MONTANA STATE UNIVERSITY

A biomechanical description of the Taekwondo turning hook kick
by Scot Gerald Wohlin

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
Montana State University
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Abstract:
The beginning of a comprehensive biomechanical description of the turning hook kick in Taekwondo was initiated. The turning hook kick as performed by three subjects was studied. These subjects represented three different skill levels. Two of the subjects were national-level competitors and were first and third degree black belts. The other subject was an Olympic competitor and a fourth degree black belt. These subjects were filmed from two different camera angles, above and to the left side of the subjects, as they performed the kick. The camera above the subjects was operated at 150 fps with an exposure time of 1/375 second. The camera to the left side of the subjects was operated at 64 fps. Estar based Ektachrome film (400 ASA) was used in both cameras. The film records of the kicks were digitized and analyzed using a computer program that was designed for two-dimensional motion.

The sequence of movement between the thigh and foot of the kicking leg resembled that of the forward kicking motions described by Plagenhoef (1971), Roberts and Metcalfe (1968), Zemicke and Roberts (1978), and Phillips, Roberts and Huang (1983). The peak acceleration of the foot toward the target occurred simultaneously with the peak deceleration of the thigh and the beginning of knee flexion. The first section of the kick, stepping forward onto the support foot, required 36 to 44 percent of the total movement time. The third section of the kick, bringing the kicking foot from the floor to the target, required the greatest amount of the total movement time, from 48 to 53 percent The researcher suggested that studying ways of reducing first and third section times might greatly enhance the performance of the turning hook kick. Prior to foot/target contact, the thigh was moving slowly and knee flexion was responsible for continuing the motion of the foot to the target. However, peak rates of knee flexion occurred after the foot/target contact Specific exercises were suggested to develop the application of torque on the floor, turning the body as a unit, and maintaining the body in a high rotational inertia configuration while the torque is being applied to the floor be employed to train individuals in the turning hook kick. The researcher also suggested that exercises be developed to increase the rate of knee flexion after extension.

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ii

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ACKNOWLEDGEMENTS

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES--<u>Continued</u>

LIST OF FIGURES--Continued

ABSTRACT

The beginning of a comprehensive biomechanical description of the turning hook kick in Taekwondo was initiated. The turning hook kick as performed by three subjects was studied. These subjects represented three different skill levels. Two of the subjects were national-level competitors and were first and third degree black belts. The other subject was an Olympic competitor and a fourth degree black belt. These subjects were filmed from two different camera angles, above and to the left side of the subjects, as they performed the kick. The camera above the subjects was operated at 150 fps with an exposure time of 1/375 second. The camera to the left side of the subjects was operated at 64 fps. Estar based Ektachrome film (400 ASA) was used in both cameras. The film records of the kicks were digitized and analyzed using a computer program that was designed for two-dimensional motion.

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CHAPTER 1

INTRODUCTION

The spinning or turning hook kick used in Taekwondo is a complex skill. The performer of the turning hook kick must coordinate a rapid rotation of the body with a quick extension of the hip and knee of the kicking leg. One might suspect that maintaining balance and control would be very difficult as the body spins and as the kicking leg is suddenly extended. The rotational inertia of the body changes dramatically during the turn and the possibility of losing one's equilibrium is large. To compound the difficulty of performing the turning hook kick, the kicker must use it in a combative situation requiring speed and decisiveness. During part of the kick, the performer's back is turned toward the opponent and the target is out of view. The opponent may take advantage of this vulnerable position by pushing or hitting the exposed back of the kicker. From the above observations, one may surmise that the turning hook kick is a very physically and mentally demanding sport skill.

