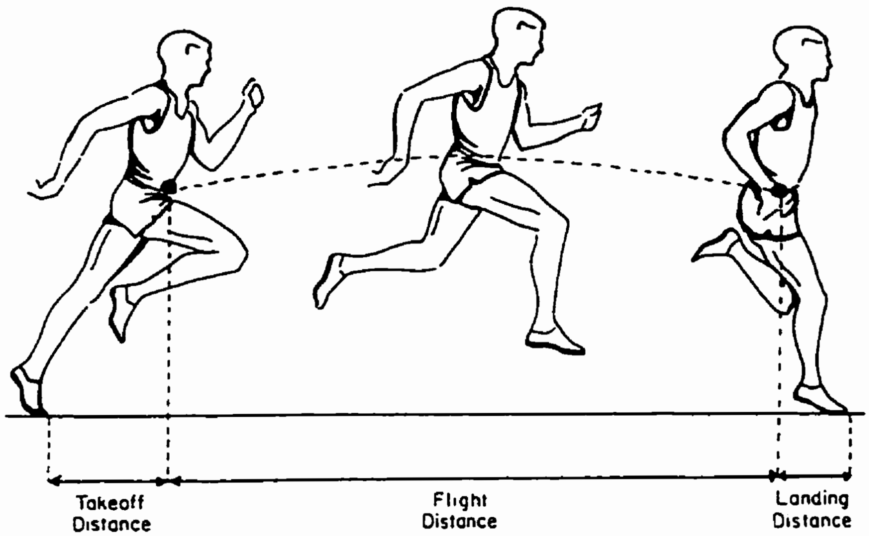


Figure 2-5. Contributions to step length in sprinting (Hay, 1993, p. 398).

The average maximum step length of top male sprinters has been reported as 2.25 m (Nummela, Vuorimaa, & Rusko, 1992) in national level sprinters, while Hoskisson and Korchemny (1991) have found values in elite junior sprinters ranging from 2.25 to 2.36 m. Maximum step lengths for the eight finalists from the 100 metre final at the 1991 World Championships in Athletics ranged from 2.52 to 2.72 m (Ae, Ito, and Suzuki, 1992) which may indicate that step length is a very individual characteristic, even in elite sprinters. For women, values from 1.81 to 2.17 m have been reported for internationally ranked sprinters (Levtshenko, 1990) with similar values of 1.87 to 2.02 m found in German and American female sprinters in an international dual meet (Baumann, 1985). These values may be used as a guide for "normal" stride lengths of male and female sprinters, but there was no indication in these reports of the heights of the athletes. It is incorrect to state that these reported values are ideal for all sprinters. Mero, Luhtanen and Komi (1986) reported step lengths of 2.16 m for male sprinters (mean height = 1.80m), and 1.91m for female sprinters (mean height = 1.67m). The value for males is noticeably lower than those of Nummela, Vuorimaa, and Rusko (1992) and Hoskinsson and Korchemny (1991), but the sprinters in this study were not elite level (mean 100m time = 10.84 sec), so their stride length would expectedly be less. Hoffman (1971), in performing a regression analysis on sprinter's height and stride length, found the maximum stride length of male sprinters with personal best 100 metre times of 10.7 seconds or less is equal to 1.265 times the athlete's overall standing height. This is similar to Chengzhi (1991), who found that the average step length of the eight finalists for the men's 100 metres at the 1988 Olympics was 1.24 times the average height of the athletes.

According to Adrian and Cooper (1989), as the speed of running increases, the non-support time increases and the support time decreases. Hay (1993) reported the time in the support phase may be as low as 40% to 45% of the step time. Mann and Herman (1985), in a kinematic study of the men's 200 metres at the 1984 Olympics, found the the gold and silver medalists were in support for 43.4% and 45.8% of step time, respectively. They also found the eighth place finisher in the race was in support 52% of step time. This may indicate that the time period of ground contact is important as it may be directly related to the velocity the sprinter can generate (Mann, 1986), which is based on the impulse-momentum relationship. Impulse is the product of force multiplied by time, while momentum is the product of mass multiplied by velocity. Increases in running velocity would result in a greater impulse applied to the ground during contact. If the time over which this impulse is applied decreases, the result would be an increase in the force applied to the ground, and therefore an increase in the ground reaction forces acting to propel the sprinter forward. Hay and Reid (1988) reported that the support phase in elite sprinters is approximately 0.07 to 0.09 seconds when running at maximum speed. This is similar to the support time of 0.09 seconds reported by Mero, Luhtanen and Komi (1986), and the 0.10 seconds found by Burt (1994) in studies of elite sprinters. In a study comparing collegiate level and elite level sprinters, Mann and Herman (1985) found significant differences in the stride frequency (elite higher) and support time (elite lower). No significant differences were found, however, in stride length or non-support time. These results may suggest which factors are more important in sprinting success, that a greater stride frequency and a shorter support time may increase performance, and that improving stride length and non-support may not result in faster sprinting speeds.

According to Mero, Luhtanen, and Komi (1986), top female sprinters achieve a step frequency of 4.55 steps per second when running at maximum speed. This is similar to the 4.48 steps per second found by Hoffman (1971). For males, Hoskisson and Korchemny (1991) reported step frequencies up to 5.17 steps per second in elite junior sprinters. Stride frequencies of the eight finalists of the 100 metres at the 1991 World Championships in Athletics ranged from 4.75 to 5.02 steps per second (Ae, Ito, and Suzuki, 1992). Mann (1985) reported "good" male sprinters achieve a stride rate of 4.8 steps per second, while "average" male sprinters achieve 4.5 steps per second and "poor" male sprinters achieve 4.2 steps per second. It may expected that elite level male sprinters will have a greater step frequency than females, as they have a faster running velocity, and possess greater strength and power.

Lower Body Kinematics

The keys to successful sprinting lie in the kinematics of the lower body, as it is the movements of the legs throughout the sprint stride which influence the ground reaction forces generated during ground contact to produce high running speeds. According to Mann (1986), sprinting improvement lies in the leg action just prior to and during ground contact, as it was found that elite sprinters minimize upper leg range of motion during ground contact, as well as producing greater support leg speed. Thus, ground contact time is decreased by generating high leg speed prior to ground contact, touching down closer to the body centre of mass, maintaining the leg speed during ground contact, and getting airborne as quickly as possible. Early researchers (Bunn, 1978, Dillman, 1975) have stated that one of the most common errors in sprinters is incomplete leg extension at take-off and after take-off. This is in contrast to Mann (1985), who found that in elite sprinters there was a lack of knee extension at toe-off, which helps to minimize ground contact time (see Figure 2-6.). Kinematic studies confirm this, in which maximum knee extension angles of 155.7^0 (Hoskisson & Korchemny, 1991) and 165^0 (Tupa, Dzhalilov, & Shuvalov, 1991) have been noted. As stated by Mann (1986, p.3001) "in the possible tradeoff of greater leg extension to increase speed versus abbreviated leg extension to decrease ground contact time, it appears that the latter produces better results."

As the driving foot leaves the ground, the entire leg must rotate forward, accelerating to catch up and pass the body, and then rotate back in order to push against

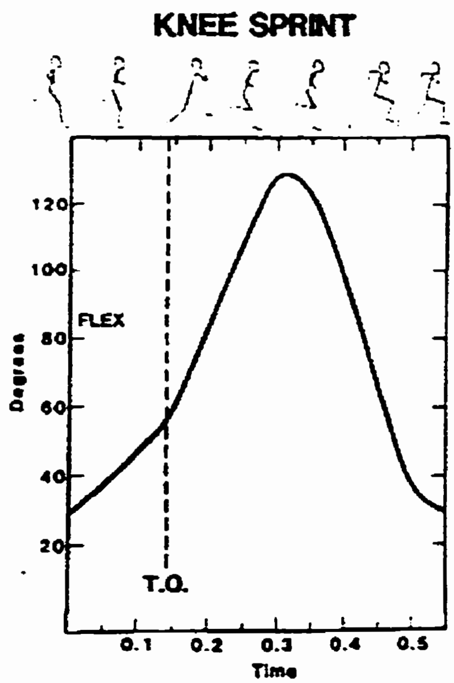


Figure 2-6. Range of motion at the knee during sprinting (Mann et al., p. 505).

the ground again. The faster the horizontal velocity of the sprinter, the faster the leg must recover. An increased recovery speed is accomplished by more forceful hip flexion torque, and by increased flexion at the knee and dorsiflexion at the ankle. These movements act to decrease the length of the lever, thus decreasing the moment of inertia of the leg. Moment of inertia (symbol I) is the resistance of a body or object to angular motion (Hay, 1993). It is the product of the mass of the body or object (m) and the radius of gyration (k) squared, which is the "distance from the axis of rotation to a point where the body's mass could be concentrated without altering its rotational characteristics" (Hall, 1995, p. 439). The units for moment of inertia are kg m^2.

$$I\ (\mathrm{kg\ m^2}) = m\ (\mathrm{kg}) \times k^2\ (\mathrm{m^2})$$

According to Dare (1994), the amount of knee flexion of the recovery leg is to some extent an individual characteristic of a sprinter, depending on individual morphology. Some runners have maximal knee flexion, in which the foot comes into contact with the buttocks, while in others it is less pronounced and the foot simply follows the action of the knee and is swung forward. Ideally, the knee flexion should be maximal for each sprinter, as it will decrease effort and save energy (Tupa, Dzhalilov, & Shuvalov, 1991). Hoskisson and Korchemny (1991) found the angle of maximum knee flexion between the thigh and the shank to be 32.5^0. This is somewhat smaller than the 38.7^0 found by Tupa, Dzhalilov, and Shuvalov (1991) which may indicate that the amount of knee flexion is indeed an individual characteristic of sprinters.

Lemaire and Robertson (1990), in a study of internationally ranked Canadian and American sprinters, found knee flexion angular velocities of 1030 degrees/second. Chengzhi and Zongcheng (1987) found larger knee flexion angular velocities of approximately 1400 degrees/second in sprinters with personal best 100 metre times of 10.0 to 10.1 seconds. These peak knee angular velocity values occur as a result of hip flexion during the forward swing of the recovery leg. This knee flexion occurs passively, as EMG studies (Wiemann & Tidow, 1995; Mann, et al., 1986) have found that there is no activity of the hamstring muscles during this knee flexion.

As the foot accelerates ahead of the body, hip flexion occurs and the thigh is driven forwards and upwards. It is this forceful hip flexion which increases the forces applied to the ground, thus increasing the ground reaction forces which act to propel the sprinter forwards. This is based on Newton' s third law of motion, which states "to every action, there is always opposed an equal reaction" (Hamill & Knutzen, 1995, p. 397). Therefore, the greater the hip flexion torque, the greater the ground reaction force. In an article by Dare (1994), hip flexion is described as being a result of the ground reaction forces imparted to the leg in contact with the ground: the greater the ground reaction force, the greater the running speed, and therefore more hip flexion. It is incorrect to describe hip flexion as being a result of ground reaction force, as this method of thinking does not follow the law of "action-reaction."

Hoskisson and Korchemny (1991) found the minimum angle of hip flexion between the trunk and the thigh to be 101.2^0 in elite junior sprinters, with Mann et al. (1986) reporting a similar value of approximately 100^0 (see Figure 2-7.). High knee lift is a necessary component of fast sprinting, as it helps to ensure the production of hip extension angular velocity (Mann & Herman, 1985), possibly by initiating a stretch reflex of the hip extensor muscles.

Lemaire and Robertson (1990) found a hip flexion angular velocity value of 969 degrees/second. This is similar to the approximately 900 degrees/second reported by Chengzhi and Zongcheng (1987), but is considerably larger than the hip flexion angular velocity value of almost 600 degrees/second reported by Mann (1985). The large discrepancy between these angular velocities are interesting, as the subjects in each of these studies were elite level sprinters, and demonstrated ideal maximum knee flexion angles of approximately 33^0 (Chengzhi & Zongcheng, 1987) and 31^0 (Mann, 1985).

Ground contact of the foot should occur as closely beneath the centre of mass as possible (Deshon & Nelson, 1968), with distances of 6-8 centimetres from foot contact to centre of mass reported (Mann, 1985). The closer the ground contact occurs beneath the centre of mass, the smaller the horizontal braking force will be which slows down the sprinter. Payne, Slater, and Telford (1968), however, found that even when the foot was placed directly beneath the centre of mass, it was still not able to prevent unwanted braking.

Hip extension angular velocities of 912 degrees/second have been reported by Lemaire & Robertson (1990), which are much larger than the values of approximately 600 degrees/second (Chengzhi & Zongcheng, 1987) and 500 degrees/second (Mann, 1985) which have been reported in other studies. Hip extension angular velocity should be maximized in sprinting in an attempt to achieve a linear velocity of the foot at the instant of ground contact which is equal to or greater than the horizontal velocity of the centre of mass in the opposite direction, which is commonly referred to as "negative foot velocity." According to Hay (1993), during the flight phase the centre of mass of the

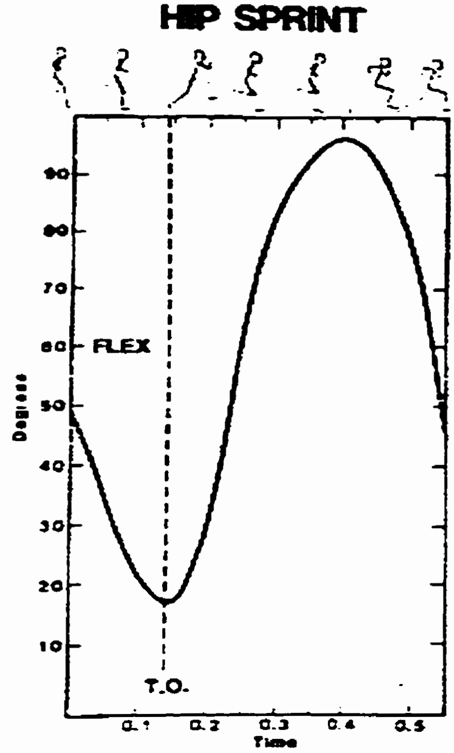


Figure 2-7. Range of motion at the hip during sprinting (Mann et al., 1986, p. 504).

sprinter is moving forward with a constant horizontal velocity as determined at the instant of take-off, neglecting the effects of air resistance. The other parts of the body are moving forwards or backwards relative to the centre of mass, and will therefore have a horizontal velocity which will be greater or less than the horizontal velocity of the centre of mass. For example, in Figure 2-8(a), the horizontal velocity of the centre of mass of the sprinter is 10 m/s, while at the instant of ground contact the foot is moving backwards with a velocity of 7 m/s. This means the foot is moving backwards with a horizontal velocity of 3 m/s relative the centre of mass. In Figure 2-8(b), the horizontal velocity of centre of mass is 10 m/s, and the foot is moving backwards with a velocity of 12 m/s, indicating that the foot is moving backwards with a horizontal velocity of -2 m/s.

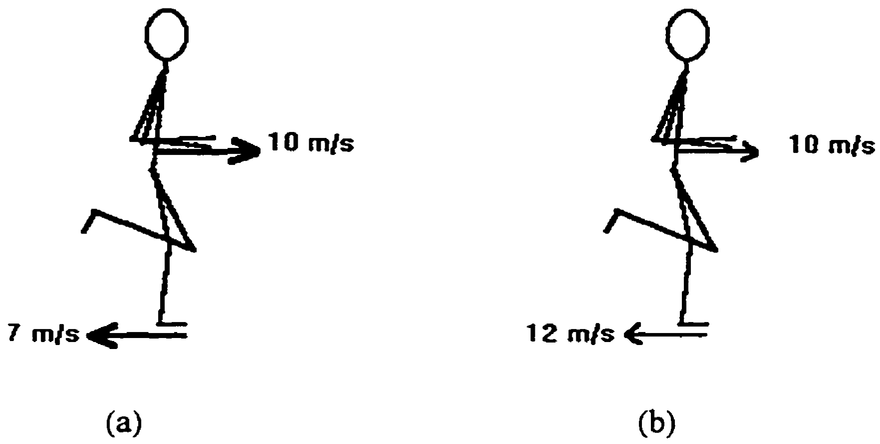


Figure 2-8. Horizontal velocity of the foot at the instant of contact relative to the centre of mass. a) The foot is moving backwards with a velocity of 3 m/s relative to the centre of mass, resulting in a braking force. b) The foot is moving backwards with a velocity of -2 m/s relative to the centre of mass, resulting in a propulsive force.

The horizontal velocity of the foot determines if there is a braking effect at the instant of ground contact (Hay, 1993). If the foot is moving backwards with a horizontal velocity less than that of the centre of mass, the result will be a braking force on contact. Therefore to prevent unwanted braking, sprinters attempt to generate a negative foot velocity which is equal to or greater than the horizontal velocity of the centre of mass. According to Mann (1985), no sprinter has been able to recover the foot so that it is moving backwards with a horizontal velocity greater than the forward horizontal velocity of the centre of mass. Mann and Herman (1985) found foot horizontal velocities of -7.93, -5.84, and -6.47 m/s in 200 metre sprinters, where the negative sign indicated the direction of foot travel was backwards with respect to the centre of mass. These athletes achieved average centre of mass horizontal velocities of 10.21, 9.93, and 9.29 m/s respectively, indicating the backwards horizontal foot velocity did not exceed that of the centre of mass forward and there would have been a braking force on contact. Mann

(1985) found that "good" male 100 metre sprinters attained horizontal foot velocities of approximately 1.7 m/s relative to the centre of mass, while "average" sprinters achieved approximately 2.6 m/s and "poor" sprinters achieved approximately 3.5m/s. Better sprinters are able to minimize the braking force on ground contact by decreasing the horizontal velocity of the foot at the instant of ground contact.

Recovery knee extension angular velocities of 1200 degrees/second (Lemaire & Robertson, 1990) and approximately 1300 degrees/second (Chengzhi & Zongcheng, 1987) have been reported. Knee extension occurs passively, as Wiemann and Tidow (1995) and Mann et al. (1986) found that there is minimal EMG activity in the quadriceps during this portion of recovery. These values were found late in the recovery phase, and occurred in association with the deceleration of hip flexion followed by rapid hip extension (see Figure 2-9.). This is due to the summation of speed principle, which states

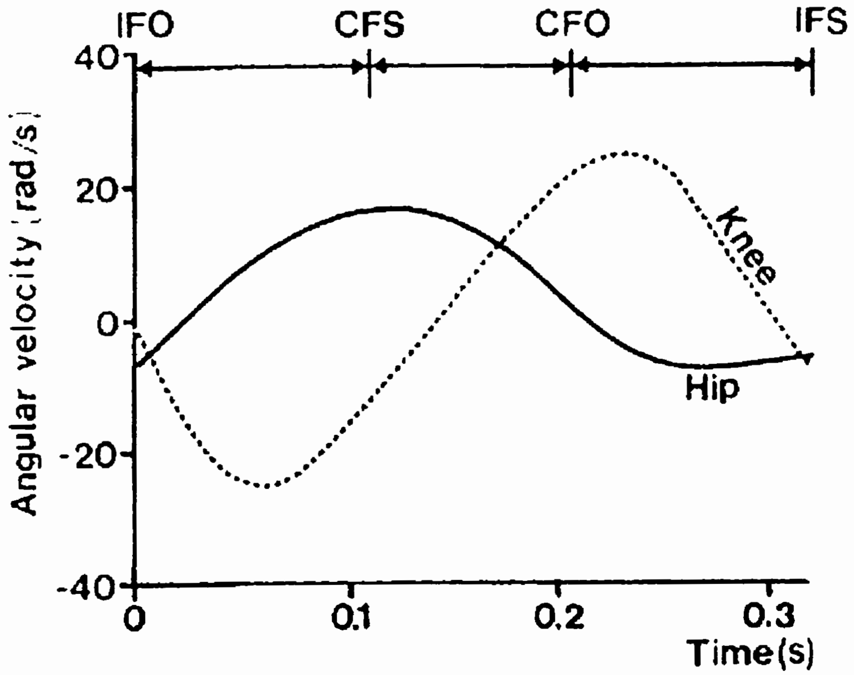


Figure 2-9. Angular velocity curves of the hip and knee for the swing leg during recovery. IFO = ipsilateral foot take-off; CFS = contralateral foot strike; CFO = contralateral foot take-off; IFS = ipsilateral foot strike (Chengzhi & Zongcheng, 1987, p. 826).

that body segments move in sequence, starting with the more proximal segments and ending with the more distal segments, with the motion of each segment starting at the moment of greatest speed of the preceeding segment. The summation effect is such that the more distal the segment, the faster it will eventually move (Dyson, 1986).

At the ankle, the foot is primarily plantarflexed throughout the sprinting stride (see Figure 2-10.). It is only during the support phase when the body passes over the foot in contact with the ground that dorsiflexion occurs, with a value of approximately 10^0.

Maximum plantarflexion occurs at the toe-off, where values of approximately 24^0 have been reported (Mann et al, 1986) in male sprinters, although the ability of these athletes was not indicated. Hoskisson and Korchemny (1991), reported maximum plantarflexion values in elite junior sprinters of 14.2^0. A decreased range of

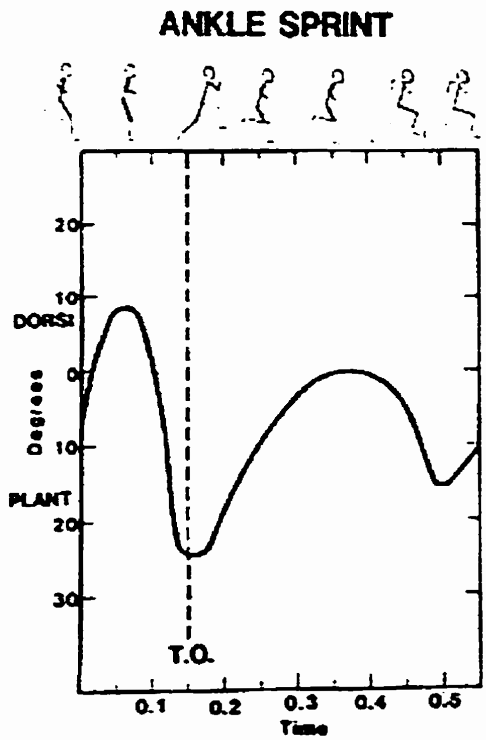


Figure 2-10. Range of motion at the ankle during sprinting (Mann et al., 1986, p. 507).

plantarflexion may be more desirable in sprinting, as limiting the amount of plantarflexion may help decrease the contact time. After toe-off, dorsiflexion occurs at the ankle, but the foot is only brought approximately to a neutral position. This action may help decrease the moment of inertia or the resistance to angular motion of the recovery leg, allowing it to swing forward faster and with less muscular effort.

Upper Body Kinematics

During running, pelvic rotation occurs in association with the phases of the leg action. When the left thigh is flexed late in the recovery phase and the right thigh is extended in the propulsion phase, there is a rotation of the pelvis towards the right. As the left thigh is extended through the support phase and the right thigh is flexed in recovery, there is a rotation of the pelvis towards the left. Maximum pelvic rotation occurs when the left thigh approaches maximum flexion (Hay, 1993). The movements of the legs and pelvis produce angular momentum about the longitudinal axis of the sprinter through the centre of mass. This angular momentum must be balanced by actions of the trunk and arms to ensure that the total angular momentum is minimized and the athlete runs with minimal trunk rotation. At slow running speeds, this is accomplished by a slight twisting of the trunk, with moderate accompanying arm action. Because the trunk is more massive, its rotation will counteract most of the angular momentum, while the arms simply swing easily with the body. At sprinting speeds, the trunk cannot twist and untwist fast enough to keep up with the legs. Therefore, counteracting the angular momentum of the legs and pelvis is the role of the arms, which means a forceful arm action is more evident and more important in skilled sprinting.

The actions of the arms during running, both at the shoulder and at the elbow, are closely associated with the movements of the legs. Hinrichs (1985) stated that shoulder flexion ended shortly after ipsilateral toe-off, while shoulder extension ended shortly after contralateral toe-off (Figure 2-11.). Throughout the running stride, the shoulder angle is

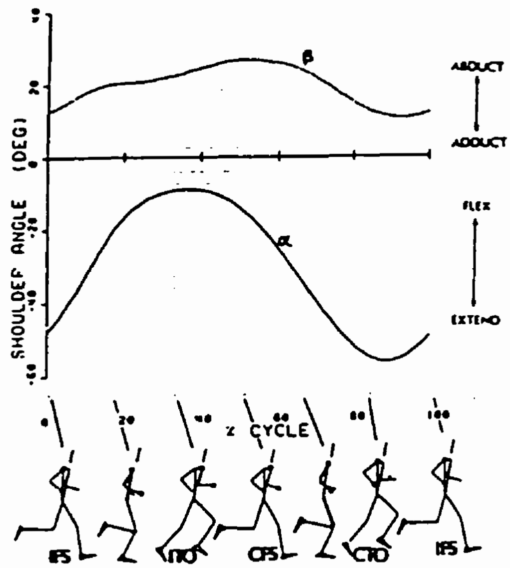


Figure 2-11. Range of motion at the shoulder during running (Hinrichs, 1985, p. 339).

one of extension relative to the trunk. The shoulder does not reach a position of flexion at slow running speeds. During sprinting, there is a greater range of motion seen at the shoulder, in which the shoulder flexes relative to the trunk during ipsilateral toe-off.

At the elbow, instead of a single phase of flexion and hyperextension per cycle as in the shoulder, the elbow showed two phases per cycle. The primary extension phase (PEP) occurred around ipsilateral foot strike, followed by a much smaller secondary extension phase (SEP) around contralateral foot strike. Maximum elbow flexion occurred during ipsilateral toe-off (Figure 2-12.). The elbow was maintained in a flexed position at an angle of approximately 100^0, with small derivations from this angle throughout the running stride.

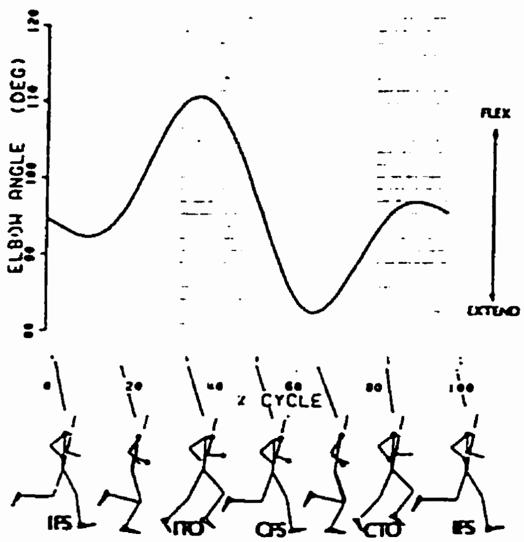


Figure 2-12. Range of motion at the elbow during running (Hinrichs, 1985, p. 340).

According to Dare (1994), there are four key characteristics of the arm action in sprinting:

1) The arms swing parallel to one another, primarily in the sagittal plane.

2) The arm action in the forward direction is forceful, fast and upward, where angle between the upper arm and the forearm is approximately 60^0. The upward motion of the hand concludes between the nipple and the chin.

3) The arm action in the backwards direction is forceful, and there is an extension of the elbow resulting in an angle between the forearm and upper arm of approximately 100-115^0. The hand extends to the buttocks.

4) The hand is held in a closed, loose fist-hand or open-flat hand with the thumbs pointing upwards.

Mann and Herman (1985) found shoulder flexion angles of 80^0, 75^0, and 81^0 relative to the trunk in the first, second, and eighth place finishers of the men's 200 metre sprint at the 1984 Olympics. They also reported shoulder hyperextension angles of 55^0,

47^{0}, and 37^{0} relative to the trunk for the same three competitors. Mann (1985), in his analysis of elite sprinters and hurdlers, found that "good" sprinters demonstrate shoulder flexion angles of approximately 80^{0}, and shoulder hyperextension angles of approximately 52^{0}, as measured from the trunk. These values are similar to those of "average' sprinters, but "poor" sprinters show greater angles of shoulder flexion (88^{0}) and shoulder hyperextension (62^{0}). According to Mann (1985), this excessive arm action is a sign of uneconomical arm motion, and is an indication of overstriding. It may also be an indication that the sprinter lacks the upper body strength to control the angular motion of the arm at the shoulder. Similarly, Mann (1985) found that "good" sprinters minimize the range of motion at the elbow, where a maximum elbow flexion angle of 140^{0} from full extension and a minimum elbow flexion angle of 73^{0} from full extension were noted. The maximum elbow flexion angle was found during the forward swing of the arm, and the minimum elbow flexion angle was found during the backward swing. "Average" sprinters demonstrate similar range of motion values to those of "good" sprinters, while "poor" sprinters again showed greater maximum and minimum angles of elbow flexion.

Mann and Herman (1985), in their study of the men's 200 metre sprint at the 1984 Olympics, found the average shoulder flexion angular velocity of the first, second, and eighth place finishers to be 525, 500, and 490 degrees/second. They also found average shoulder extension angular velocities of these same three finishers to be 740, 558, and 572 degrees/second.

An EMG analysis of the upper body during running by Hinrichs (1985) found that the arm action consists of a forward swing (flexion phase of the shoulder) which ends shortly after ipsilateral toe-off, and is followed by a backward swing (extension phase of the shoulder) which ends shortly after contralateral toe-off. This study did not analyze the EMG activity of the arms during sprinting, nor did it discuss how the muscular activity might be similar or different in sprinting as compared to running.

In a study by Mann (1986), in which the kinematics of college and elite sprinters were compared, it was found that neither the arm velocity, arm position, or anything that the arms were doing was significantly related to any of the variables critical to sprinting speed (that is, horizontal velocity, stride rate, and support time). What was found to be different was the time spent at the "dead-end" position, the position when the arm's angular velocity decreases to zero and begins to accelerate in the opposite direction. Elite level sprinters did not hesitate in this position as long as the college level sprinters. Thus, this researcher stated that increasing the angular velocity of the arms may not be necessary to increase running velocity, but decreasing the time in the dead-end positions.

The terms "lift" and "drive" refer to segmental contributions of the arms to the impulses of the runner during the propulsive phase of the running cycle. Lift refers to the impulses in the vertical direction, while drive refers to the impulses in the anteroposterior direction. Hinrichs (1990) reported that at slow running speeds the arms contributed approximately 5% of the total lift, while the trunk contributed -3% and the legs 98%. At fast running speeds, the arms contributed 7%, while the trunk contributed -3% and the legs 96%. This suggests that as running speed increases, the contribution of the arms to lift increases, while the contribution by the legs decreases. In the forward direction, the arms did not provide any significant contributions to drive at any running speed. This was because the forward momentum of one arm was canceled out by the backward relative momentum of the other arm.

Luhtanen and Komi (1978) found the arms contribute a mean of 199 N to the vertical component of the ground reaction force during the propulsive phase of sprinting. The mean ground reaction force acting on the entire body was 1452 N, which indicated that the arms contributed 13.7%. This contribution was considerably different from that reported by Hinrichs (1990), and may be attributed to the fact that the subjects in this study were sprinting while Hinrich's subjects were fast running. During sprinting, the arms make a significant contribution to the vertical component of the ground reaction force. In the horizontal direction, the arms did not make any beneficial contribution to the ground reaction force. The arms contributed a mean of -124 N, which indicated that the arms actually acted to slow the sprinter down by decreasing the force in the horizontal direction.

Kinematics of the Trunk

Forward lean of the trunk is key for proper sprint mechanics. During the initial portion of a run there is excessive trunk lean, where the centre of mass is located in front of the supporting foot to increase acceleration. At constant running speeds, trunk lean is less pronounced. According to Hay (1993), trunk lean assists in controlling the rotation of the sprinter which occurs due to the off-centre forces acting on the body. During the propulsive phase of sprinting, the ground reaction force acting to propel the sprinter forward may be divided into horizontal and vertical components: R_H and R_V. (see Figure 2-13.). There is also an air resistance force (A) acting to oppose motion. Each of these are off-centre or eccentric forces acting at a distance from the centre of mass of the athlete with perpendicular distances of Y_H, X, and Y_A, respectively. Therefore, each force produces a torque about the centre of mass. The horizontal component of the ground reaction force (R_H) and the air resistance (A) produce torques or moments which would to rotate the sprinter backwards about the left-right axis, while the vertical component of the ground reaction force results in a moment which would rotate the sprinter forwards.

At the start of a race when the sprinter accelerates out of the blocks, R_H is large. Therefore, the sprinter leans well forward, decreasing Y_H, and increasing X to maintain equilibrium. In successive steps, it becomes more difficult for the sprinter to exert horizontal forces similar to those at the start because of the horizontal velocity attained so the trunk is slowly raised. This action increases Y_H and decreases X, preventing the forwards rotating moment from dominating and causing a loss of balance. When

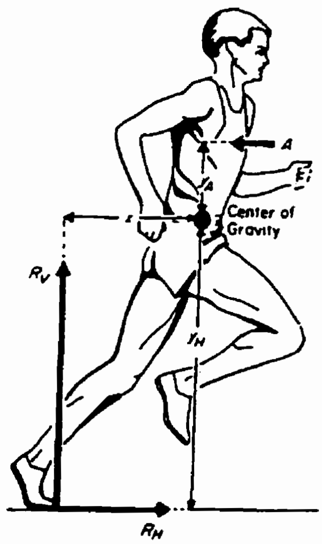


Figure 2-13. Forward trunk lean during sprinting at maximum velocity, in which the eccentric forces acting about the centre of mass to determine the optimum angle of inclination (Hay, 1993, p. 411).

sprinting at maximum velocity R_H is further reduced, so the sprinter assumes an upright position, increasing Y_H and decreasing X to maintain equilibrium. In this position, though, the affect of air resistance (A) is most evident, due to the large surface area oriented perpendicular to air flow. Therefore, to maintain a balance within the system, the sprinter leans forward slightly to counter the backwards rotating affect of A by decreasing Y_H and increasing X.

According to Bruce (1994), the body lean should be between 2^0 and 4^0, with similar values of 3.75^0 reported by Hoskisson and Korchemny (1991). Mann (1986) stated that elite sprinters run more upright when compared to good sprinters, which is significant because most coaches feel the opposite is true.

Position of the Head in Sprinting

The position and movements of the head in sprinting can have a considerable effect on the rest of the body, based on the fact that the mass of the head is approximately 7% of the total mass of the body, and that it is positioned on the spine which is a direct link to the trunk and limbs (Dyson, 1986). The head should be kept in a natural alignment with the shoulders, with the eyes looking forward. The effects of poor head position are often seen at the end of a race when runners are tiring. The head is thrown back, which causes the trunk to straighten and become more erect, shortening the running stride (Hay, 1993).

Ground Reaction Forces During Sprinting

Through the contact phase of sprinting, the force of gravity acting on the sprinter and the torques produced by the limbs of both the upper and lower body result in forces being applied to the ground. Based on Newton's third law of motion which states "for every force that is exerted by one body on another there is an equal and opposite force exerted by the second on the first" (Hay, 1993, p. 68), the ground applies an equal and opposite force on the sprinter. This equal and opposite force is called the ground reaction force. Appropriate production of this force is crucial to sprint performance, as it is the ground reaction forces produced during the resistive phase which decelerate the sprinter and in the propulsive phase which accelerate the sprinter. Ideally, sprinters want to minimize the ground reaction forces produced during the resistive phase to prevent slowing down, and maximize the ground reaction forces in the propulsive phase to maintain or increase velocity.

The resultant ground reaction force may be divided into vertical and horizontal components. During constant speed sprinting, large vertical force components are produced in both the resistive and propulsive phases, while the horizontal focus are relatively small (see Figure 2-14.). The horizontal resistive force should be minimized to avoid loss of horizontal velocity, while the horizontal propulsive force should be maximized to increase velocity. The direction of the resultant force in the resistive phase should be as vertical as possible to prevent braking, and as horizontal as possible in the propulsive phase to promote horizontal velocity. Increased running velocity results in increased horizontal and vertical ground reaction forces, both in the resistive and propulsive phases (Mero, Komi, & Gregor, 1992).

Mero and Komi (1987) analyzed the ground reaction forces during the resistive and propulsive phases of maximal sprint running in 6 male sprinters. During the resistive

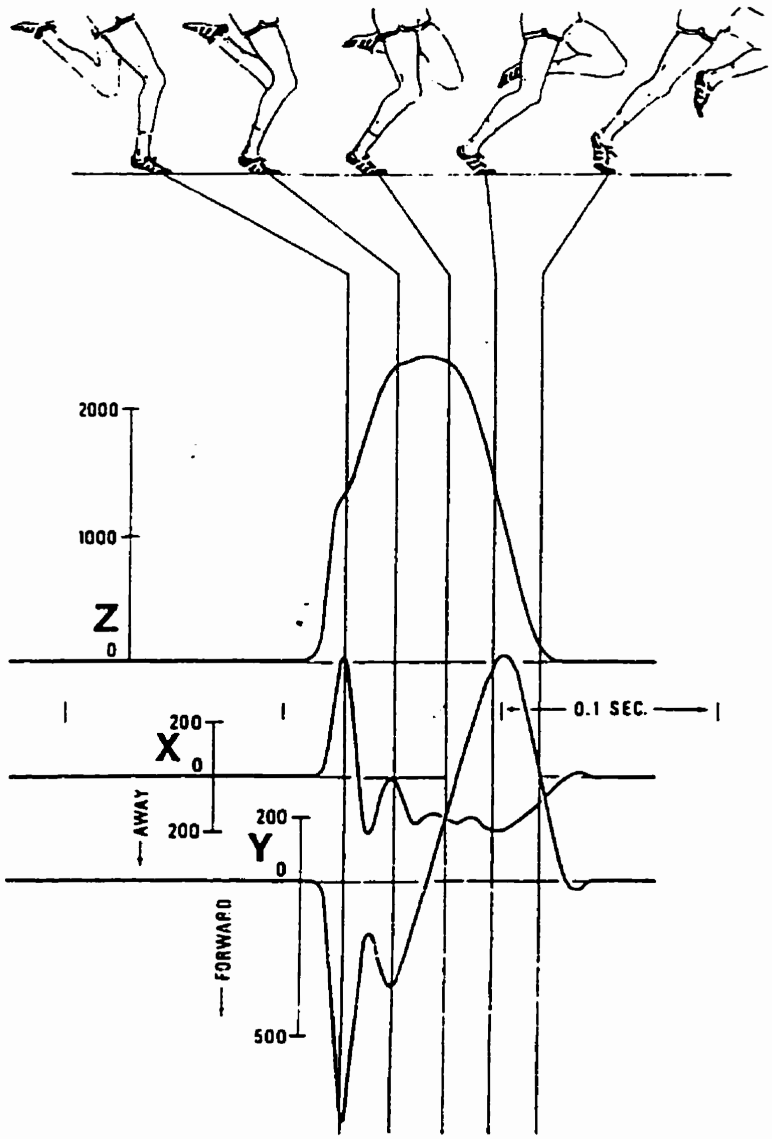


Figure 2-14. Ground reaction forces during sprinting (Payne, 1983, p. 749).

phase, the average vertical ground reaction force (including bodyweight) was 1707 Newtons (N), while the average horizontal ground reaction force was 445 N. The average resultant force was 1766 N acting at an angle of 75^0 from the horizontal. During the propulsive phase, the average vertical and horizontal ground reaction forces were found to be 797 and 312 N, respectively. The average resultant force was 857 N acting at 68^0 from the horizontal. Nummela, Rusko, and Mero (1994) reported peak vertical ground reaction forces in male 400 metre sprinters of approximately 3100 N, with peak horizontal ground reaction forces of approximately 550 N. The resultant force during the resistive phase was approximately 1750 N, and the resultant force in the propulsive phase was approximately 1200 N.

Greater ground reaction forces are found during the resistive phase as compared to the propulsive phase, yet the athlete is able to maintain peak horizontal velocity. This is because the impulse of the resistive phase is equal to the impulse of the propulsive phase, resulting in no overall change in momentum. In the study by Mero and Komi (1987), the time in the resistive phase was 0.043 seconds, resulting in a resistive impulse of 19.13 Ns. In comparison, the time in the propulsive phase was 0.058 seconds, resulting in a propulsive impulse of 18.10 Ns. These similar impulse values indicate that there would be no overall change in momentum in the horizontal direction, as the momentum lost in the resistive phase would equal the momentum gained in the propulsive phase.

Payne (1983) compared the ground reaction forces produced by Olympic level sprinters who run heel/ball of the foot to those produced by sprinters who run on the ball of the foot only. Sprinters who run heel/ball of the foot produce a short initial vertical force during the braking phase, and have a prolonged horizontal braking force. Sprinters who run on the ball of the foot do not demonstrate the same initial vertical force peak, but have a higher peak horizontal braking force. During propulsion, these sprinters show a grater peak horizontal force.

Mero and Komi (1978) determined the vertical and horizontal ground reaction forces produced by different body segments during the propulsive phase of sprinting. In the vertical direction, the trunk, legs, and arms contributed 661, 593, and 199 N, respectively. In the horizontal direction, the contribution was 557, 316, and -124 N. This indicates that the mass of the trunk plays a significant role in the production of ground reaction forces, simply because of its large mass. It also shows the importance of both the legs and arms in producing vertical forces, and of the legs in producing horizontal forces. Ground reaction forces are produced by the legs as a result of hip extension of the support leg and hip flexion of the recovery leg while the sprinter is in contact with the ground. The arms contribute to vertical ground reaction forces as a result of the shoulder flexion and extension which occur during the arm drive. The arms are detrimental to horizontal force generation because the negative force produced by the shoulder in extension is greater than the propulsive force produced by the shoulder in flexion. The legs are responsible for producing the additional force for propulsion.

Mero and Komi (1986) found significant correlations between the net resultant ground reaction force in the propulsive phase and both velocity and step length, where the greater the ground reaction force, the greater the velocity and the greater the step length. They reported 10.6% greater step length values in male sprinters as compared to female sprinters, attributing this difference to increased ground reaction forces in the males.