The turning hook kick usually begins with the kicker facing the opponent (Figure 1). The target is often the head of the opponent. The kicker steps toward the opponent with the support leg and turns this leg, foot, and the body so that the heel of the support leg foot faces the opponent; this event will be
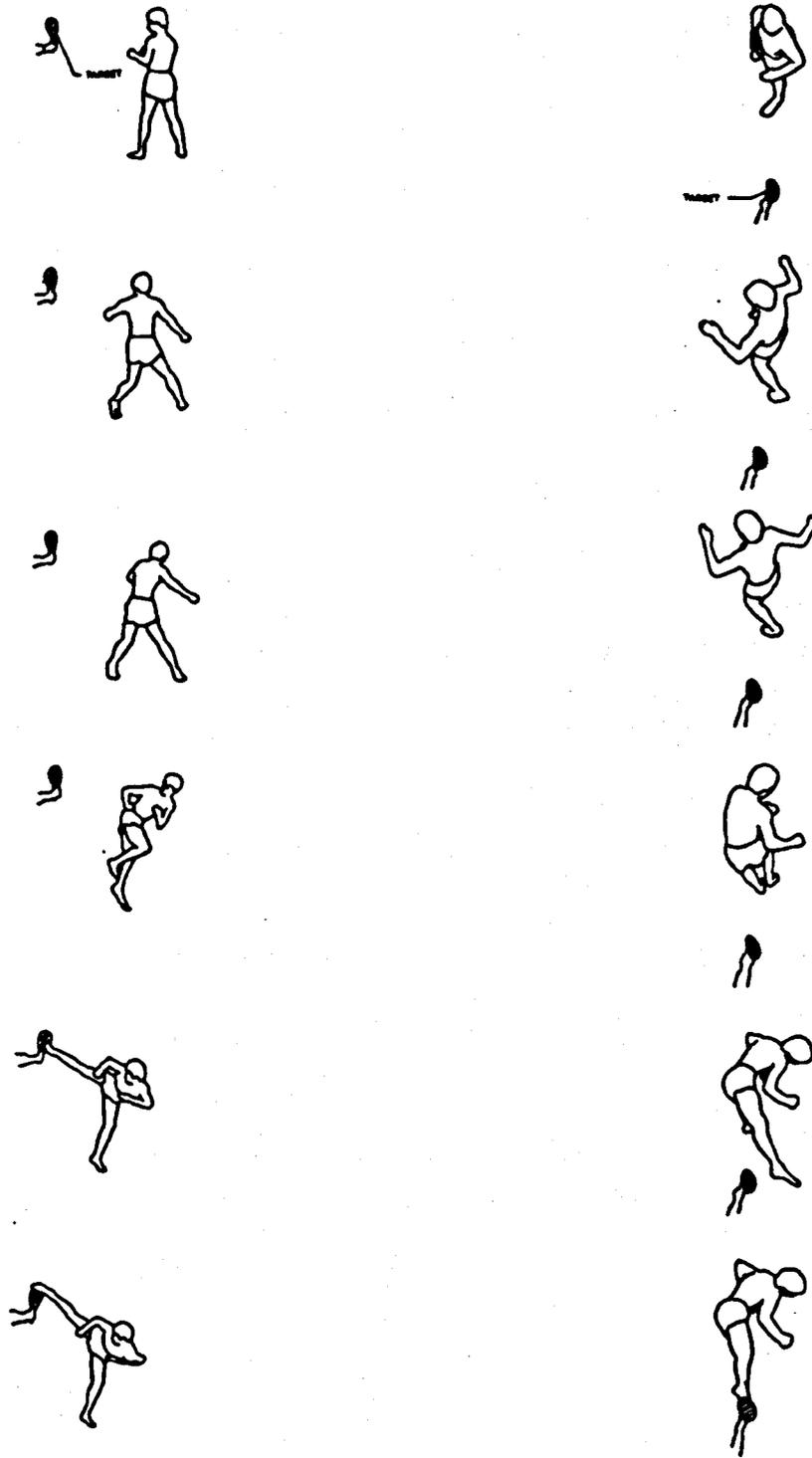
Figure 1. The turning hook kick from initial stance to foot/target contact: Side and top views.

referred to as *support foot plant.* The kicker's body continues this initial rotation, turning his or her back toward the opponent. The kicking foot leaves the ground, an event that will be referred to as *kicking foot liftoff.* The kicking leg is brought in toward the body by hip and knee flexion. As body rotation continues, the trunk moves toward the ground and the kicking leg is raised upward toward the target. The support leg remains in a vertical position throughout the kick. The kicking leg rapidly extends. The body is still turning when the kicking foot strikes the target. This kick is different than the typical kicking motion in which the hip flexes and the knee extends, as in soccer and football. In the turning hook kick motion, the leg is driven toward the target backwards so that the heel, ball, or sole of the foot strikes the target. The kicking knee flexes and the leg begins to descend as the trunk begins to rise to the vertical; the kicker stands up and prepares for the next move.

The kicker is hopeful that the opponent was surprised by the turning hook kick and did not react quickly enough to take advantage of the temporarily vulnerable positioning through which the kicker moved. Warwick (1987) stated that if the kicker scores with this technique, then he or she scores in a resounding way. If the kick is improperly executed, then the kicker may experience total failure.