Angular Momentum

According to Hall (1995), the quantity of angular motion that a body possesses is known as angular momentum (symbol H). Angular momentum is the product of the moment of inertia which is the body's resistance to angular motion (I), and angular velocity (ω):

$$H = I \times \omega$$

$$H = mk^2 \times \omega$$

$$\text{units} = \text{kg m}^2/\text{sec}$$

The three factors which affect the magnitude of a body's angular momentum after it is produced by a torque are the mass of the body (m), the distribution of the mass of the body about the axis of rotation (k), and the angular velocity of the body (ω). Any increase (or decrease) in mass or angular velocity results in a proportional increase (or decrease) in angular momentum if H is constant, but a change in the distribution of the mass about the axis of rotation (k) has a more significant influence on the angular momentum. This is because the angular momentum is proportional to the square of the radius of gyration (k).

During sprinting, the angular momentum about a given axis is not constant. Changes in angular momentum result from the constant application of torques, and from changes in the radius of gyration and/or in angular velocity. The joints which are the most influential to angular momentum of the body are the hip and the shoulder, because of the ability of the athlete to manipulate the radius of gyration at these joints.

For multisegmental motion, the angular momentum of a body about a given axis is the sum of the angular momenta of the individual segments about the given axis and about their own axis of rotation. The angular momentum of a single segment with respect to the principal axis of rotation passing through the total body centre of mass is equal to the segment's angular momentum about its own centre of mass (the local term) plus the angular momentum about the total body centre of mass (the remote term):

$$H = I_s\omega_s + mr^2\omega_g$$

For the local term, I_s and ω_s are the moment of inertia and angular velocity of the segment with respect to its own centre of mass. For the remote term, m is the mass of the segment, r is the linear distance from the centre of mass of the entire body to the centre of mass of the individual segment, and ω is the angular velocity of the segment with respect to the principal axis. This indicates that during activities such as sprinting or performing the A and B drills, movements at the hip, knee, shoulder, and elbow all contribute to the total angular momentum of the body, and the further the joint centres are away from the principal axis the greater the contribution to H.

When an external torque acts on a system, there is a predictable change in the amount of angular momentum. These changes depend on the magnitude and direction of the torque (T), and on the length of time over which the torque acts (t), also known as the angular impulse. When an angular impulse acts, there is a change in the total angular momentum of the system. The angular impulse-momentum relationship is expressed as

$$Tt = \Delta H$$

$$Tt = (I\omega)_f - (I\omega)_i$$

where subscript i represents the angular momentum value before the angular impulse was applied, and subscript f represents the angular momentum value after the angular impulse.

Although the angular momentum about a given axis is not constant during sprinting, the role of the opposing actions of the arms and legs is to try to maintain the total angular momentum at a near constant value. When the athlete's right foot is in contact with the ground, as he/she moves from support flexion to propulsion during the support phase there is a clockwise rotation of the pelvis. Hip flexion torque at the left hip and hip extension torque at the right hip act over a brief period of time to produce angular impulse. This angular impulse creates clockwise angular momentum of the lower body about the longitudinal axis. In order to maintain a constant angular momentum, the arms must move in opposition to the legs to produce equal angular momentum in the opposite direction. While the clockwise rotation of the pelvis is occurring, there is a counterclockwise rotation of the upper trunk. At the shoulder, flexion torque at the right shoulder and extension torque at the left shoulder act over time to produce angular impulse. This angular impulse produces counterclockwise angular momentum about the longitudinal axis. This angular momentum is similar in magnitude to the clockwise angular momentum produced by the legs, which means the total angular momentum of the body is constant. Although the ideal is to maintain a constant orientation of the trunk, athletes with very vigorous leg or arm motions may produce unwanted rotations of the trunk around the longitudinal axis.

Sprint Training

In sprint training, the main objective is to train the athlete to run as fast as possible. To do this, the sprinter's training program must include certain key components, which develop the energy, strength, and technical aspects of the sport. As every coach will agree, there is no perfect sprint training program. Coaches are constantly trying to develop the right combination for training all the different and necessary components for their athletes. The following is a description of the key components required in a successful sprint training program.

The first component of the sprinter's training program is work done on the track. There are numerous types of running workouts that the sprinter performs, to train the various energy system components of sprinting (see Table 2-1.). The first type of run is called extensive tempo (Bowerman & Freeman, 1991). These are long runs and are performed at a relatively low intensity (60-70% maximum running velocity). Because of the slow pace, rest between repetitions is short. An example of an extensive tempo workout for a sprinter would be [2 x 4 x 300m, 45s/2min] (which is read as two sets of four reps at 300 metres, with 45 seconds rest between reps and 2 minutes between sets) Runs of this type mainly train the aerobic system.

Table 2-1. Energy System Training for Sprint Events (Bowerman & Freeman, 1991).

	Physiological objectives		Training run pattern			
					Rest intervals* between	
Work type	Biomotor component trained	Energy system trained	Length (m)	Intensity (% of best performance)	reps	sets
Extensive tempo	Aerobic capacity	Aerobic	>200	<70	<45 s	<2
	Aerobic power	Aerobic	>100	70-79	30-90 s	2-3
Intensive tempo	Anaerobic capacity	Mixed aerobic and anaerobic	>80	80-89	30 s-5	3-10
Speed	Speed, anaerobic power	Anaerobic alactic	20-80	90-95 95-100	3-5	6-8
Speed endurance	Alactic short speed endurance, anaerobic power	Anaerobic alactic	50-80	90-95 95-100	1-2 2-3	5-7 7-10
	Glycolytic short speed endurance, anaerobic capacity, anaerobic power	Anaerobic glycolytic	<80	90-95 95-100	1 1	3-4 4
	Speed endurance, anaerobic power	Anaerobic glycolytic	80-150	90-95 95-100	5-6 6-10	— —
Special endurance I	Long speed endurance, anaerobic power	Anaerobic glycolytic	150-300	90-95 95-100	10-12 12-15	— —
Special endurance II	Lactic acid tolerance	Lactic acid tolerance	300-600	90-95 95-100	15-20 Full recovery	— —

The second type of run is called intensive tempo. These runs are shorter in duration than extensive tempo, but are performed with a greater intensity (80-90% maximum running velocity). An intensive tempo workout may be [2 x 4 x 200m, 2min/4min]. Intensive tempo trains both the anaerobic and aerobic systems.

The third component of training, and possibly the most important for the sprinter is speed training. Speed training consists of short runs at maximum or near maximum velocity. Because of the high intensity, the athletes are given an adequate amount of rest between intervals. Typical speed workouts could be [3 x 3 x 30m, 3min/5min] or [2 x 3 x 60m, 5min/7min]. Speed training develops anaerobic power in the athlete, and trains the anaerobic alactic system.

The fourth type of work is speed endurance. Runs of this type are similar to those used in speed training in that the speed is maximum or near maximum, but they are either longer runs, or are short runs with less rest between intervals. For speed endurance, there are three types of runs, each training a different energy system. The first is alactic short speed endurance. These are short runs at near maximum speed, with little rest between repetitions, but sufficient rest between sets. An example of this type of workout is [2 x 4 x 60m, 2min/5min]. The second type of speed endurance is glycolytic short speed endurance, which consists of short runs at maximum or near maximum velocity, with minimal rest between reps and sets. An example of this type of workout is [2 x 4 x 50m, 1min/3min]. The third type of speed endurance consists of longer runs at maximum or near maximum velocity. When performing runs of this type, sufficient rest is allowed between reps. An example of this type of speed endurance workout is [4 x 120m, 6-8min].

The final type of runs the sprinter will perform are called special endurance runs. These are long runs, longer than the sprinter would perform in a race, and are completed at maximum or near maximum velocity. The athletes are given long rests between reps. Special endurance I develops long speed endurance. An example of this workout is [3 x 250m, 12-15min]. Special endurance II develops lactic acid tolerance, which is necessary for long sprint events. An example of this workout is [2 x 400m, 15-20 min].

Strength Training

Another major component of the sprinter's training program is strength training. As stated by Lopez (1995), sprinters must have explosiveness, and must be able to work at maximum frequency over a prolonged period, and avoid injuries which could be caused by the execution of high speed movement. According to Dick (1985), strength training for sprinters can be divided into two components, the first of which is general strength. This is the phase in which the athlete develops their maximum strength. Athletes still in the developmental stages of training aim for higher strength levels, while experienced athletes aim to re-establish the strength levels reached the previous year (Szczepanski, 1986). Exercises performed for general strength includes cleans, bench press, squats, chin-ups, shoulder press, sit-ups, and back extensions (Bruce, 1996). The amount of weight lifted is based on the percentage of maximum the individual can lift. This weight varies from 60 percent of maximum at the beginning of the general strength phase where 12 to 15 repetitions are performed, to 90 percent of maximum at the end of the phase, where only two repetitions are performed (Lopez, 1995). Strength training of this type is performed early in the preparatory phases of training, prior to competition

(Bompa, 1994).

The second component of strength training for sprinters is dynamic strength training. According to Dick (1986), the most important effect of strength training for the sprinter is the development of dynamic strength. Dynamic strength determines and influences the degree of development of speed and technique of sprinting. Delecluse, van Coppenolle, Willems, van Leemputte, Diels, and Goris (1995) concluded that dynamic training produced significant increases in initial acceleration, maximum speed, and a significant decrease in 100 metre time. In developing dynamic strength, it is necessary to combine exercises that replicate the appropriate speed in performance. Exercises of this type include bounding (Mach, 1980) and jumping (Carr, 1991) exercises. In addition, weights can be lifted dynamically. Bruce (1996) has his athletes perform the same weight exercises as in general strength, but with only 50 percent of maximum weight, and the execution is to be fast. Another type of dynamic workout is with the use of a medicine ball (Bompa, 1994). Here, the athlete performs a wide variety of throws and jumps using the weight of the medicine ball as resistance, incorporating all the major muscle groups of the body in the workout.

Drills in Sprinting

While both running and strength training develop the energy systems of the athlete, neither emphasizes the technical components which make up a good sprinter. McFarlane (1994a) noted speed involves learning through kinesthesis - teaching the body to feel certain sensations. Therefore, sprinters regularly perform drills as part of their training. McFarlane (1994b) stated that technical skill development for speed involves specific drills which are designed to isolate and combine joints to rehearse a series of sensations that establish the exact motor pathways. Bell (1995) believed drills create patterns of movement and if done properly can enhance performance. A movement done numerous times correctly will lead to more efficient neuromuscular patterns, which will in turn lead to better and more consistent performances.

The Basic Technical Model for sprinting can be defined as exercises which exhibit a high degree of specificity and meet the motor demands for sprinting (McFarlane, 1994a, 1994b). In this model, there are two drills which are the basic exercises for developing proper sprint technique. These drills are termed the A and B drills. They are also known as the "Mach Drills" from the developer of the drills, Gerard Mach. Born in Poland, Mach was the Polish national sprint champion and record holder on several occasions. He became the Polish national sprint coach, and was responsible for developing numerous athletes who became European and Olympic medalists. Mach immigrated to Canada, where the Mach system quickly brought Canada to the international level in the sprints. Mach became the head coach of the sprints and hurdles in Canada in 1973, and was appointed Canadian national team head coach in 1976.

The Mechanics of the A Drill

The A drill may be described as a marching action (see Figure 2-15.). The legs alternate from a position of support to a position of hip flexion with the knee flexed. As with sprinting, this drill may be divided into a series of phases. The first is support, when one leg is in contact with the ground, supporting the weight of the body, with the supporting foot slightly behind the centre of mass. This leg should be fully extended (Carr, 1991) with the hip extended (McFarlane, 1994). The sprinter should be up on the toes (Carr, 1991). Following support is the driving phase, where there is rapid and vigorous flexion of the hip, bringing the thigh to horizontal (Carr, 1991). At the same time, there is flexion of the knee, where the foot is brought up close to the buttocks (Figure 2-15, photo 1). The foot dorsiflexes, bringing the toes towards the shank. These actions decrease the moment of inertia of the leg, allowing the hip flexion to occur faster, and with less muscular force. The next phase is recovery, where the hip and knee rapidly extend, and the foot plantarflexes (Figure 2-15, photos 2-4). The foot contacts the ground in a position behind the centre of mass. These phases alternate between the legs, in that when one leg is in support, the other is at the end of the driving phase. The legs then reverse roles, and the support leg drives upward and the other leg recovers to support. While the legs are in the driving and recovery phases, there is a short period when there is no contact with the ground.

When performing the A drill, the mechanics of the upper body should resemble those of sprinting. There should be a slight forward body lean, with the head aligned in a neutral position above the shoulders. There should be a vigorous arm action, with movements primarily in the sagittal plane, moving slightly towards the midline in front. The elbows should remain at approximately 90^0, with the elbows flexing slightly when driving forward and extending slightly when driving backward. The hands should be relaxed, in a loose fist or open flat, with the thumbs pointing upward. Carr (1991) outlines various coaching tips for the A drill, including look forward and try not to lean backwards, concentrate on raising your thighs to at least horizontal, and keep the arms moving strongly back and forth to balance the leg action.

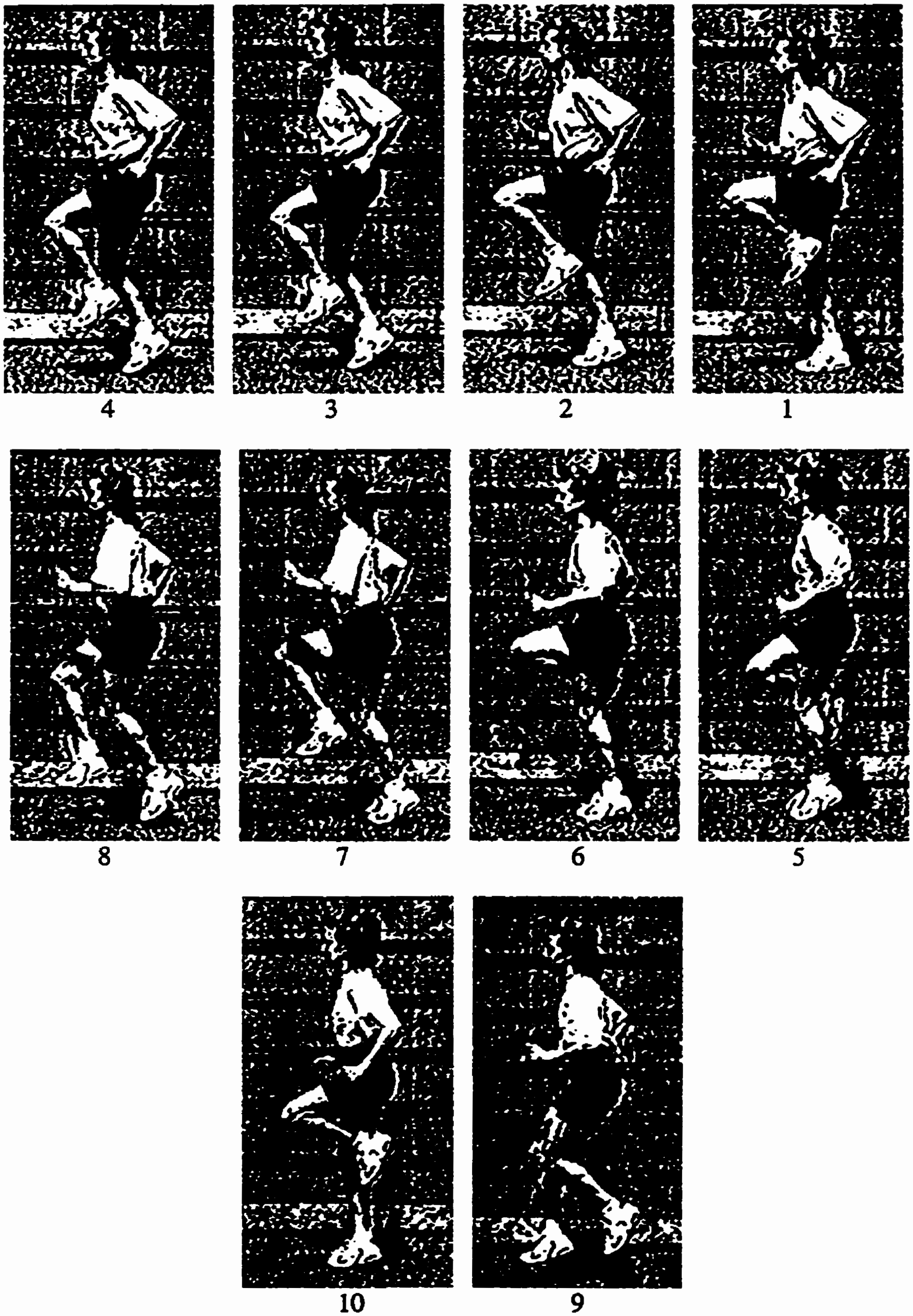


Figure 2-14. Photosequence of the A drill.

The Mechanics of the B Drill

The mechanics of the B drill are similar to those of the A drill, with one distinct difference, this being the path of the leg in recovery (see Figure 2-16.). The first phase is support, where one leg is in contact with the ground, the foot slightly behind the centre of mass. The support leg and hip are extended, and the foot is plantarflexed. The next phase is the driving phase, where there is rapid and forceful hip flexion, along with knee flexion and dorsiflexion. The foot is brought to a position near the buttocks (Figure 2-16, photo 1). Following this phase is recovery. Here, instead of hip and knee extension to bring the foot straight down under the body, the initial action is an extension of the knee Figure 2-16, photo 3). Once this has begun, the hip begins to extend (Figure 2-16, photo 4). The result is a movement of the foot in a circular path in front to a position under the body. According to Carr (1991), this action simulates the prancing of a horse. Ground contact is slightly in front of the centre of mass, and the body is pulled in front of the support leg.

The mechanics of the upper body are similar to those of sprinting. There should be a slight forward body lean, with the head in a neutral position above the shoulders. The arm action should be vigorous with the arms remaining at approximately 90^0, flexing slightly when driving forward and extending slightly when driving backward. These movements should be primarily in the sagittal plane, coming towards the midline slightly in front. The hands should be relaxed, in a loose fist or open flat, with the thumbs pointing upward.

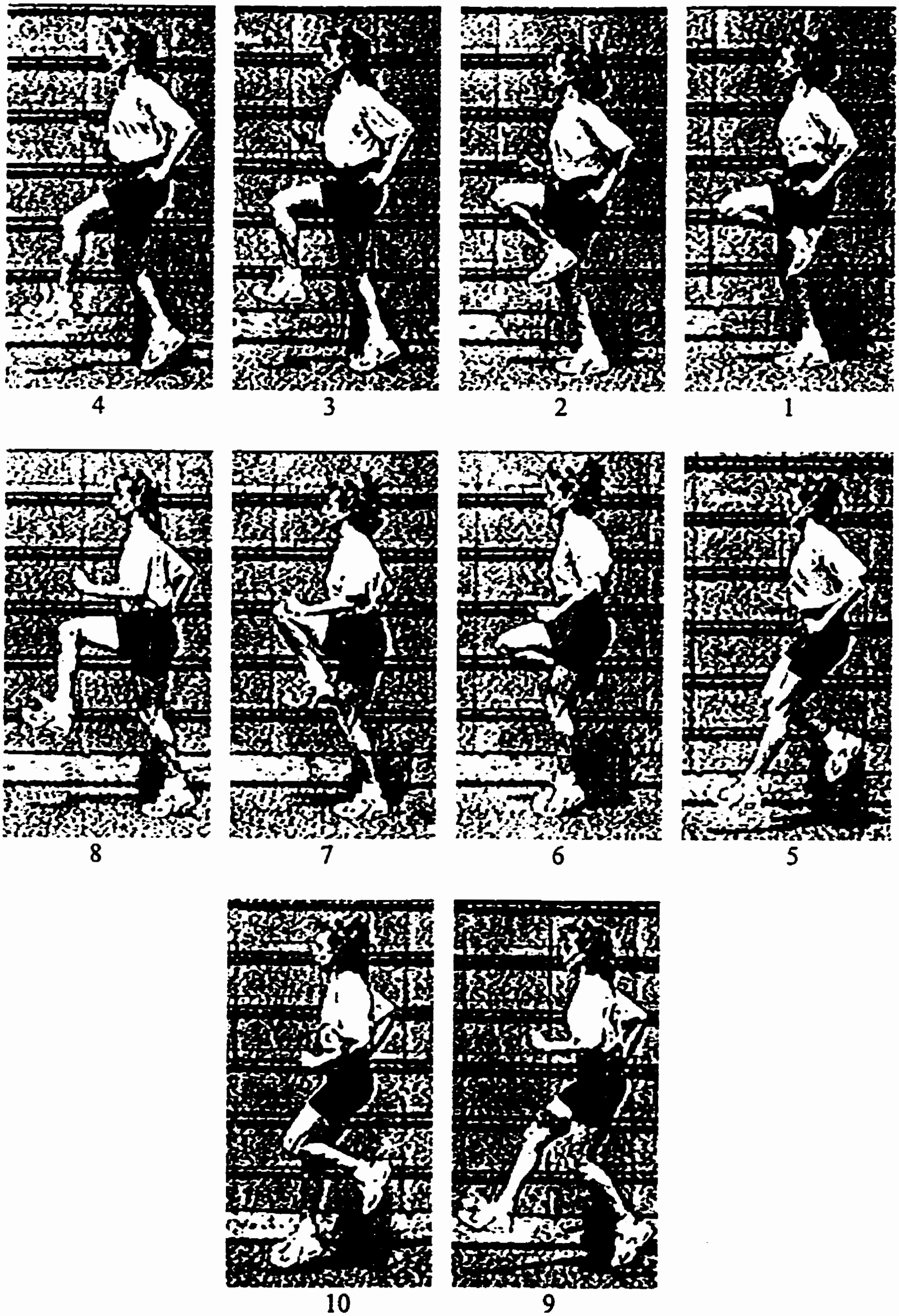


Figure 2-15. Photosequence of the B drill.

Performing the B drill well is a difficult task. It usually requires years of practice and a sufficient level of strength to be able to perform it with correct technique. Carr (1991) describes various coaching tips for the B drill, including set up the rhythm while running in place then try to move forward at a slow jog, increasing the speed of the legs, and use a rhythm pattern of "up-step out, up-step out."

The Use of the A and B Drills

Various articles (McFarlane, 1994a; McFarlane, 1994b; Lopez, 1995) and books (Carr, 1991; Bowerman & Freeman, 1991; Mach, 1980) advocate the use of the A and B drills in sprint training. They are often referred to as "high knee" drills (Carr, 1991, Lopez, 1995). To determine how extensively these drills are used by coaches and athletes, an informal electronic-mail (e-mail) and telephone investigation was conducted. Using the internet (Netscape 2.0), e-mail addresses and telephone numbers of sprint coaches from across Canada and the United States were obtained, and several of these individuals were contacted. These addresses and phone numbers were found from track and field web sites, and from the home pages of various universities. In addition, the sprint coaches from the University of Manitoba were asked about their use of the A and B drills in sprinting. All of the coaches who were asked said that they use the drills as part of their training plan. Myrtle Ferguson (1996), women's sprint coach at the University of Tennessee, said she frequently uses the drills as part of training. She feels the drill emphasize proper sprint mechanics, and build muscular strength and endurance. Glenn Bruce (1996), sprint coach at the University of Manitoba, believes the drills develop the neuromuscular system, improving the speed of nerve conduction and enhancing the proper sequencing of muscular contractions. Alex Gardiner, former national sprint coach and now director of Athletics Canada, believes the drills put the athlete in the correct anatomical position for sprinting, reinforcing the "whole" sprint model compared to drills which only work on a "piece" (Gardiner, 1997).

Andy McInnis (1997), Canadian national team sprint coach, uses both drills, but differently from the other coaches. He frequently uses the A drill, but rarely uses the B drill in training. He uses the A drill as a recovery mechanics drill, training the hip flexors to contract more forcefully, and improving knee flexion to decrease the moment of inertia of the recovery leg. He also believes this drill is a hip/knee/ankle stability drill, as the muscles of the knee and hip must contract to stabilize the joints, as they are required to be fully extended while supporting the body. McInnis (1997) considers the B drill a force application drill, training the sprinter to minimize the resistive phase by contacting the ground as close to the centre of mass as possible. He noted that a great deal of hip extensor strength is required to perform this drill properly, and therefore uses it primarily with elite sprinters and rarely with developing sprinters.

The ways in which the A and B drills are used in training depends on the type of workout being performed on a given day. Bruce (1996), uses the A and B drills differently on training days when the emphasis is speed, as compared to when it is extensive tempo. A typical example of the use of the A's and B's on a speed day would be four repetitions of ten metres of each drill, where the emphasis is on performing the drills fast, and with perfect technique. These drills would be completed during the warm-up, to prepare the athlete for the maximum speed runs which will follow. On a tempo day, a typical example of these drills would be four repetitions of 20 metres, where the emphasis is not so much on speed, but on maintaining perfect technique over the entire distance. Again, these drills are performed as part of the warm-up, prior to the runs to be completed for the workout. In comparison, Ferguson (1996) uses the drills during the tempo workout. She has her athletes perform between four and six repetitions of the A drill for a time period of 20 seconds, followed by 20 seconds of rest. The athletes will then run one or two laps of the track, and then repeat with the B drill. Bruce (1996) also uses these drills after the workout has been completed. The sprinters will perform three or four repetitions of fifteen to twenty metres, with the emphasis being on perfect technique. This type of cool-down is completed after any type of workout, and helps develop muscular strength and endurance, to enable the athletes to maintain proper sprinting technique towards the end of a race, when fatigue sets in and technique begins to break down.

Andy McInnis (1997) does not advocate covering distances greater than 5 metres when performing these drills. He feels the athlete should move forward very slowly, or even remain stationary. By covering these longer distances, the athlete begins to take steps larger than required, contacting the ground far out in front of their centre of mass. Therefore, they are training themselves to increase their resistive phase, which is not representative of proper sprint mechanics. In addition, slow moving or stationary drills will allow for better hands on training from the coach. He has his athletes perform a given number of cycles of the drill (ie: 30 cycles, where one cycle is the same as one step in sprinting), and the emphasis is placed on maintaining a high rate of rhythm, rather than the distance covered. Alex Gardiner (1997) agreed with McInnis, stating that his sprinters would perform the drills moving slowly forward, with an emphasis on performing the drills at a stride rate similar to that of sprinting. The sprinter would stop when technique begins to break down.

Neuromuscular Adaptations to Ballistic Movements

According to Zehr and Sale (1994), ballistic muscular actions can be considered those movements that are performed with maximal velocity and acceleration. Under this definition, various movements involved in sprinting may be considered ballistic, as angular velocities of approximately 1300 degrees/second have been reported for knee extension (Chengzhi & Zongcheng, 1987). Similarly, the A and B drills may be considered ballistic due to the dynamic nature of the movements.

Based on the specific coordination strategies and control schemes required during ballistic movements, training of this type or movements requiring this type of contraction result in very specific neuromuscular adaptations. Hainaut, Duchateau, and Desmedt (1981) had subjects train their adductor pollicis isometrically or fast isotonically for 3 months. It was found that the fast isotonically trained subjects had produced a shorter latent period and a shorter contraction period than in subjects who trained with isometric contractions. In a similar study, Duchateau and Hainaut (1984) found dynamic training of the adductor pollicis produced a rate of tension development 13% faster than that produced by isometric training. The maximal shortening velocity was also increased by 21% following dynamic training, whereas there was no change after isometric training. Dynamic training also decreased twitch time to peak by 11% and peak twitch force by

10%. Peak twitch force decreased as a result of the reduced time given to the contractile elements to stretch the muscle elastic components. Duchateau and Hainaut (1984) concluded that human muscle has the capacity to adapt differently to isometric and dynamic training and that the contractile kinetics can be altered by exercises performed under physiological conditions. For sprinting, this indicates that beneficial muscular adaptations may occur from dynamic training exercises, including the A and B drills, such as decreased muscle shortening velocity and increased rate of tension development.

Cracraft and Petajan (1977) have suggested that dynamic and isometric training regimens could induce changes in individual motor unit firing patterns that could affect muscular adaptation. This conclusion was based on their finding that static and dynamic training regimens produced changes in motor unit firing patterns in tibialis anterior muscle. Cracraft and Petajan suggested that the pattern of usage (isometric vs. dynamic) had a direct effect on the trained motor neurons and that plasticity in control of motor unit firing could lead to changes in muscle fibre composition.

Neural factors and muscular adaptations could interact in different ways to produce a training effect following different types of training, particularly strength or power training. It has been shown that the gains in strength or power following training have an initial neural basis (Cannon & Cafarelli, 1987). Training has been shown to affect motor neuron excitability in humans, causing an increased ability to raise excitability during effort (Sale, MacDougall, Upton, & McComas, 1983). Milner-Brown, Stein, and Lee (1975) demonstrated that training could potentially affect supraspinal connections from the motor cortex to spinal motor neurons to produce synchronization of motor units during contractions. In addition, ballistic training may induce neural adaptations involving reflex responses. Mortimer and Webster (1983) found karate-trained (ballistically trained) subjects to show greater decreases in the latency period preceding muscle contraction, greater limb acceleration, and shorter rise times in initial agonist burst than untrained subjects. This is significant for training, as ballistic training may develop the reflexive responses to the rapid movements involved in sprinting.

Behm and Sale (1993) examined the responses of men and women to ballistic isometric and ballistic high velocity isokinetic training. During training contractions, subjects were instructed to contract as rapidly and forcefully as possible and to then relax as quickly as possible. Following 16 weeks of training, isokinetic peak torque results exhibited a velocity-specific training effect, with the greatest peak torque increase seen at the highest training velocity. Voluntary isometric peak torque and rates of torque development and relaxation also increased after training. These results showed that the velocity-specific response to the isometric and concentric isokinetic training was the same. They concluded that it was the intent to contract ballistically, rather than the actual ballistic movement, that determined the velocity-specific response. Accordingly, the changes in evoked contractile properties considered to increase high velocity ballistic strength performance also did not depend on actual rapid concentric actions, but rather on the attempt to make such actions. These results have significant implications for sprint training drills. Although the A and B drills may not be performed at the same rate or with similar velocities to those of sprinting, it may be that the intent of the athlete to perform the drills as rapidly as possible that will result in positive muscular adaptation.

Angle-Angle Diagrams

In certain human activities, the motions of the various body segments are cyclic in nature, meaning they are repetitive with the end of the one cycle being followed immediately by the next. Sprinting, the A drill and the B drill are all examples of cyclical activities in sport. In these skills, an angle-angle diagram may be useful to represent the relationship between two joint angles during the movement. An angle-angle diagram is the plot of one joint angle as a function of another angle at equal intervals of time. That is, one joint angle is used for the x-axis and the other for the y-axis. In an angle-angle diagram, one angle is usually a relative angle such as the hip relative to the vertical, and the other is an absolute angle such as the absolute knee angle. For the angle-angle graph to be meaningful, a functional relation between the angles should exist, such as a comparison of the hip and knee or the knee and ankle.

According to Grieve (1968), angle-angle diagrams emphasize the relationships between angles more clearly than with separate plots. With practice, they convey to the researcher an impression of changing inertias, contributions to stride, and vertical movements, which are not to be found from angle time graphs. Milner, Dall, McConnell, Brennan, and Hershler (1973), feel the angle-angle diagram can be a useful method of presenting data, because of the considerable amount of information conveyed very simply and also in view of the distinct patterns obtained from the subjects tested.

Angle-angle diagrams have proved very useful in examining various components of running and gait patterns. Williams (1985) used angle-angle diagrams to analyze movement patterns during running by comparing the knee angle as a function of the angle at the hip and at the ankle. Bates, James, and Osternig (1978) used angle-angle diagrams to study knee flexion as a function of sub-talar joint inversion/eversion to look at the degree of tibial rotation seen during running. In a similar study, van Woensel and Cavanagh (1992) used knee-rearfoot angle-angle diagrams to compare lower extremity motion with different types of running footwear, and found that there were adaptations in timing and velocity patterns at the knee in the sagittal plane kinematics to the shoe perturbations.

Angle-angle diagrams are also used in clinical settings, particularly in studying pathological gait patterns. Milner, Dall, McConnell, and Brennan (1973) used angle-angle diagrams to compare and contrast gait patterns between healthy and diseased hips in individuals requiring total hip reconstruction. DeBruin, Russel, Latter, and Sadler (1982) used angle-angle diagrams to assist in the quantification and monitoring of gait patterns in children with cerebral palsy.

Filming Techniques

There are two main techniques which can be used when filming a sporting event - high speed cinematography (Kennedy, Wright, & Smith, 1989; Ito, Fuchimoto & Kaneko, 1987) and video taping methods (Abraham, 1987; Kennedy et al., 1989). Cinematography involves the use of motion picture cameras to collect the kinematic parameters. The 16mm movie camera has been the common choice of most researchers due to the combination of qualitative accuracy and minimal expense. Video taping methods involve using fairly sophisticated video cameras to film the event, which include a variable shutter speed and a zoom lens.

Purpose of Filming

The purposes of filming sporting events, including sprinting, are to calculate the following parameters: linear and angular displacements, linear and angular velocities (Mann & Herman, 1985), accelerations and centre of mass (Denoth, Gruber,, Ruder, & Keppler, 1984), and centre of rotation of a joint (Allard, Nagata, Duhaime, & Labelle, 1987). Force values can also be estimated using the acceleration values from the film.

Cinematography Versus Video Filming

According to Angulo and Dapena (1992), there are a number of limitations of the video filming technique, which include the number of frames that can be filmed per second, the quality of the video image, and the accuracy of the coordinate values due to resolution of the monitor. High speed cinema cameras are capable of filming at 500 frames per second, while conventional video cameras are limited to filming at 60 frames per second. This means the video filming of movements which have high velocities and accelerations are limited, due to the low frequency response of the system.

There are also limitations to cinematography, such as in pitching, when there are very high velocities (600 ms^{-1} and 10^5 degrees per second) With these extremely high values, even high speed cinematography is limited (Denoth, Gruber, Ruder, & Keppler, 1984). Attempting to calculate these high velocity values using the video analysis system would prove inaccurate.

One of the most important factors when comparing high speed filming to video is the accuracy of the coordinate values. This is influenced by the resolution and quality of the video image; which is limited by the size of the pixels used on the monitor (Angulo &

Dapena, 1992). Kennedy et al. (1989) compared the accuracy of predicting the points in the x, y, and z planes for the two filming methods. They found the average error of the coordinates of the points of their 2 metre control object to be 4.8 mm for film, and 5.8 mm for video. The researchers stated that the 1 mm difference was not large enough to consider cinematography to be more accurate in terms of point production, even though the cinematographic method was found to be statistically significant (p 0.05).

Angulo and Dapena (1992), found that when using a large field of view (8 metres), there was a greater error in accuracy for video. A resultant error of 10 mm was recorded for the reconstructed coordinates for the control object, as compared the 4 and 5 mm for the large and small video image, respectively. For the external landmarks in the "xy" plane, the resultant error for the video technique was larger (39 mm) than the larger (29 mm) and smaller (28 mm) film image techniques. Although the accuracy of the video analysis technique was affected by the larger view, Angulo and Dapena (1992) noted that within the volume of the control object, the video technique was accurate enough for most applications.

Scholz and Millford (1993) evaluated the accuracy and precision of the Peak Performance Technologies video motion analysis system for three dimensional angle reconstruction, and found the system to be both accurate and reliable. Two cameras, positioned so that the optical axes formed an angle of 60 degrees, videotaped the pendular motion of a bar at three different positions with respect to optical axes of the two cameras. The video taped motion was digitized and 32 angles between 18 markers were calculated. Intraclass correlation coefficients (ICC) between trials within each pendular orientation and across orientations revealed excellent ICC's of greater than 0.999 which suggested that calculated angles from each trial were extremely consistent from trial to trial. Scholz and Millford (1993) also compared the angles derived from the system with those calculated using trigonometry. Deviations from the actual angle were relatively small and averaged 0.0 to 0.8 degrees across all angles and orientations. In addition, intraclass correlation coefficients were greater than 0.999, suggesting that the results were consistent. In terms of planar movements, such as the one use in the experiment by Sholz and Millford, it appears that the Peak Performance Technologies motion analysis system can provide accurate and reliable results.

The use of high speed cinematography has obvious advantages over video filming, however, Robertson and Sprigings (1987) and Abraham (1987) stated that the cost of high speed cinematography has made the use of video taping for movement analysis a popular option for many researchers. Abraham (1987) also stated that for moderate speed movements, the more affordable video system provided reasonable image resolution, freeze-frame analysis, and single frame advance. Kennedy et al. (1989) and Robertson and Sprigings (1987) felt that video film analysis was relatively easier to use and had an inexpensive and shorter film processing time. The images are immediately available which can allow the investigator to control the quality of the image during the recording session (Angulo & Dapena, 1992).

Direct linear transformation is a process by which an investigator records an event with a minimum of two cameras, and a computer algorithm converts the two-dimensional data to three-dimensional data (Wood & Marshall, 1986). This procedure involves the filming of a reference structure, the removal of the structure and the substitution of the subject in the same object space. Once the reference structure has been filmed, the cameras must remain stationary during the filming (Wood & Marshall, 1986). Shapiro (1976) also stated that several ground reference markers should be placed in the field of view for each camera to accommodate for any movement that might take place during the filming procedure.

The advantage of DLT as a method of analysis is flexibility. The cameras can be set up at any particular angle to one another (Shapiro, 1976). However, Wood and Marshall (1986) stated that the best results are obtained by placing the cameras at 90^0 to each other. With the cameras placed in this configuration, the errors for both the calculated positional and acceleration data resulted in less than 5 % error of the actual values (Shapiro, 1976). However, according to Wood and Marshall (1986), the chance of error significantly increases as the points of interest move outside the space occupied by the scaled control points. Because these points lay outside the scaled control area, their positions must be interpolated by the computer since there are no surrounding values with which they can be compared. Therefore, this causes an increase in the likelihood of an error being introduced into the data collection.

Ideally, all cameras used during analysis will record each marker at every instant in time. In real situations, though, this is not the case as markers are frequently lost from view. In video analysis, these markers are lost until they are once again visible to the camera. The position of a marker at a given point in time is calculated using only those cameras that "see" the marker, which may have an influence on the camera placements and camera numbers used during analysis. In general, noise in coordinates decreases with an increasing number of cameras (Nigg & Cole, 1994). A greater number of cameras, however, does not indicate there will be an increase in the accuracy of the determined marker positions.

When filming is complete, the film must then be analyzed. This involves digitizing the reference structure and the subject, and the computer then calculates the parameters required to change the two-dimensional data to three-dimensional data (Shapiro, 1976). Shapiro (1976) explained that the minimum number of reference points that can be digitized is six, which represents a cube. These six points are required in order to develop a set of equations to calculate the three-dimensional representation of the data. The best estimates of direct linear transform occur when between 12 and 20 reference points are used (Shapiro, 1976). One problem that is inherent in both video and high speed film analysis techniques is the time required to digitize the film (Higgs, 1984). According to Roberts (1970), digitizing can be very time consuming, even with the semi-automatic forms of digitizing equipment. However, Roberts believed that the time required to analyze the data was worth the effort, because the value of the results outweighed the amount of time taken to analyze the data.

Data Smoothing

When the kinematic measurement of segmental motion is required, a problem that arises is how to measure the variables, as they cannot be measured directly. The typical procedure involves recording body position at discrete intervals in time, and other kinematic variables are obtained by numerical differentiation (Wood, 1982). Velocity calculations require the positional data to be differentiated once, and the accelerations require double differentiation of the positional data. While differentiation of positional data provides adequate results, there is a problem associated with the numerical differentiation process. Velocities and accelerations calculated by differentiation result in an increase in the measurement errors (Chao & Rim, 1973; Wood, 1982). The error associated with positional data is referred to as noise. This "noise is the term used to describe components of the final signal, which are not due to the process itself" (Winter, 1990). Sources of noise can be caused by vibration or improper alignment of the cameras, improper alignment of the film, human error in digitizing, and machine error. As a result, the signal has an additional random component of error (Winter, 1990). Consequently, various methods of data smoothing have been devised, to help reduce the noise. These methods have become very elaborate in sport biomechanics, as accurate procedures are required in the measurement of subtle differences between high level performers (Wood, 1982).

Wood (1982) suggests using 1) digital filtering, 2) Fourier or 3) spine smoothing routines. These routines will provide an adequate description of the displacement-time data, while at the same time minimizing measurement error.

Digital filtering is designed to read data from equally spaced time intervals, reduce the noise, and produce data that closely resembles the original data (Wood, 1982). The initial positional data is passed though a series of formulae, which remove some of the noise, and produce uniform, flowing lines with few sharp peaks. One problem associated with this method is that the investigator must decide which frequency must be used to smooth the data (Wood, 1982). Another problem associated with digital filtering is the slight distortion that occurs where the signal and noise overlap (Winter, 1990). The recommended frequency for digital filtering is around 6 Hz when the filming speed is 60 Hz (Winter, 1990).

Spline functions, on the other hand, piece together a number of different polynomials of low degree with the junction point of the different functions known as knots. The fact that the final smoothed data is represented by a series of equations allows the line to adapt quickly to rapid changes in direction (Wood, 1982). There are three decisions that need to be made when using this method of smoothing: the degree of spline, how accurate the spline is to be, and the number of knots to be used. The general rule of thumb when using splines is

> 1. there should be as few knots as possible, ensuring that there are at least four or five points per interval; 2. there should not be more than one extremum point ... or one inflection point per interval; 3. extremum points should be centered [sic] in the interval; 4. inflection points should be close to the knots (Wood, 1982, p.327).

While Wood (1982) and Challis and Kerwin (1988) believe splines are an acceptable method of data smoothing, there are a large number of variables that must be taken into consideration when using this method. However, Wood (1982) also stated that the use of this method required that there be enough data points and that the accuracy of the data is well known.

The Fourier series uses sine and cosine curves of increasing frequency to fit the curve. The first sine curve is drawn within the data, and is known as the first harmonic.

Subsequently, the amplitude and frequency of the signals are changed in multiples of the first harmonic until the proper weighting of the appropriate sine and cosine values results in an approximation of the displacement-time curve (Winter, 1990). Furthermore, it has been shown that little of the signal exists beyond the seventh harmonic for normal walking (Wood, 1982). This method has been proven to be very effective , and a better approximation than polynomial approximations (Wood, 1982).

Wood (1982) found that digital filtering, Fourier smoothing, and spline smoothing produce valid results for motion analysis. Therefore, the method of filtering to be used depends on the data to be smoothed, the investigator's preferences, and the availability of the program routine.

CHAPTER III

METHODOLOGY

Introduction

The purpose of this study was to determine the kinematics of the A and B drills used in sprint training, and to compare them to those of sprinting. A group of university level sprinters were selected, based on their technical ability to perform the drills. Video film was used to determine selected kinematic variables associated with the drills and sprinting. Statistical analysis was used to determine if there were significant relationships between the kinematic variables of each drill and sprinting.

Subjects

Eight subjects were recruited for this study, four males and four females. The subjects were members of the University of Manitoba track and field team, or athletes who had completed their five years of eligibility for CIAU track and field competitions within the past two years and were still training with the team. The selection criteria was based on two factors. The first was that the participants must all be sprinters, in that they compete in distances of 400 metres or less (Carr, 1991). The second criteria was each individual's ability to perform the A and B drills. Their ability to execute the drills was assessed by the researcher, based on advice and input from the University of Manitoba sprint coaches.

The prospective subjects were initially contacted by the researcher three weeks prior to the testing date. They were given a written description of the testing procedures, and a consent form (see Appendix A). The consent form included a description of the testing procedure, an awareness of the risks involved, a guarantee of confidentiality, and the assurance that they have the right to withdraw from the study at any time. Prior to testing, the study received ethics approval.

Video Filming

Filming for the biomechanical analysis was performed on Thursday, June 12, 1997, during a regular training session for the athletes which is the precompetitive portion of the outdoor season. The filming site was the outdoor track located at the Pan-Am stadium at the University of Manitoba. The subjects were asked to arrive at the testing area one hour prior to filming, and were instructed to wear their racing bodysuit to ensure anatomical landmarks were not hidden by loose clothing. The subjects were asked to complete their own warm-up, this being the race warm-up they would normally complete prior to competition.

Video taping for the three-dimensional analysis was completed in both the frontal and sagittal views. Camera 1 was a Panasonic PV-S770A-K, and filmed in the sagittal view. Camera 2 was a Panasonic Digital D-5100, was aligned not at an exact right angle to the frontal view. The cameras filmed at a speed of 60 Hz, with a shutter speed of 1/2000 second to help reduce blurring of segmentation. The cameras were linked together by a time code generator, which synchronized the video cameras and placed the identical time codes on both tapes. This allowed the investigator to begin digitizing each subject at the same position on the film, which was essential for accurate three-dimensional representation of the skill. The distance from each camera to the centre of the field of view was at a distance such that sufficient cycles of the sprint stride could be analyzed. This distance was approximately 15 metres from the sagittal view and 12 metres from the frontal view.

The field of view in the sagittal view was eight metres horizontally by two metres vertically. The manual digitization mode was utilized on the Peak Performance Technologies motion analysis system, which indicates the number of pixels on the video monitor was 512 horizontally by 512 vertically. The actual size of each pixel in the horizontal direction was:

800 centimetres / 512 pixels

= 1.56 centimetres per pixel

The lens of camera 1 had an aspect ratio, which is the width to height ratio of the lens, of 0.8513773. This indicated that the actual size of each pixel in the vertical direction was:

1.56 centimetres per pixel / 0.8513773

= 1.83 centimetres per pixel

Similarly, the field of view in the frontal plane at the mid-point of the filming area on the track was 7 metres horizontally by 2 metres vertically. This gave an actual pixel size in the horizontal direction of 1.36 centimetres. The lens of camera 2 had an aspect ratio of 0.8564799, which indicated that the actual size of each pixel in the vertical direction was 1.59 centimetres.

The Panasonic Digital D-5100 camera was linked to a portable video cassette recorder, and both units will be powered by a 12 volt car battery. The Panasonic PV-S770A-K camera used its own internal battery as a power source. The time code generator was linked to the car battery. The entire system was connected as shown in Figure 3-1.

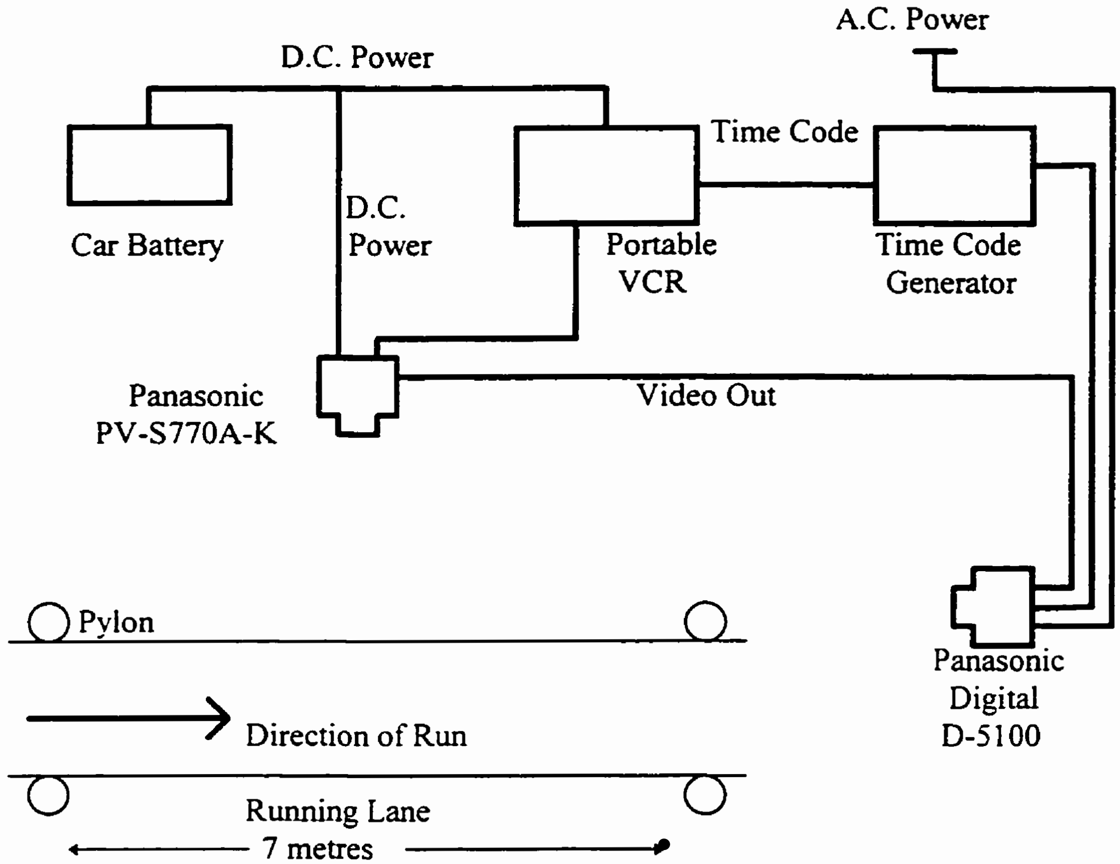


Figure 3-1. Camera set up that was used in filming the A and B drills and maximal sprint.

Four pylons were laid out on the track to indicate the filming area. The first two were placed on the lines of one of the lanes of the track, and represented the start of the filming area. The second two were placed at a distance of seven metres from the first two, on the lines of the same lane, and represented the end of the filming area. This grid was located 45 metres from the start line on the track, which allowed for analysis of sprinting technique during the second portion of the testing, the timed sprint. For calibration of the two cameras, a calibration tree was located in the middle of this grid. This calibration tree consisted of eight arms on which 24 white balls were located, each about the size of a ping-pong ball (see Figure 3-2.). The size of the tree was 2.2m x 2.0m x 1.6m.

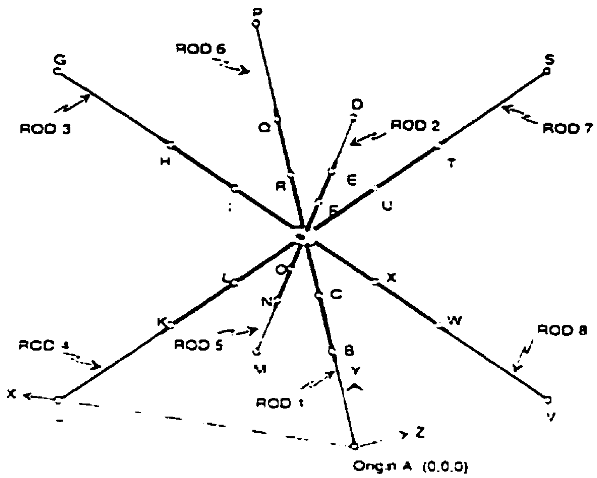


Figure 3-2. The calibration tree used for DLT calculations. From Peak Performance Technologies User's Reference Manual (Version 5.2.0), 1994, p. 5-37.

The balls were located at exact distances from one another (see Appendix B), with the distances taken from the Peak Performance User's Reference Manual (version 1.0) and entered into the project file. This tree was later digitized when setting up the project, first by the Panasonic PV-S770A-K camera, then by the Panasonic Digital D-5100 camera. The order of digitizing of these balls was the same for both camera views, which enabled the computer to produce accurate three dimensional data from the two camera views via direct linear transformation (DLT) parameters.

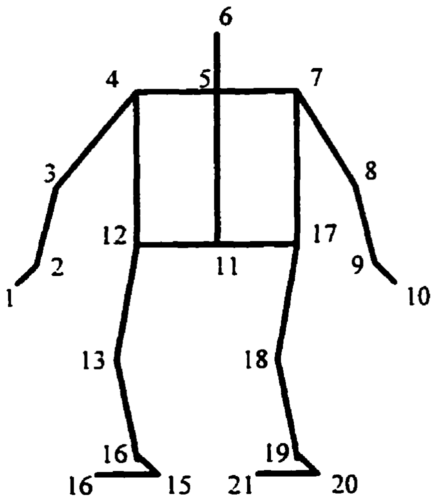
Once the filming of the calibration tree had been completed, the subjects were filmed. The subjects first performed the A drill, followed by the B drill. For these drills, the subjects began at the first pylons from a standing start, and were instructed to perform the drill to the second pylons, a distance of seven metres. They were asked to perform the drills as fast and technically perfectly as possible. For the drills, the subjects were given rest between trials, approximately 2 to 3 minutes. Between the A and B drills, the subjects were given 5 minutes rest. Each subject performed three repetitions of each drill. They wore their training flats during this part of the testing, as this is the customary footwear worn when performing the drills.

After completing the A and B drills, the subjects then performed timed 60 metre runs, which took place on the same lane as the drills. Starting from blocks with a typical race start, the subjects performed two runs at maximum speed. They sprinted through the seven metre pylon grid, at which time they were filmed for analysis. Each subject was allowed 12 to 15 minutes rest between trials. These runs were timed electronically using the Accutrack timing system. The sprinters wore spikes during these runs as this is the normal footwear they would wear when running to achieve maximum speed.

Film Data Analysis

The spatial model used in the present study consisted of 21 segmental endpoints, which allowed for kinematic analysis of the A and B drills and of sprinting. The endpoints were: right and left fingertip, right and left wrist, right and left elbow, right and left shoulder, middle of chest, top of head, middle of hip, right and left hip, right and left knee, right and left ankle, right and left heel, right and left toe (see Figure 3-3.). Each subject was marked with reflective tape at these segmental endpoints to provide greater repeatability when digitizing. Segmental masses and centre of mass locations used in the spatial model were taken from Humanscale (Diffrient, Tilley, and Bardagjy, 1978).

For both the A and B drills and the sprint, three consecutive steps were digitized. For the drills, the three steps digitized were from the trial which the researcher believed



ANATOMICAL LANDMARKS IN THE SAGITTAL VIEW FROM ANATOMICAL POSITION

1,10) Distal phalanx of third finger
2,9) Styloid process of radius
3,8) Centre of lateral epicondyle of humerus
4,7) Point on the humerus 2 centimetres inferior to the acromion process of the scapula
5) Sternal notch
6) Vertex of head
11) Mid-point between 12 and 17
12,17) Point 2 centimetres superior to the greater trochanter in line with the ASIS
13,18) Centre of lateral condyle of femur
14,19) Malleolus of fibula
15,20) Centre of calcaneus
16,21) Distal phalanx of great toe

ANATOMICAL LANDMARKS IN THE FRONTAL VIEW FROM ANATOMICAL POSITION

1,10) Distal phalanx of third finger
2,9) Mid-point between styloid processes of radius and ulna
3,8) Mid-point between medial and lateral epicondyles of humerus
4,7) Point on the humerus 2 centimetres inferior to the acromion process of the scapula
5) Mid-point between anterior and posterior walls of thorax at the level of the sternal notch
6) Vertex of head
11) Mid-point between 12 and 17
12,17) Point 2 centimetres superior to the greater trochanter in line with the ASIS
13,18) Mid-point between medial and lateral condyles of femur
14,19) Mid-point between malleolei of tibia and fibula
15,20) Centre of calcaneus
16,21) Distal phalanx of third toe

Figure 3-3. Graphical representation of the spatial model used in the present study (above), and the anatomical landmarks which were used in the digitizing process in both the sagittal and frontal views (below).

had been performed the most skillfully, based on visual inspection of the videotape. For the sprint, not all the subjects completed three steps in the viewing area. Therefore, two steps were digitized for these subjects from one sprint trial, with one being digitized from the second. The number of steps digitized in the present study was greater than the number of steps analyzed in previous studies involving kinematic sprint analysis: one stride (Lemaire & Robertson, 1990; Chengzi & Zongcheng, 1987; Mann and Herman, 1985).

The raw data from this study was conditioned using the Fast Fourier Transform filter. This type of filter is effective in removing amplitude noise from data that is cyclic in nature (Wood, 1982), and therefore was a suitable filter for smoothing data from the A and B drills and sprinting. For these data, an appropriate cut-off frequency was selected for each point based on visual analysis of the positional and velocity data at different frequencies. The cut-off frequencies ranged from 4 to 8 Hz, and were controlled for points across all subjects. The smoothed data produced by the settings used in this study best represented the raw data by removing extraneous noise yet maintaining the shape of the curve. Alexander (1989), in a study of elite sprinters, selected a cut-off frequency of 4 Hz, as it was found to be optimal. According to Winter (1990), the recommended frequency for digital filtering is around 6 Hz when the filming speed is 60 Hz.

Film Variables Calculated

This study consisted of a three-dimensional kinematic analysis, and the following variables were calculated for both the A and B drills and for sprint technique, using the Peak Performance Technologies motion analysis system (software version 5.3):

- vertical displacement of the centre of mass was determined by the difference between the height of the centre of mass at its highest point minus the height at its lowest point.
- vertical velocity of the centre of mass was the maximum vertical velocity achieved at the centre of mass.
- step frequency was calculated directly from video analysis by counting the number of frames to complete two or three steps.
- support time was determined directly from video analysis by counting the number of frames the subject was in contact with the ground.
- non-support time was determined directly from video analysis by counting the number of frames the subject was in flight.
- shoulder range of motion was the range achieved at the shoulder from maximum shoulder flexion to maximum shoulder hyperextension, in relation to the trunk.
- peak shoulder angular velocities were the maximum angular velocities achieved about the shoulder during shoulder flexion and shoulder extension.
- elbow range of motion was the maximum range at the elbow, from a position of minimum flexion to maximum flexion.
- peak elbow angular velocities were the maximum angular velocities achieved about the elbow in elbow flexion and elbow extension.
- trunk flexion was calculated as the maximum angle of forward flexion of the trunk from the vertical.
- trunk rotation was the range of rotation of the trunk about a longitudinal axis.

- pelvic rotation was the range of rotation of the pelvis about a longitudinal axis.
- hip flexion was the maximum angle of flexion found at the hip in relation to the vertical.
- peak hip angular velocities were the maximum angular velocities calculated about the hip during hip flexion and hip extension.
- knee range of motion was the maximum range at the knee, from the greatest angle of knee flexion to the smallest angle of knee flexion.
- peak knee angular velocities were the maximum angular velocities achieved about the knee during knee flexion and knee extension.
- ankle range of motion was the range found at the ankle, from maximum plantarflexion to maximum dorsiflexion.
- peak ankle angular velocities were the greatest angular velocities about the ankle during plantarflexion and dorsiflexion.

The peak value for each step digitized were averaged to give one number which will be representative of that variable. Therefore, for both the A and B drills and for sprinting, the value for each variable was be the average of the peak values of three steps. This method of determining one representative number was used by Mann and Herman (1985) in their analysis of the men's 200 metre final at the 1984 Olympics, although their study involved averaging two steps.

Angle-angle diagrams were devised to outline the simultaneous movements at the right hip and right knee for one stride during the A drill, the B drill, and sprinting. Angular displacement values at the right hip and knee for the three skills at intervals of

0.0167 seconds were used for these diagrams. Only the right hip and knee joints were compared. The values at the hip were measured from the vertical, with positive angles representing hip flexion and negative angles representing hip hyperextension. The greater the angle, the greater the hip flexion/hyperextension. For the knee, an angle of 0^0 represented full knee extension with larger angles indicated greater knee flexion.

Equipment and Facilities

The entire project was conducted at the Pan-Am stadium located at the University of Manitoba. The equipment necessary for the completion of this project was located in the biomechanics laboratory in the Health, Leisure, and Human Performance Institute at the University of Manitoba. This included the Panasonic Digital D-5100 and Panasonic PV-S770A-K video cameras, an IBM 486 computer, an NEC Multisync 2A computer monitor, a Sony Trinitron Colour Video Monitor, a Sanyo GVR-S955 SVHS Video Cassette Recorder, and a Hewlett-Packard 7475A Plotter. The entire film data acquisition system was linked and controlled by software (version 5.3) produced by Peak Performance Technologies (Englewood, CO).

Statistical Analysis

To determine if differences exist among the A drill, B drill and sprinting for each variable, the scores were compared using a one-way analysis of variance (ANOVA). By employing this type of statistical analysis, it was assumed that the data followed a normal distribution, and that the treatment groups were equally variable (Hassard, 1991). The independent variables for this study were the three skills being performed (A drill, B drill, and sprinting), while the dependent variables was the kinematic variables selected for analysis. If significant differences were found, a Tukey's multiple comparison test was used to determine where the differences exist. A level of significance of $P < 0.05$ was used for all tests. All statistics were performed on a Macintosh LC 475 computer using a statistical software package (StatView, version 4.02 for Macintosh).

Pilot Study

A pilot study was conducted on January 15, 1997, in which two sprinters from the University of Manitoba track and field team were recruited as subjects. One was a former CIAU champion sprinter over 60 metres, the other was a former CIAU long jump champion and a member of the 4x200 metre relay team. The goal of the pilot study was: (1) to collect data that would provide the investigator with the opportunity to gain some practical experience in the analysis of data, (2) to make possible comparisons among the A and B drills and sprinting based on select kinematic variables, (3) to determine if the proposed study was a feasible undertaking.

The results of the pilot study are similar to those of the present study. The methodology and results for the pilot study are found in Appendix C.

CHAPTER IV

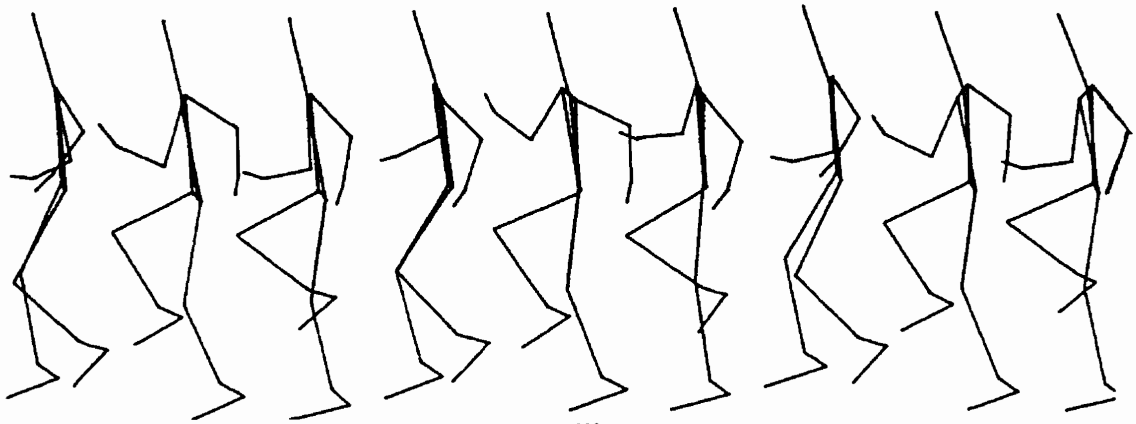
RESULTS

Subjects

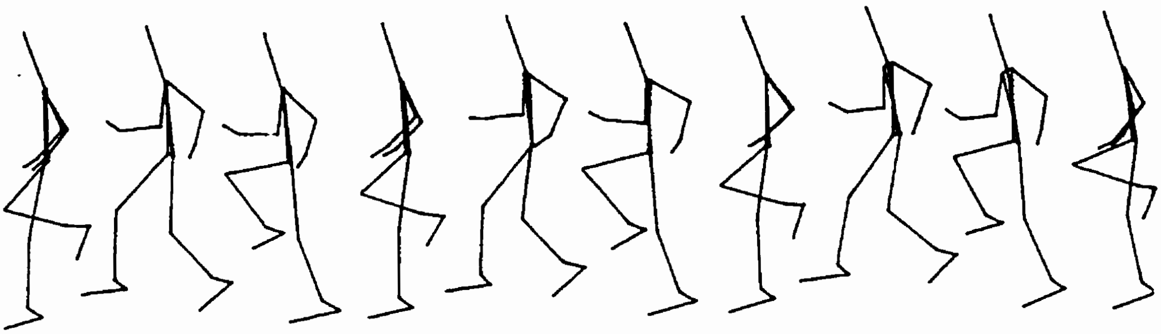
There were eight subjects recruited for this study, four males and four females. They were all top calibre university level athletes, each having qualified for the CIAU championships during their careers, whether it was individually or as part of a relay. Testing for this study took place during the precompetition phase of the outdoor season, so all athletes were in condition to complete the testing with maximal effort. A description of the eight subjects is found in Table 4-1, along with the best of the two times achieved during the 60 metre runs. Figure 4-1 illustrates stick figure representations of the A drill, B drill, and sprinting, as displayed by the Peak Performance Technologies motion analysis system.

Table 4-1. Subject Characteristics

SUBJECT	SEX	AGE	HEIGHT (m)	MASS (kg)	YEARS TRAINING	100M PB	60M
1	F	25	1.70	55	7	12.10	8.34
2	F	19	1.72	59	3	11.92	8.03
3	F	23	1.62	57	5	12.05	8.04
4	F	24	1.75	62	6	11.85	7.77
5	M	18	1.76	82	3	10.86	7.06
6	M	19	1.80	75	4	10.95	7.30
7	M	24	1.75	77	7	10.62	7.01
8	M	23	1.92	77	6	10.74	7.12



A Drill



B Drill

Sprint

Figure 4-1. Stick figure representations of the A drill, B drill, and sprinting.

For each of the three skills analyzed, the mean value calculated for each variable from the scores for each of the eight subjects are reported in Table 4-2, with standard deviation. For the variables which were found to have a significant difference between the means, a Tukey's multiple comparison test was employed to determine where the differences existed. The results of these statistical tests are found in Table 4-2.

Vertical Displacement

The vertical displacement of the centre of mass during both the A drill and the B drill were found to be smaller than during sprinting. The average vertical displacement during the A drill was 0.03 metres, while for the B drill it was 0.04 metres and for sprinting it was 0.06 metres (see Figure 4-2.). Standard deviations for each skill are outlined on the graph.

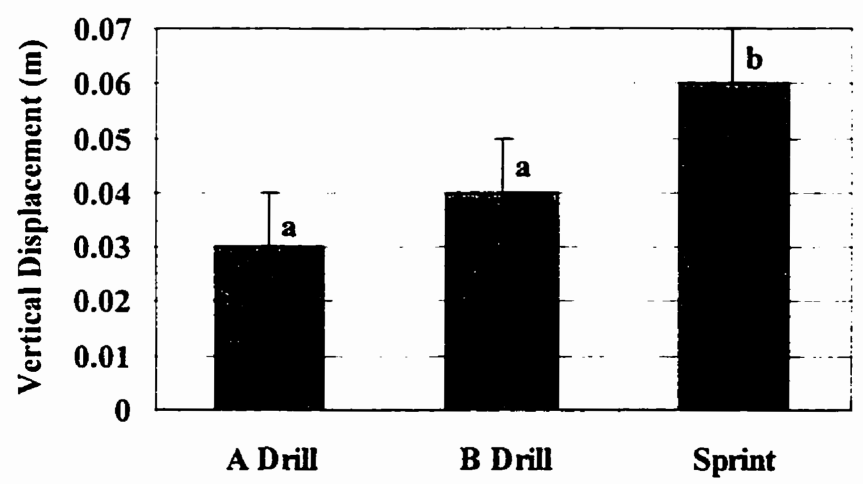


Figure 4-2. Average vertical displacement of the centre of mass during the A drill, B drill, and sprinting. a,b - means with the same letter are not significantly different, $p < 0.05$

Table 4-2. Results

VARIABLE	A DRILL MEAN	A DRILL S.D.	B DRILL MEAN	B DRILL S.D.	SPRINT MEAN	SPRINT S.D.	F VALUE	TUKEY'S VALUE
Vertical Displacement (m)	0.03^{a}	0.01	0.04^{a}	0.01	0.06^{b}	0.01	23.41	0.01
Vertical Velocity (m/sec)	0.30^{a}	0.07	0.42^{b}	0.11	0.58^{c}	0.07	21.81	0.11
Step Frequency (steps/sec)	4.83^{a}	0.44	4.08^{b}	0.42	4.60^{a}	0.37	6.94	0.52
Support Time (sec)	0.11^{a}	0.01	0.12^{a}	0.02	0.09^{b}	0.01	40.75	0.01
Non-support Time (sec)	0.10^{b}	0.02	0.13^{a}	0.02	0.13^{a}	0.01	7.67	0.02
Shoulder ROM (deg)	81	15	78	15	104	9	10.46	16.72
Shoulder Flexion AV (deg/sec)	518^{a}	82	448^{b}	86	583^{a}	98	4.62	112.29
Shoulder Extension AV(deg/sec)	637	196	479	113	589	90	2.68	
Elbow ROM (deg)	75	18	66	26	70	13	0.36	
Elbow Flexion AV (deg/sec)	1042^{a}	249	687^{b}	266	990^{a}	179	5.32	296.20
Elbow Extension AV (deg/sec)	693	136	621	217	770	202	1.25	
Trunk Flexion (deg)	5^{a}	1	6^{b}	1	7^{c}	1	9.04	0.87
Trunk Rotation (deg)	12^{a}	5	12^{a}	4	19^{b}	6	7.31	6.11
Pelvic Rotation (deg)	14^{a}	3	17^{a}	4	25^{b}	4	17.06	4.73
Hip Flexion (deg)	83^{a}	9	82^{a}	7	57^{b}	4	34.53	8.93
Hip Flexion AV (deg/sec)	647	125	663	114	681	188	0.11	
Hip Extension AV (deg/sec)	525^{b}	70	584^{a}	68	652^{a}	88	5.66	95.70
Knee ROM (deg)	114	14	125	9	122	3	2.52	
Knee Flexion AV (deg/sec)	1017	118	1113	81	1120	59	3.35	
Knee Extension AV (deg/sec)	760^{b}	94	865^{a}	123	1090^{a}	68	23.75	123.34
Ankle ROM (deg)	27^{a}	6	37^{b}	6	49^{c}	8	19.57	8.63
Plantarflexion AV (deg/sec)	393^{a}	107	445^{a}	114	790^{b}	266	11.73	224.99
Dorsiflexion AV (deg/sec)	407^{a}	146	463^{a}	103	805^{b}	201	15.35	196.17

a, b, c - means with the same letter are not significantly different, $p < 0.05$.

There were significant differences in the mean vertical displacement between the two drills and sprinting. Tukey's post hoc test revealed that the vertical displacement was significantly greater for sprinting.

Vertical Velocity

Figure 4-3 outlines the differences in the vertical velocity values among the A drill, B drill, and sprinting. The A drill showed an average vertical velocity of 0.30 metres/second, with the B drill an average vertical velocity of 0.42 metres/second and sprinting an average vertical velocity of 0.58 metres/second.

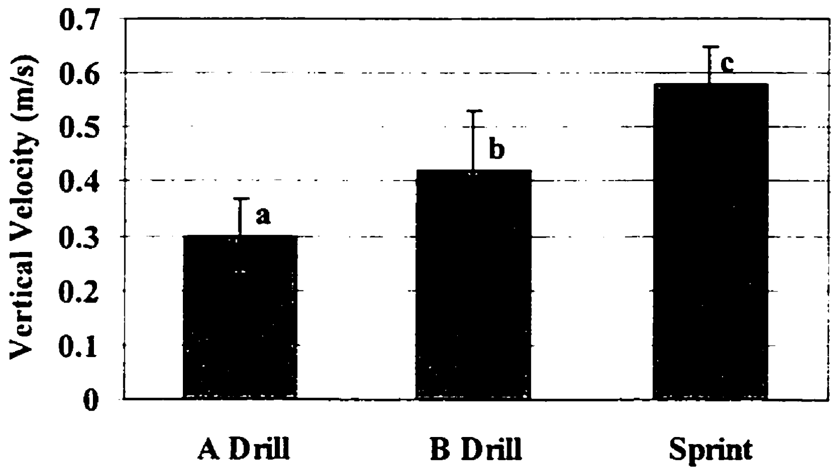


Figure 4-3. Average vertical velocity for the A drill, B drill, and sprinting.
a,b,c - means with the same letter are not significantly different, $p < 0.05$

There are significant differences in vertical velocity among the three skills, as Tukey's multiple comparison test determined that the vertical velocities of the three skills were all significantly different from one another.

Step Frequency

In the present study, the A drill was found to be performed with the greatest frequency with an average of 4.83 steps/sec for the eight subjects, followed by sprinting at 4.60 steps/sec. The B drill was found to be performed with the slowest frequency with an average value of 4.08 steps/sec (see Figure 4-4.).

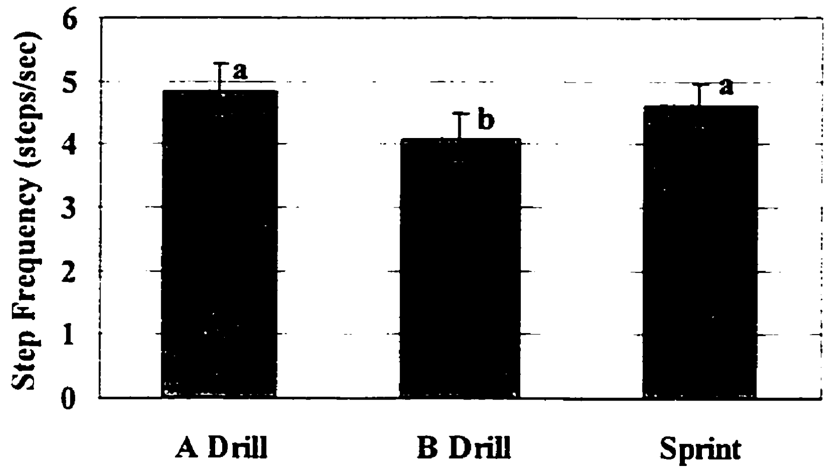


Figure 4-4. Average step frequency for the A drill, B drill, and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

Significant differences exist among the A drill, B drill, and sprinting in terms of step frequency, as post hoc tests showed that the B drill was significantly different from both the A drill and sprinting.

Support Time and Non-Support Time

In the present study, the average support time for the A drill was 0.11 seconds, which represented 52% of the total step time, while the average non-support time was 0.10 seconds, which represented 48% of the total step time. For the B drill, the average support time was 0.12 seconds, which was 48% of the total step time, while the average non-support time was 0.13 seconds which was 52% of the total step time. For sprinting, the average support time was 0.09 seconds, which represented 41% of the total step time, while the average non-support time was 0.13 seconds, which represented 59% of the total step time (see Figure 4-5.).

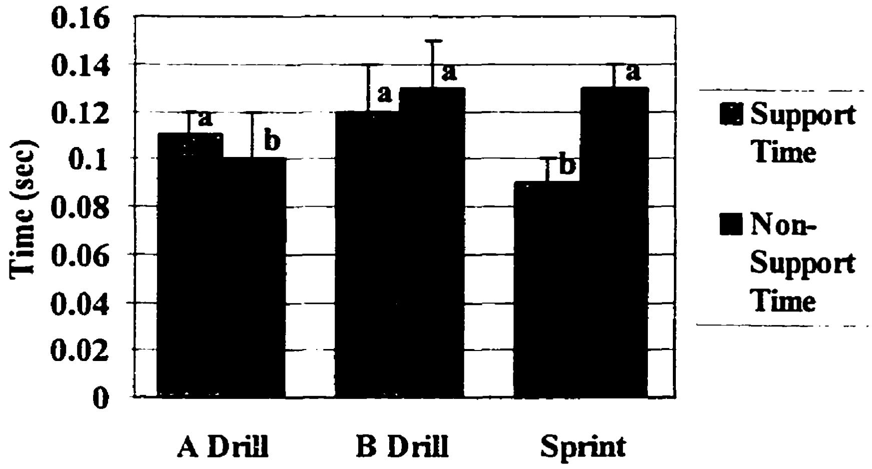


Figure 4-5. Average support time and non-support time for the A drill, B drill, and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

There were found to be significant differences among the three skills, as the support time during sprinting was significantly shorter than those of the A and B drills. In comparing the support time, both the A and B drills showed times of support which were larger than sprinting. There were also significant differences in non-support time among the three skills, as the non-support time for the A drill was significantly shorter than those of the B drill and of sprinting.

__Kinematics of the Shoulder__

The average range of motion at the shoulder during the A drill was 81^0, with a similar average value found for the B drill of 78^0. The range of motion at the shoulder was found to be greater for sprinting, with an average value of 104^0 (see Figure 4-6.). Statistical analysis indicated that these differences were significant, as Tukey's multiple comparison test revealed that the shoulder range of motion for sprinting was significantly different from the range of motion seen during the two drills.

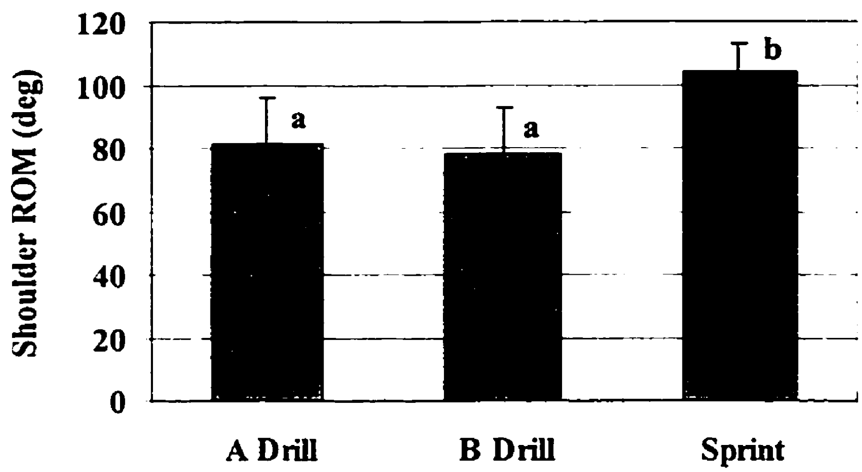


Figure 4-6. Average shoulder range of motion for the A drill, B drill, and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

The shoulder flexion angular velocity was found to be fastest for sprinting, where an average value of 583 degrees/second was reported for the eight subjects. The average shoulder flexion angular velocity for the A drill was found to be 518 degrees/second, while for the B drill the average shoulder flexion angular velocity was found to be 448 degrees/second (see Figure 4-7.). There were significant differences in the shoulder flexion angular velocity among the three skills, as post hoc comparisons revealed that the B drill was significantly different from the A drill and sprinting.

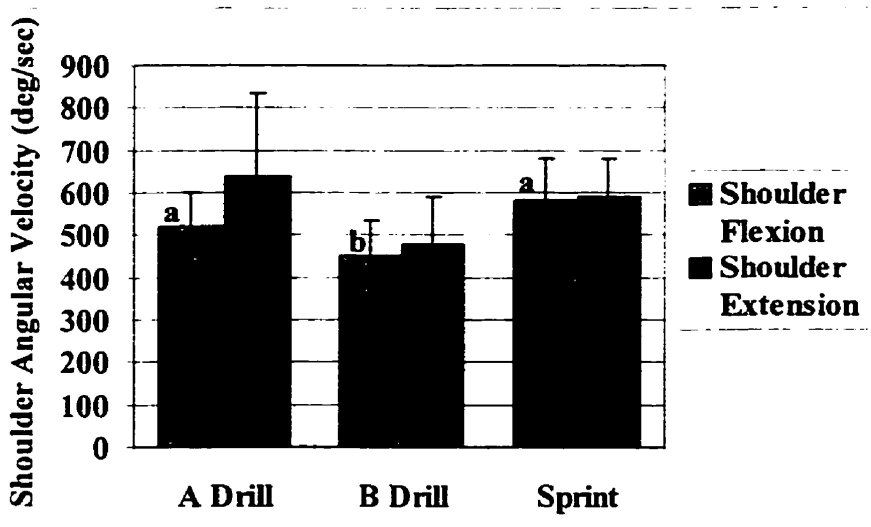


Figure 4-7. Average shoulder flexion and extension angular velocity for the A drill, B drill, and sprinting. a,b - means with the same letter are not significantly different, $p < 0.05$

The average shoulder extension angular velocity was found to be fastest for the A drill, where an average shoulder extension angular velocity of 637 degrees/second was found. The average shoulder extension angular velocity for sprinting was found to be 589 degrees/second, while for the B drill it was found to be 479 degrees/second.

There were no significant differences in shoulder extension angular velocity among the two drills and sprinting.

Kinematics of the Elbow

The range of motion at the elbow was found to be greatest for the A drill, in which an average value of 75^0 was calculated. The average range of motion at the elbow for sprinting was found to be 70^0, while for the B drill the average range of motion was found to be 66^0 (see Figure 4-8.). There were no significant differences in elbow range of motion among the three skills.

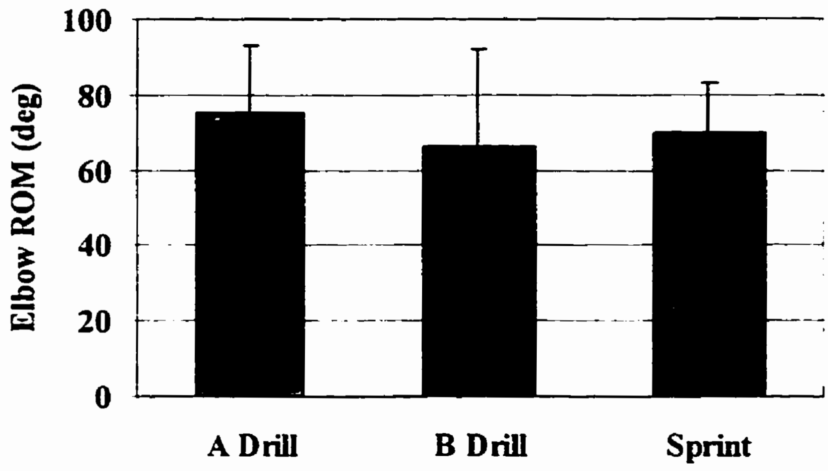


Figure 4-8. Average elbow range of motion for the A drill, B drill, and sprinting.

At the elbow, the average elbow flexion angular velocity was found to be greatest for the A drill, with a value of 1042 degrees/second. For sprinting, the average elbow flexion angular velocity was found to be 990 degrees/second, while for the B drill the average elbow flexion angular velocity was found to be 687 degrees/second (see Figure 4-9.).

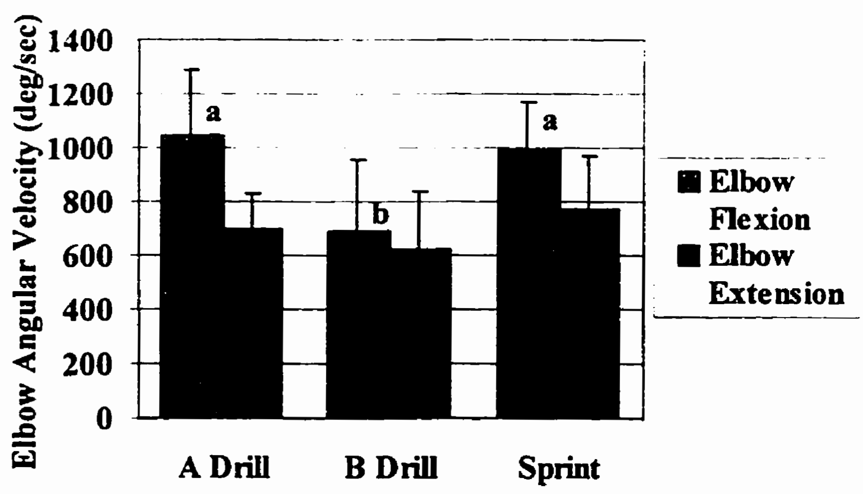


Figure 4-9. Average elbow flexion and extension angular velocity for the A drill, B drill, and sprinting. a,b - means with the same letter are not significantly different, $p < 0.05$

There were significant differences among the three skills, as Tukey's multiple comparison test determined that the elbow flexion angular velocity for the B drill was significantly different from both the A drill and from sprinting.

The fastest elbow extension angular velocity was found during sprinting, with an average value of 770 degrees/second being found. The average elbow extension angular velocity for the A drill was found to be 693 degrees/second, while the average elbow extension angular velocity was found to be 621 degrees/second. The means were not statistically different.

Kinematics of the Trunk and Pelvis

In the present study, maximum forward trunk flexion was found to be greatest for sprinting, with an average value of 7^0 for the eight subjects. Forward trunk flexion for the A and B drills was found to be 5^0 and 6^0, respectively (see Figure 4-10.).