4

Purpose of the Study

From precursory observations of subjects performing the turning hook kick, several differences in technique appeared to exist. One of the subjects appeared to flex the knee and hip more than the other two. One of the subjects appeared to keep the kicking leg relatively straight. One of the subjects appeared to lower the trunk further than the other two. The subjects were of differing body types: two male, one slim and the other heavily muscled; and one female, tall and well-muscled. One might presume that a greater amount of hip and knee flexion would reduce the rotational inertia of the body, and therefore increase the rate of turning, which might contribute to a shorter time to complete the kick. A slim person would have less inertia in the limbs to accelerate, but a muscular person may have more power available for acceleration. One might also wonder whether the mechanics of the turning hook kick, a backward kick, are similar to those observed in typical forward kicking motions. Thus, several topics appeared to deserve consideration. The angular kinematics and kinetics of the body should be investigated. The rotational movements of the head, shoulders, and hips with respect to one another should be studied. The sequence of the kinematics of the thigh and leg should also be studied. Finally, the kinematics of the foot as it approached the target must be considered. This study investigated these topics.

Definition of Terms

(1) <u>Force arm</u>: A force arm is the perpendicular distance from the line of force to the axis of rotation (Kreighbaum & Barthels, 1985).

(2) <u>Rotational inertia</u>: The rotational inertia is a property of a body to resist changes in its angular momentum (Kreighbaum & Barthels, 1985).

(3) <u>Support leg</u>: For the purpose of this study, the support leg will refer to the leg on which the kicker stands while executing a kick with the kicking leg.

(4) <u>Torque</u>: Torque is the result of a force acting on a body in which the line of action does not pass through the axis of rotation (Kreighbaum & Barthels, 1985).

Importance of the Study

Taekwondo has now been made an Olympic demonstration sport, and as such is internationally recognized. Biomechanical studies of Taekwondo could help the United States be more competitive in this event. The turning hook kick is just one of the techniques that characterize Taekwondo. The turning hook kick was chosen for study because of the difficulty in executing this kick and the effectiveness of the kick when successfully performed. Because the kicker turns the back toward the opponent, visual information about the actions of the opponent is lost during this period of time, but if the kicker hits the opponent with the turning hook kick, the result is usually a knockdown. The results of this

study may assist the coach in teaching this powerful, and potentially hazardous, technique.

Limitations of the Study

The test conditions may not have included important variables that affect actual competition. The subjects kicked a stationary paddle. In competition, the target is a moving opponent. Reaction time was not investigated in this study; thus, no response to a visual stimulus, as would occur in actual competition, was included. Also, the psychological pressure and motivation that would occur during a match was not replicated.

The warmup period was to have been 15 minutes for each subject. The subjects practiced for an hour immediately prior to the filming session. Fifteen minutes before the proposed start of the filming, all subjects warmed up under the direction of one of the subjects. Due to a problem with the electrical system in the building, filming was delayed for approximately 30 minutes. The subjects stated that they were beginning to feel cold and so continued to exercise. The cold and duration of the warmup period may have fatigued the subjects. The fact of becoming somewhat chilled while waiting for the filming may have affected the movement of the subjects.

After the first set of kicks for subject JW, the subject stated that the kicks did not "feel right." Therefore, following the kicks of the other subjects, JW was filmed for an additional set of kicks. JW did not express a better feeling about

the second set of kicks. The other subjects did not express any displeasure with their performances.

Perspective error exists when viewing the world with the human eye or with the camera. When viewing the world through a lens, parallel lines appear to converge in the distance. An object that travels toward the viewer in a straight line will appear to have some displacement away from the optical axis of the observer unless the object happens to be travelling along the optical axis. In the latter case the more peripheral points of the object will appear to move away from the optical axis and the object will appear to increase in size. In the present study the effects of perspective error were not taken into account except for the velocity of the foot at contact with the target. Finally, due to the small number of subjects (three) who participated in the study, the results could not be explicitly generalized.

Delimitations of the Study

The following delimitations were placed on this study:

(1)   Only three subjects participated in the study.

(2)   The subjects were all members of the same Bozeman area team.

(3)   All subjects were national-level competitors.

(4)   Only right leg kicks were used.

(5) The subjects were requested to strike the target with the metatarsal-phalangeal joint. In competition the kicker may strike with either the heel or metatarsal-phalangeal joint.

(6) Only cinematographical methods were employed.

(7) Only the turning hook kick was investigated.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The review of related literature is divided into three parts: studies of Taekwondo and combative sports that involve striking movements, studies of unrestrained limb movements such as occur in the recovery phase of running and in kicking, and studies of activities that involve twist of the body as would occur in gymnastics and dance.