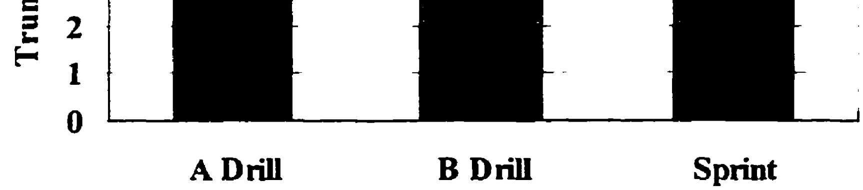


Figure 4-10. Average trunk flexion for the A drill, B drill, and sprinting.
a,b,c - means with the same letter are not significantly different, $p < 0.05$

There were significant differences in trunk flexion, as post hoc testing indicated that the average trunk flexion for both the A and B drills were significantly different from that of sprinting.

The greatest amount of trunk rotation was found during sprinting, in which an average value of 19^0 was found for the eight subjects. Smaller values were seen for the A and B drills, in which average peak values of 12^0 were seen for both drills(see Figure 4-11.). There were significant differences in trunk rotation among the three skills, as the trunk rotation during sprinting was significantly different from both the A and B drills.

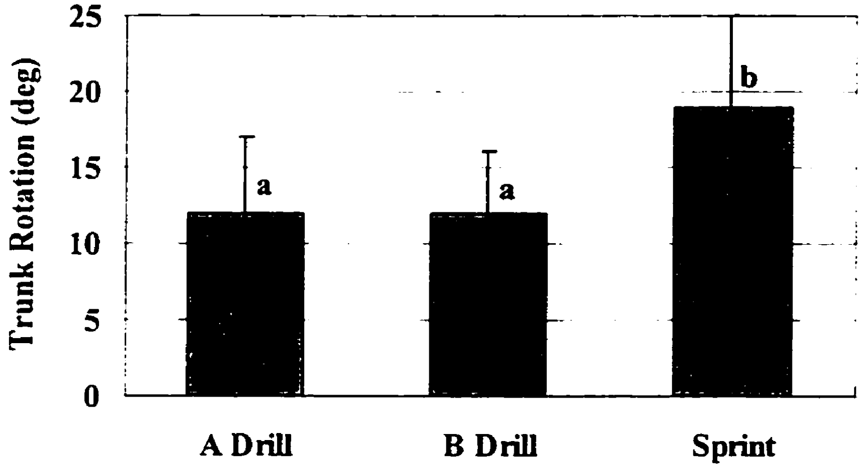


Figure 4-11. Average trunk rotation for the A drill, B drill, and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

The greatest amount of pelvic rotation was found during sprinting, in which an average pelvic rotation of 25^0 was seen in the eight subjects. During the A and B drills, the average pelvic rotation was found to be 14^0 and 17^0, respectively (see Figure 4-12.). There were significant differences among the three skills in pelvic rotation, as the pelvic rotation seen during sprinting was significantly different from that seen in both the A and B drills.

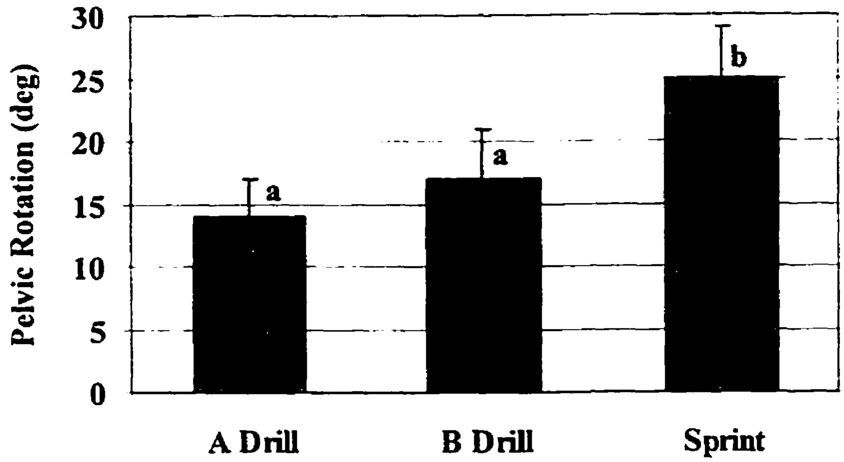


Figure 4-12. Average pelvic rotation for the A drill, B drill, and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

Kinematics of the Hip

At the hip, the greatest amount of hip flexion was seen during the A drill, where an average of 83^0 from the vertical was seen among the subjects. During the B drill, the average peak hip flexion was 82^0, while for sprinting, the average hip flexion was 57^0 (see Figure 4-13.). There were significant differences in hip flexion range of motion among the three skills, as the maximum hip flexion during sprinting was significantly different from that of the two drills.

The greatest hip flexion angular velocity was seen during sprinting, where an average peak hip flexion angular velocity of 681 degrees/second was calculated. Similar average hip extension angular velocity values were found for both the A and B drills, with

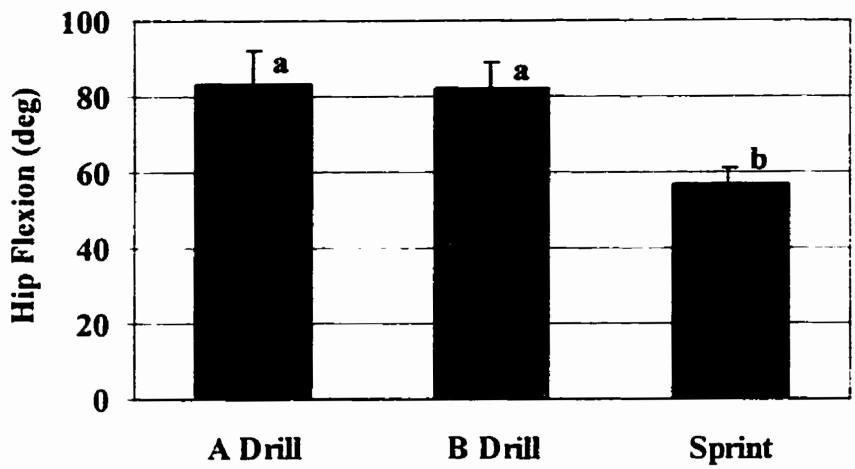


Figure 4-13. Average hip flexion for the A drill, B drill and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

values of 647 and 663 degrees/second, respectively (see Figure 4-14.). There were no significant differences in hip flexion angular velocity among the three skills.

The greatest hip extension angular velocity was seen for sprinting, where an average peak hip extension angular velocity value of 652 degrees/second was reported. For the B drill, the average peak hip extension angular velocity was 584 degrees/second,

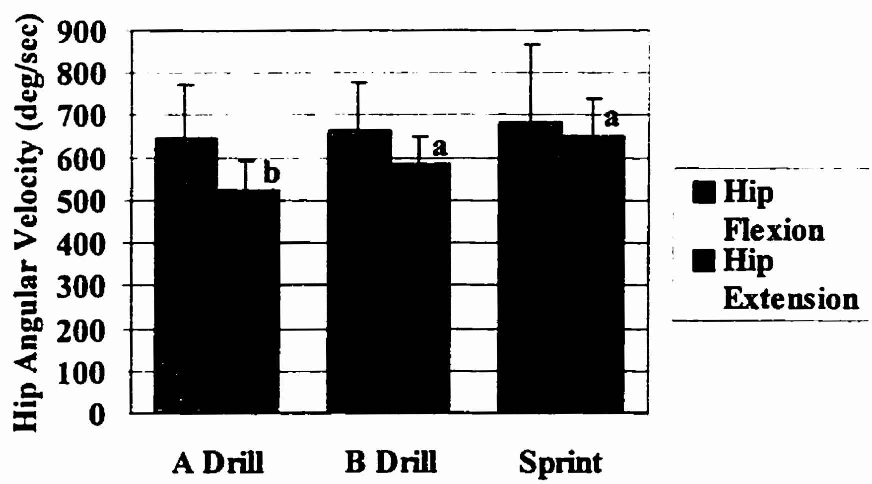


Figure 4-14. Average hip flexion and extension angular velocity for the A drill, B drill and sprinting.
a,b - means with the same letter are not significantly different, $p < 0.05$

while the average value for the A drill was 525 degrees/second. There were significant differences in hip extension angular velocity among the two drills and sprinting, as post hoc tests revealed that the A drill was significantly different from the B drill and sprinting.

Kinematics of the Knee

At the knee, similar range of motion values were seen during sprinting and the B drill, where average range of motion values of 122^0 and 125^0 were seen for the respective skills (see Figure 4-15.). For the A drill, a smaller range of motion value of 114^0 was found. There were no significant differences in knee range of motion among the three skills.

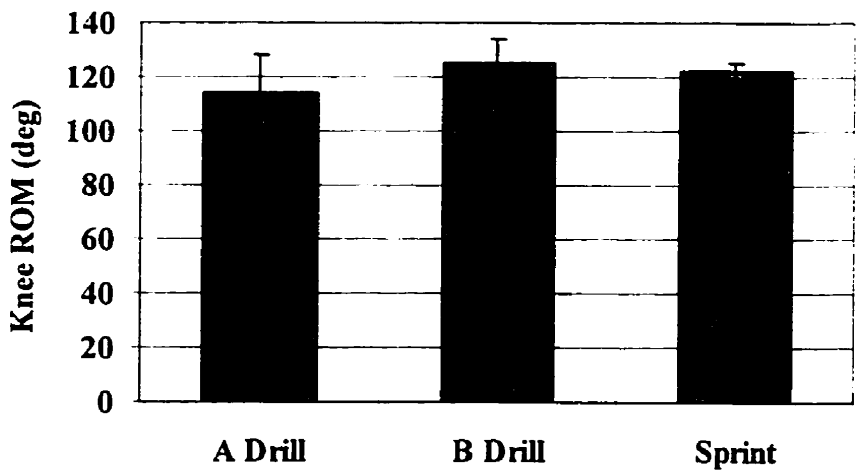


Figure 4-15. Average knee range of motion for the A drill, B drill and sprinting.

The greatest average flexion angular velocity was found during sprinting with a value of 1120 degrees/second. The average knee flexion angular velocity for the B drill was 1113 degrees/second, while for the A drill the value was 1017 degrees/second (see

Figure 4-16.). There were no significant differences among the A drill, B drill, and sprinting in knee flexion angular velocity.

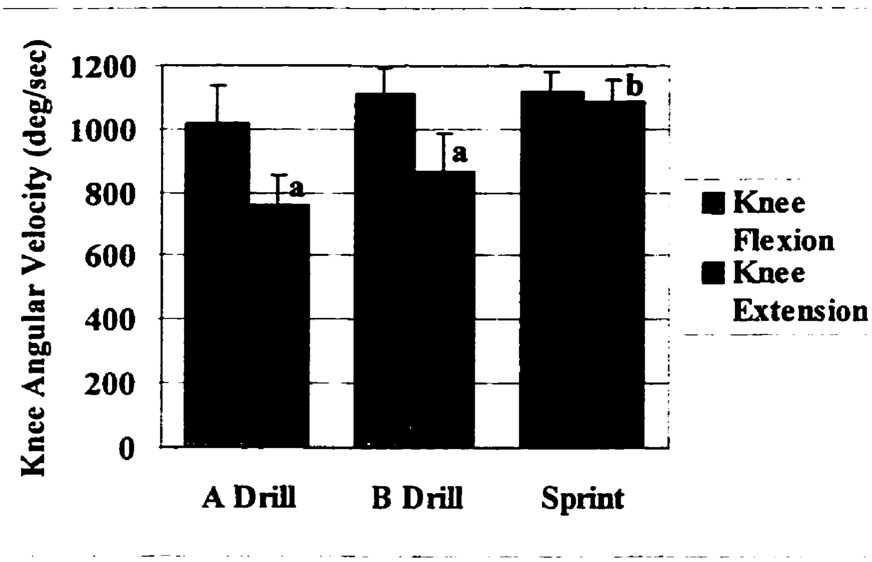
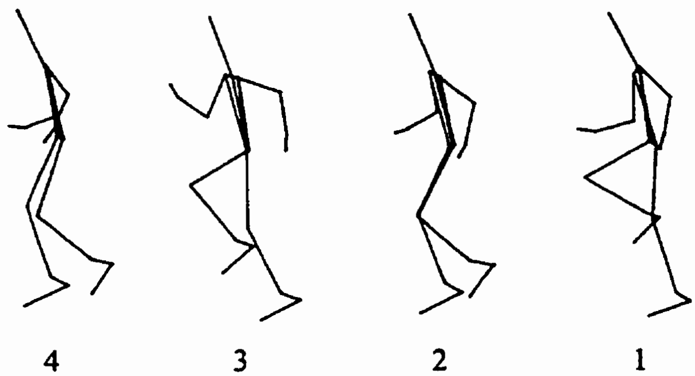


Figure 4-16. Average knee flexion and extension angular velocity for the A drill, B drill, and sprinting. a,b - means with the same letter are not significantly different, $p < 0.05$

The greatest average peak knee extension angular velocity was found for sprinting, with smaller values for the A and B drills. For sprinting, the average peak value was 1090 degrees/second. For the A and B drills, the average peak value was 760 and 865 degrees/second, respectively. There were significant differences in knee extension angular velocity among sprinting, the A drill and the B drill, as it was determined that the knee extension angular velocity for the two drills were significantly slower than that of sprinting.

Figures 4-17 (a) and (b) outline the angle-angle diagrams for subjects 3 and 1 for the right hip and knee during one stride of the A drill. The numbered stick figures above the graphs correspond to the numbers on each graph. Point 1 is the support phase, where there is a small angle of flexion at both the hip and the knee while the foot is in contact



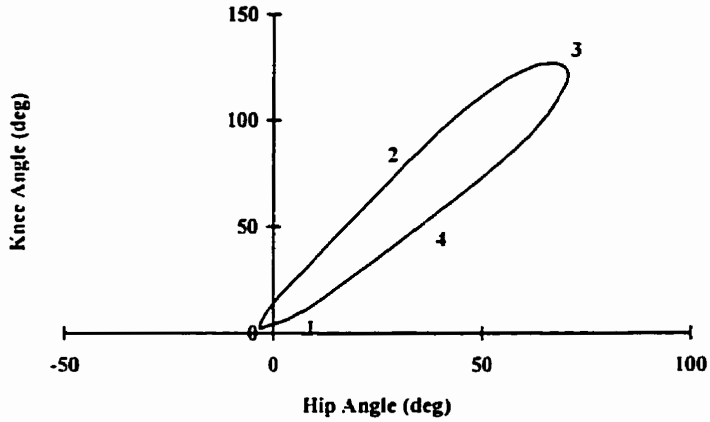


Figure 4-17(a). Angle-angle diagram for the right hip and knee for subject 3. The numbers 1,2,3,4 correspond to the positions illustrated above.

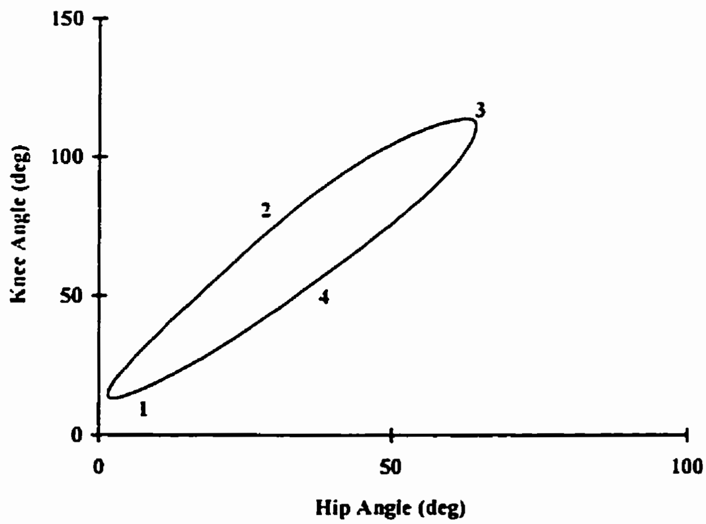


Figure 4-17(b). Angle-angle diagram for the right hip and knee for subject 1. The numbers 1,2,3,4 correspond to the positions illustrated above.

with the ground. Point 2 is early in the flight phase, as simultaneous hip and knee flexion bring the heel to the buttocks. Maximum hip and knee flexion occur at point 3, followed by hip and knee extension at point 4, as the foot is brought back to the ground.

Figures 4-18 (a) and (b) outline the angle-angle diagrams for subjects 3 and 1 for the right hip and knee during one stride of the B drill. The numbered stick figures above the graphs correspond to the numbers on each graph. The drill begins with the support phase at point 1, with a small amount of support flexion at the knee. Points 2 and 3 outline the progression of hip and knee flexion, reaching a maximum at point 4. The knee then extends, followed by extension at the hip, as the foot is brought back to the ground (point 5).

Figures 4-19 (a) and (b) outline the angle-angle diagrams for subjects 3 and 1 for the right hip and knee during one stride of sprinting. The numbered stick figures above the graphs correspond to the numbers on each graph. There is a distinct support flexion phase (point 1), followed by hip hyperextension and knee extension in propulsion (point 2). At point 3, flexion of the knee occurs in the recovery phase, with the hip still in a hyperextended position. The hip is then flexed (point 4), and the knee is extended in preparation for ground contact (point 5).

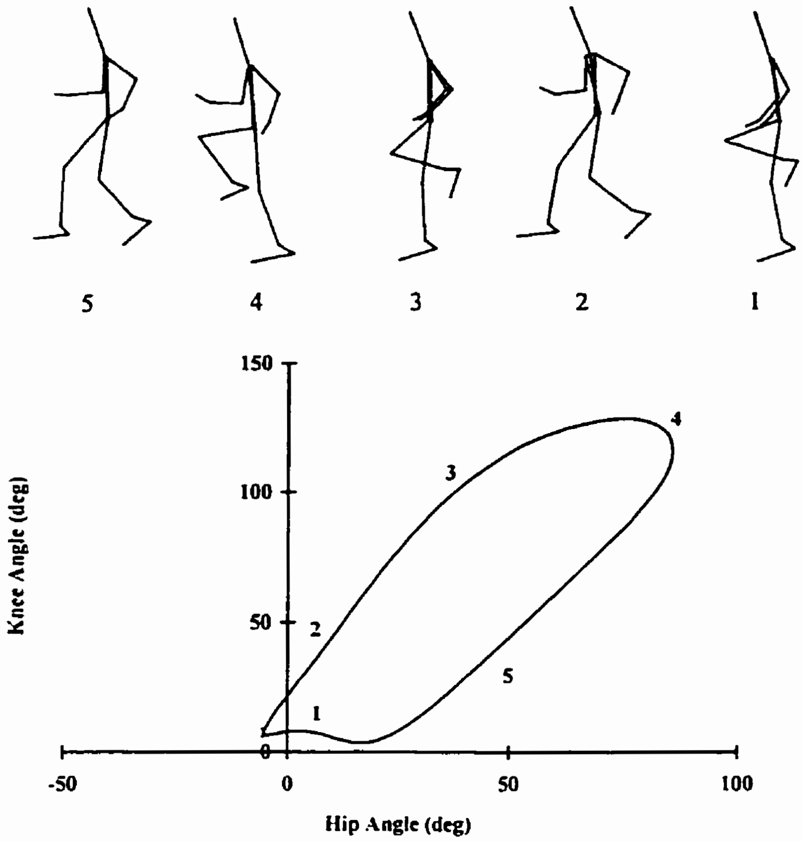


Figure 4-18(a). Angle-angle diagram for the right hip and knee for subject 3. The numbers 1,2,3,4,5 correspond to the positions illustrated above.

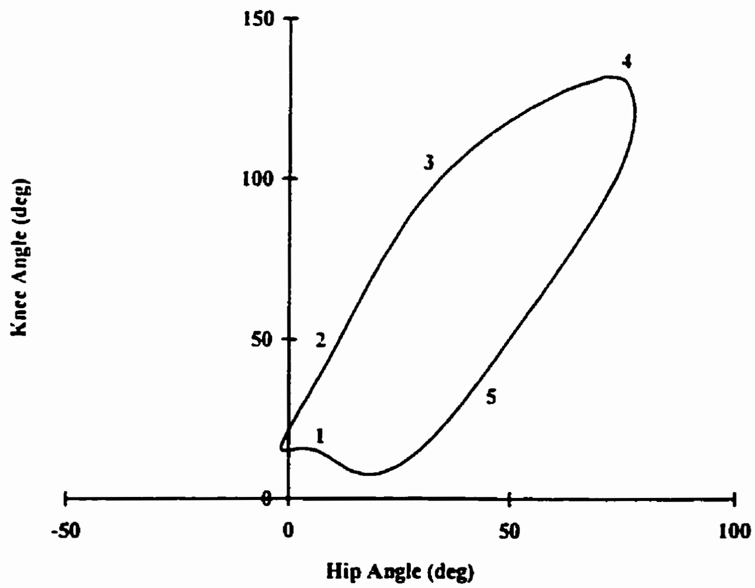


Figure 4-18(b). Angle-angle diagram for the right hip and knee for subject 1. The numbers 1,2,3,4,5 correspond to the positions illustrated above.

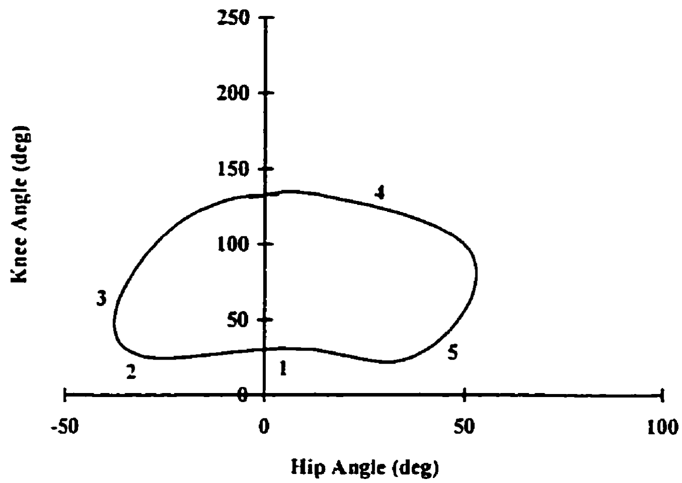


Figure 4-19(a). Angle-angle diagram for the right hip and knee for subject 3. The numbers 1,2,3,4,5 correspond to the positions illustrated above.

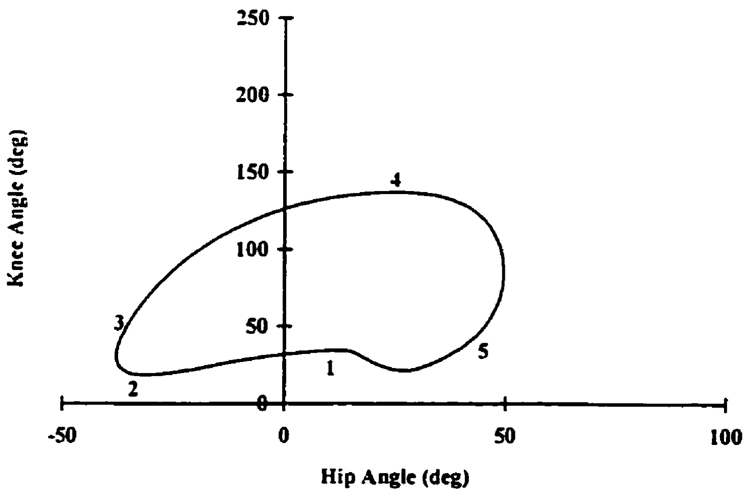


Figure 4-19(b). Angle-angle diagram for the right hip and knee for subject 1. The numbers 1,2,3,4,5 correspond to the positions illustrated above.

Kinematics of the Ankle

At the ankle, the range of motion was found to be greatest during sprinting, where an average range of motion of 49^0 was found for the eight subjects. For both the A and B drills, a decreased range of motion was seen, with values of 27^0 and 37^0 (see Figure 4-20.). Significant differences exist in range of motion among the three skills, and multiple comparison test revealed that the ranges of motion were significantly different from one another.

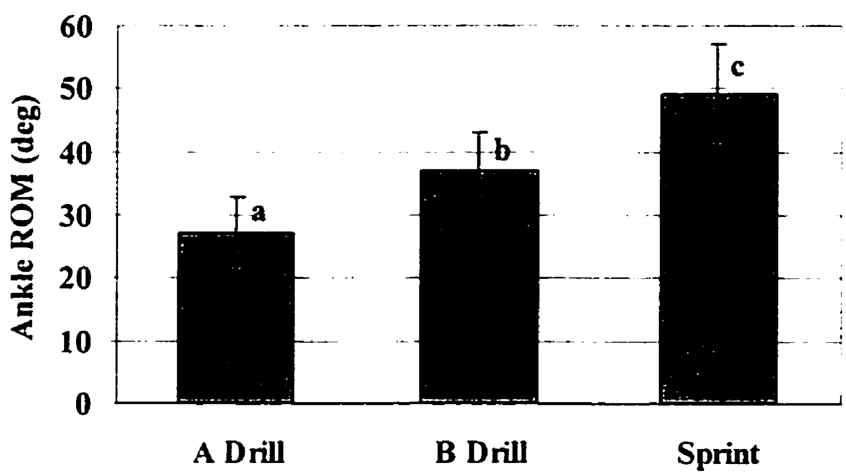


Figure 4-20. Average ankle range of motion for the A drill, B drill, and sprinting.
a,b,c - means with the same letter are not significantly different, $p < 0.05$

The greatest average plantarflexion angular velocity was seen during sprinting, in which a value of 790 degrees/second was found. Smaller values of 393 degrees/second for the A drill and 445 degrees/second for the B drill were found (see Figure 4-21.). There were significant differences among the three skills, with Tukey's multiple comparison test indicating that the angular velocity seen during sprinting was significantly different from those seen during the two drills.

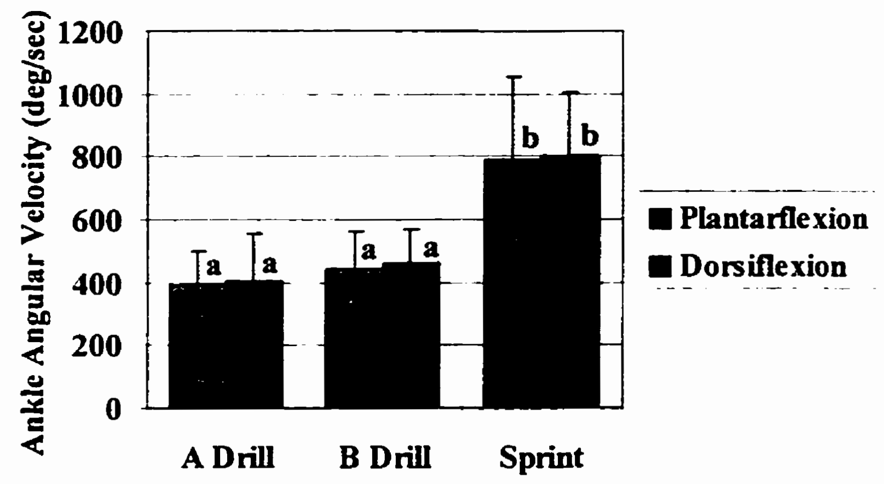


Figure 4-21. Average ankle plantarflexion and dorsiflexion angular velocity for the A drill, B drill, and sprinting. a,b - means with the same letter not are significantly different, $p < 0.05$

Similar trends were seen for dorsiflexion, in which the greatest average angular velocity was seen during sprinting, with a value of 805 degrees/second. Smaller values were seen for the A and B drills, in which values of 407 degrees/second and 463 degrees/second were reported, respectively.

CHAPTER V

DISCUSSION

Vertical Displacement

Throughout the sprinting stride, the centre of mass follows a parabolic arc, reaching the highest point midway through the flight phase and the lowest point during support flexion of the contact phase. Consequently, there is a vertical displacement of the centre of mass between the highest and lowest points.

During the A drill, simultaneous flexion of the hip and knee brings the foot to a position near the buttocks. The foot is then brought directly back to the ground through hip and knee extension. This direct path of the foot means a larger vertical displacement of the centre of mass is not required. During the B drill, the path of the foot from its position near the buttocks back to the ground is not straight but in an arc forward due to knee extension following hip flexion, and is therefore not direct and not as rapid. This means a greater vertical displacement of the centre of mass is required in order for there to be sufficient time for the foot to contact the ground under the body. The situation is similar for sprinting, but more displacement is required than for the B drill because the recovery leg must move from a position behind the body to one in front and then to the ground. In addition, vertical displacement during the two drills is smaller than that of sprinting because of the emphasis coaches put on technique, instructing the athletes to "stay tall" while performing the drills, to keep the support leg straight and to maintain an upright position in the trunk. In this position, the amount of support flexion is minimized, and the athlete is unable to extend the knee as forcefully during propulsion to increase the vertical displacement.

Vertical Velocity

The resultant velocity of the centre of mass of the sprinter may be divided into two components, horizontal and vertical. Horizontal velocity was not analyzed in the present study as the A and B drills are not performed by moving horizontally and therefore any comparison of peak horizontal velocity values would be meaningless.

There is an optimal amount of vertical velocity required during sprinting. Too much vertical velocity means the sprinter will be applying too much force in the vertical direction, where the majority of the force should be applied horizontally during the propulsive phase. Too little vertical velocity means there would be too little time for the forward swing of the leg in recovery, and stride length will be compromised.

The results from the present study indicate that the vertical velocity of the centre of mass during the A drill, B drill, and sprinting are significantly different, with the smallest vertical velocity seen during the A drill, followed by the B drill and sprinting. This is similar to the decreased vertical displacement of the centre of mass seen during the two drills.

Previous studies have reported vertical velocity values of 0.62 m/s for a group of female sprinters (mean 100 metre time = 11.95 seconds) and 0.69 m/s for a group of male sprinters (mean 100 metre time = 10.84 seconds) (Mero, Luhtanen, & Komi, 1986). Mann (1985) found that "good" male sprinters achieve a vertical velocity of 0.52 m/s, while "average" sprinters reach 0.61 m/s and "poor" sprinters 0.69 m/s. The vertical velocity value found during sprinting in the present study of 0.54 m/s for the females is slower than that reported previously, with the male vertical velocity value of 0.62 m/s being slower than that reported by sprinters of similar calibre. The male vertical velocity would classify the participants in this study as "average" sprinters if based on Mann's standards. However, there are widely differing skill levels between the present subjects and Mann's highly skilled sprinters, so these values are not directly comparable.

Step Frequency

Step frequency is the number of steps per second, where one step is from the time one foot terminates contact with the ground until the other comes into contact with the ground (Adrian & Cooper, 1989). Step frequency is important in sprinting, as average running speed is the product of step frequency and step length. If step length is maintained, the greater the step frequency, the greater the running speed.

The A drill was performed at a greater frequency, which may be explained by the difference in the timing of the movements of the legs as compared to sprinting. The leg movements for the A drill are simultaneous hip and knee flexion followed by hip and knee extension, which occur almost simultaneously. The B drill, in comparison, involves hip and knee flexion, followed initially by knee extension and then by hip extension. It is the knee extension prior to hip extension which slows down the step frequency of the B drill, since knee extension increases the moment of inertia of the leg and requires greater torque for hip extension.

The fact that the A drill is performed at a frequency greater than that of sprinting may suggest it is the superior of the two drills for the development of step frequency.

One issue regarding the efficacy of the A drill is that the movement patterns of this drill are quite different from those of sprinting. Perhaps the B drill, which has movement patterns which may be more similar to sprinting, would be the better drill to perform even though the step frequency is less than that of sprinting. Behm and Sale (1993), in their study comparing isometric ballistic and high velocity isokinetic training, concluded that it was the intent to contract ballistically, rather than the actual ballistic movement, that determined the velocity-specific response. This finding may suggest that even though the B drill is not performed with the same high frequency as the A drill or sprinting, simply by attempting to perform the drill as rapidly as possible would there be the most beneficial effects.

The average sprinting step frequency of 4.34 steps per second achieved by the female subjects is smaller than the 4.55 steps per second reported by Mero, Luhtanen, and Komi (1986) and the 4.48 steps per second reported by Hoffman (1971) in their studies of elite female sprinters. This difference may be explained by the fact that the subjects in the present study are university level athletes. The average sprinting step frequency of 4.85 steps per second achieved by the male subjects is within the range of 4.75 to 5.02 steps per second reported for the eight finalists of the men's 100 metres at the 1991 World Championships in Athletics. Mann (1985) reported that "good" male sprinters achieve a step frequency of 4.8 steps per second. The value reported in this study is smaller, though, than the 5.17 steps per second reported by Hoskisson and Korchemny (1991) in their study of elite junior sprinters.

Support Time and Non-Support Time

Support time is the time in which the sprinter is in contact with the ground, while non-support time is the time in which the sprinter is airborne. Ideally, the sprinter wants to minimize the contact time, and the effect of support time can be described by the linear impulse-momentum relationship, which states that a force applied over a period of time results in a change in the linear momentum of a body.

$$Ft = mv_f - mv_i$$

With no change in mass, the impulse results in a change in the linear velocity of the body.

Initial analysis of this relationship reveals that a decreased contact time may not be beneficial, as it conflicts with the idea that a greater impulse would result in a greater change in momentum. However, if the athlete is somehow able to increase the force produced during contact, and the increase in the force is greater than the decrease in the contact time, the result would be a greater change in momentum. Under such circumstances there would be an increase in the resultant velocity achieved by the sprinter. According to Hay (1993), how an athlete is able to decrease contact time while simultaneously increasing the force applied has yet to be completely explained. It appears that the forced eccentric action of the muscles of the support leg may enhance the explosive concentric action of the leg in propulsion by utilizing the elastic components of these muscles and/or a stretch reflex mechanism (Dapena, 1987).

For the A drill, the support time is slightly larger than the non-support time, which is due to the timing of the movements of the legs when performing the drill. When one hip and knee are extending, the opposite hip and knee are flexing. There is a very brief period when the sprinter is in flight and then the foot contacts the ground. For the B drill, the non-support time is slightly larger than the support time, which is a result of the increased range of motion seen in the legs. In order for the leg to complete this range, there must be an increased time spent in the flight phase. This increased time in non-support is associated with the increased vertical displacement and velocity seen in the B drill, as compared to the A drill. In sprinting, the support phase is considerably shorter than the non-support phase, with a mean support time of 0.09 seconds and a mean non-support time of 0.13 seconds found for the eight subjects. This is because the athletes are trying to minimize the time on the ground and to produce a larger impulse, which is force times time. The non-support phase must be larger than the support phase in order for there to be sufficient time for the leg to recover from a position behind the body after toe-off to one in front, and then drive forcefully to the ground. For this sequence of movements to occur, there must be sufficient vertical displacement of the centre of mass, which indicates that there will be a corresponding increase in non-support time, since vertical velocity is the sole determinant of time in the air.

Both the A and B drills attained support times which were larger than sprinting. This implies that the change in direction of the centre of mass is occurring more slowly. It is important that sprinters attempt to decrease the support time during the drills, to increase the speed at which the direction of the centre of mass is changed. This is because it is during this rapid reversal of direction in the vertical direction where most of the force and energy are expended during sprinting (Mann, 1986).

The A drill attained non-support times which were significantly shorter from the B drill and from sprinting. This shorter non-support time may be explained by the timing of the movements of the legs when performing the drill. When one hip and knee are extending, the opposite hip and knee are flexing. There is a very brief period when the sprinter is in flight and then the foot contacts the ground. It is also a result of the smaller vertical displacement and velocity seen during the A drill, as compared to the B drill and sprinting.

For sprinting, the average support time of 0.09 seconds is similar to those reported by Mero, Luhtanen, and Komi (1986) and Burt (1994) of 0.09 and 0.10 seconds, respectively, in elite sprinters running at maximum speed. The 41% of the total step time spent in contact during sprinting is similar to Hay's (1993) findings that the time in the support phase may be as low as 40% to 45% of total step time.

The value obtained in this study for support and non-support time may be used for comparison, but it may be inaccurate to consider them correct due to the limitations in the filming speed. The cameras filmed at a frequency of 60Hz, limiting the accuracy in determining the exact frame in which touchdown or toe-off occurred. More accurate measurements of support time would have been obtained with video cameras which filmed at a higher frequency, if these had been available.

Kinematics of the Shoulder

During sprinting, pelvic rotation occurs in association with the phases of the leg action. When the left thigh is flexed late in the recovery phase and the right thigh is extended in the propulsion phase, there is a rotation of the pelvis to the right. As the left thigh is extended through the support phase and the right thigh is flexed in recovery, there is a rotation of the pelvis to the left. Maximum pelvic rotation occurs when the thigh approaches maximum flexion (Hay, 1993). Hip flexion and extension torques act over a period of time to generate angular momentum about the longitudinal axis through the body's centre of mass. This is based on the angular impulse-momentum relationship:

$$Tt = (I\omega)_f - (I\omega)_i$$

This relationship states that a torque applied over a period of time results in a change in the angular momentum of a body about a given axis of rotation. The angular momentum about the longitudinal axis produced by the legs must be balanced by actions of the trunk and arms to ensure that the total body rotation is minimized. At slow running speeds, this is accomplished by slight rotation of the trunk, with moderate accompanying arm action. Because the trunk is more massive, rotation will counteract most of the angular momentum, while the arms simply swing easily with the body. At sprinting speeds, the trunk is unable to rotate fast enough to keep up with the legs. Therefore, balancing the angular momentum of the legs and pelvis is one role of the arms, which means a forceful arm action is more evident and more important.

There is an optimal value for the range of motion at the shoulder during sprinting. If the range of motion is too large, Mann (1985) stated that it may be an indication of overstriding. If the shoulder range of motion is too small, the angular momentum of the upper body will be smaller than the angular momentum of the lower body, thus decreasing the range of motion of the legs to ensure a minimal angular momentum of the entire body is maintained. Also, decreasing the range of motion at the shoulder would decrease the contribution of the arms to the vertical ground reaction force, or "lift." In the present study, significant differences were found in the range of motion at the shoulder, with the range of motion during the A and B drills significantly smaller than sprinting. The decreased range of motion may be attributed to the decreased range of motion at the hip and the decreased rotation of the pelvis. At the hip , the thigh does not hyperextend for the two drills as it does in sprinting. This means there is a decreased pelvic rotation as compared to sprinting, thus the angular momentum of the lower body is decreased. Consequently, the angular momentum to be produced during the drills by the upper body to balance the angular momentum of the lower body is decreased. and the range of motion at the shoulder is minimized.

Figures 5-1 and 5-2 outline the right shoulder angular displacement-time graphs for three steps during the A drill. B drill and sprinting. The "sprint" line for subject 4 ends at right touchdown (event 5) as only two steps were digitized. The following events are indicated on the graphs: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. Positive values represent angles of shoulder flexion relative the trunk, while negative values represent shoulder extension angles relative the trunk. Both subjects show increased range during sprinting as compared to the drills. The motion at the shoulder for subject 3 during the two drills was different from that of sprinting, as the shoulder did not reach an angle of flexion relative to the trunk. A greater angle of shoulder extension was also seen for the A and B drills as compared to sprinting. Subject 4 showed a greater shoulder range of motion in both the flexion and extension directions for sprinting.

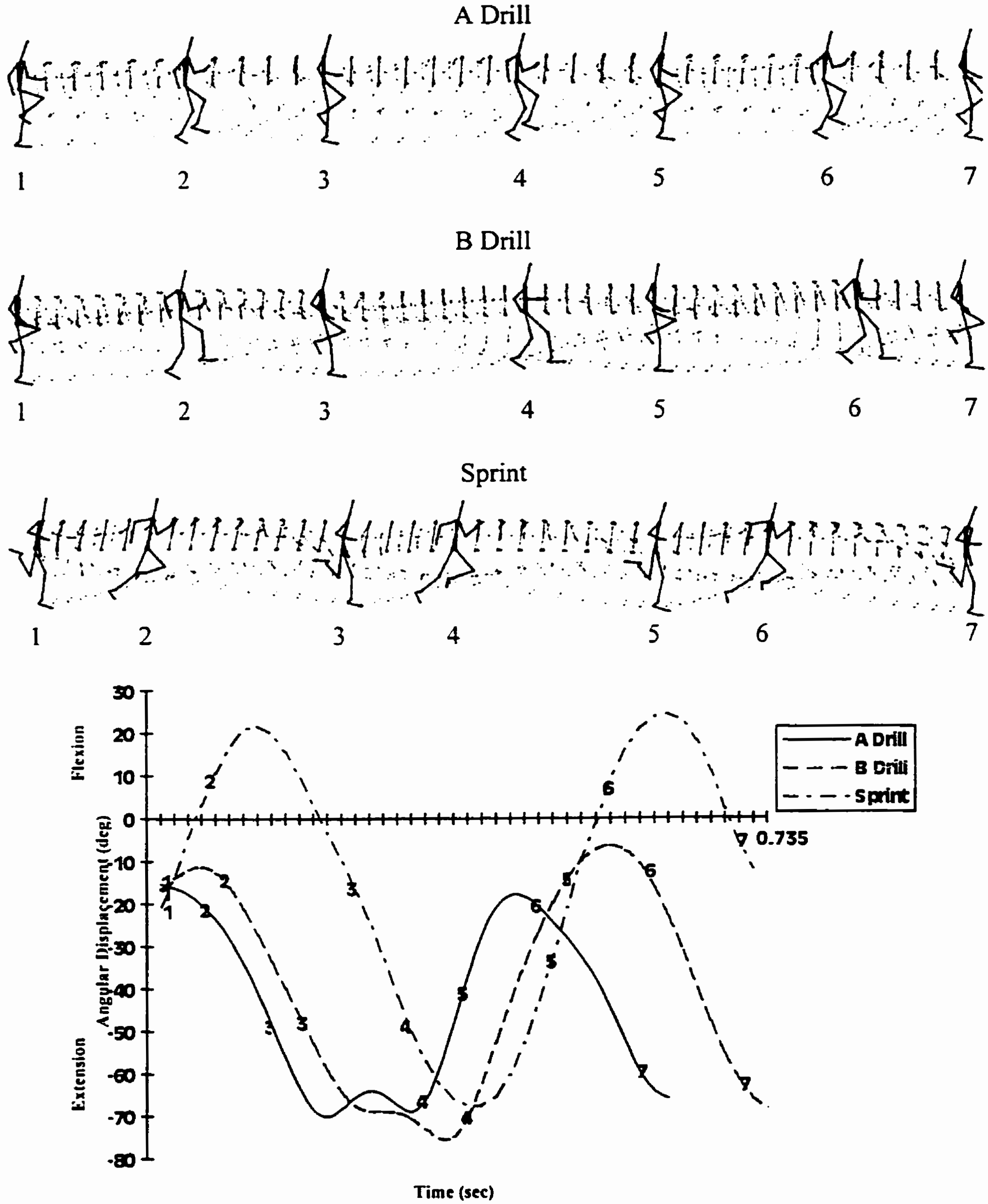


Figure 5-1. Angular displacement/time curves for subject 3 for the right shoulder during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe- off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

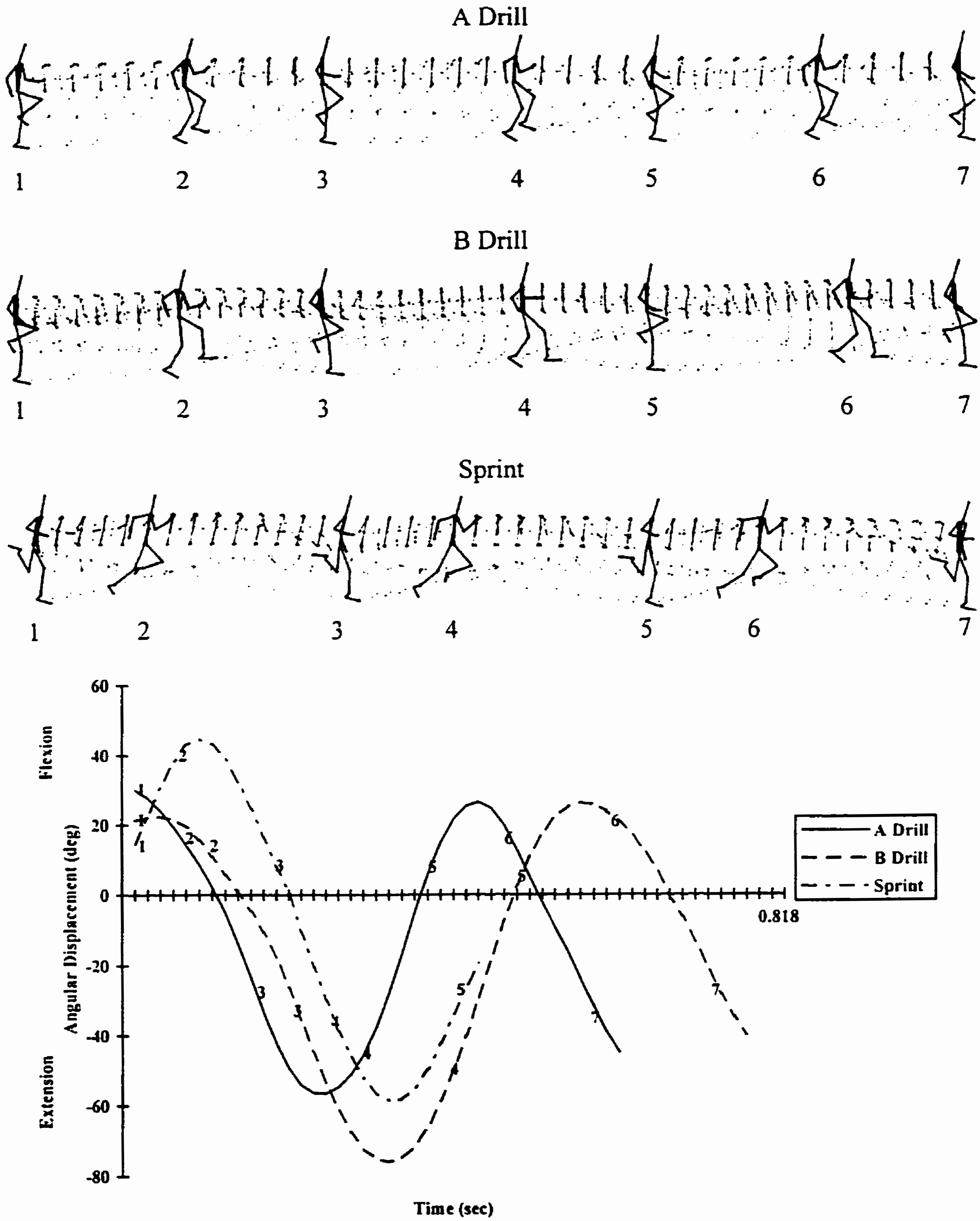


Figure 5-2. Angular displacement/time curves for subject 4 for the right shoulder during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

Mann and Herman (1985), in their study of the men's 200 metre final at the 1984 Olympics, found shoulder ranges of motion of 135^0, 122^0, and 118^0 in the first, second, and eighth place finishers. Mann (1985) reported "good" male sprinters produced a shoulder range of motion of 132^0, with "average" sprinters showing similar range of motion but "poor" sprinters demonstrate a range of motion of 150^0. The shoulder range of motion values found in the present study for sprinting are significantly smaller than those reported in previous studies. It is interesting to note that the average range of motion seen in the university level sprinters used in this study showed a decreased range of motion as compared to the elite sprinters of other studies, yet Mann (1985) found that the shoulder range of motion in average sprinters was similar to those of elite level. It is possible that there are differences in shoulder range of motion between average and good sprinters. or that Mann's average sprinters were more highly skilled than the present subjects.

Mann and Herman (1985) found shoulder flexion angular velocities of 525, 500 and 490 degrees/second in the first, second, and eighth place finishers, respectively. These researchers also found shoulder extension angular velocities of 740, 558, and 572 degrees/second in the same athletes. In the present study, a similar trend was found with the shoulder extension angular velocity being greater than the shoulder flexion angular velocity for the A and B drills and for sprinting. It is important that the angular velocity at the shoulder in the extension direction is greater than in the flexion direction, as the extending arm must rotate faster in order to generate sufficient angular momentum to balance the angular momentum generated by the contralateral leg. This leg is extending rapidly at the hip, with the knee extended creating a long lever. Angular momentum is the product of moment of inertia and angular velocity. If the leg is extended, it has a greater moment of inertia because of the greater radius of gyration, as moment of inertia is the product of the mass and the radius of gyration squared. This large moment of inertia combined with the rapid hip extension angular velocity produces a large angular momentum.

The shoulder extension angular velocity was greatest for the A drill because of the decreased range of motion seen at the shoulder. In order to maintain angular momentum with the decreased range of motion, the angular velocity had to increase. For the B drill, there was a similar limited range of motion at the shoulder, but because of the decreased frequency of movement seen in the legs for this drill, with knee extension occurring before hip extension, the shoulder extension angular velocity required to maintain angular momentum was decreased. For sprinting, a high shoulder extension angular velocity is required because of the rapid hip extension angular velocity. This fast movement of the extended leg generates a large amount of angular momentum in the lower body. In order to maintain equilibrium, there must be a corresponding rapid shoulder extension angular velocity.

Figures 5-3 and 5-4 compare the angular velocity-time graph for the right shoulder for three steps during the A drill, B drill, and sprinting for subjects 3 and 4, beginning with shoulder flexion. The “sprint” line for subject 4 ends early, as only two steps were digitized for this subject for sprinting. The positive values represent shoulder flexion angular velocities, while negative values represent shoulder extension angular velocities.

The following events are indicated on the graphs: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown.

For sprinting, for each of the three times toe-off occurred (events 2, 4, and 6), there was a positive angular velocity value, which indicates that the shoulder was at maximum velocity or had just passed maximum velocity in the flexion or extension direction at the instant of toe-off, and there would be a significant contribution of the arms to the production of ground reaction forces.

This situation is not the case for either the A or the B drill, however. At the same three instances, there is a small extension angular velocity at the right shoulder (event 2 and 6), or a small flexion angular velocity (event 4). This means that at the times when the arms should be making a contribution to the production of ground reaction forces, they are not doing so.

Generating a high shoulder angular velocity in both the flexion and the extension directions is important in sprinting, as the arms make a significant contribution to vertical ground reaction forces. Mero and Komi (1978) found that in the vertical direction, the arms contributed 199 N to the total ground reaction force generated during the propulsive phase. In the horizontal direction, though, the same high angular velocity values are detrimental, as the negative force generated by the shoulder in extension is greater than the propulsive force generated by the shoulder in flexion. Mero and Komi (1978) reported that the arms contribute -124 N in the forward horizontal direction. The larger

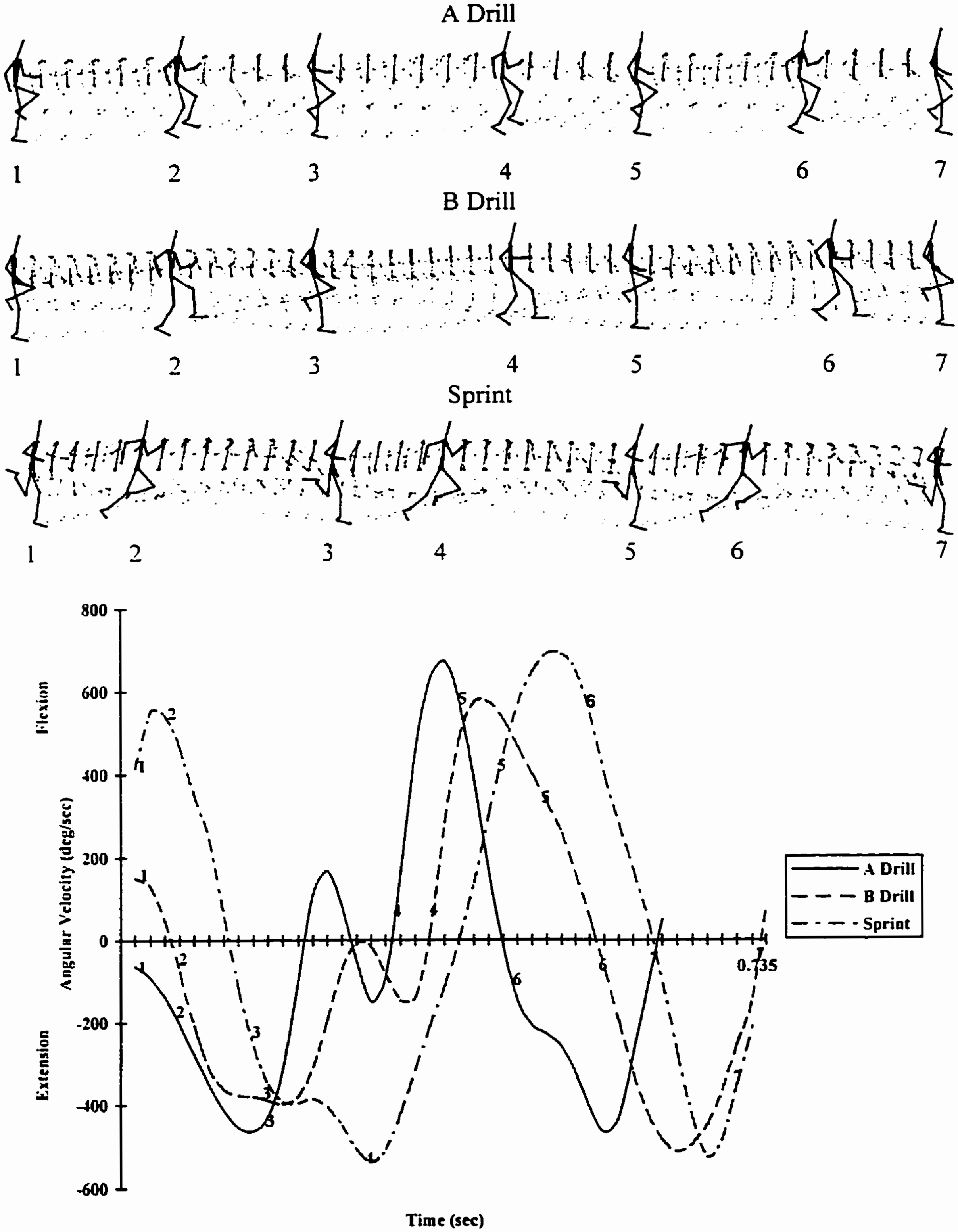


Figure 5-3. Angular velocity/time curves for subject 3 for the right shoulder during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

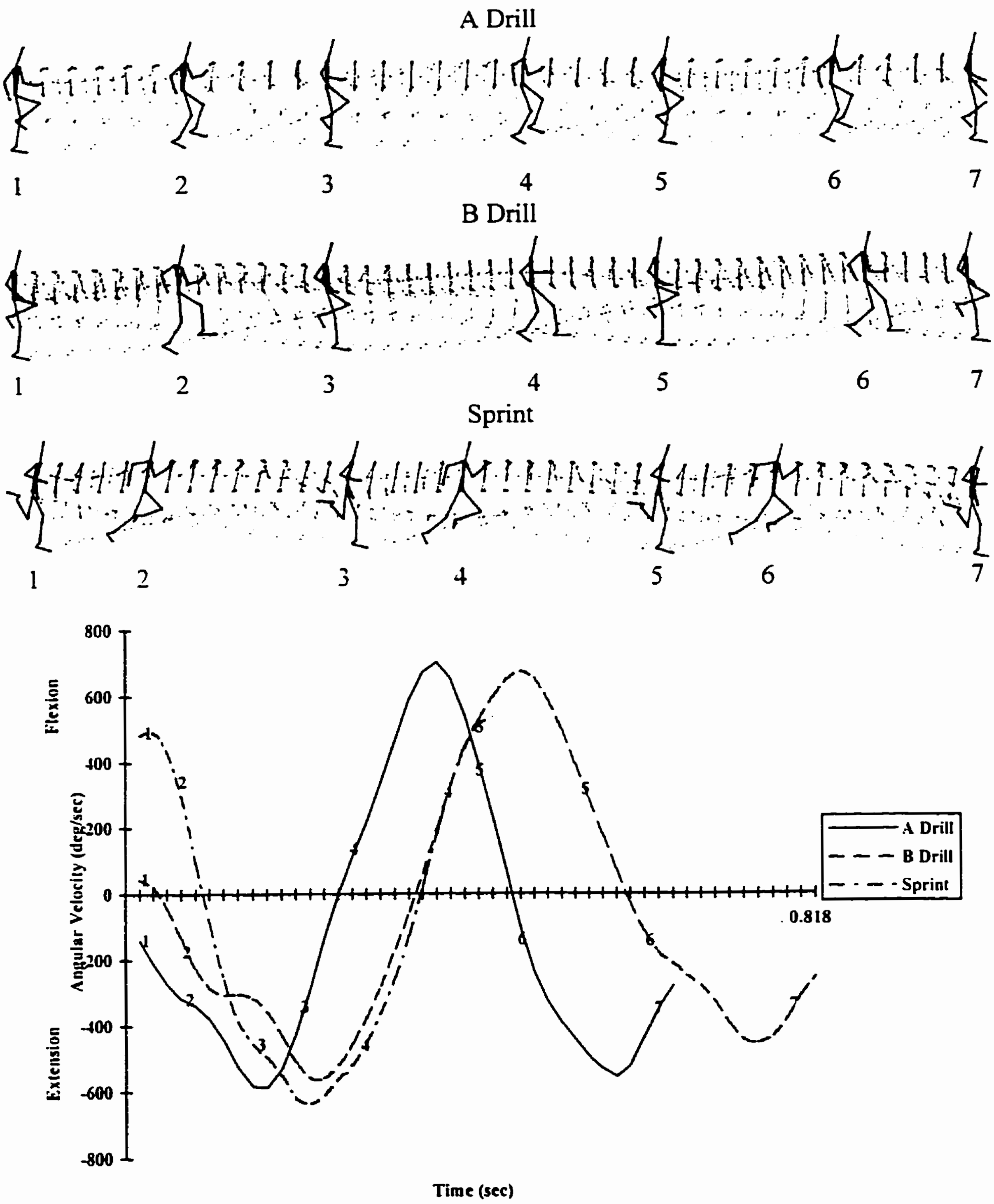


Figure 5-4. Angular velocity/time curves for subject 4 for the right shoulder during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

angular velocity values during the A drill indicate that there is a potential for increased ground reaction force contribution than for sprinting, but peak shoulder angular velocity does not occur at a point during the drill cycle when it can make a significant contribution. During the B drill, both the shoulder flexion and extension angular velocities are smaller than those of sprinting, but there is a similar difference in the timing of peak angular velocity during the drill, so there is no contribution of the arms to the ground reaction force.

Peak shoulder flexion angular velocity was seen prior to right foot toe-off (event 2 and 6) during sprinting. On the shoulder angular displacement-time graph, this corresponds to a shoulder flexion angle of approximately 0^0 for subject 3 and 30^0 for subject 4. For the A and B drills, the same event was seen between left toe-off and right contact (events 4 and 5), when the angle at the shoulder was approximately 40^0 of extension for subject 3 and 20^0 of extension for subject 4.

In comparing the peak shoulder flexion and extension angular velocities with the shoulder angular displacement data, differences are seen in the range at which the peak angular velocities occur. Peak shoulder extension was seen at the time of left foot toe-off (event 4) or slightly before. This event corresponds to a shoulder angle of approximately 35^0 of extension for both subjects 3 and 4 on the angular displacement-time graph. For the A drill, peak shoulder extension angular velocity was seen prior to left touchdown (event 3) at a shoulder angle of approximately 50^0 of extension for subject 3 and 30^0 of extension for subject 4. For the B drill, peak shoulder extension angular velocity was seen after left touchdown (event 3) at a shoulder angle of approximately 50^0 of extension for subject 3 and 35^0 for subject 4. These results indicate that there are distinct differences in the range at which peak shoulder flexion and extension angular velocity occur for the A and B drill when compared to sprinting.

Kinematics of the Elbow

During running, the movements at the elbow joint are closely associated with those of the shoulder. According to Hinrichs (1985), there are two phases to the extension movements at the elbow. The primary extension phase (PEP) occurs around ipsilateral foot strike, followed by a much smaller secondary extension phase (SEP) around contralateral foot strike. Maximum elbow flexion occurs during ipsilateral toe-off. The elbow is maintained in a flexed position at an angle of approximately 100^0, with small deviations from this angle throughout the running stride.

In the present study, the greatest range of motion at the elbow was found during the A drill. This increased range of motion is probably due to errors in technique displayed by the sprinters. Ideally, the range of motion at the elbow should be minimized. An increase in range of motion, particularly in elbow extension, increases the moment of inertia of the arm at the shoulder. Moment of inertia (I) is the body's resistance to angular motion, and is the product of the mass (m) and the radius of gyration (k) squared:

$$I = m \times k^2$$

The greater the moment of inertia, the greater the torque required at the shoulder for angular movement ($T = I \times \alpha$), since angular acceleration is proportional to torque. Therefore, minimizing elbow range of motion is encouraged during sprinting.

Mann (1985) found "good" sprinters minimize the range of motion at the elbow, with an elbow range of motion of 67^0. "Average" sprinters demonstrate similar ranges of motion, while "poor" sprinters show greater ranges of motion. In the present study, the elbow range of motion for the B drill was similar to the "good" sprinters as described by Mann, but the values found for the A drill and sprinting are larger than desirable.

Average peak elbow flexion angular velocity was greatest for the A drill, while average peak elbow extension angular velocity was greatest for sprinting. The peak flexion angular velocity seen during the A drill is an indication of errors in the technique of the athletes, possibly associated with the increased elbow range of motion also seen during this drill. Average peak elbow angular velocity in both the flexion and extension directions should have been greatest for sprinting, as it may make a contribution to the angular momentum about the longitudinal axis of the athlete, only if accompanied by shoulder medial or lateral rotation. The angular momentum of a single segment with respect to a principle axis of rotation through the total body centre of mass is the sum of the angular momentum about its own segmental centre of mass (the local term) and the angular momentum about the total body centre of mass (the remote term):

$$H = I_s\omega_s + mr^2\omega_g$$

In the local term, I_s and ω_s are the moment of inertia and angular velocity of the segment with respect to its own centre of mass. For the remote term, m is the mass of the segment, r is the linear distance from the centre of mass of the entire body to the centre of mass of the individual segment, and ω is the angular velocity of the segment with respect to the principal axis. This means the rapid flexion and extension seen at the elbow during sprinting makes a contribution to maintaining a minimal total angular momentum about the longitudinal axis by opposing the angular momentum of the lower body. Angular velocities of the same magnitude are not required at the elbow during the A and B drills, as the total angular momentum of the sprinter about the longitudinal axis is smaller than sprinting. This is due to the decreased angular momentum of the lower body during the drills which comes as a result of decreased pelvic rotation and hip range of motion.

For both the flexion and extension directions, the average peak angular velocity seen for the eight subjects was greater for the elbow than for the shoulder. This follows the summation of speed principle, which states that body segments move in sequence, starting with the more proximal segments and ending with the more distal segments, with the motion of each segment starting at the moment of greatest speed of the preceding segment. The summation effect is such that the more distal the segment, the faster it will eventually move (Dyson, 1986).

During each of the three skills, there was a large variation in the peak elbow flexion and extension angular velocities for the eight subjects. This is seen in the large standard deviation found for each value. This may indicate that there are distinct individual differences in the amount of motion at the elbow during sprinting, and it may also be a source of concern for coaches. Although a certain amount of angular velocity may be inevitable due to the rapid flexion and extension at the shoulder, excessive movement at the elbow is detrimental as increased elbow extension increases the moment of inertia and produces a greater resistance to fast movement.

Kinematics of the Trunk and Pelvis

Forward trunk lean is key for proper sprint mechanics. During the initial portion of a run there is excessive trunk lean, where the centre of mass is located in front of the supporting foot, creating a state of instability and increasing acceleration. At constant running speeds trunk lean is less pronounced, although some forward lean is required to oppose the torque produced by the air resistance acting on the trunk. According to Hay (1993), trunk lean assists in controlling the rotation of the sprinter which occurs due to the off-centre forces acting on the body created during the propulsive phase. Hoskisson and Korchemny (1991) reported forward trunk lean values of 3.75^0, with Bruce (1994) reporting similar values of 2^0 to 4^0 forward of vertical

The greatest amount of trunk flexion was seen during sprinting followed by the B drill and the A drill. The small differences among the three skills may be due to the increased air resistance against the trunk which occurred during sprinting, or to individual differences in the technique demonstrated by the subjects. There may also be discrepancies with the values found for trunk flexion in this study due to the difficulty in accurately digitizing the joint markers used to measure this variable. The two joint markers used to determine trunk position were chest centre and middle of pelvis. When pictured from the sagittal view, it is evident that it is difficult to be accurate and consistent in the location of these points from a filmed image.

Trunk rotation occurs during sprinting in order to maintain a minimal angular momentum of the body about the longitudinal axis. Trunk rotation should be minimized during sprinting, as the trunk is not able to rotate fast enough to keep up with the legs, thus slowing down the frequency of leg movement. For both the A and B drills, trunk rotation is minimized as compared to sprinting. This is because there is a decreased rotation of the pelvis due to the limited range of motion seen at the hip. This reduced pelvic rotation means the angular momentum by the lower body is reduced, therefore reducing the angular momentum required by the upper body to maintain equilibrium. The majority of the angular momentum generated by the upper body originates from the movements at the shoulder and the elbow, as is seen by the high angular velocity values at each joint.

Pelvic rotation is minimized during the A and B drills, with significantly smaller values than for sprinting. This is a result of the limited range of motion at the hip seen during the two drills. The anterior movements of the legs in the sagittal plane of the A and B drills are similar to those of sprinting in that there is a degree of hip and knee motion in front of the body. The posterior movements in the sagittal plane, however, are virtually non-existent during the drills. There is only a very small degree of hip hyperextension; the hip simply extends to bring the foot to a position beneath the body for support. This means the pelvic rotation for the drills is reduced.

The small amount of pelvic rotation that is seen for the A and B drills comes as a result of the increased hip flexion seen when performing the drills. In order to flex the hip to bring the thigh to a position near parallel with the ground, a small amount of pelvic rotation must occur. Also, when performing the drills, athletes move slowly forward covering a distance. This means there is a small step length associated with each cycle of the two drills. In order to achieve this small step length, a small amount of pelvic rotation is required.

Kinematics of the Hip

Previous studies have reported minimum angles of hip flexion between the trunk and the thigh of 101.2^0 in elite junior sprinters (Hoskisson and Korchemny, 1991) and approximately 100^0 in elite sprinters (Mann, 1986). A high knee lift is a key component of fast sprinting, as it helps to ensure the production of hip extension angular velocity into and during contact (Mann & Herman, 1985). This is accomplished by utilizing the elastic components of the hip extensor muscles (gluteus maximus, hamstrings) to increase the hip extension torque. A high knee lift is also a important contributor to the production of ground reaction forces (Mero & Komi, 1978).

Figures 5-5 and 5-6 outline the angular displacement-time graphs for the right hip of subjects 3 and 1 during three steps of the A drill, B drill, and sprinting. The following events are indicated on the graphs: (1) right touchdown, (2) right toe-off, (3) left touchdown. (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. The positive values represent hip flexion angular displacement, while the negative values represent hip extension angular displacement. In comparing the A and B drills to sprinting, it is clear that there are differences in the range of motion at the hip. Both subject 3 and 1 reached hip extension angles of approximately 50^0 from the vertical, while the hip during A and B drills only reaches the vertical or a small angle of extension.

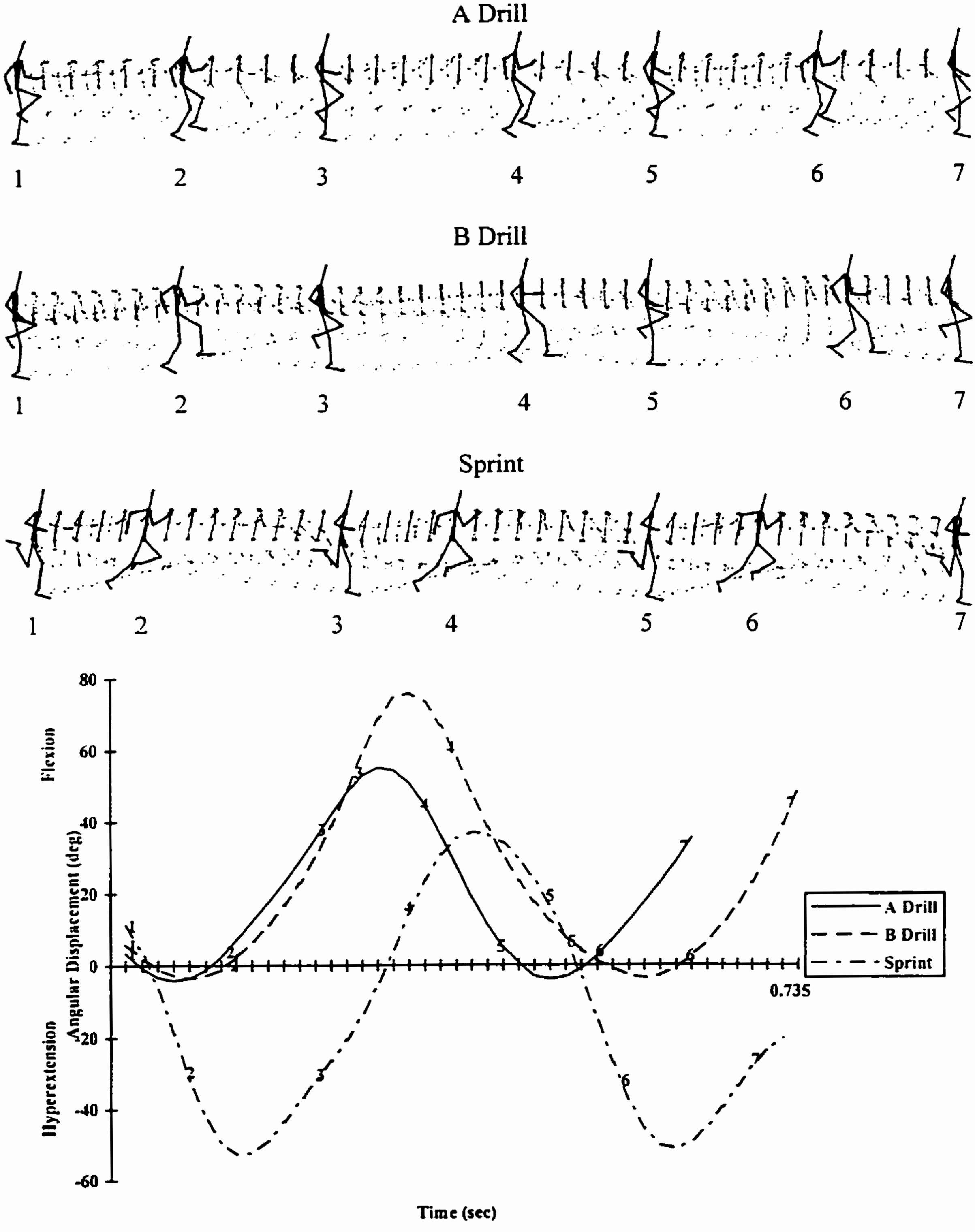


Figure 5-5. Angular displacement/time curves for subject 3 for the right hip during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown

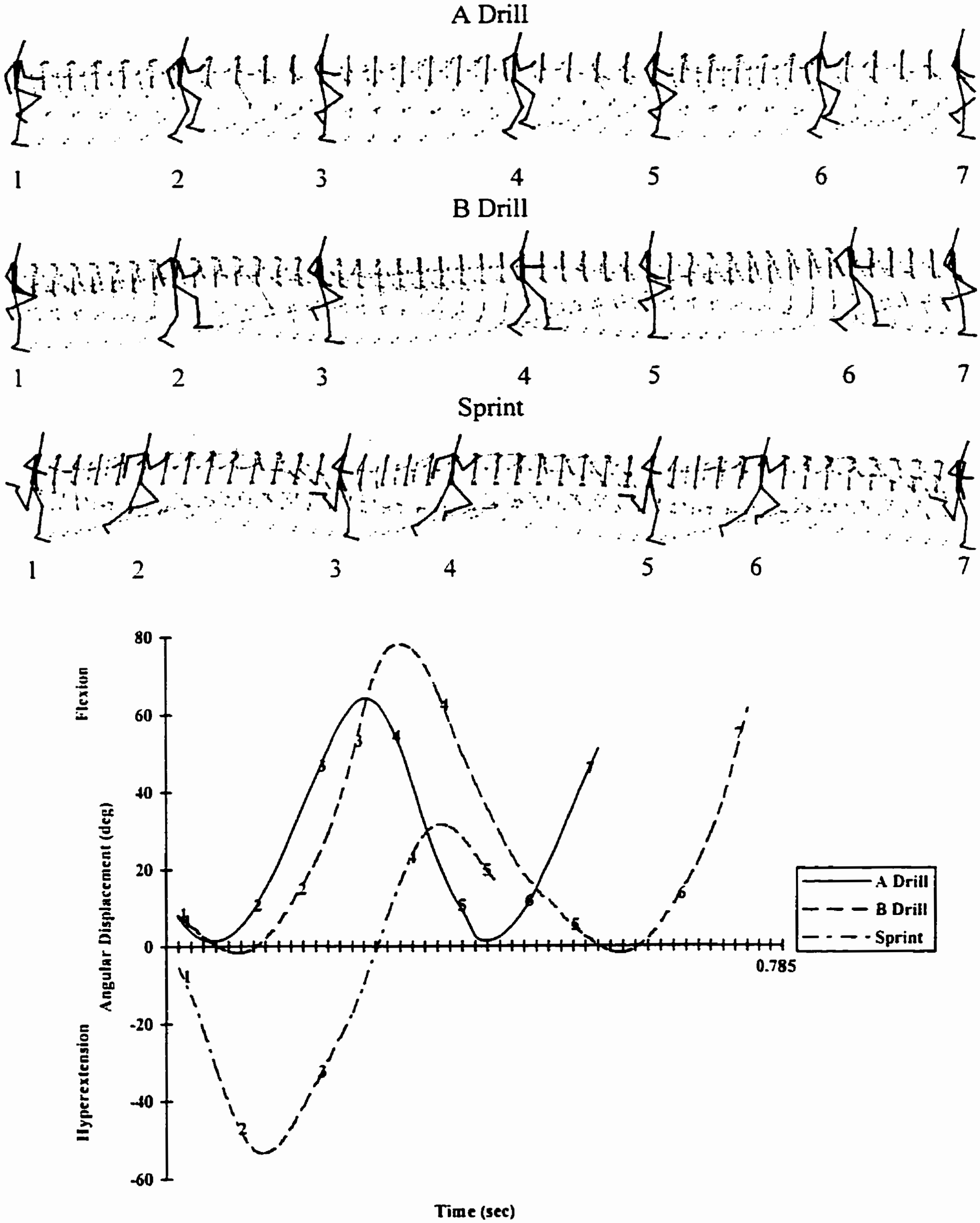


Figure 5-6. Angular displacement/time curves for subject 1 for the right hip during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe -off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

Both the A and B drills produced greater angles of hip flexion from the vertical, significantly larger than for sprinting. Although there are differences, it may be beneficial for the drills to be performed with a greater amount of hip flexion than sprinting, as it may develop hip flexor strength and power during sprinting. If the amount of hip flexion during the drills was decreased to the same level as sprinting, the mechanics of the entire body would be affected. Decreasing the range of motion at the hip would mean there would be a decreased range of motion at the shoulder, in order for the timing of events to remain the same. With this decreased range of motion, the frequency of movement may increase because of the smaller angular displacement, but there may be a decrease in the peak angular velocity at these joints. This is because there may be insufficient time for the torque to produce a change in the angular velocity, based on the angular impulse-momentum relationship.

It is necessary to maximize hip flexion angular velocity, for two reasons. Firstly, the greater the hip flexion angular velocity, the greater the ground reaction forces produced to propel the sprinter forward. Mero and Komi (1978) found that during the propulsive phase of sprinting, hip flexion acceleration contributes 316 N horizontally and 593 N vertically. Secondly, greater hip flexion angular velocity will increase the rate at which the recovery leg moves from a position behind the body to one in front in preparation for ground contact, which may increase step frequency.

In this study, there were no significant differences in the magnitude of the hip flexion peak angular velocity. This may indicate that both the A and B drills have the potential for training the athlete to generate ground reaction force and to increase the velocity of the recovery leg. This is not the case, though, as seen in Figures 5-7 and 5-8, which outline the hip angular velocity/time relationship for the right hip for three steps during the A drill, B drill, and sprinting for subjects 3 and 1, respectively. The following events are indicated on the graphs: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. The positive values represent hip flexion angular velocities, while the negative values represent hip extension angular velocities.

Peak right hip flexion angular velocity during the A and B was found to occur after toe-off of the right foot (events 2 and 6), which indicates that the rapid flexion of this hip is not making a full contribution to the ground reaction force, as peak angular velocity occurs once the foot has left the ground. Because peak hip flexion angular velocity occurs after toe-off, this may indicate that the A and B drills may be more effective in developing recovery hip flexion angular velocity than in the production of ground reaction forces. During sprinting, peak hip flexion angular velocity occurs at the time of toe-off of the left leg (event 4) as seen in subject 3, or prior to toe-off as seen in subject 1. This suggests that hip flexion may make a significant contribution to the production of ground reaction forces acting to propel the sprinter forward.

Lemaire and Robertson (1990) found a peak hip flexion angular velocity value of 969 degrees/second in a study of elite sprinters. This is similar to the peak angular velocity of almost 900 degrees/second reported by Chengzhi and Zongcheng (1987), but is considerably larger than the hip flexion angular velocity value of almost 600 degrees/second reported by Mann (1985). The hip flexion angular velocities found in this study are similar to those of Mann (1985), but considerably smaller than those of other

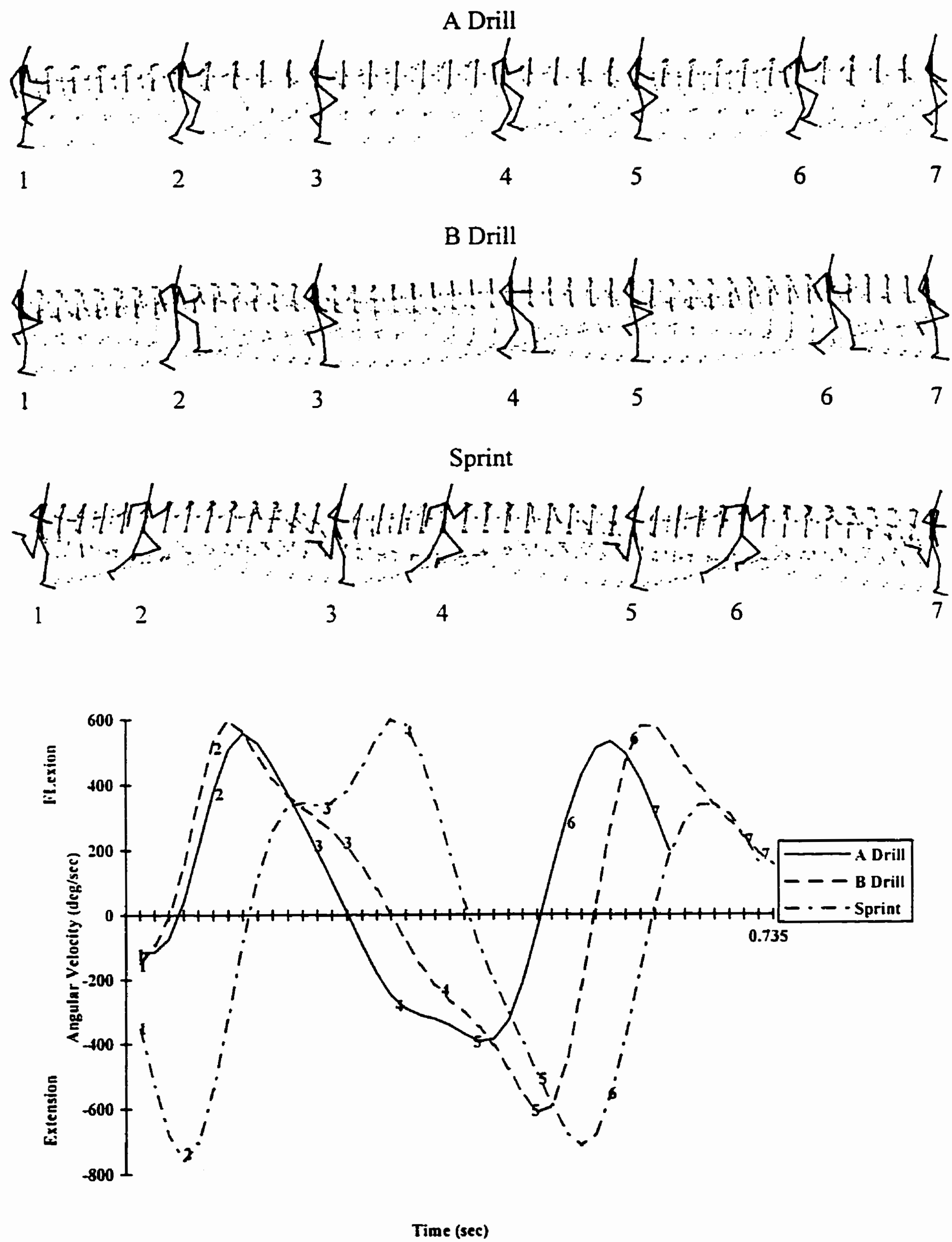


Figure 5-7. Angular velocity/time curves for subject 3 for the right hip during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

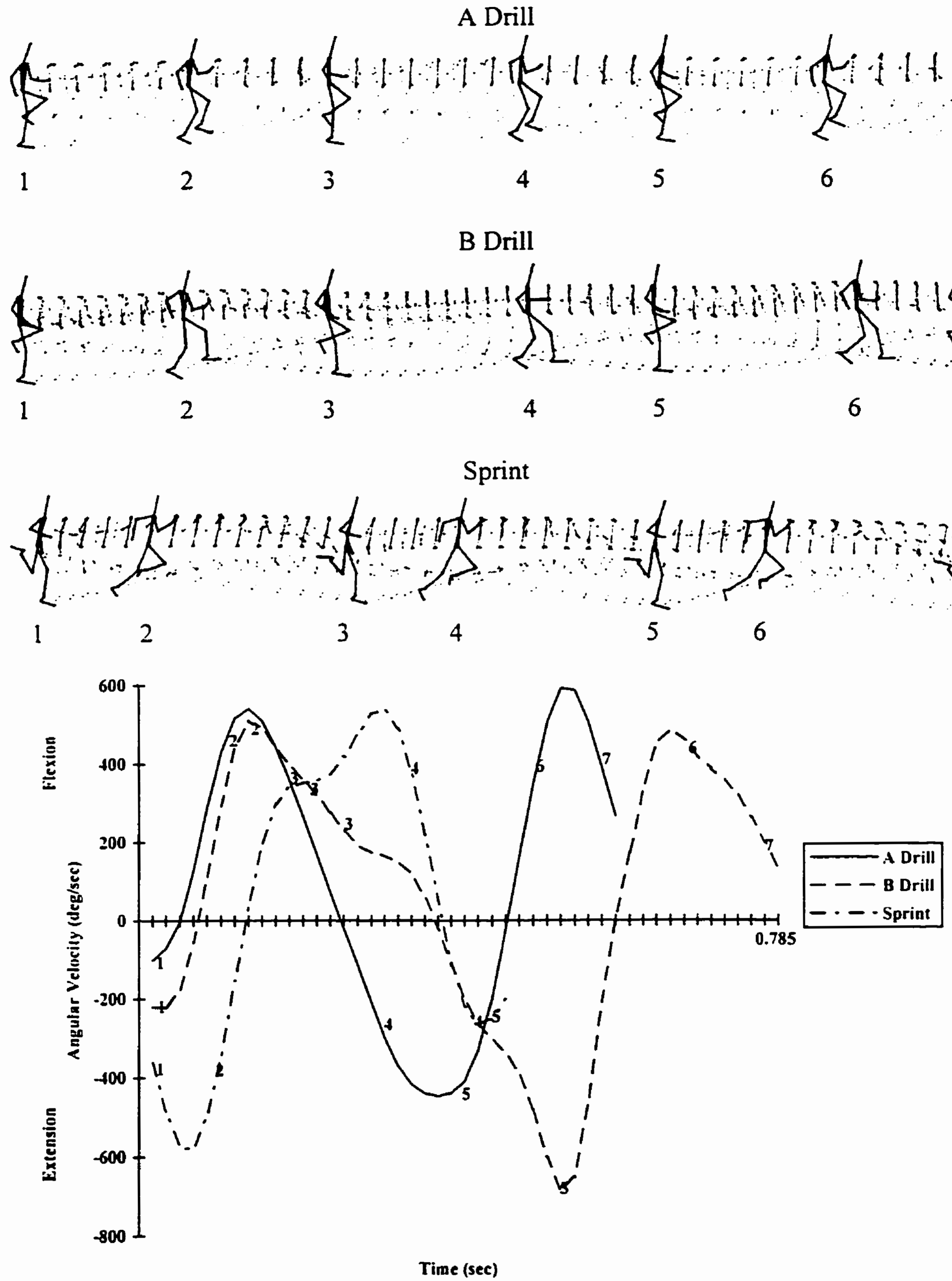


Figure 5-8. Angular velocity/time curves for subject 1 for the right hip during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

studies. The reason for this may be the fact that the subjects in this study are less skilled than the elite sprinters used in other studies, and it is also determined by the cutoff frequency used in smoothing the data.