Taekwondo and Karate

Steiner (1987) investigated two variations of the turning hook kick. In one variation of the kick, the trunk of the body was maintained in a relatively vertical position. In the other variation of the kick, the trunk was lowered as the kicking foot moved upward to strike the target. Steiner compared the linear velocity of the metatarsal-phalangeal joint of the kicking foot at contact with the target for the two styles of the kick. Similar velocities of 15 meters per second were found for both variations. One subject performed 10 kicks for each of the two variations. The target was a hand-held paddle suspended at the head height of the performer. The frame rate was 64 fps.

Joon, Guk, Jong, and Kyu (1987) produced a fairly comprehensive overview of nine Taekwondo kicks. Movement and reaction times and the linear velocity of the foot at impact were recorded. The subjects were filmed simultaneously from the left and right sides and from the front. The subjects were four members of the national Korean Taekwondo team. Two 16mm cameras and one video camera were used. The shutter speed on the camera was 1/200 second. No frame rate was reported. Each sample was started at the discharge of a flashbulb. Movement time was defined as the time from kicking foot liftoff to contact with the target. Reaction time was defined as the time from the flash to kicking foot liftoff. For the subjects performing the spin back kick to the face of an opponent, the researchers found an average total time, reaction time plus movement time of 0.799 seconds, and kicking foot speed of 14 meters per second. For the spinning hook kick to the abdomen of the body, the researchers reported a total time of 1.053 seconds; no speed for the kicking foot at impact was given.

The velocity of the foot or hand relative to the target is important but is not the only variable that must be considered. Feld, McNair, and Wilk (1979) filmed themselves performing seven different Karate techniques. Filming was done stroboscopically at a flash rate of 120 flashes per second. The authors reported speeds of 5.7 to 0.8 meters per second for a front forward punch, 10 to 14 meters per second for the downward hammerfist, and 9.9 to 14.4 meters per second for the front kick. The researchers also filmed two breaking techniques, the downward hammerfist and the downward palm heel. The frame rate was 1/1000

second; no shutter speed was reported. Dots placed on the second and fifth metacarpals revealed the deformation of the hand during impact. Due to hand deformation, the collision between the hand and the target could not be considered an inelastic collision. An inelastic collision would require less energy to break the target than an elastic collision because no energy would be used to deform the hand. From the inelastic collision model, the authors calculated an energy requirement of 6.4 joules to break wood and 8.9 joules to break concrete. When the authors used an elastic collision model of the hand and block, they obtained values of 12.3 joules to break wood and 37.1 joules to break concrete. These last energy levels correspond to hand speeds of 6.1 meters per second and 10.6 meters per second; the hand would have to be moving at these speeds relative to the target in order to carry enough energy to perform the breaks. The authors stated that such findings as those above support their experiences; beginning practitioners of Karate may be capable of achieving hand speeds of 6.1 meters per second in order to break wood, but beginners are rarely able to generate hand speeds of 10.6 meters per second needed to break concrete.

Ahn (1985) analyzed the front snap kick and the front thrust kick. Ahn filmed one subject performing both kicks. A frame rate of 100 fps was used. No shutter speed was given. Ahn found that during the first part of the kicks the resultant velocities of the centers of gravity of the thigh and leg increased together. During the later part of the kicks, the thigh slowed as the leg velocity increased. Ahn characterized the first portion of the kick as simultaneous and the

motion of the second part of the kick as sequential. The kinematic data from Ahn's study were used to solve torque equations for the hip and knee. The hip and knee torques remained positive throughout the kicks. The positive torques indicated flexion at the hip and extension at the knee. Thus, Ahn conjectured that the knee extensors were undergoing eccentric contraction during the first part of the kicks.

Unrestrained Limb Movements

Several investigators have studied the kinetics and kinematics of the lower extremity segments in unrestrained movements such as kicking and the recovery phase of running. Roberts and Metcalfe (1968) filmed subjects performing soccer kicks and football placekicks and punts. Three simultaneous camera views were taken. The frame rate was 64 fps and the shutter speed was 1/400 second. These researchers noted that the thigh decelerates rapidly as knee extension begins and that the angular velocity of knee extension was the most important variable affecting foot speed. Maximum foot speeds just prior to contact were 18 to 24 meters per second for soccer kicks and football punts respectively. The researchers questioned whether or not the rapid slowing of the thigh contributed to the kicking foot speed. They stated that a reasonable explanation of the mechanics observed in kicking was that the knee extensors were actively stretched during the first part of the kick and that the stretch reflex of these muscles then accelerated the leg when the thigh slowed.