The greatest hip extension angular velocity in this study was found for sprinting, with the angular velocity for A drill being significantly smaller than the B drill and sprinting. This difference may be explained by the small range seen during the A drill. With this limited amount of motion, there is simply not enough time to generate higher extension angular velocity. The difference is not significant between the B drill and sprinting because there is an increase in the range of motion and the time during which angular velocity can be produced.

It is important to maximize hip extension angular velocity, as the greater the angular velocity of the hip, the smaller the relative linear velocity of the foot will be at the instant of ground contact. By decreasing the relative velocity of the foot, the braking force acting to slow the sprinter down will be decreased. No sprinter has been able to produce a negative foot velocity greater than the forward velocity of the centre of mass (Mann, 1985), and therefore a braking force is always produced on contact. It is also important to maximize extension angular velocity because of the ground reaction forces produced during the propulsive phase of support by the rapid extension of the hip just prior to toe-off. In Figures 5-7 and 5-8, peak right hip extension angular velocity for the A and B drills occurs at the time of right foot touchdown. This indicates that the drills may be beneficial in developing negative foot velocity. This is probably the case more for the B drill than for the A drill, simply because the angle of the path of the foot during the B drill is more similar to sprinting than the A drill. At the time of right toe-off (event 2 and 6), when peak extension should be occurring in order to maximize ground reaction forces of the contact leg, the hip is already in hip flexion. This means there is no contribution to the production of ground reaction forces made by hip extension for the two drills. For sprinting, right hip extension angular velocity is approaching maximum at right foot touchdown (event 5), which indicates the athlete is attempting to maximize negative foot velocity. Peak hip extension angular velocity occurs just prior to right foot toe-off (event 2 and 6) which means there is a significant contribution made by this leg to the production of ground reaction forces.

Hip extension angular velocities of 912 degrees/second have been reported by Lemaire and Robertson (1990), which are much larger than the values of approximately 600 degrees/second (Chengzhi & Zongcheng, 1987) and 500 degrees/second (Mann, 1985) which have been reported in other studies. The values found in this study are similar to those of Mann (1985), but considerably smaller than those of other studies. This may be due to the fact that the subjects in this study are university level sprinters and not at an elite level as in other studies, and that there may be differences in the cutoff frequency selected for data smoothing.

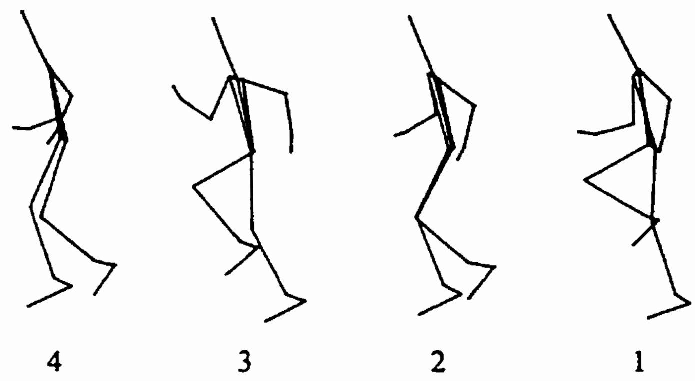
In comparing the peak hip flexion and extension angular velocities with the hip angular displacement data, no differences are seen in the range at which the peak angular velocities occur. Peak hip flexion angular velocity for the A and B drills was seen after right foot toe-off (event 2), when the hip was at an angle of approximately 0^0 to 10^0. For sprinting, peak hip flexion angular velocity was seen prior to or at the time of left foot toe-off (event 4), when the hip was at a similar range of approximately 10^0.

Peak hip extension angular velocity for the A and B drills and sprinting was seen approximately at the time of or just after right foot touchdown (event 5). As seen on angular displacement-time graph, for the A drill, B drill, and sprinting this peak extension angular velocity corresponds to an angle of approximately 5^0 to 10^0. These results indicate that peak hip flexion and extension angular velocities for the A and B drills are achieved at the same range as for sprinting.

Kinematics of the Knee

Figures 5-9, 5-10, and 5-11 outline the angle-angle diagrams for subjects 3 and 1 for the right hip and knee for one stride during the A drill, the B drill, and sprinting, respectively. The values at the hip are measured from the vertical, with positive angles representing hip flexion and negative angles representing hip hyperextension. The greater the angle, the greater the hip flexion/hyperextension. For the knee, an angle of 0^0 represents full knee extension with larger angles indicating greater knee flexion. Stick figure representations of each skill displaying the positions of the hip and knee are located above the graph, with the corresponding figure number located on the graph.

In comparing the three graphs, it is evident that there are distinct differences in the patterns seen in the concurrent movements at the hip and knee joints. The angle-angle diagram for the A drill is linear in shape. Hip and knee flexion occur simultaneously as



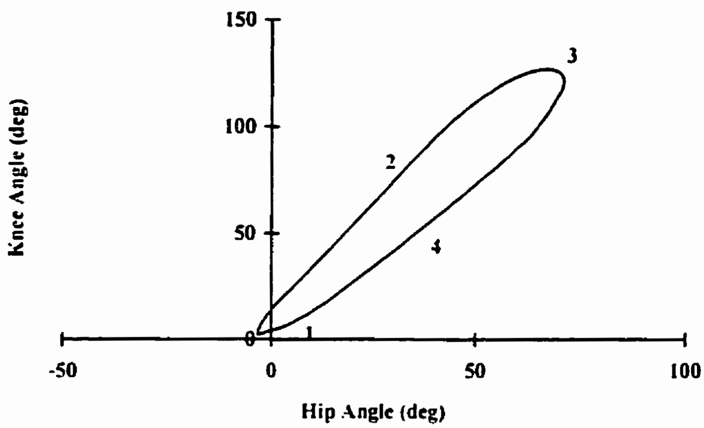


Figure 5-9(a). Angle-angle diagram for the right hip and knee for subject 3. The numbers 1,2,3,4 correspond to the positions illustrated above.

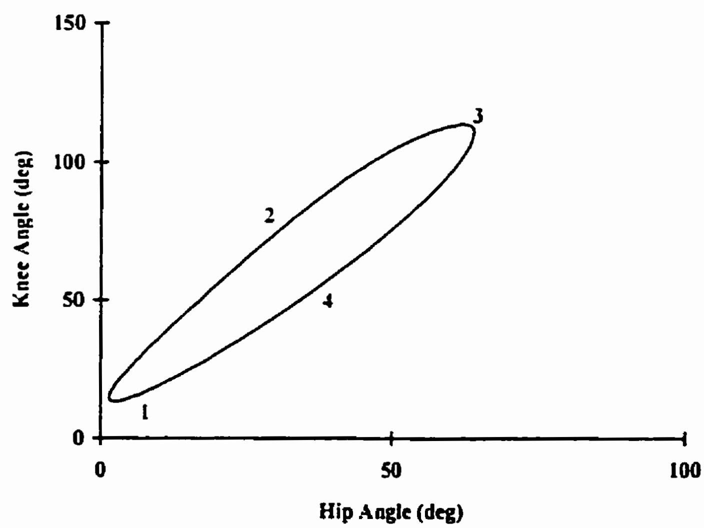


Figure 5-9(b). Angle-angle diagram for the right hip and knee for subject 1. The numbers 1,2,3,4 correspond to the positions illustrated above.

the hip is flexed approximately to 90^0 from the vertical and the knee is flexed bringing the heel to the buttocks. These flexion movements are quickly followed by simultaneous hip and knee extension as the foot is brought back to the ground for support, with no support flexion phase seen during the A drill. Maximum hip flexion occurs at the same time as maximum knee flexion, late in the recovery phase. Maximum hip hyperextension occurs at the same time as maximum knee extension, late in the support phase. There is only a small portion of the loop on the left side of the axis, which indicates there is only a small amount of hip hyperextension, occurring late in the support phase.

For the B drill, the angle-angle diagram is similar in shape to the A drill, but it assumes more of an oval shape. Simultaneous hip and knee flexion bring the thigh to approximately 90^0 from the vertical and the heel to the buttocks, but knee flexion ends prior to hip flexion resulting in a leveling off of the graph. There is a vertical drop of the graph line, which shows that knee extension occurs prior to hip extension. Simultaneous extension of the hip and knee then return the foot to the ground for support, with only a small support flexion phase seen at point 1. Only a small angle of hip hyperextension is reached late in the support phase, as there is only a small portion of the loop on the left side of the axis. Maximum knee flexion is seen prior to maximum hip flexion, late in the recovery phase. Maximum knee extension occurs prior to maximum hip hyperextension, with maximum knee extension occurring prior to ground contact and maximum hip hyperextension occurring late in the support phase.

The pattern for sprinting is different from those of the two drills. There is a greater range of motion at the hip, resulting in a more rounded shape of the graph. A

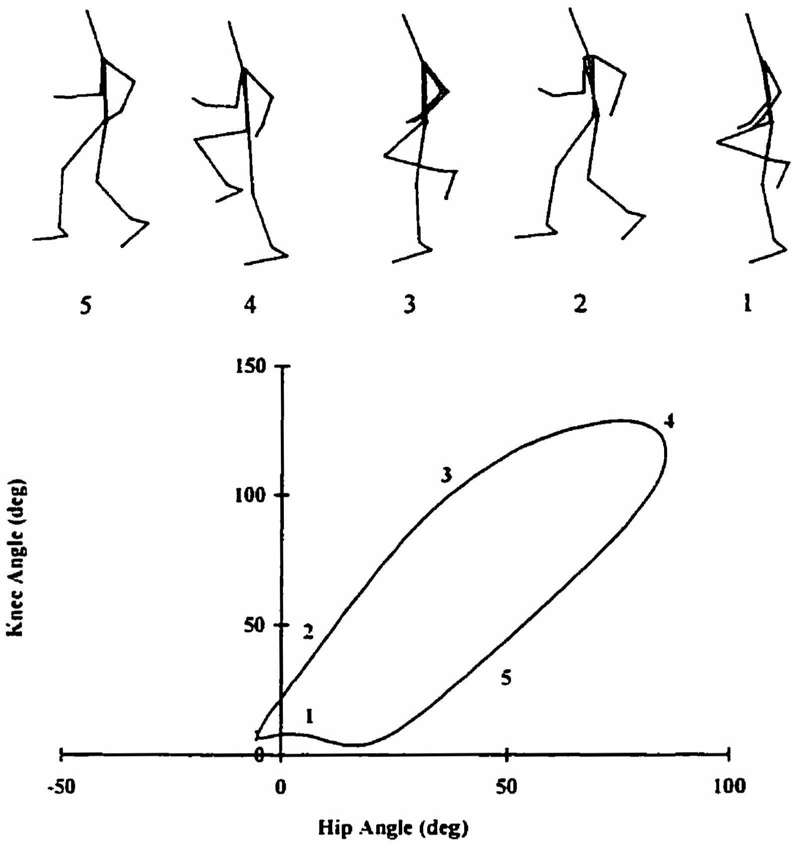


Figure 5-10(a). Angle-angle diagram for the right hip and knee for subject 3. The numbers 1,2,3,4 correspond to the positions illustrated above.

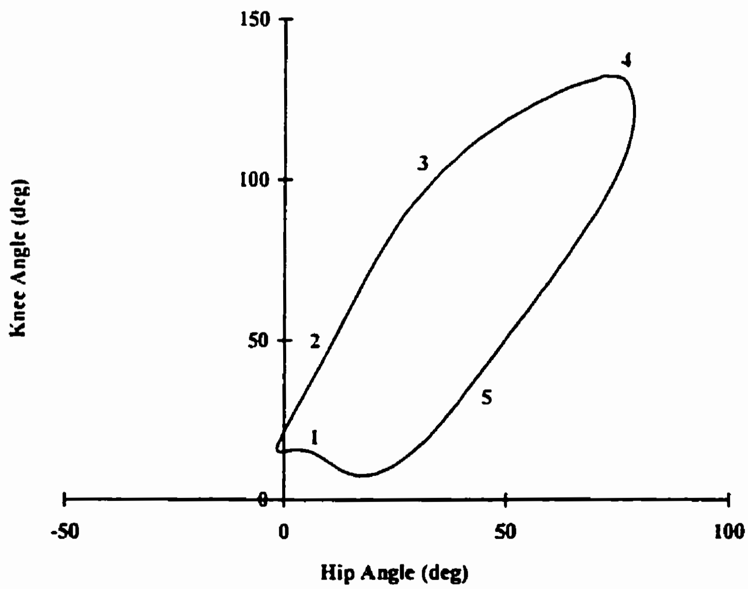
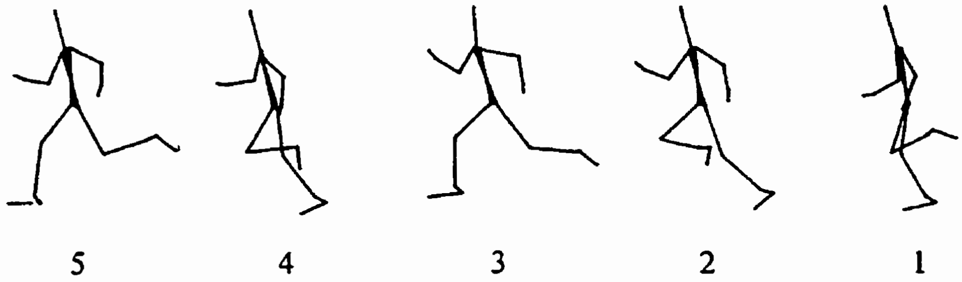


Figure 5-10(b). Angle-angle diagram for the right hip and knee for subject 1. The numbers 1,2,3,4 correspond to the positions illustrated above.



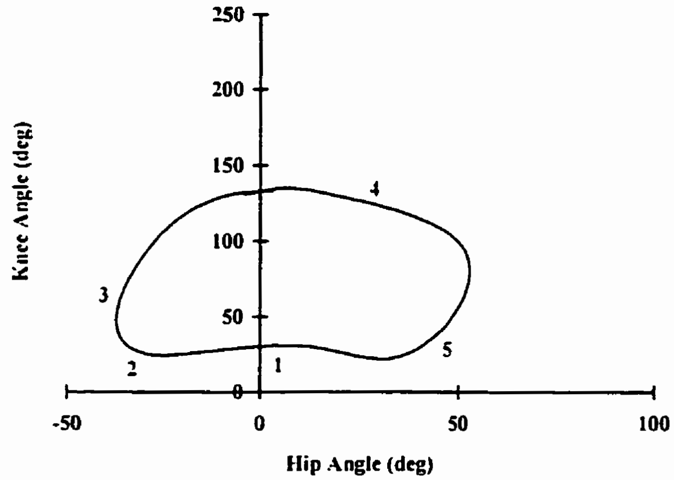


Figure 5-11(a). Angle-angle diagram for the right hip and knee for subject 3. The numbers 1,2,3,4 correspond to the positions illustrated above.

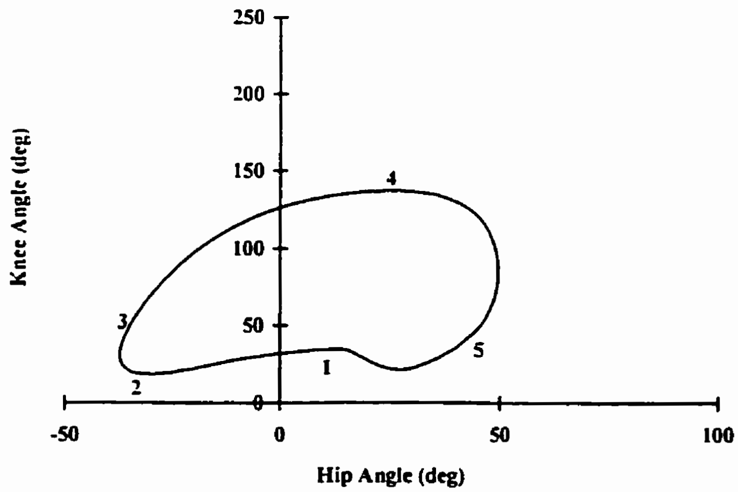


Figure 5-11(b). Angle-angle diagram for the right hip and knee for subject . The numbers 1,2,3,4 correspond to the positions illustrated above.

maximally as the heel was brought to the buttocks. For sprinting, there was slight variation in the maximum knee flexion, in which some subjects maximally flexed the knee, while others did not during the recovery phase. Generally, there was neardistinct support flexion phase is seen at point 1. After toe-off there is a steep vertical slope representing recovery knee flexion without a significant change in hip angle. The hip then begins to flex as the leg is brought forward from a position behind the body. A vertical drop in the line signifies the initiation of knee extension, which is seen prior to hip extension. The large portion of the loop on the left side of the axes illustrates the greater range of hip hyperextension seen in this skill. Maximum knee flexion occurs prior to maximum hip flexion, with maximum knee flexion occurring during recovery as the leg is swung forward, when the hip is at an angle of approximately 5^0 of flexion. Maximum hip flexion occurs late in the recovery phase. Maximum knee extension is seen prior to ground contact, while maximum hip hyperextension is seen after toe-off as the knee has started to flex in recovery.

Figure 5-12 outlines the angular displacement-time graph of the right knee for three steps during the A drill, B drill, and sprinting for subject 3. Figure 5-13 shows the angular displacement-time graph for the right knee for subject 2. The following events are indicated on each graph: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. On the graph, an angle of 180^0 represents full knee extension, with smaller angles representing greater angles of knee flexion. For both subjects 2 and 3, there are similarities in the range of

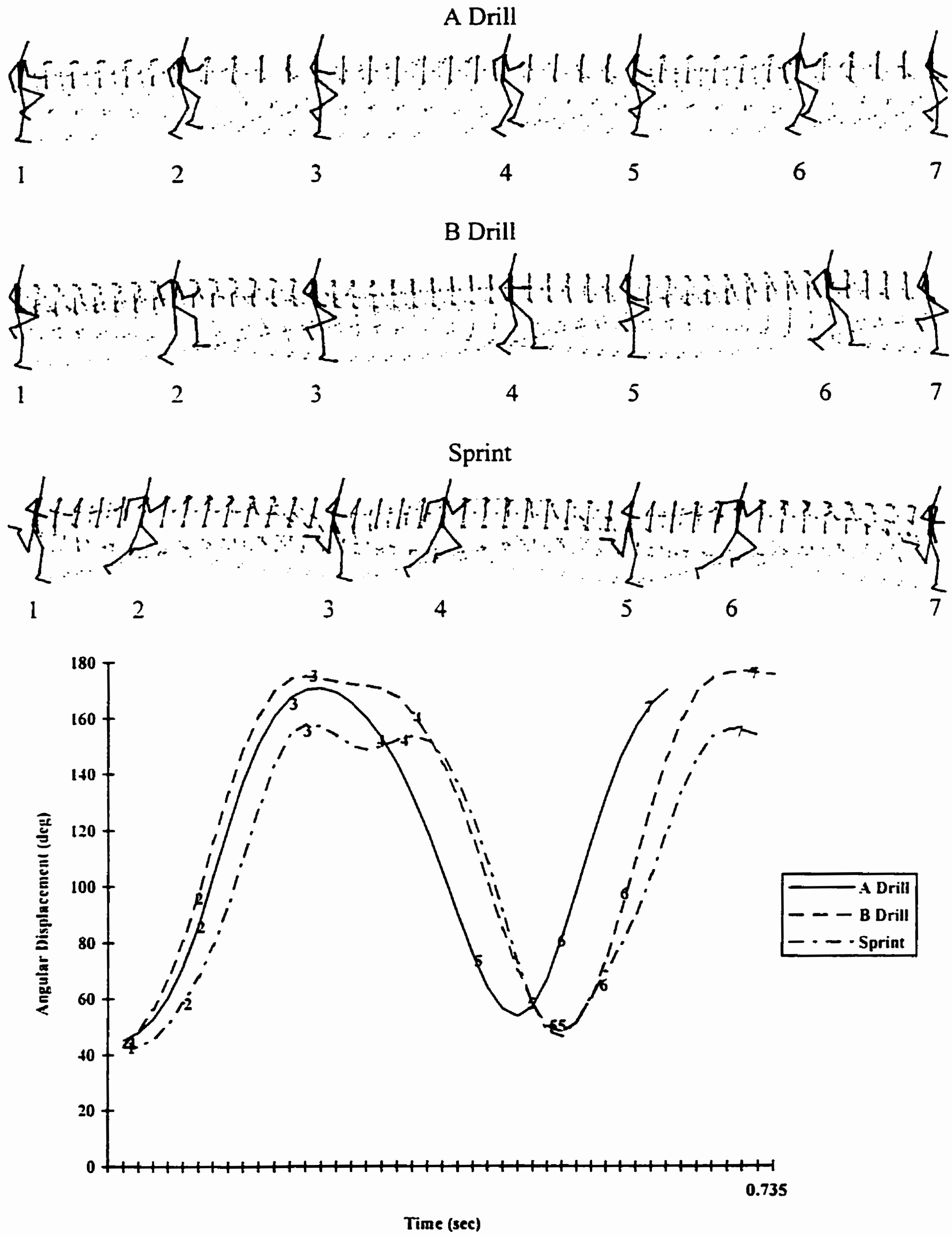


Figure 5-12. Angular displacement/time curves for subject 3 for the right knee during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

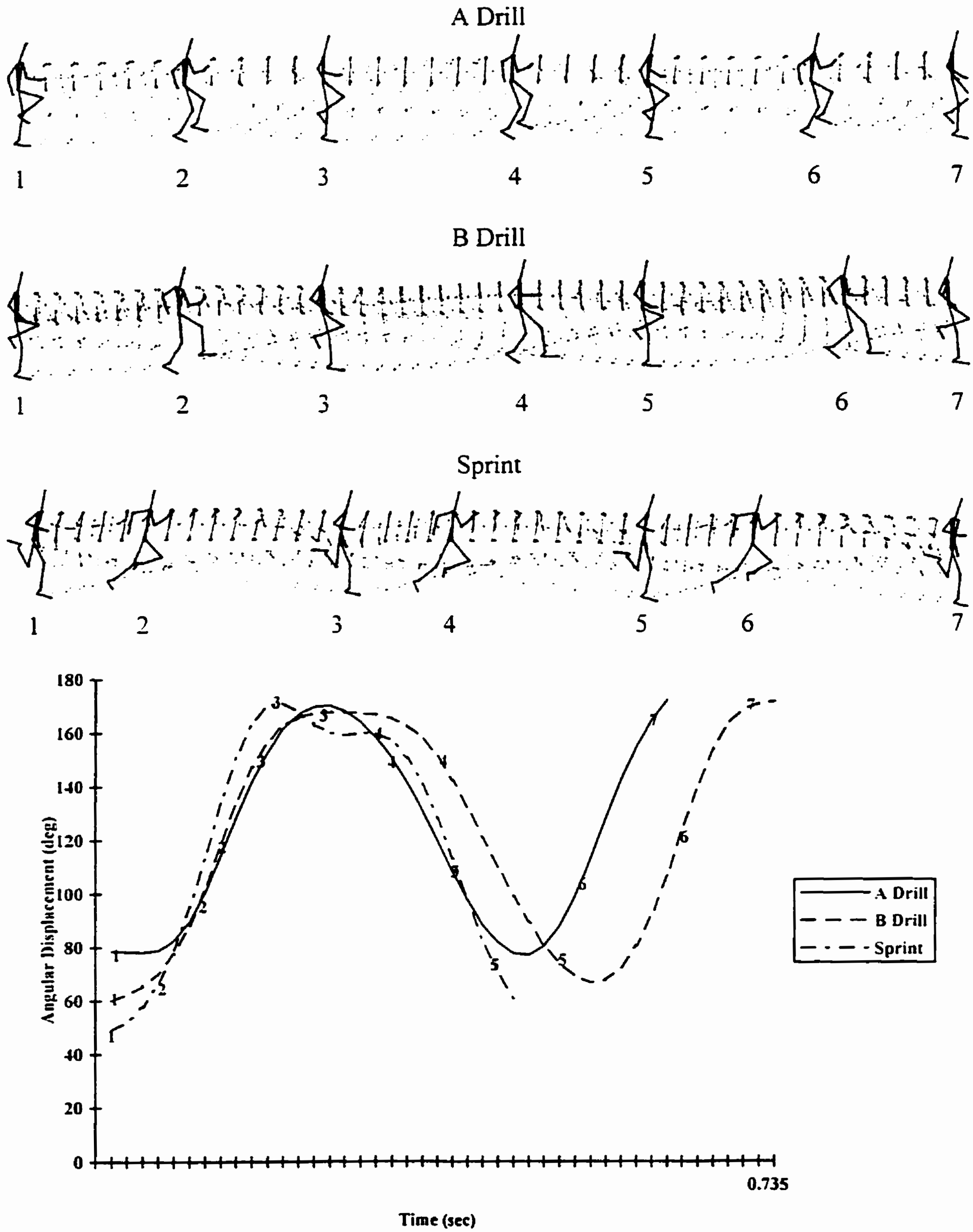


Figure 5-13. Angular displacement/time curves for subject 2 for the right knee during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

motion at the knee for sprinting and the B drill, with the A drill showing a decreased range of motion, particularly in knee flexion. For the B drill, the knee was flexed maximum knee flexion of the recovery leg. For the A drill, the knee was not flexed maximally as the heel was brought towards the buttocks, resulting in a decreased range of motion. Distinct differences were also seen in support flexion among the three skills. There is no support flexion seen for the A drill, and only a small degree of support flexion for the B drill. It is only during sprinting is there a noticeable flexion of the knee during support.

Knee flexion angular velocity was found to be greatest for sprinting, although similar values were found for the two drills. There are distinct differences, though, in the timing of this velocity among the three skills. Figure 5-14 outlines the angular velocity-time graph of the right knee for three steps during the A drill, B drill, and sprinting for subjects 3. Figure 5-15 shows the angular velocity-time graph for the right knee for subject 2. The following events are indicated on each graph: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. The positive values represent knee flexion angular velocities, while the negative values represent knee extension angular velocities. For the A and B drills, peak knee flexion angular velocity occurs at the time of right foot toe-off (events 2 and 6), as the knee is flexed and the heel is brought towards the buttocks. For sprinting, peak knee flexion angular velocity occurs after right foot toe-off (events 2 and 6). The right leg continues to rotate backwards after toe-off, and the knee passively flexes very rapidly as the right hip begins to flex in recovery.

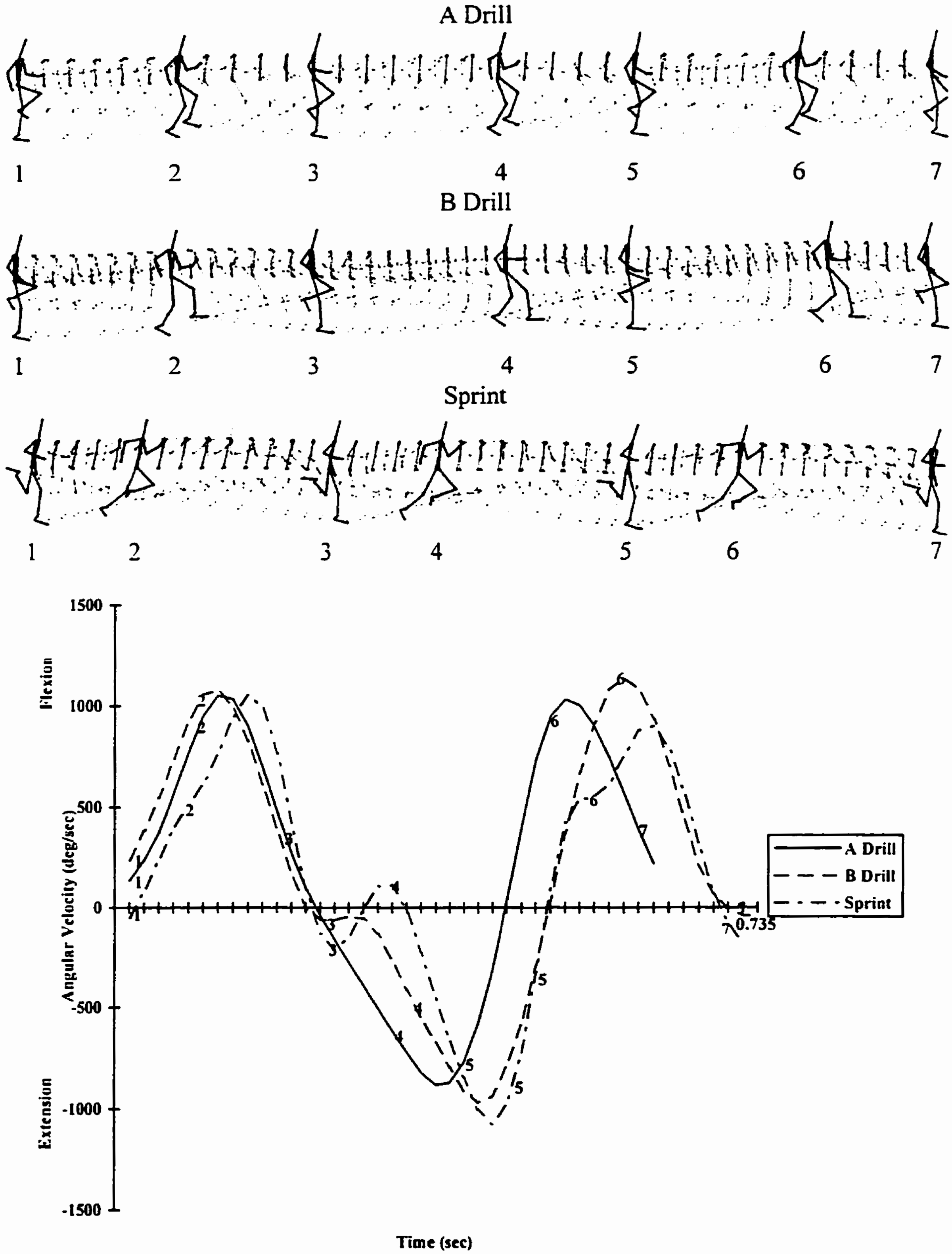


Figure 5-14. Angular velocity/time curves for subject 3 for the knee during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

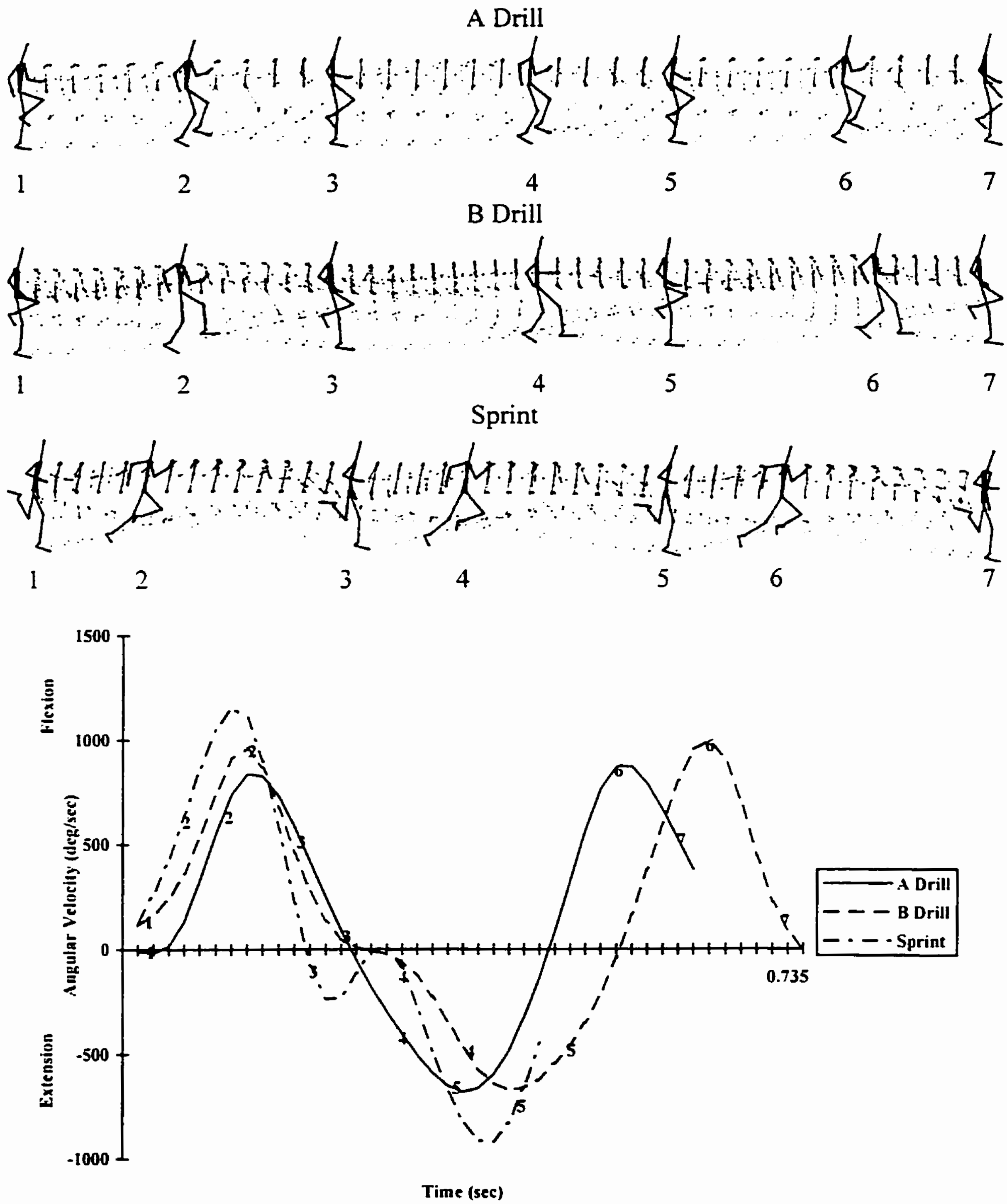


Figure 5-15. Angular velocity/time curves for subject 2 for the knee during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

For peak knee extension angular velocity, figures 5-14 and 5-15 reveal that in the A drill it occurs very close to the time of touchdown of the right foot (event 5), as the leg rapidly extends to the ground for support. In the B drill and sprinting, peak knee extension angular velocity occurs prior to ground contact of the right foot (event 5). Peak extension velocity takes place as the recovery leg extends in preparation for ground contact, and occurs closer to the time of touchdown for sprinting than for the B drill.

In comparing the timing of the hip and knee extension among the three skills, the two joints extend simultaneously for the A drill, as is seen by the peak extension angular velocity occurring at right foot touchdown (see Figure 5-7 and 5-8, event 5). For the B drill, peak hip extension angular velocity occurs at right foot touchdown, but peak knee extension angular velocity occurs a considerable time prior to touchdown. This means the rapid knee extension occurs independently of hip extension. For sprinting, the right hip is extending at the time of right foot touchdown, with peak hip angular velocity coming during support. The right knee reaches peak extension angular velocity prior to ground contact. This indicates that the swing of the leg during sprinting does not follow the summation of speed principle, which states that body segments move in sequence from proximal to distal, with the motion of each segment starting at the moment of peak velocity of the preceding segment. The summation effect is such that the more distal the segment, the faster it will eventually move (Dyson, 1986). This is because peak hip extension angular velocity must occur before peak knee extension angular velocity, which is not the case for sprinting.

Peak knee flexion angular velocities of 1030 degrees/second have been reported by Lemaire and Robertson (1990) in a study of internationally ranked male Canadian and American sprinters. Chengzhi and Zongcheng (1987) found larger knee flexion angular velocities of approximately 1400 degrees/second in male sprinters with personal best 100 metre times of 10.0 to 10.1 seconds. These values were reported during the recovery phase, as the knee rapidly flexed to decrease the moment of inertia of the leg. The knee flexion angular velocities found in the present study for sprinting, the A drill, and the B drill are comparable to those of Lemaire and Robertson, but smaller than those of Chengzhi and Zongcheng.

Peak knee extension angular velocities of 1200 degrees/second (Lemaire & Robertson, 1990) and approximately 1300 degrees/second (Chengzhi & Zongcheng, 1987) have been reported in previous studies. These values were found late in the recovery phase as the knee extended in preparation for ground contact. The knee extension angular velocities found in the present study for sprinting, the A drill, and the B drill are all considerably smaller than those reported in previous studies. Perhaps there may be differences in sprinting kinematics between university level and elite level sprinters, or else in the smoothing procedures used by each.

In comparing the peak knee flexion angular velocities with the knee angular displacement data, similarities are seen in the range at which the peak angular velocities occur. Peak knee flexion angular velocity for the A drill, B drill, and sprinting was seen after right foot toe-off (event 2). For all three skills, the range at which peak velocity occurred was approximately 90^0. Similarly, peak knee extension angular velocity for the

A drill was seen at right foot touchdown (event 5), while for sprinting and the B drill, it was seen prior to right foot touchdown. In all three cases, the knee angle at which peak extension angular velocity occurred was approximately 90^0. This indicates that there are similarities in the angle at which peak angular velocity occurred for the A and B drills as compared to sprinting.

Kinematics of the Ankle

At the ankle, the joint is primarily in a plantarflexed position throughout the sprint stride. It is only during the support phase when the body passes over the foot in contact with the ground that dorsiflexion occurs. Mann (1986) reported ankle range of motion values of approximately 34^0 in elite male sprinters.

Figures 5-16 and 5-17 outline the angular displacement-time graphs for the right ankle for subjects 7 and 8 during the A drill, B drill, and sprinting. The following events are indicated on each graph: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. The positive values represent angles of plantarflexion, while the negative values represent angles of dorsiflexion. Significant increases in range of motion are seen at the ankle during sprinting, both in the plantarflexion and dorsiflexion directions. In comparing the two drills, a significantly greater range of motion is seen in the B drill.

The greater plantarflexion angular velocity seen during sprinting demonstrates the significantly greater contribution made by the ankle, as the larger the plantarflexion angular velocity, the greater the ground reaction force produced to increase the propulsion

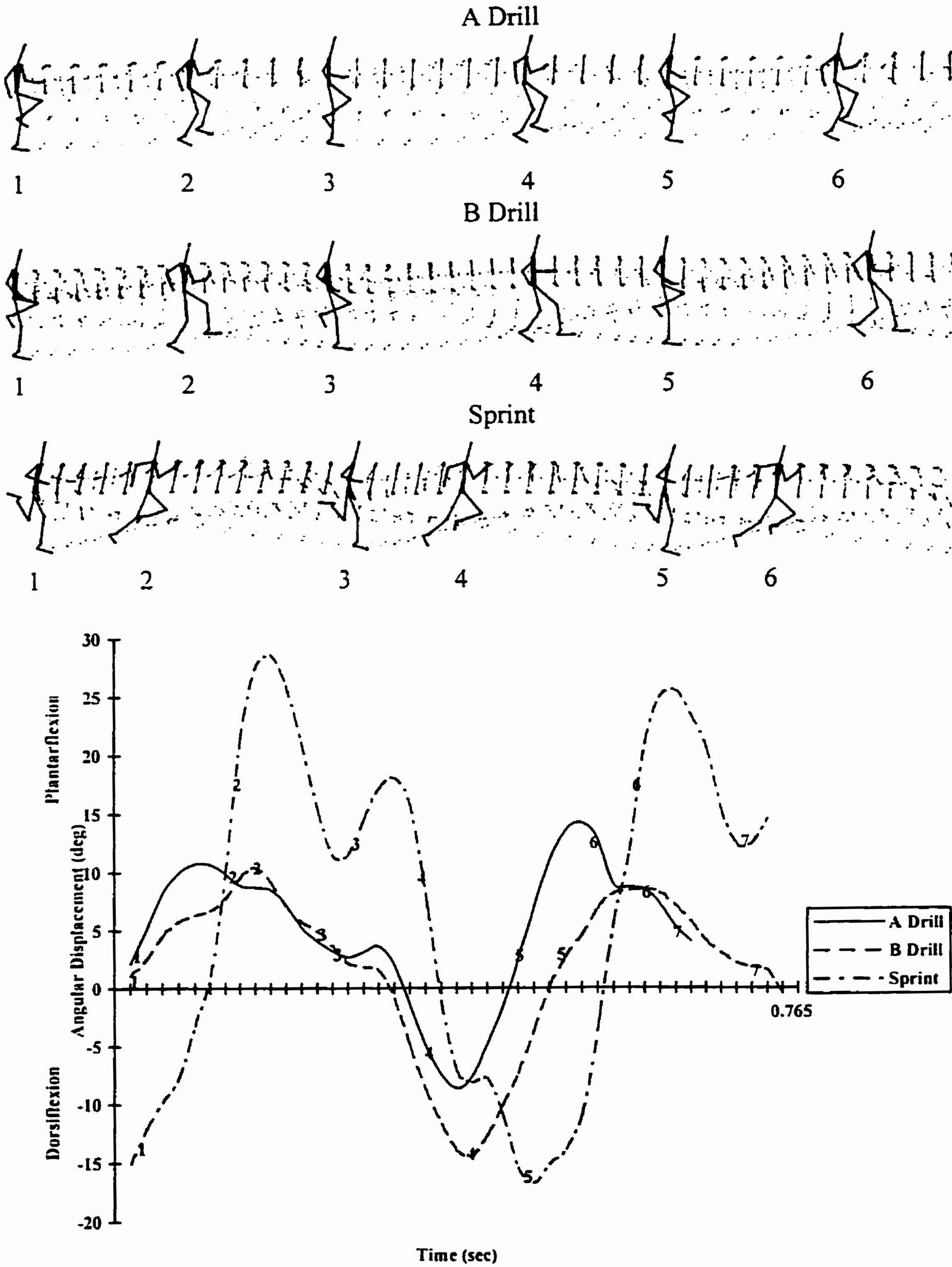


Figure 5-16. Angular displacement/time curves for subject 7 for the right ankle during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

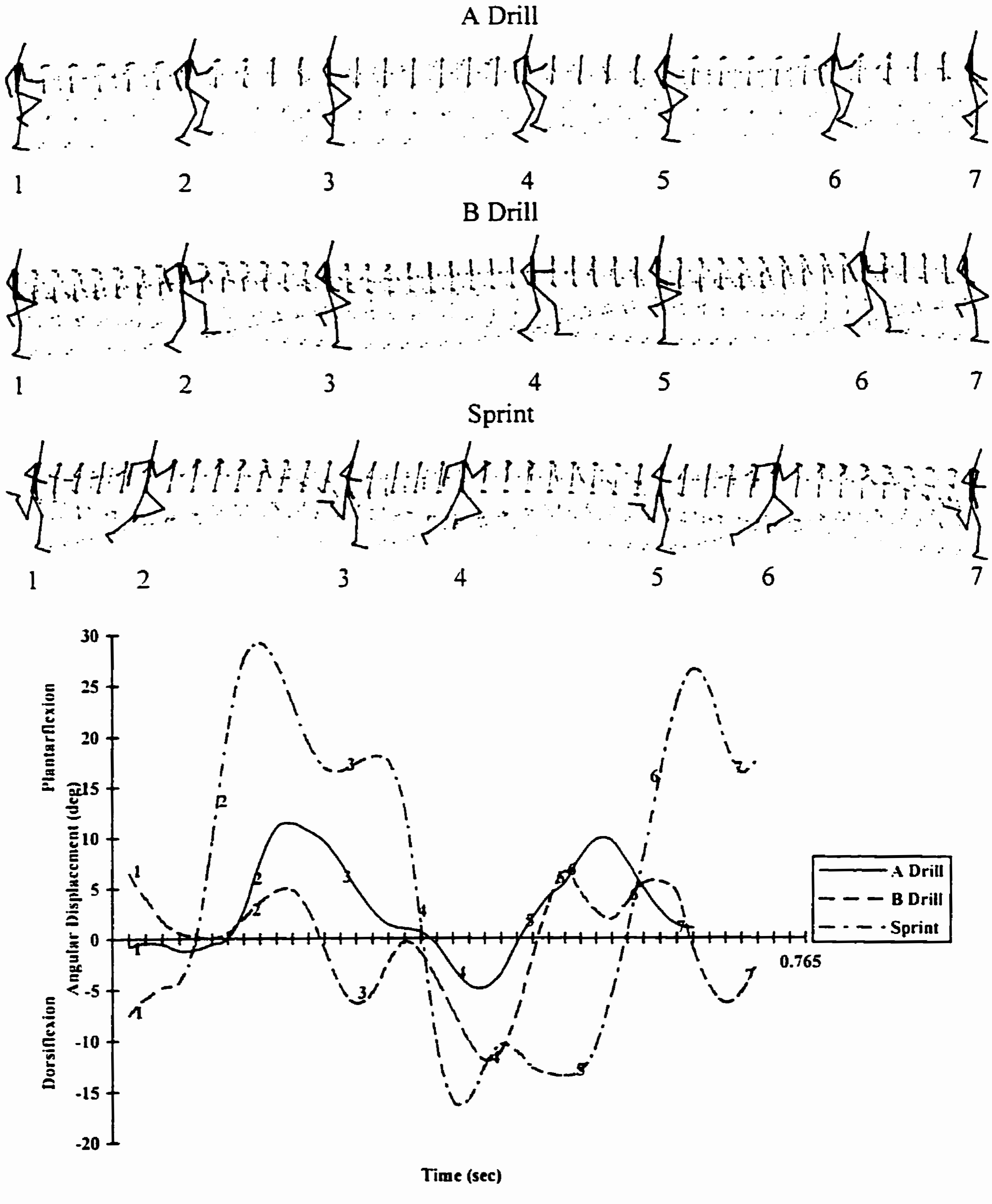


Figure 5-17. Angular displacement/time curves for subject 8 for the right ankle during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

of the athlete. For the A and B drills, plantarflexion angular velocity is minimized, but is still crucial to the performance of the drill. This is because it is the role of the ankle to produce the ground reaction forces required to create the vertical displacement of the centre of mass needed to complete the movements of the legs. One of the coaching tips for both the A and B drills is to stay tall, meaning keep the support leg straight. If this leg is straight however, it is unable to apply any force to the ground. This means the only joint which is capable of producing any significant vertical ground reaction force is the ankle joint. In the present study, the average plantarflexion angular velocity for the B drill was slightly larger than that of the A drill. This is closely associated with the vertical displacement seen for the two drills, in which the vertical displacement of the B drill (0.04 metres) was also slightly larger than the A drill (0.03 metres).

The greatest dorsiflexion angular velocity seen during sprinting as compared to the A and B drills. The emphasis during these drills should be to maximize the dorsiflexion angular velocity, as this would better replicate the movements seen during sprinting, and would better decrease the moment of inertia of the recovery leg to increase the entire leg rotational velocity.

Figure 5-18 and 5-19 outline the angular velocity-time graph of the right ankle for three steps during the A drill, B drill, and sprinting for subjects 7 and 8, respectively. The following events are indicated on each graph: (1) right touchdown, (2) right toe-off, (3) left touchdown, (4) left toe-off, (5) right touchdown, (6) right toe-off, (7) left touchdown. The positive values represent plantarflexion angular velocities, while the negative values represent dorsiflexion angular velocities.

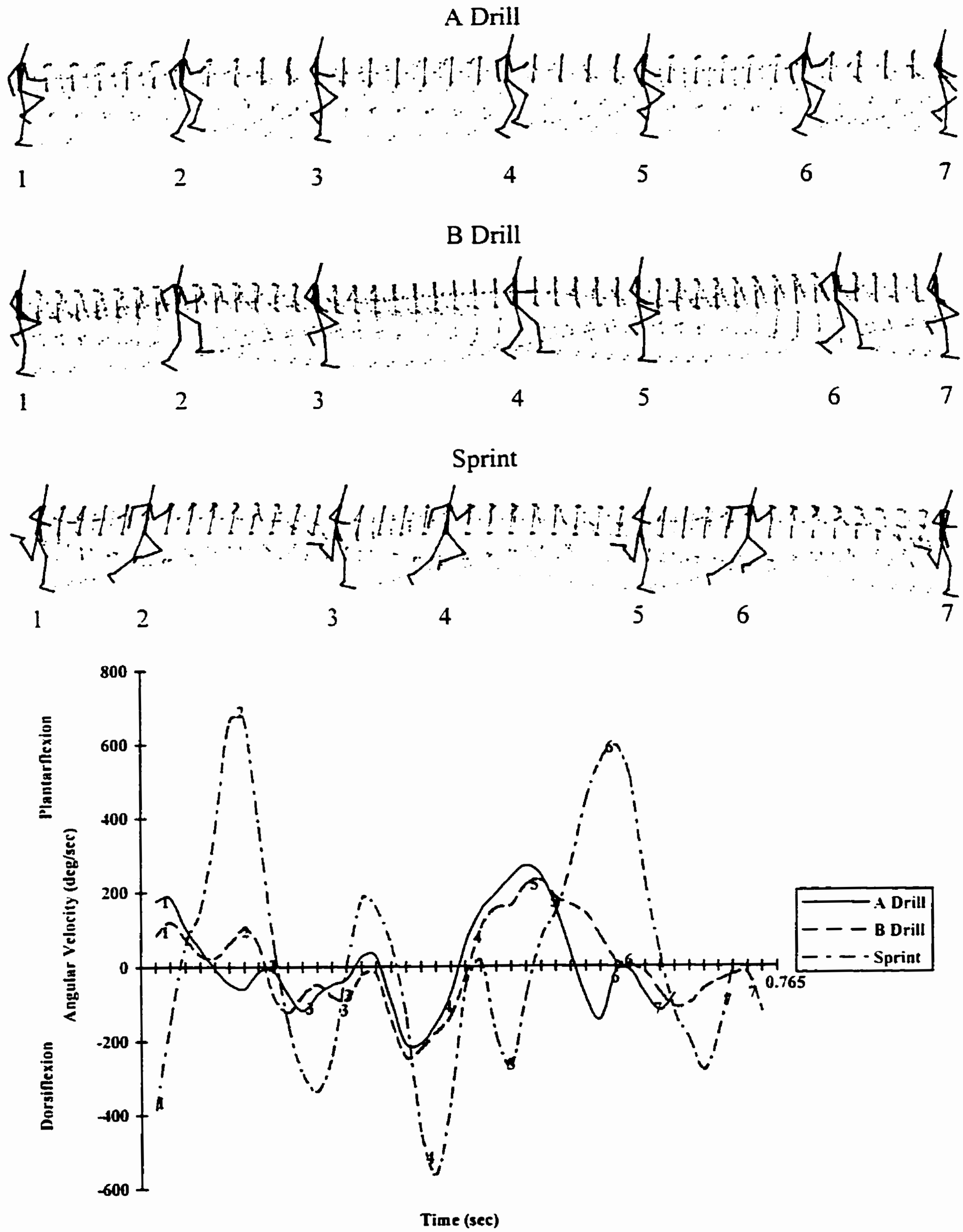


Figure 5-18. Angular velocity/time curves for subject 7 for the right ankle during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

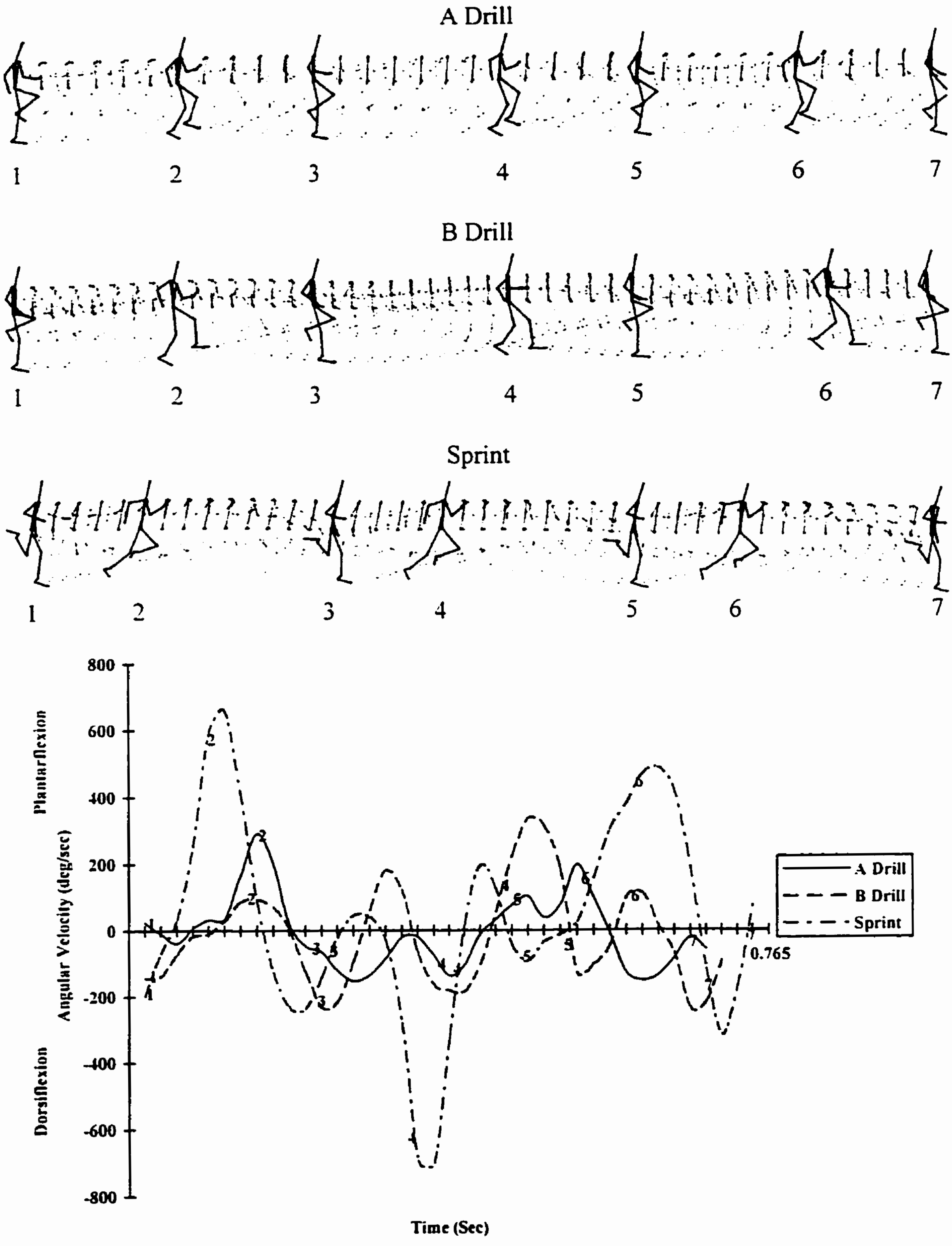


Figure 5-19. Angular velocity/time curves for subject 8 for the right ankle during sprinting, the A drill, and the B drill. (1) = right touchdown, (2) = right toe-off, (3) = left touchdown, (4) = left toe-off, (5) = right touchdown, (6) = right toe-off, (7) = left touchdown.

Peak plantarflexion angular velocity for the right ankle during sprinting occurred at or just after right toe-off (event 2 and 6). For the A and B drills, peak plantarflexion angular velocity was seen between left toe-off (event 4) and right touchdown (event 5). This indicates that there are differences in the timing of peak plantarflexion angular velocity for the A and B drills and sprinting. A small plantarflexion peak was seen at the time of right toe-off (event 2), which shows that the ankle makes a contribution to the production of ground reaction forces for propulsion.

Peak dorsiflexion angular velocity for sprinting was seen during recovery of the right leg (between event 3 and 4), as the leg was swung forward. This action decreased the moment of inertia of the recovery leg, which is the resistance to angular motion, enabling it to swing forward faster. Peak dorsiflexion angular velocity was seen during similar instances for the A and B drills, as the ankle was rapidly dorsiflexed during recovery.

In comparing the peak plantarflexion and dorsiflexion angular velocities with the ankle angular displacement data, differences are seen in the range at which the peak angular velocities occur. Peak plantarflexion angular velocity was seen for sprinting at right foot toe-off (event 2). On the angular displacement-time graph, this corresponds to an angle of approximately 17^0. Peak plantarflexion angular velocity was seen for the A and B drills between left toe-off and right touchdown (events 4 and 5) as the foot prepared for ground contact. The timing of this event on the angular displacement-time graph corresponds to an angle of approximately 5^0 of dorsiflexion.

Peak dorsiflexion angular velocity was seen for all three skills between left contact (event 3) and left toe-off (event 4). This peak velocity was seen at an angle of approximately 15^0 of plantarflexion for sprinting, and at an angle of approximately 0^0 for the A and B drills. These results indicate that there are differences in the range at which peak plantarflexion and dorsiflexion angular velocities are seen in the A and B drills.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to compare the kinematics of the running A and B drills to sprinting. The running A and B drills are two drills which are commonly used by sprinters as part of training. This comparison was accomplished by a kinematic analysis of select variables associated with sprint performance. It was hypothesized that there would be no differences among the majority of the variables for the A drill, B drill, and sprinting.

A group of university level sprinters were recruited to participate in the study. They first completed the running A drill followed by the running B drill, as this is the order in which the drills are completed during practice. The participants were instructed to perform the drills as fast and as technically perfectly as possible. They then completed two 60 metre runs at maximum speed. While performing the drills and sprinting, the participants were videotaped from the frontal and sagittal views. These videotapes were then used to derive a three dimensional model of the performance via DLT, which was then used to complete the kinematic analysis using the Peak Performance Technologies motion analysis system. From the spatial model, 23 kinematic variables describing performance in the three skills were calculated.

Both the vertical displacement and vertical velocity of the centre of mass for sprinting were found to be significantly greater than both the A and B drills. Step frequency was found to be greatest for the A drill, followed by sprinting and the B drill. The support time in sprinting was found to be significantly shorter in duration, while the non-support time for the A drill was significantly shorter. Shoulder range of motion was found to be significantly greater for sprinting, as well shoulder flexion angular velocity was faster in sprinting. There were no significant differences found in shoulder extension angular velocity among the three skills. There were no significant differences in elbow range of motion or elbow extension angular velocity among the three skills. Elbow flexion angular velocity was significantly slower for the B drill than the other two skills. Sprinting produced greater range of motion values for trunk flexion, trunk rotation, and pelvic rotation. At the hip, greater maximum hip flexion was seen for the A and B drills than for sprinting. Hip flexion angular velocity was similar across all three skills, while hip extension angular velocity was greatest for sprinting. Knee range of motion was similar for all three skills. Sprinting produced greater knee angular velocities than the drills in both the flexion and extension directions. Ankle, range of motion, plantarflexion angular velocity, and dorsiflexion angular velocity were significantly greater for sprinting.

Differences among the three skills were seen in the timing of peak angular velocity at the shoulder, hip, and knee. Differences among the three skills were also seen in the point at which peak angular velocity occurred at the shoulder and ankle joint range of motion.

Conclusions

Based on the results of this study, the following conclusions appear justified:

1. There are differences in the range of motion seen at several joints during the running A and B drills when compared to sprinting. Decreases in range of motion are seen at the shoulder and ankle, as well as a decreased range in trunk rotation, pelvic rotation and trunk flexion in the drills as compared to sprinting. Increases in range of motion are seen in hip flexion in the running A and B drills. No differences in range of motion are seen at the knee and at the elbow joints between the drills and sprinting.

2. There are differences in the peak angular velocity during the running A and B drills, compared to sprinting. Decreased peak angular velocity is seen in shoulder flexion, elbow flexion, hip extension, knee extension, plantarflexion and dorsiflexion in the drills. There are no differences in peak angular velocity for shoulder extension, elbow extension, and knee flexion in the drills compared to sprinting.

3. There is a decreased vertical displacement and vertical velocity of the centre of mass during the running A and B drills as compared to sprinting.

4. The running A drill is performed at a frequency greater than that of sprinting, while the running B drill is performed at a slower frequency than sprinting.

5. Sprinters are in contact with the ground for a significantly longer period of time for the running A and B drills than in sprinting, while the running B drill is similar to sprinting in non-support time.

Recommendations

Based on the present study, the following recommendations should be considered for future studies that intend on using a similar methodology:

1. The filming speed in the present study may have been too slow to accurately determine all variables. A faster filming speed would produce more precise values for support time and non-support time. The faster filming rate would produce more frames to digitize per second, which would improve the accuracy in determining the exact instant of ground contact or toe-off.

2. Elite level sprinters should be used. Although the athletes recruited for the present study were all skilled university level sprinters and were proficient at the drills. elite athletes may demonstrate better technique with more similarities to sprinting.

3. Further studies on the biomechanics of sprint training are necessary. Prior to the completion of this study, the running A's and B's were believed by many coaches to be drills which replicate the sprint stride. This study revealed that there are differences in the kinematics of the running A and B drills as compared to sprinting, as well as differences in the timing of events among the three skills. Although these drills are only one type of sprint training exercise, this study has suggested coaches may require a greater understanding of specificity of training in drill selection. Further research in the area of drill analysis may assist coaches in devising sprint training regimens which better simulate the kinematics of sprinting. Although there is no single "ideal" sprint training drill (aside from sprinting itself), the drills which are used in training should possess characteristics similar to sprinting in the following areas: range of motion, peak angular velocity occurring at the same joint angle through the range of motion, step frequency, vertical displacement and vertical velocity, and support time and non-support time.

4. Since there were differences found in the kinematics of the running A and B drills, there should be careful evaluation by coaches as to how these drills are used in training, taking into consideration the time of season, type of workout being performed, and the level of the athlete.

BIBLIOGRAPHY

Abraham, L.D. (1987). An inexpensive technique for digitizing spatial coordinates from videotape. In B. Jonsonn (Ed.), *Biomechanics X-B*. Champaign, Human Kinetics, pp. 1107-1110.

Adrian,M.J., & Cooper, J.M. (1989). *The Biomechanics of Human Movement.* Indianapolis: Benchmark Press, Inc.

Ae, M., Ito, A., & Suzuki, M. (1992) The men's 100 metres. *New Studies in Athletics,* 7(1), pp. 47-52.

Alexander, M.J.L. (1989). The relationship between muscle strength and sprint kinematics in elite sprinters. *Canadian Journal of Sport Sciences*, 14(3), pp. 148-157.

Allard, P., Magata, S.D., Duhaime, M., & Labelle, H. (1987). Application of stereophotogrammetry and mathematical modelling in the study of ankle kinematics. In B. Jonsson (Ed.), *Biomechanics X-B*. Champaign: Human Kinetics, pp. 1111-1115.

Angulo, R.M., & Dapena, J. (1992). Comparison of film and video techniques for estimating three-dimensional coordinates within a large field. *International Journal of Sport Biomechanics*, 8, pp. 145-151.

Anshell, M.H.(Ed.), Freedson, P., Hamill, J., Haywood, K., Horvat, M., & Plowman, S.A. (1991). *Dictionary of the Sport and Exercise Sciences*. Champaign: Human Kinetics.

Armstrong, L., Costill, D.L., & Gehlsen, G. (1984). Biomechanical comparison of university sprinters and marathon runners. *Track Technique*, 87, pp. 2781-2782.

Bates, B.T., James, S.L., & Osternig, L.R. (1978). Foot function during the support phase of running. *Running*, 24, pp. 28-31.

Bates, B.T., Osternig, L.R., Mason, B.R., & James, S.L. (1979). Functional variablilty of the lower extremity during the support phase of running. *Medicine and Science in Sports and Exercise*, 11(4), pp. 328-331.

Baumann, W. (1985). Biomechanical analysis of the 100m sprint for women. In IAAF Development Program (Ed.), *Women's Track and Field Athletics*. Darmstadt, Germany: Deutcher Leichtathletic-Verband, pp. 232-240.

Behm, D.G., & Sale, D.G. (1993). Intended rather than actual movement velocity determines velocity-specific training responses. *Journal of Applied Physiology*, 74, pp. 359-368.

Bell, S. (1995). Drills which lead to better sprint performance. *Track and Field Coaches Review*, 95(1), pp. 13-15.

Bobbert, M.F., Huijing, P.A., & van Ingen Schenau, G.J. (1986). Calculation of vertical ground reaction force estimates during running from positional data. *Journal of Biomechanics*, 24, pp.1095-1105.

Bompa, T.O. (1994). *Power Training for Sport: Plyometrics for Maximum Power Development*. Oakville, Ontario: Mosaic Press.

Bowerman, W.J., & Freeman, W.H. (1991). *High Performance Training for Track and Field (2nd Ed.)*, Champaign: Leisure Press.

Bruce, G.A. (1996). Sprint coach, The University of Manitoba. *Personal Communication*. November 19, 1996.

Bruce, G.A. (1994). *Sprint to Victory* [Video]. Copyright Glenn A. Bruce.

Bunn, J.W. (1978). *Scientific Principles of Coaching (2nd Ed.)*. Englewood Cliffs: Prentice Hall, Inc.

Burt, M. (1994). Increasing leg speed. *US Track Coaches Review*, 89, pp. 8-9.

Cannon, R.J., & Cafarelli, E. (1987). Neuromuscular adaptations to training. *Journal of Applied Physiology*, 63, pp. 2396-2402.

Carr, G.A. (1991). *Fundamentals of Track and Field*. Champaign: Leisure Press.

Cavanagh, P.R., & Komi, P.V. (1979). Electromechanical delay in human skeletal muscle under concentric and eccentric contractions. *European Journal of Applied Physiology*, 42, pp. 159-163.

Chaffin, D.B., & Andersson, G.B.J. (1991). *Occupational Biomechanics (2nd Ed.)*. New York: Wiley.

Challis, J., & Kerwin, D. (1988). An evaluation of splines in biomechanical data analysis. In G. de Groot, A.P. Hollander, P.A. Huijing & G.J. van Ingen Schenau (Eds.), *Biomechanics XI-B*. Amsterdam: Free University Press, pp. 1057-1062.

Chao, E.Y., & Rim, K. (1973). Application of optimization principles in determining the applied moments in human leg joints during gait. *Journal of Biomechanics*, 6, pp. 497-510.

Chengzhi, L., & Zongcheng, H. (1987). Temporal and kinematic analysis of swing leg or elite sprinters. In B. Jonsson (Ed.) *Biomechanics X-B*. Champaign: Human Kinetics, pp. 825-829.

Cracraft, J.D., & Petajan, J.H. (1977). Effect of muscle training on the pattern of firing of single motor units. *American Journal of Physical Medicine*, 56, pp. 183-193.

Dapena, J. (1987). Basic and applied research in the biomechanics of high jumping. In B. van Gheluwe & J. Atha (Eds.), *Current Research in Sports Biomechanics*. Basel, Switzerland: Karger, pp. 19-33.

Dare, B. (1994). Technique analysis: an overview of running mechanics. *Track Technique*, 87, pp. 2834-2836.

DeBruin, H., Russel, D.J., Latter, E., & Sadler, J.T.S. (1982). Angle-angle diagrams for the monitoring and quantification of gait patterns for children with cerebral palsy. *American Journal of Physical Medicine*, 61, pp. 176-182.

Delecluse, C., van Coppenole, H., Willems, E., van Leemputte, M., Diels, R., & Goris, M. (1995). Influence of high-resistance and high-velocity training on sprint performance. *Medicine and Science in Sports and Exercise*, 27(8), pp. 1203-1209.

Denoth, J., Gruber, K., Ruder, H., & Keppler, M. (1984). Forces and torques during sports activities with high accelerations. In S.M. Perren & E. Schneider (Eds.), *Biomechanics: Current Interdisciplinary Research*. Drodrecht: Martinus Hijhoff Publishers, pp. 663-668.

Deshon, D.E., & Nelson, R.C. (1968). A cinematographical analysis of sprint running. *The Research Quarterly*, 35, pp. 451-455.

Dick, F.W. (1985). Strength training - women's sprints. In A. Foulkes (Ed.), *Women's Track and Field Athletics*. Darmstadt, Germany: Deutscher Leichathletick Verband, pp. 275-285.

Diffrient, N., Tilley, A.R., & Bardagjy, J.C. (1978). *Humanscale 1/2/3*. Cambridge: MIT Press.

Dillman, C.J. (1975). Kinematic analysis of running. *Exercise and Sports Science Review*, 3, pp. 193-218.

Duchateau, J.E., & Hainaut, K. (1984). Isometric or dynamic training: differential effects on mechanical properties of a human muscle. *Journal of Physiology, 56*, pp. 296-301.

Dyson, G.H.G. (1986). *Dyson's Mechanics of Athletics (8th Ed.).* New York: Holmes & Meier.

Ferguson, M. (1996). Women's sprint coach, The University of Tennessee. *Personal Communication.* November 13, 1996.

Gagnon, M., Robertson, G., & Norman, R. (1987). Kinetics. In D.A. Dainty & R.W. Norman (Eds.), *Standardized Biomechanical Testing in Sport.* Champaign: Human Kinetics, pp. 21-57.

Gambetta, V. (1991). Essential considerations for the development of a teaching model for the 100 metres sprint. *New Studies in Athletics*, 6(2), pp. 27-32.

Gardiner, A. (1997). Director, Athletics Canada; former Canadian national sprint coach. *Personal Communication.* January 7, 1997.

Grieve, D.W. (1968). Gait patterns and the speed of walking. *Biomedical Engineering,* 3, pp. 119-122.

Hainaut, K., Duchateau, J., & Desmedt, J.E. (1981). Differential effects of slow and fast motor units of different programs on brief daily muscle training in man. In J.E. Desmedt (Ed.), *Progress in Clinical Neurophysiology, Vol. 9: Motor Unit Types, Recruitment, and Plasticity in Health and Disease*, pp. 241-249. Basel: Karger.

Hall, S.J. (1995). *Basic Biomechanics (2nd Ed.)* Toronto: Mosby-Year Book.

Hamill, J. & Knutzen, K.M. (1995). *Biomechanical Basis of Human Movement.* Philadelphia: Williams & Wilkins.

Hassard, T.H. (1991). *Understanding Biostatistics.* Toronto: Mosby-Year Book.

Hay, J.G. (1993). *The Biomechanics of Sports Techniques (4th Ed.).* Englewood Cliffs: Prentice-Hall, Inc.

Hay, J.G. & Reid, J.G. (1988). *Anatomy, Mechanics, and Human Motion (2nd Ed.).* Englewood Cliffs: Prentice-Hall, Inc.

Higgs, C. (1984). Cinematographic techniques in biomechanical analysis. In M. Alexander, C. Higgs, G. Robertson,. & J. Stevenson (Eds.), *Technology for Biomechanical Analysis of Athletes.* Ottawa: CAHPER/ASCEPL, pp. 3-22.

Hinrichs, R.N. (1990). Upper extremity function in distance running. In P.R. Cavanagh (Ed.), *Biomechanics of Distance Running*. Champaign: Human Kinetics, pp. 107-133.

Hinrichs, R.N. (1985). A three-dimensional analysis of the net moments at the shoulder and elbow joints in running and their relationship to upper extremity EMG activity. In D.A. Winter, R.W. Norman, R.P. Wells, K.C. Hayes, & A.E. Patla (Eds.), *Biomechanics IX-B*. Champaign: Human Kinetics, pp. 337-342.

Hoffman, S.J. (1971). Effect of practice on consistency in performance technique; a cinematographic study. *Journal of Motor Behavior*, 6(2), pp. 125-129.

Hommel, H. (1991). NSA photosequence 24: sprint stride of Florence Griffith-Joyner. *New Studies in Athletics*, 6(2), pp. 73-77.

Hoskisson, J.L. (1989). Sprinting: a new look. *Track and Field Quarterly Review*, 89(1), pp. 13-19.

Hoskisson, J.L., & Korchemny, R. (1991). 1990 TAC Junior Sprint Project Evaluation. *Track Technique*, 116, pp. 3691-3699.

Ito, A., Fuchimoto, T., & Kaneko, M. (1985). Quantitative analysis of EMG during various speeds of running. In Winter, D.A., Norman, R.W., Wells, R.P., Hayes, K.C., & Patla, A.E. (Eds), *Biomechanics IX-B*. Champaign: Human Kinetics, pp. 301-306.

Kennedy, P.W., Wright, D.L., & Smith, G.A. (1989). Comparison of film and video techniques for three-dimensional DLT productions. *International Journal of Sport Biomechanics*, 5, pp. 457-460.

Kreighbaum, E., & Barthels, K.M. (1985). *Biomechanics: A Qualitative Approach for Studying Human Movement* (2nd Ed.). New York: MacMillin Publishing Company.

Lemaire, E.D. & Robertson, D.G.E. (1990). Power in sprinting. In J.Jarver (Ed.), *Sprints and Relays: Contemporary Theory, Technique, and Training (3rd Ed.)*. Mount View CA: Tafnews Press, pp. 16-21.

Levtskenko, A. (1990). Some questions and answers on women's sprinting. In J.Jarver (Ed.), *Sprints and Relays: Contemporary Theory, Technique, and Training (3rd Ed.)*. Mount View CA: Tafnews Press, pp. 85-87.

Lopez, V. (1995). An approach to strength training for sprinters. *Track and Field Coaches Review*, 95(1), pp. 16-20.

Luhtanen, P., & Komi, P.V. (1978). Mechanical factors influencing running speed. In P.V. Komi (Ed.), *Biomechanics VI-B*. Baltimore: University Park Press, pp. 23-29.

Mach, G. (1980). *Sprints and Hurdles*. Vanier, ON: Canadian Track and Field Association.

Mann, R. (1985). Biomechanical analyses of the elite sprinter and hurdler. In N.K. Butts, T.T. Gushiken, & B. Zarins (Eds.), *The Elite Athlete*. Jamaica, N.Y.: Spectrum Publications, pp. 43-80.

Mann, R. (1986). The biomechanical analysis of sprinters. *Track Technique*, 94, pp. 3000-3003.

Mann, R. & Herman, J. (1985). Kinematic analysis of Olympic sprint performance: men's 200 metres. *International Journal of Sport Biomechanics*, 1(2), pp. 151-162.

Mann, R. & Sprague, P. (1983). Kinetics of Sprinting. *Track and Field Quarterly Review*, 83(2), pp. 4-9.

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

McArdle, W.D., Katch, F.I. & Katch, V.L. (1991). *Exercise Physiology: Energy, Nutrition and Human Performance (3rd Ed.)*. Philadelphia: Lea & Febiger.

McFarlane, B. (1994a). Hurdles... a basic and advanced technical model. *Track Technique*, 128, pp. 4073-4079.

McFarlane, B. (1994b). Speed...a basic and advanced technical model. *Track Technique*, 126, pp. 4016-4020.

McInnis, A. (1997). Canadian national sprint coach. *Personal Communication*, January 26, 1997.

Mero, A., Jaakkola, L., & Komi, P.V. (1991). Relationship between muscle fibre characteristics and physical performacne capacity in trained athletic boys. *Journal of Sports Sciences*, 9(2), pp. 161-171.

Mero, A., & Komi, P.V. (1987). Electromyographic activity in sprinting at speeds ranging from sub-maximal to supra-maximal. *Medicine and Science in Sports and Exercise*, 19(3), pp. 266-274.

Mero, A., Komi, P.V., & Gregor, R.J. (1992). Biomechanics of sprint running: a review. *Sports Medicine*, 13(6), pp. 376-392.

Mero, A., Luhtanen, P., & Komi, P. (1986). Segmental contribution to velocity of centre of gravity during contact at different speeds in male and female sprinters. *Journal of Human Movement Studies*, 12, pp. 215-235.

Milner, M., Dall, D., McConnell, V.A., Brennan, P.K., & Hershler, C. (1973). Angle diagrams in the assessment of locomotor function. *South African Medical Journal of Laboratory and Clinical Medicine*, 47, pp. 951-957.

Milner-Brown, H.S., Stein, R.B., & Lee, R.G. (1975). Synchronization of human motor units: Possible roles of exercise and supraspinal reflexes. *EEG in Clinical Neurophysiology*. 38, pp. 145-254.

Mortimer, J.A. & Webster, D.D. (1983). Dissociated changes of short- and long-latency myotatic responses prior to a brisk voluntary movement in normals, in karate experts, and in Parkinsonian patients. In J.E. Desmedt (Ed.), *Advances in Neurology, Vol. 39: Motor Control Mechanisms in Health and Disease*, pp. 541-554. New York: Raven.

Nigg, B.M., & Cole, G.K. (1994). Optical methods. In B.M. Nigg & W. Herzog (Eds.), *Biomechanics of the Musculo-skeletal System*. Toronto: John Wiley & Sons, pp. 254-286.

Nordin, N., & Frankel, V.H. (1989). *Basic Biomechanics of the Musculoskeletal System* (2nd Ed.). Philadelphia: Lea & Febiger.

Northrip, J.W., Logan, G.A., & McKinney, W.C. (1974). *Introduction to Biomechanic Analysis of Sport*. Dubuque: W.C Brown.

Nummela, A., Rusko, H., & Mero, A. (1994). EMG activities and ground reaction forces during fatigued and nonfatigued sprinting. *Medicine and Science in Sports and Exercise*, 26(5), pp. 605-609.

Nummela, A., Vuorimaa, T., & Rusko, H. (1992). Changes in force production, blood lactate and EMG activity in the 400-m sprint. *Journal of Sport Sciences*, 10, pp. 217-228.

Payne, A.H. (1983). Foot to ground contact forces in elite runners. In H. Matsui & K. Kobayashi (Eds.), *Biomechanics VIII-B*, pp. 746-753.

Payne, A.H., Slater, W.J., & Telford, T. (1968). The use of a force platform in the study of athletic activities. *Ergonomics*, 11, pp. 123-143.

Philips, B, & Tibshirani, R. (1997). Who is the world's best sprinter? *Athletics*, January, pp. 12-14.

Radford, P. (1984). The nature and nurture of a sprinter. *New Scientist*, 2, pp. 13-15.

Roberts, E.M. (1970). Cinematography in biomechanical investigation. In Cooper, J.M. (Ed.), *Selected topics in biomechanics: proceedings of the C.I.C. symposium on biomechanics*. Chicago: The Athletic Institute, pp. 41-50.

Robertson, G., & Sprigings, E. (1987). Kinematics. In D.A. Dainty & R.W. Norman (Eds.), *Standardized Biomechanical Testing in Sport*. Champaign: Human Kinetics Publishers, pp. 9-20.

Rodgers, M.M, & Cavanagh, P.R. (1984). Glossary of biomechanical terms, concepts, and units. *Physical Therapy*, 64, pp. 1886-1900.

Sale, D.G., MacDougall, J.D., Upton, A.R.M., & McComas, A.J. (1983). Effect of strength training upon motoneuron excitability in man. *Medicine and Science in Sports and Exercise*, 15, pp. 57-62.

Schmolinski, G. (Ed.). (1992). *Track and Field: The East German Textbook of Athletics*. Toronto: Sports Book Publisher.

Scholz, J.P. & Millford, J.P. (1993). Accuracy and precision of the PEAK performance technologies motion measurement system. *Journal of Motor Behavior*, 25(1), pp. 2-7.

Shapiro, R. (1976). Direct linear transformation method for three-dimensional cinematography. *The Research Quarterly*, 49, pp. 197-205.

Simonsen, E.B., Thomsen, L., & Klausen, K. Activity of mono- and biarticular leg muscles during sprint running. *European Journal of Applied Physiology*, 54, pp. 524-532.

Szczepanski, T. (1986). Training methods for strength development in Polish women 100m hurdlers. In A. Foulkes (Ed.), *Women's Track and Field Athletics*. Darmstadt, Germany: Deutscher Leichathletick Verband, pp. 287-296.

Tupa, V., Dzhalilov, A., & Shuvlaov, G. (1991) Sprinting: visual evaluation of technique. *Soviet Sports Review*, 26(2), pp.70-73.

van Woensel, W., & Cavanagh, P.R. (1992). A perturbation study of lower extremity motion during running. *International Journal of Sport Biomechanics*, 8, pp. 30-47.

Wiemann, K, & Tidow, G. (1995). Relative activity of hip and knee extensors in sprinting - implications for training. *New Studies in Athletics*, 10(1), pp. 29-49.

Williams, K.R. (1985). Biomechanics of running. *Exercise and Sports Science Reviews*, 14, pp. 389-441.

Winter, D.A. (1990). *Biomechanics and Motor Control of Human Movement* (2nd Ed.). New York: John Wiley & Sons, Inc.

Wood, G.A. (1982). Data smoothing and differentiation procedures in biomechanics. *Exercise and Sport Science Reviews*, 10, pp. 308-362.

Wood, G.A., & Marshall, R.N. (1986). Technical note: The accuracy of DLT extrapolation in three dimensional film analysis. *Journal of Biomechanics*, 19, pp. 781-785.

Zehr, E.P. & Sale, D.G. (1994). Ballistic movement: Muscle activation and neuromuscular adaptation. *Canadian Journal of Applied Physiology*, 19(4), pp. 363-378.

APPENDIX A

PERSONAL CONSENT FORM

PERSONAL CONSENT FORM

You have been selected to participate in a study entitled "A Comparison of the A and B Drills with the Kinematics of Sprinting."

The purpose of this study is to analyze the mechanics of the A and B drills, and to compare them to those of sprinting. It is hoped that this study will determine if these drills are in fact replicating the biomechanics of the sprint stride, possibly confirming their use as one of the key components of the sprinter's training regimen.

In the following study, you will first be asked to warm up as you would prior to competition. You will then be asked to perform three repetitions of the A run for a distance of seven metres. Next, you will be asked to perform three repetitions of the B run for a distance of seven metres. Both drills will be performed as fast and as technically perfect as possible. Finally, you will be asked to perform two runs of sixty metres, starting from blocks, at maximum speed. These runs will be started by an experienced starter, and will be timed electronically. Between all trials, you will be allowed sufficient time for rest.

During your completion of the drills and sprinting, two cameras will film your performance, and the tapes will then be used to calculate various parameters required for biomechanical analysis. Your name, height, weight, age, and years of sprint training will be recorded for identification by the investigator, however, your identity will remain confidential. The recorded films will not be redistributed or used for any purpose other than this biomechanical research study.

As a university level sprinter, it is assumed that you are capable of performing the A and B drills and running at maximum speed, and the risk of injury is low. Possible injuries may include muscle strains and ligament sprains.

I, ____, have read the above information and understand the testing procedure, the risks involved, and I agree to participate at my own risk. I acknowledge that the A and B drills and running at maximum speed are well within my capability and I can successfully perform these actions on a regular basis. I also understand that I have the right to withdraw at any time. In the case of injury, I relieve the University of Manitoba, and the Investigator of any liability that may arise as the result of my participation.