In the studies by Ahn (1985) and Roberts and Metcalfe (1968), the thigh slowed as the lower leg accelerated to contact. This movement pattern has puzzled investigators. Should the thigh slow and thereby aid the leg in accelerating or should the thigh continue to drive throughout the kicking motion? Plagenhoef (1971) attempted to explain these movements from a relative motion perspective. Plagenhoef stated that in activities such as kicking, the proximal segment should accelerate to increase the velocity of the limb as a whole and then decelerate to assist the next distal segment in acceleration. This movement pattern could be used to determine the proficiency of certain sport skills. The better performers should exhibit the proper sequence of proximal segment acceleration and deceleration and acceleration of the next distal segment. Evidence for this theory was presented in Plagenhoef's study of Hubert Vogelsinger kicking a soccer ball and a football. The author filmed the subject performing kicks, but did not disclose the frame rate or the shutter speed. Plagenhoef noted that in the kicks in which the thigh had the greatest deceleration, the knee had the greatest knee extension rate. Also, the kicks with the greater foot velocities were not necessarily the kicks that resulted in the greatest ball velocities.

With regard to the last observation, Plagenhoef stated that the part of the foot that contacted the ball was more important than the velocity of the foot at contact. The deformation of the shoe and foot reduced the energy and momentum transferred to the ball. As further evidence of the effect of the deformation

of the foot at impact, Plagenhoef cited a punter who consistently kicked a football 10 yards further with a bare foot than while wearing a shoe.

Plagenhoef wrote that deceleration of the thigh would increase the velocity of the leg. Putnam (1983) had a different explanation for the relationship between thigh motion and leg motion. Putnam presented evidence that the deceleration of the thigh occurred due to the action of the leg acceleration on the thigh and not the deceleration of the thigh contributing to the acceleration of the leg. Eighteen subjects were filmed as they punted soccer balls. The frame rate was 300 fps. The kinematic data were used to calculate the torques about the hip and knee. The torque equations were written from a relative motion perspective and hence contained motion dependent forces. One trial was chosen for presentation in the paper and was said to be representative of the sample. Putnam found that at the point at which the thigh began to negatively accelerate, the motion dependent torque on the leg due to the velocity of the thigh began to decrease, while the torque on the lower leg due to the acceleration of the thigh became negative; positive hip and knee angular displacement was in direction of hip flexion and knee extension. The torque acting on the thigh due to the velocity and acceleration of the lower leg was negative throughout the kick. The muscular hip torque was relatively large and positive throughout the kick. Putnam concluded that the deceleration of the thigh hampered the acceleration of the lower leg and that this deceleration occurred due to the extension of the lower leg.

Phillips, Roberts, and Huang (1983) also conducted a computer simulation study of intersegmental reactions during unrestrained limb movements. Instead of using a kicking motion, the researchers used the recovery phase of running. An elite middle-distance runner was filmed and the calculated kinetic record of the hip joint of this runner was used to "move" the thigh of a two-segment model. The knee joint musculature was left out of this model in order to investigate to what extent intersegmental mechanics accounted for the observed swing phase motion of the thigh and leg. Muscular knee movements were added to the model at certain points in order to make it more closely resemble the observed motion. The researchers found that a small knee extensor movement was required in the first part of swing phase in order to prevent the leg from flexing beyond anatomical limits. During the middle of swing phase, where the knee begins to extend, the researchers found that knee extension could be accomplished by slowing the flexion of the thigh at the hip. Knee extension at the end of swing occurred without the aid of knee extensor torque. The thigh was slowing toward zero angular velocity during this phase. Knee extension continued past anatomical limits and, thus, a small flexor torque was required in the model. From the results of their study, the researchers concluded that intersegmental mechanical reactions could account for much of the unrestrained limb motions in human movements; deceleration of the proximal segment could be used to accelerate the next distal segment.

Zernicke and Roberts (1978) calculated the forces and torques acting on the thigh, leg, and foot for five subjects kicking a soccer ball at three different resultant ball speeds (15.2, 21.3, and 27.4 meters per second). The subjects were filmed from the side. The frame rate was 300 fps and the shutter speed was 0.00055 second. The researchers found that forces and torques increased more at the proximal joint than at the distal joint of the same body segment. The hip torque ranged from 118.5 Nm for the slow kick to 273.5 Nm for the fast kick. The knee joint torque ranged from 52.2 Nm to 122 Nm. The ankle torque ranged from 9.03 Nm to 23.1 Nm. Maximum hip torque occurred at the beginning of hip flexion, 30 to 40 milliseconds after the foot left the ground. Maximum knee torque occurred just prior to knee extension. For fast kicks, a slight negative torque was observed in both joints just prior to contact.

The research results of Zernicke and Roberts (1978) seem to support the ideas of Plagenhoef (1971). Plagenhoef stated that due to the action of one limb segment on the adjoining limb segment, the muscular torque at the proximal joint could be made greater and the torque at the distal joint reduced for the same angular velocity at the distal end of the distal segment. The implication of this idea was that the stronger, proximal joint muscles could be used to exert more force so that the weaker, more distal joint muscles would not be overly stressed.

Body Rotation in Movement Activities

During the pushoff phase of the turning hook kick, the kicker is generating the angular momentum necessary for execution of the kick. The production of angular momentum of the body in the turning hook kick is similar to that of turns in dance. Laws (1984) has applied mechanics to dance. A dancer develops angular momentum by applying a torque to the floor. The torque is created by the force of the feet acting in opposite directions and separated from each other by some distance. The closer the feet are together, the smaller the torque arm. Thus, turns that are begun with a relatively wider separation are easier than turns begun with the feet closer together because of the mechanical advantage of the larger torque arm in the first case. In order to create the same angular momentum in the second case where the feet are closer together, the force exerted by the feet on the floor would have to be greater than for the first case. Turns may also be accomplished by exerting a torque on the floor with one foot. In this case, Laws envisioned the foot applying two equal and opposite forces, one at the heel and the other at the toes. The torque arm for one foot on the floor can be no greater than the length of that foot and the generated torque would be less than that produced when both feet are used.

Laws (1978) quantified the angular momentum of a dancer performing three different types of pirouettes. The experimental apparatus consisted of a large inertia platform that was free to rotate (Laws considered the friction to be

negligible), an oscilloscope to measure the angular momentum of the platform, a camera operated at 63 fps, an undisclosed shutter speed, and an electrical contact point at the pushoff foot to synchronize the film record with the oscilloscope record. One subject, a dancer with the New York City Ballet, performed the turns on the platform. The angular momentum of the platform was assumed to be equal to the angular momentum of the dancer. Laws found that the angular momentum increased from zero to a fairly constant value once the dancer's support heel left the platform. Laws explained the plateau of the angular momentum as the end of the subject's ability to exert torque on the floor. Without the ability to exert torque on the floor, the angular momentum of the dancer remained constant.

CHAPTER 3

METHODOLOGY

The data collection and analysis techniques that were used are described in four sections. These sections are the selection and preparation of the subjects, filming protocol, data collection, and data retrieval and analysis.

Selection and Preparation of the Subjects

Three subjects were selected to participate in this study. They represented slightly different skill levels. Two subjects were national-level competitors in Taekwondo and were first and third degree black belts respectively. One subject was an Olympic competitor in Taekwondo and was a fourth degree black belt. All subjects were able to perform the turning hook kick in competition.

The subjects completed consent forms before the data collection began (Appendix A). Each was dressed in shorts (men) or tee-shirt and shorts (women). Sixteen body points on each subject were marked with light reflective patches. These points were located at the fifth metatarsal-phalangeal, lateral and medial malleoli, lateral and medial epicondyles of the femur, greater trochanter, iliac crest superior to the greater trochanter, lateral and medial epicondyles of the humerus, and styloid processes on both sides of the body. The heights, weights, and

segmental lengths of the subjects were recorded (Appendix B). These segmental

lengths were the forearm, arm, trunk, pelvis, thigh, leg, and foot of the right side.

Protocol

Two high-speed 16mm motion picture cameras were used. A Photec IV was

positioned directly above the target at a height of 5.75 meters from the floor

(Figure 2). A Beaulieu was positioned opposite the subjects' kicking leg side (the

right side) at a distance of 9.25 meters with the optical axis parallel to the x-axis

and one meter in the positive y-direction. This camera was 1.5 meters above the
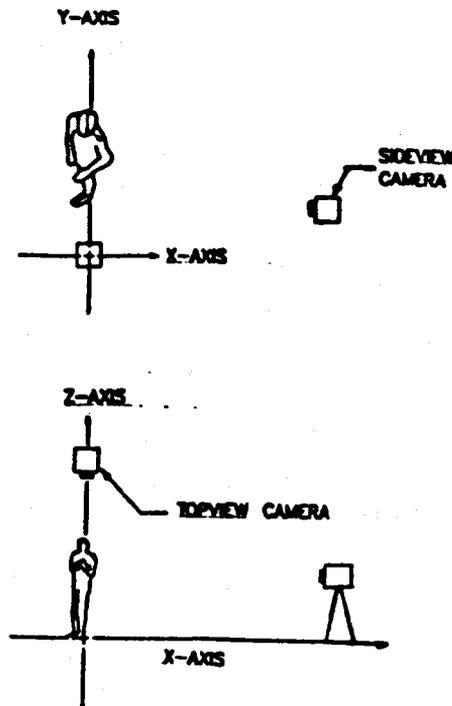
floor.