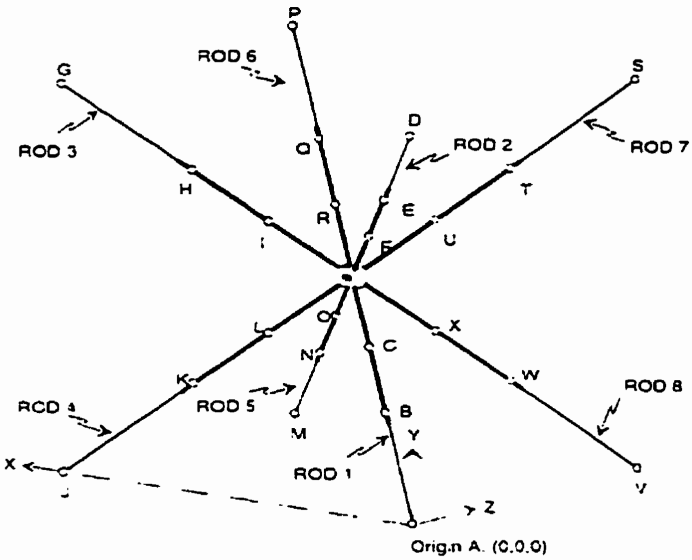
______________________________ ______________________
Signature of Investigator Date

______________________________ ______________________
Signature of Subject (Parent/Guardian) Date

______________________________ ______________________
Witness Date

APPENDIX B

X,Y,Z COORDINATES OF INDIVIDUAL POINTS ON CALIBRATION TREE



Point	Label	X	Y	Z
1	A	0.0	0.0	0.0
2	B	480.3	424.0	343.1
3	C	825.1	725.7	589.0
4	D	-17.8	1913.5	9.6
5	E	464.3	1505.4	338.2
6	F	523.3	1212.2	587.6
7	G	2229.1	1914.5	12.1
8	H	1740.5	1505.8	337.1
9	I	1391.8	1211.7	587.2
10	J	2216.1	0.0	0.0
11	K	1735.6	424.3	342.4
12	L	1390.7	726.0	589.1
13	M	2217.7	3.0	1582.6
14	N	1736.7	425.9	1239.8
15	O	1391.2	726.8	993.3
16	P	2230.6	1916.8	1591.0
17	Q	1741.4	1506.9	1242.5
18	R	1392.5	1212.6	993.6
19	S	-14.6	1914.3	1594.0
20	T	474.6	1506.4	1243.4
21	U	824.0	1212.3	994.1
22	V	1.5	0.0	1585.0
23	W	480.2	424.3	1238.9
24	X	825.4	726.2	993.6

From Peak Performance Technologies User's Reference Manual (version 1.0), 1992

APPENDIX C

PILOT STUDY

PILOT STUDY

Procedures

The filming site was the Max Bell High Performance Centre indoor track located at the University of Manitoba. The subjects were asked to arrive at the testing area one hour prior to filming, were asked to complete their competition warm-up.

Video filming for the three-dimensional analysis was completed in both the frontal and sagittal views. Camera 1 was Panasonic PV-S770A-K, and filmed in the sagittal view. Camera 2 was a Panasonic Digital D-5100, and filmed in the frontal view. The cameras filmed at a speed of 60 Hz, with a shutter speed of 1/1000. The cameras were linked together by a time code generator, which synchronized the video cameras and place the identical time codes on both tapes and allowed the investigator to begin digitizing each subject at the same position on the film. The distance from each camera to the field of view was approximately 15 metres, a distance in which the subjects were large enough to allow for detection of anatomical landmarks, but far enough to allow for sufficient cycles of the sprint stride for analysis. The Panasonic Digital D-5100 camera was linked to a portable video cassette recorder, and both units will be powered by a 12 volt car battery. The Panasonic PV-S770A-K camera used its own internal battery as a power source. The time code generator was linked to the car battery.

Four pylons were laid out on the track to indicate the filming area. The first two were placed on the lines of one of the middle lanes of the track, and represented the start of the filming area. The second two were placed at a distance of ten metres from the first two, on the lines of the same lane, and represented the end of the filming area. This grid was located approximately 45 metres from the start line on the infield of the track, which allowed for analysis of sprinting technique. For calibration of the two cameras, a calibration tree was located in the middle of this grid. This tree was later digitized when setting up the project to produce accurate three dimensional data via direct linear transformation (DLT) parameters.

Once the filming of the calibration tree was completed, the subjects were filmed. The subjects first performed the A drill, followed by the B drill. For these drills, the subjects began at the first pylons from a standing start, and were instructed to perform the drill to the second pylons, a distance of ten metres. They were asked to perform the drills as fast and technically perfectly as possible. For the drills, the subjects were given sufficient rest between trials, approximately 2 to 3 minutes. Between the A and B drills, the subjects were given 5 minutes rest. Each subject performed three repetitions of each drill. They were wearing their training flats during this part of the testing, as this is the customary footwear worn when performing the drills.

After completing the A and B drills, the subjects performed two acceleration runs. From a standing start, they accelerated down the track, reaching maximum speed as they approached the pylon grid, at which time they were filmed for analysis. The subjects were allowed sufficient rest between trials, approximately 12 to 15 minutes. The sprinters wore spikes during these runs as this is the normal footwear the sprinters would wear when running at maximum speed.

The spatial model to be used in the pilot study consisted of 21 segmental endpoints or anatomical landmarks, which will allow for kinematic analysis of the A and B drills and of sprinting. The endpoints were: right and left fingertip, right and left wrist, right and left elbow, right and left shoulder, middle of chest, top of head, middle of hip, right and left hip, right and left knee, right and left ankle, right and left heel, right and left toe. Segmental masses and centre of gravity locations used in the spatial model were taken from Humanscale (Diffrient, Tilley, and Bardagjy, 1978).

For both the A and B drills and the sprint, one trial was digitized with the subject completing three consecutive steps. The raw data was conditioned using the Fast Fourier Transform filter at a cut-off frequency of 4 Hz as it was found to reduce the noise from the positional data and velocity data, yet maintain the shape of the curve.

Results

Since only two subjects were used in the pilot study, the data was of a descriptive nature. The physical and performance characteristics of the two subjects are outlined in Table 1. The subjects have distinctly different physiques, but are two of the more accomplished sprinters at the University of Manitoba, with 7 and 6 years of training experience.

Table 1. Physical characteristics of the two pilot subjects.

	Age (yrs)	Height (m)	Mass (kg)	100m PB (sec)	Yrs Training
Subject 1	27	1.72	74	10.51	7
Subject 2	22	1.89	76	10.68	6

Table 2 outlines the kinematic variables calculated from the pilot study. Vertical displacement and velocity were found to be similar among the drills and sprinting. The A drill is performed at a similar step frequency as sprinting, but the B drill is performed at a slower rate.

In the arm action, there was a decreased range of motion at the shoulder in the drills as compared to sprinting, but the elbow shows increased range of motion. At the shoulder, subject 1 had the greatest angular velocity values during sprinting, while in subject 2, the greatest angular velocity values were demonstrated during the A drill. Subject 1 showed greater shoulder extension than flexion angular velocities in two of the skills (sprint and A drill), while subject 2 showed greater shoulder flexion angular velocities for all three skills.

Trunk flexion was found to be greatest during the A drill, with smaller values for sprinting and the B drill. For trunk rotation, subject 1 demonstrated less rotation in sprinting as compared to the drills, while subject 2 showed more trunk rotation during sprinting. The values for trunk rotation were similar between the two drills. Pelvic rotation was greatest during sprinting, with small decreases found in the B drill. Further decreases in pelvic rotation were found in the A drill.

At the hip, the smallest angle of maximum hip flexion was found for sprinting, with increased hip flexion occurring in the A and B drills. Hip angular velocity was greatest during sprinting, in both the flexion and extension directions. Both the A and B drills showed considerably less angular velocity. In sprinting and the B drill, hip extension angular velocity was greater than hip flexion angular velocity, while in the A drill, hip flexion angular velocity was the larger of the two.

Table 2. Pilot Study Results

	Subject 1			Subject 2		
Variable	**Sprint**	**A Drill**	**B Drill**	**Sprint**	**A Drill**	**B Drill**
Vertical Displacement (m)	0.06	0.07	0.08	0.07	0.07	0.06
Vertical velocity (m/s)	0.51	0.60	0.60	0.60	0.51	0.45
Step Frequency (steps/sec)	5.29	5.00	4.61	5.00	5.00	4.61
Ground Contact (m)	0.20	0.08	0.06	0.18	0.05	0.13
Support Time (sec)	0.10	0.12	0.12	0.09	0.11	0.12
Non-support Time (sec)	0.12	0.10	0.12	0.13	0.11	0.12
Shoulder ROM (deg)	126.64	115.56	112.22	117.90	99.53	95.58
Shoulder Flexion AV (deg/sec)	609.04	475.57	482.75	451.89	543.12	426.92
Shoulder Ext. AV(deg/sec)	655.57	501.29	401.50	431.87	487.60	367.37
Elbow ROM (deg)	81.61	86.76	89.52	79.32	87.83	71.51
Elbow Flexion AV (deg/sec)	1120.72	735.95	750.96	820.63	830.72	717.43
Elbow Extension AV (deg/sec)	781.83	981.25	768.42	745.32	1250.84	600.60
Trunk Flexion (deg)	6.03	9.44	7.11	5.07	8.14	7.48
Trunk Rotation (deg)	20.90	23.41	22.76	18.55	15.08	14.60
Pelvic Rotation (deg)	25.51	13.68	19.65	30.83	14.06	19.91
Hip Flexion (deg)	114.95	98.70	82.45	109.64	104.13	100.34
Hip Flexion AV (deg/sec)	1148.21	509.50	644.39	818.48	518.84	566.61
Hip Extension AV (deg/sec)	951.36	649.94	621.32	655.51	715.20	532.08
Knee ROM (deg)	115.63	117.85	122.17	119.57	124.48	122.11
Knee Flexion AV (deg/sec)	1038.84	818.75	817.02	971.00	1167.37	928.89
Knee Extension AV (deg/sec)	1152.85	950.51	1071.49	1123.46	766.55	992.86
Ankle ROM (deg)	35.63	22.56	33.89	38.47	23.73	34.36
Plantarflexion AV (deg/sec)	983.86	538.61	656.79	978.95	573.86	404.73
Dorsiflexion AV (deg/sec)	933.86	416.2	538.55	673.12	466.32	394.07

Knee range of motion was greatest during the drills. Subject 1 showed a greater range of motion during the B drill, while subject 2 showed greater range of motion during the A drill. Knee extension angular velocity was generally greater than knee flexion angular velocity, although subject 2 showed greater knee flexion angular velocity during the A drill. There are no distinct differences between the drills and sprinting in terms of knee angular velocity, although sprinting does show slightly larger values. The angular velocity values at the knee were larger than those found at the hip.

At the ankle, there was a decreased range of motion in the A drill, while sprinting and the B drill showed similar values. Both plantarflexion and dorsiflexion angular velocities were greater for sprinting than for the drills, with the values for plantarflexion being greater than those of dorsiflexion.

Figure 1 compares the angular displacement/time curves of the left hip for three steps during sprinting, the A and B drills. The following events are indicated on each curve: right touchdown (1), right toe-off (2), left touchdown (3), left toe-off (4), right touchdown (5), and right toe-off (6). At right toe-off (2), there was a greater angle of maximum hip flexion during the A and B drills as compared to sprinting. At ground contact of the left foot (3), the left hip during sprinting was in a greater flexed position, which may indicate ground contact was further in front of the centre of mass. The left hip also achieved a greater angle of hip hyperextension at left toe-off in sprinting (4). Maximum hip hyperextension occurred after left toe-off in sprinting, but it occurred before left toe-off during the A and B drills.

Figure 2 compares the angular velocity/time curves of the left hip for three steps during sprinting and the A and B drills, beginning with ground contact of the right foot. Negative values represent hip extension angular velocities, and positive values represent hip flexion angular velocities. For sprinting, at the instant of right foot strike (1), the left hip was approaching peak flexion angular velocity as the leg swung through in recovery. At right toe-off (2), as the hip reached maximum flexion, the flexion angular velocity decreased to zero and hip extension was initiated. During hip extension, there were two peaks in the angular velocity. The first occurred prior to ground contact as the leg was accelerated backwards towards the ground. At left touchdown (3), there was a slight decrease in hip extension angular velocity, which represented the braking which occurred during the resistive phase. As the sprinter passed through the support phase and into propulsion, hip extension angular velocity reached its maximum, just prior to toe-off (4).

In the A and B drills, there were differences seen in the hip angular velocity patterns as compared to sprinting. At right toe-off (2), the flexion angular velocity of the left hip during sprinting was decreasing to zero to initiate hip extension, but in the drills hip extension had already been initiated. Only one peak in the angular velocity seen during hip extension for the drills, which occurred prior to left touchdown (3). Hip extension angular velocity was decreasing at the instant of left touchdown (3), and at left foot toe-off (4), hip flexion had already been initiated. During recovery, there was a small peak in the hip flexion angular velocity, which occurred at left toe-off (4). Maximum hip flexion angular velocity was then reached at right foot strike (5).

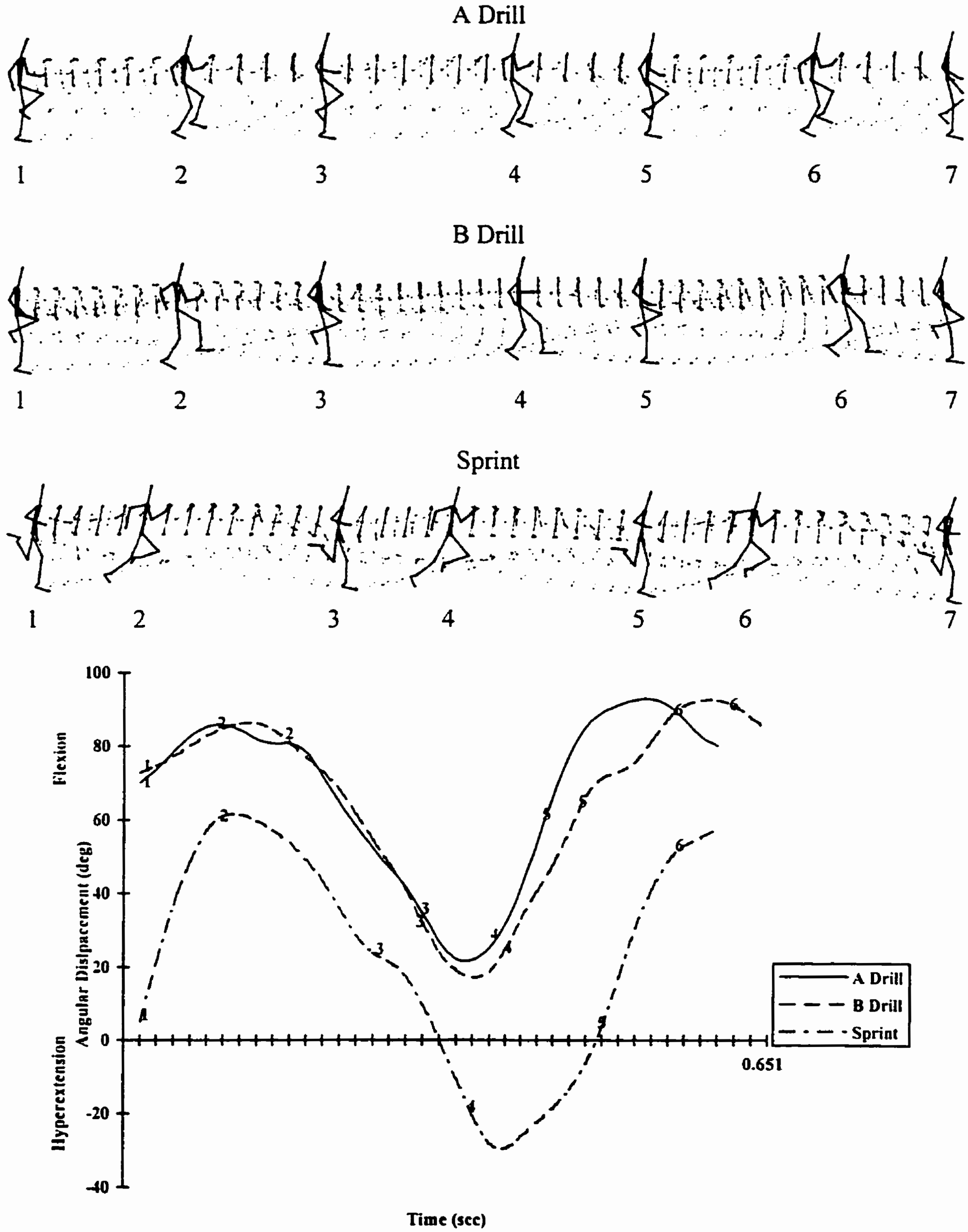


Figure 1. Left hip angular displacement/time curves for three steps during sprinting, A drill and B drill. 1 = right touchdown, 2 = right toe-off, 3 = left touchdown, 4 = left toe-off, 5 = right touchdown, 6 = right toe-off.

A Drill

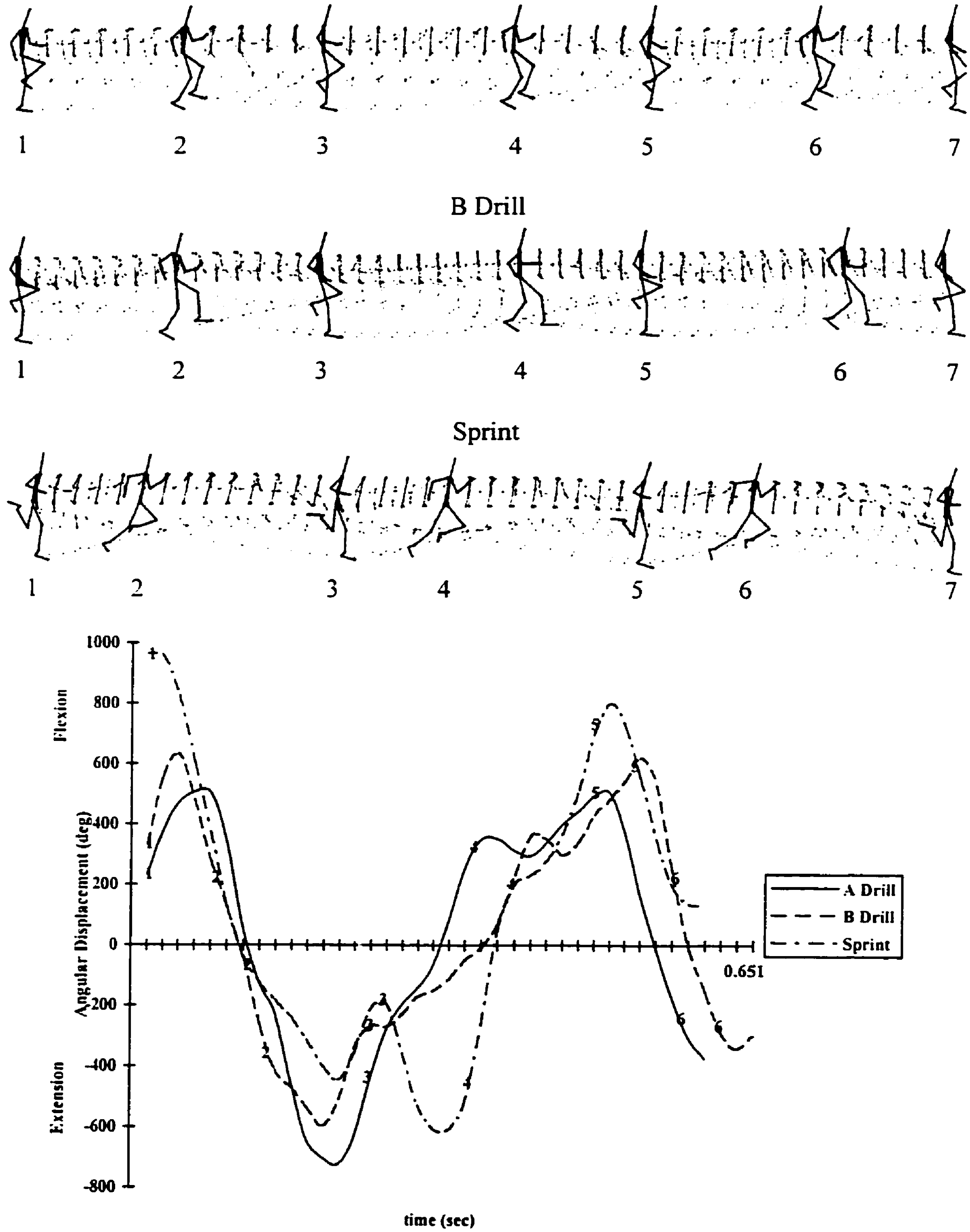


Figure 2. Left hip angular velocity/time curves for three steps during sprinting, A drill and B drill.
1 = right touchdown, 2 = right toe-off, 3 = left touchdown, 4 = left toe-off, 5 = right touchdown, 6 = right toe-off.

Figure 3 compares the angular displacement/time curves for the left knee for three steps during sprinting and the A and B drills where larger angles represent greater positions of knee extension. At right foot touchdown (1), the left knee for sprinting and the B drill was more flexed than in the A drill. At right toe-off (2), the left knee during the A drill was maximally flexed, while the left knee in sprinting and the B drill was already beginning to extend. The left knee reached full extension at left touchdown (3) in all three skills. Only during sprinting and the B drill, though, did the knee go through support flexion. Left toe-off (4) occurred with slight flexion in the left knee in all three skills.

Figure 4 shows the angular velocity/time curves of the left knee for three steps during sprinting and the A and B drills. Positive values represent knee extension angular velocities, while negative values represent knee flexion angular velocities. During sprinting, peak left knee extension angular velocity was reached just prior to right toe-off (2). There were two angular velocity peaks seen during knee flexion: the first was a small peak which occurred at left touchdown (3) which represented knee flexion in the braking phase. the second larger peak occurred after left toe-off (4) which was the passive knee flexion which occurred during recovery to decrease the moment of inertia of the leg. Between these two peaks, and there was a small knee extension angular velocity seen just prior to left toe-off, which represented the extension of the knee during the propulsive phase.

The B drill showed similarities to sprinting throughout the cycle. Significant differences were seen during left touchdown (3), where the knee did not undergo the

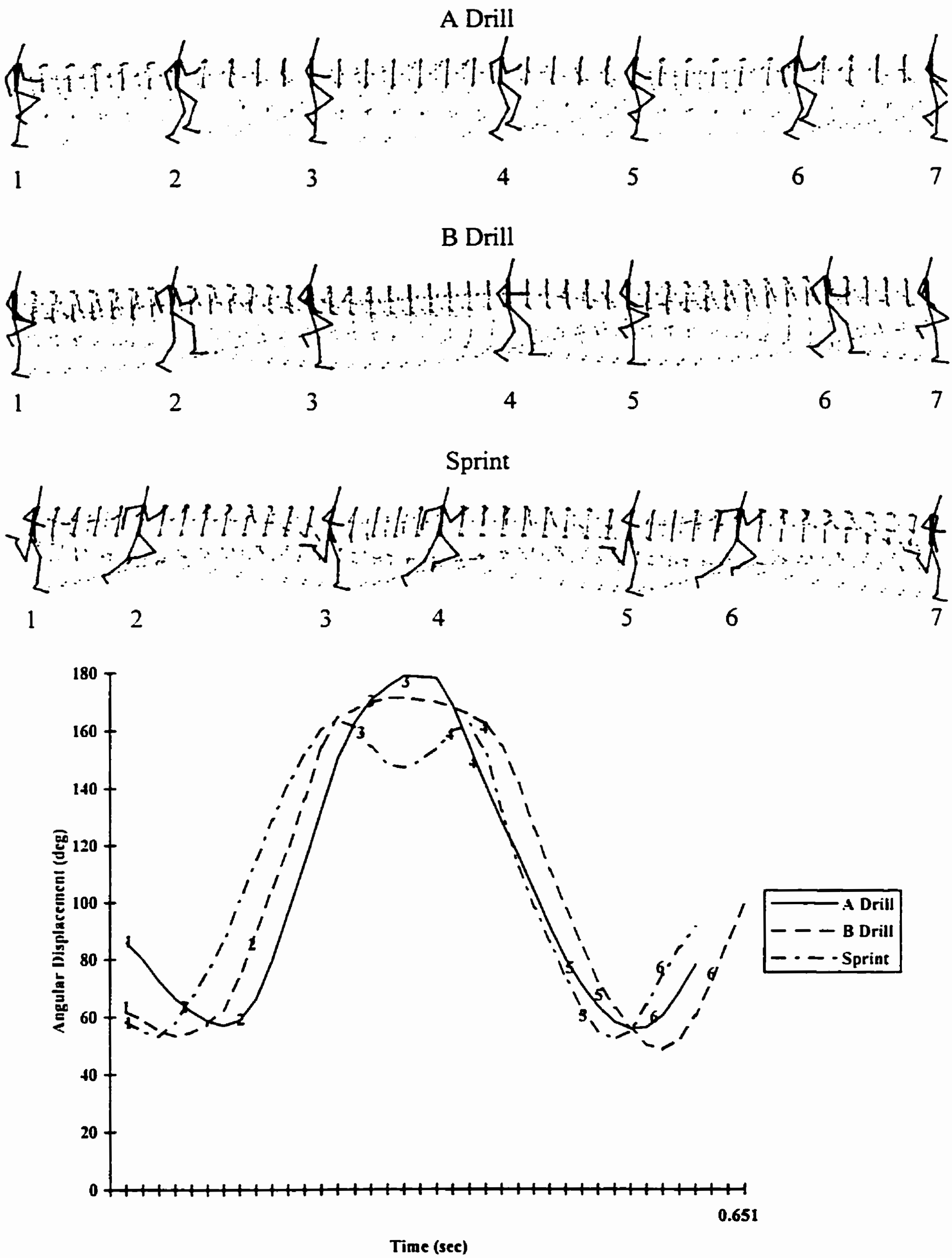


Figure 3. Left knee angular displacement/time curves for three steps during sprinting, A drill and B drill. 1 = right touchdown, 2 = right toe-off, 3 = left touchdown, 4 = left toe-off, 5 = right touchdown, 6 = right toe-off.

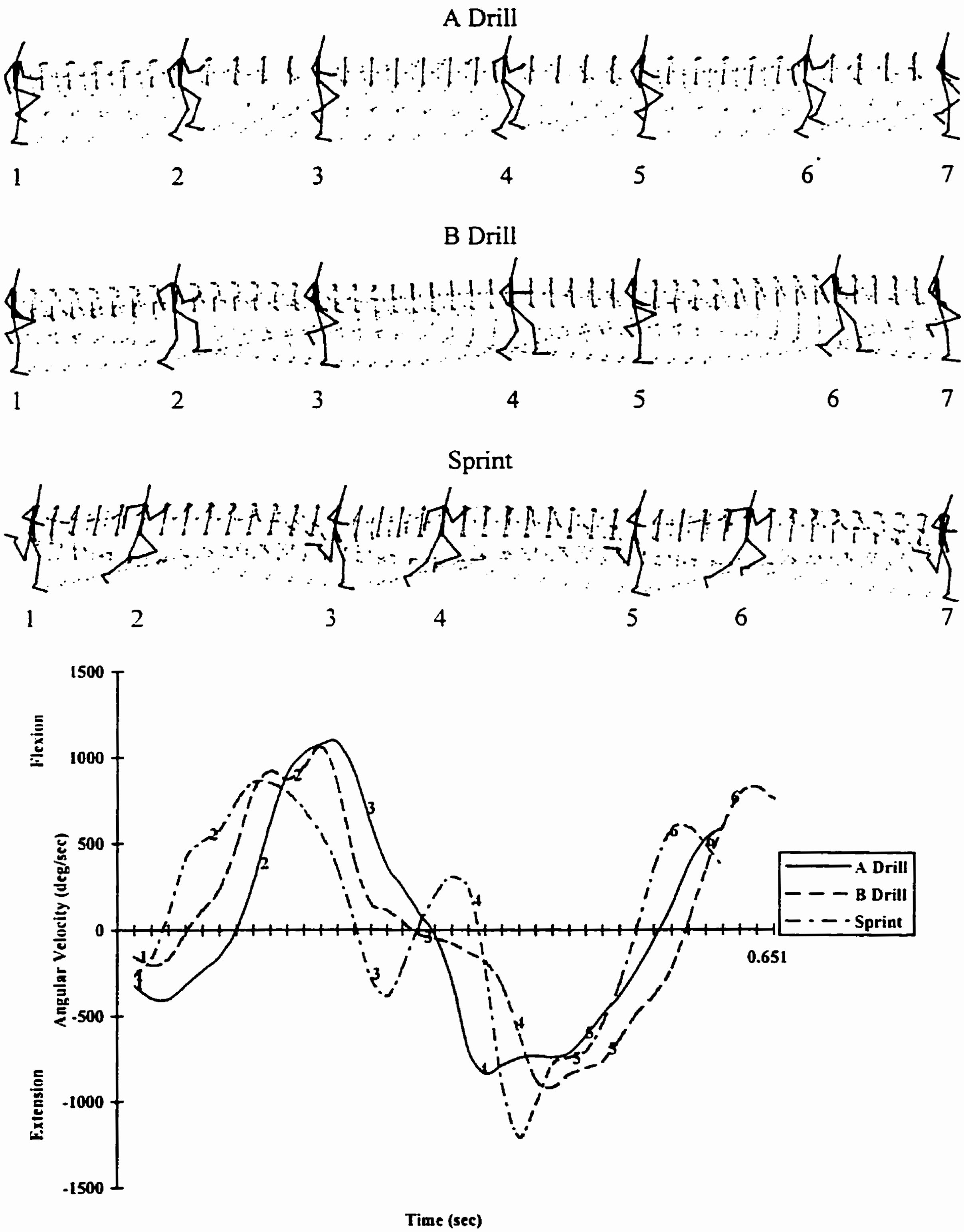


Figure 4. Left knee angular velocity/time curves for three steps during sprinting, A drill and B drill.
1 = right touchdown, 2 = right toe-off, 3 = left touchdown, 4 = left toe-off, 5 = right touchdown, 6 = right toe-off.

same support flexion as in sprinting. Other differences were seen at left toe-off (4), where the left knee during the B drill was flexing at the instant of toe-off.

The A drill showed similar patterns to the B drill and sprinting, but there were differences in the timing of events. Peak knee extension angular velocity was seen at right toe-off (6) in the A drill, as in sprinting and the B drill. At left touchdown (3), the left knee extension angular velocity was decreasing, where at left toe-off (4), the knee flexion angular velocity was approaching an initial peak. This was also seen in the B drill, but in sprinting, the knee was extending at the time of left toe-off.

The results of this pilot study indicate that there are some similarities among sprinting, the A drill, and the B drill, but there are also some distinct differences. Similarities were seen in the vertical displacement and velocity, and in the support and non-support times. Differences were seen, however, in the ranges of motion and angular velocities. Ranges of motion both increased (hip flexion, knee, elbow) and decreased (shoulder, pelvic rotation, ankle) during the drills. Generally, angular velocities were found to decrease when performing the drills. Also, the sequence of events were also found to vary among the three skills, particularly at the hip and knee. This pilot study also indicated that individual differences exist in the kinematics of sprinting and both drills, with subjects showing peak range of motion or peak angular velocity values in different positions in each of the skills.

APPENDIX D

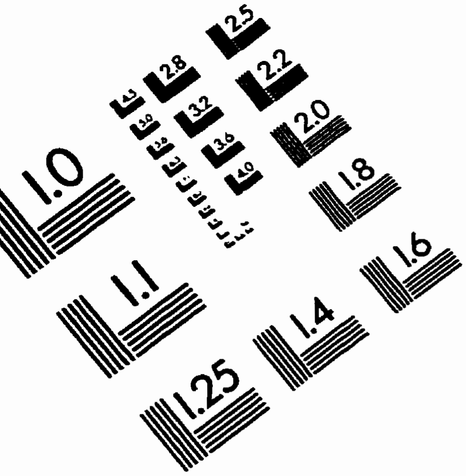
INDIVIDUAL SUBJECT DATA FOR EACH VARIABLE FOR THE A DRILL, B DRILL, AND SPRINTING

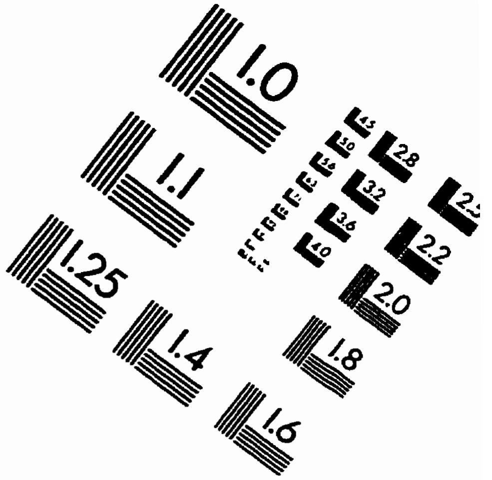
A DRILL STATS	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6	SUBJECT 7	SUBJECT 8
Vertical Displacement (m)	0.03	0.02	0.03	0.02	0.03	0.03	0.04	0.04
Vertical Velocity (m/sec)	0.38	0.20	0.27	0.27	0.24	0.39	0.35	0.28
Step Frequency (steps/sec)	5.14	4.86	4.86	4.62	5.29	3.87	5.00	5.00
Support Time (sec)	0.11	0.14	0.11	0.09	0.10	0.11	0.12	0.11
Non-support Time (sec)	0.08	0.06	0.09	0.11	0.09	0.14	0.10	0.11
Shoulder ROM (deg)	84	65	58	94	99	87	71	89
Shoulder Flexion AV (deg/sec)	501	448	693	563	507	423	517	491
Shoulder Extension AV(deg/sec)	512	594	747	1056	692	539	456	501
Elbow ROM (deg)	51	46	70	80	87	101	79	83
Elbow Flexion AV (deg/sec)	784	847	1034	1593	1133	909	1025	1007
Elbow Extension AV (deg/sec)	541	549	602	949	754	660	767	725
Trunk Flexion (deg)	4	5	5	6	5	6	6	5
Trunk Rotation (deg)	15	10	12	11	8	10	24	10
Pelvic Rotation (deg)	12	14	11	16	11	13	16	21
Hip Flexion (deg)	93	89	85	83	91	84	73	67
Hip Flexion AV (deg/sec)	583	664	660	721	860	712	489	487
Hip Extension AV (deg/sec)	512	429	480	444	594	546	577	617
Knee ROM (deg)	103	96	126	126	94	124	120	125
Knee Flexion AV (deg/sec)	910	938	1122	1255	964	930	978	1035
Knee Extension AV (deg/sec)	777	662	948	751	667	720	833	720
Ankle ROM (deg)	26	25	35	28	16	32	29	28
Plantarflexion AV (deg/sec)	257	352	400	339	331	357	537	571
Dorsiflexion AV (deg/sec)	270	350	432	331	237	393	641	601

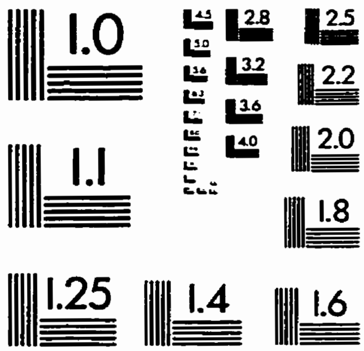
B DRILL STATS	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6	SUBJECT 7	SUBJECT 8
Vertical Displacement (m)	0.05	0.03	0.04	0.05	0.04	0.05	0.04	0.05
Vertical Velocity (m/sec)	0.47	0.40	0.41	0.45	0.45	0.58	0.18	0.39
Step Frequency (steps/sec)	3.82	4.09	4.09	3.67	4.28	3.46	4.61	4.61
Support Time (sec)	0.16	0.13	0.11	0.12	0.10	0.12	0.12	0.12
Non-support Time (sec)	0.10	0.11	0.13	0.14	0.13	0.16	0.12	0.12
Shoulder ROM (deg)	67	71	65	94	103	81	81	59
Shoulder Flexion AV (deg/sec)	405	361	614	421	537	377	419	446
Shoulder Extension AV(deg/sec)	386	395	586	434	713	439	436	441
Elbow ROM (deg)	40	28	74	54	85	105	85	60
Elbow Flexion AV (deg/sec)	395	379	586	556	1136	940	839	665
Elbow Extension AV (deg/sec)	404	330	849	383	777	660	698	865
Trunk Flexion (deg)	5	5	5	6	6	7	6	5
Trunk Rotation (deg)	11	12	10	12	7	10	22	9
Pelvic Rotation (deg)	17	18	18	20	10	15	23	16
Hip Flexion (deg)	87	91	84	79	89	82	75	70
Hip Flexion AV (deg/sec)	519	763	636	675	861	710	553	590
Hip Extension AV (deg/sec)	677	512	697	550	517	572	578	573
Knee ROM (deg)	131	112	132	140	115	123	120	125
Knee Flexion AV (deg/sec)	1013	1094	1123	1233	1195	1103	1143	1000
Knee Extension AV (deg/sec)	917	735	1072	1006	839	813	738	801
Ankle ROM (deg)	43	38	39	46	36	29	33	29
Plantarflexion AV (deg/sec)	384	244	434	479	392	446	605	577
Dorsiflexion AV (deg/sec)	361	395	527	405	414	492	680	428

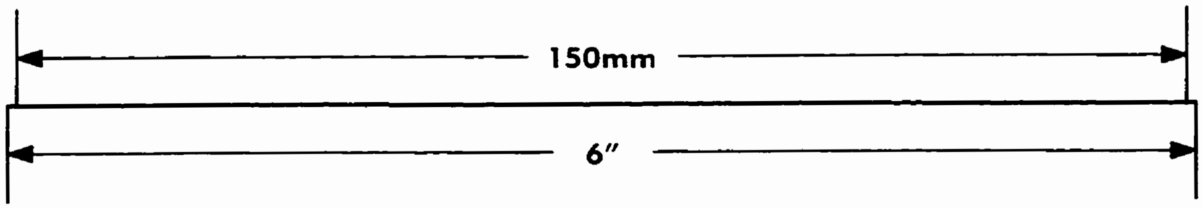
SPRINT STATS	SUBJECT 1	SUBJECT 2	SUBJECT 3	SUBJECT 4	SUBJECT 5	SUBJECT 6	SUBJECT 7	SUBJECT 8
Vertical Displacement (m)	0.06	0.05	0.07	0.04	0.06	0.06	0.06	0.07
Vertical Velocity (m/sec)	0.54	0.50	0.63	0.50	0.57	0.70	0.62	0.58
Step Frequency (steps/sec)	4.44	4.44	4.19	4.29	4.61	4.50	5.29	5.00
Support Time (sec)	0.10	0.08	0.07	0.08	0.09	0.08	0.10	0.09
Non-support Time (sec)	0.10	0.13	0.15	0.13	0.13	0.13	0.12	0.13
Shoulder ROM (deg)	119	109	104	108	111	98	97	89
Shoulder Flexion AV (deg/sec)	665	506	622	601	627	463	724	456
Shoulder Extension AV(deg/sec)	505	486	598	620	717	621	686	483
Elbow ROM (deg)	52	67	85	89	57	75	67	68
Elbow Flexion AV (deg/sec)	945	835	1078	1307	1167	941	801	846
Elbow Extension AV (deg/sec)	571	595	571	1053	826	639	1020	885
Trunk Flexion (deg)	7	7	5	7	7	7	7	6
Trunk Rotation (deg)	20	12	20	15	13	21	28	26
Pelvic Rotation (deg)	28	24	22	22	19	27	27	31
Hip Flexion (deg)	54	58	52	61	58	62	54	59
Hip Flexion AV (deg/sec)	668	610	639	506	584	508	1028	903
Hip Extension AV (deg/sec)	656	605	763	513	762	626	707	587
Knee ROM (deg)	123	124	117	126	121	121	118	124
Knee Flexion AV (deg/sec)	1152	1123	1072	1052	1242	1112	1117	1088
Knee Extension AV (deg/sec)	1108	1023	1053	1221	1111	1130	1058	1012
Ankle ROM (deg)	43	64	57	41	40	51	46	47
Plantarflexion AV (deg/sec)	559	845	1246	402	700	780	1053	736
Dorsiflexion AV (deg/sec)	793	937	1013	598	724	477	835	1059

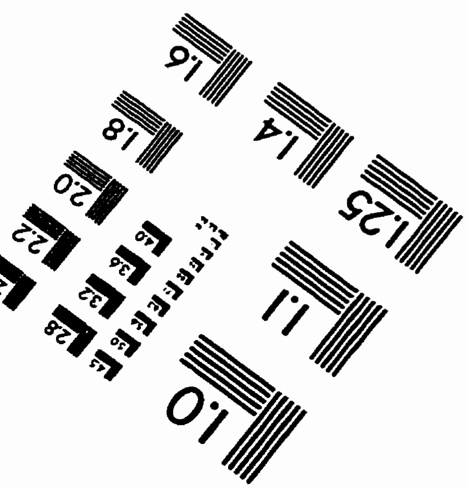
IMAGE EVALUATION TEST TARGET (QA-3)

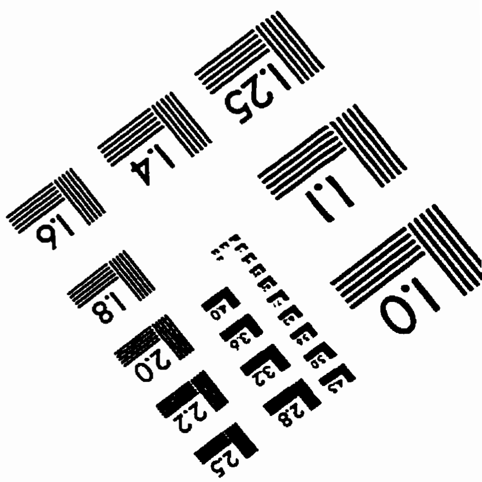












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