Figure 2. Filming schematic.

Two Palliate VIII lamps were placed approximately three meters from the subjects and two meters on either side of the target. Kodak Ektachrome estar based high speed motion picture film (ASA 400) was used. The frame rate of the Photec was 150 fps. The exposure time for the Photec was 1/375 second with a 2.5 shutter speed. An internal timing light was used to check the film rate of the Photec. This light marked the film at 1/100 second intervals. The Beaulieu was operated at 64 fps.

Data Collection

The subjects were required to warm up for 15 minutes before they were filmed. They had practiced for one hour before the filming session. The subjects were allowed to warm up in whatever fashion they chose. The warmup consisted of light jogging, stretching, and kicking, and was led by one of the subjects.

Before each subject was filmed, he or she was asked to perform seven preliminary turning hook kicks using the right leg. Subject JW felt adequately warmed up after six kicks and subjects SM and HT after five.

After the preliminary kicks, the subjects were instructed on the test procedures. The subjects were to assume whatever preparatory stance they desired. All subjects elected to use a left oblique stance; the left foot was turned at an angle with respect to the y-axis as were the shoulders and hips. The subjects were asked if they were ready to perform a kick. After an affirmative reply, the subject was asked to perform one kick "one count" after hearing the

signal "go" from one of the researchers. The cameras were started at the signal, "go." The subject performed a kick. This process was repeated six times for each subject. Subject JW expressed dissatisfaction with the first set of six kicks. Consequently, a second set of five kicks was filmed for subject JW. The target for the kicks was a hand-held kicking paddle of a type commonly used by the subjects. The target was held so that it was at the subject's head height.

Data Retrieval and Analysis

The film record of the kicks was digitized and kinematic data determined through the use of the motion analysis program *FILMDATA* on the Honeywell CP6 computer at Montana State University. For certain periods of the kick some of the body points were, inevitably, hidden from view. Therefore, the kicks were digitized in a piecewise fashion. The parts of the kick in which all of the body points were visible were digitized. In order to digitize those parts of the kicks in which some of the points were hidden, the positions of these points were esti- mated. In some instances the position of these points could be corroborated with the other camera angle. The variable that was affected by hidden points was the rotational inertia of the body at the end of the pushoff phase.

The kick with the greatest total (vector sum of x, y and z velocities) metatarsal-phalangeal velocity for each subject was selected for detailed study. The procedure of selecting a representative kick was also used by Putnam (1983) and Ahn (1985). Putnam selected the kick with the greatest velocity at the foot

and Ahn selected the "best" kick for each of two styles of kicks. The film records of one of the first six kicks for JW were of poor enough quality that they were not considered. The kick with the greatest total m-p velocity from the second set of five kicks for JW was selected to complete the set of kicks. The selected kick for JW also happened to be the kick with the greatest total velocity of all of JW's kicks.

Graphs of the kinematic data were made using the *CUECHART* and *TELLAGRAF* software on the VAX system at Montana State University. The graphs that were created were the linear velocities and accelerations of the centers-of-gravity of the thigh and leg and the trunk in the x- and y-directions as recorded by the overhead camera; the hip and knee angular displacements and velocities as recorded by the overhead camera were also graphed. The convention used in describing the hip and knee angles appears in Figure 3.
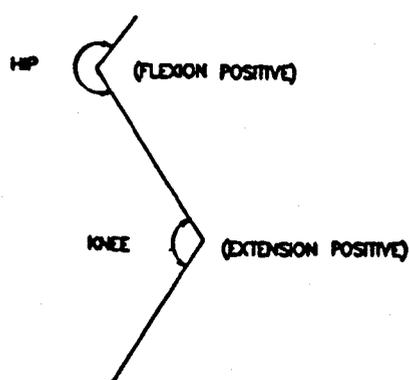
Figure 3. Hip and knee angles.

Hip extension decreased the hip angle and, thus, a negative angular velocity for the hip angle indicated that the hip was extending. Knee extension increased

the knee angle and, thus, a positive knee angular velocity indicated that the knee was extending. The x-, y-, and z-velocities of the metatarsal-phalangeal joint of the kicking foot were also graphed. The convention for the linear coordinates appears in Figure 4. A body point, the m-p for example, moving in the negative x- and y-directions and positive z-directions before foot/target contact was moving toward the target. In the graphs, time before foot/target contact was designated as negative, while time after foot/target contact was designated as positive. The instant of foot/target contact was designated as zero.
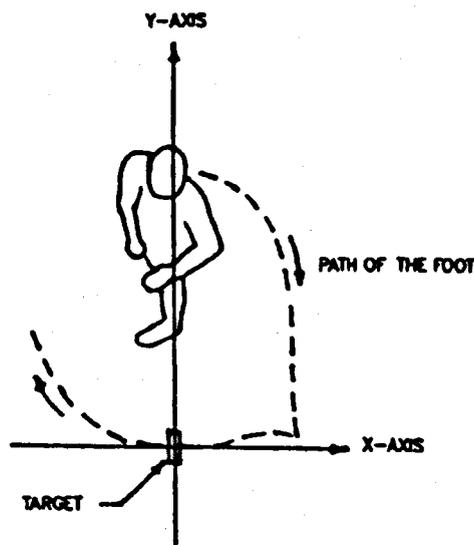
Figure 4. Coordinate system convention.

For convenience in analysis and presentation of the results, the researcher divided the turning hook kick into four major sections. The first section, the plant phase, was the first noticeable movement to the planting of the support foot. The second section, the pushoff phase, was from support foot plant to kicking foot liftoff. The third section of the kick was movement from kicking foot liftoff to

contact with the target. Two notable parts of the third section were the unweighting phase during which the support foot left the ground (i.e., a hop), and the extension of the kicking leg knee. The fourth section of the kick, the recovery phase, was movement from contact of the foot and target to resumption of the preparatory stance (Figure 1). The movement times for each of these sections of the kicks for the subjects were calculated from the film records. The movement times were averaged and standard deviations calculated. The first sections of some of the kicks were not adequately recorded and, thus, movement times for the first sections of these kicks were not available.

Tracings from the film records were made in order to help depict the rotation of the head, shoulders, and hips. When considering the relative angular positioning between the head, shoulders, and hips, the researcher assumed the head to be perpendicular to the shoulders when the sagittal plane of the head was perpendicular to the frontal plane of the shoulders.

The rotational inertia of the subjects about a vertical axis through the center-of-gravity of the body as recorded with the overhead camera was calculated in *FILMDATA*. *FILMDATA* was written to consider rotation in space. The subjects of this study had both feet in contact with the floor and their axes of rotation were not necessarily through the center-of-gravity of the body. Nevertheless, the resulting rotational inertia values provided an indication of how the subjects distributed the mass of their bodies. The rotational inertia values were normalized to the body mass of the respective subject.

The distance between the right and left metatarsal-phalangeal joints was measured in the film record made with the sideview camera. The resulting values were normalized with respect to the subject's leg length (greater trochanter to lateral malleolus).

Perspective Error

The motion of the foot at foot/target contact occurred above the plane in which the reference length was located. Therefore, a correction factor for the perspective error was needed. The reference length that was used in the top view was 0.508 meters long and was held parallel to the floor at a height of 0.93 meters. Cards were used to mark each trial. These cards were 0.1143 meters across. In the camera view of the trials, the cards appeared to be 0.099 meters across. Thus, a correction factor of 1.15 meters was needed to make the film measurement correspond with the actual measurement. If the perspective error was linear with respect to the z-direction distance, and if one considers zero error to be at 0.93 meters, then a correction equation may be used and this equation would be

$$[1 - (0.16/0.93)H] \text{ [Camera View Length]} = \text{Actual Length},$$

where $H = Z - 0.93$ meters.

The length correction would apply to any lengths that were perpendicular to the z-axis and near the y-axis. The correction factors for the metatarsal-phalangeal joint were calculated at foot/target contact. These correction factors

were used to adjust the x- and y-velocities of the metatarsal-phalangeal joint at foot/target contact. The sideview was not adjusted for perspective error because the reference length for the sideview was in the plane of the target.

CHAPTER 4

RESULTS

The results of this study are presented according to four topics. The topics are rotational kinetic considerations, the sequencing of the kinematics of the lower extremity, the velocities of the metatarsal-phalangeal joint, and the movement times for the sections of the kick. The anthropometric characteristics of the subjects appear in Table 1.

Table 1. Anthropometric characteristics of the subjects.

Characteristics	Subject		
	JW	SM	HT
General:			
Height (m)	1.85	1.92	1.75
Weight (kg)	78.6	99.1	68.2
Age (years)	31	30	25
Lengths (m)*:			
Biacromial	0.47	0.47	0.31
Arm	0.34	0.36	0.33
Forearm	0.27	0.27	0.27
Trunk	0.43	0.43	0.39
Pelvis	0.18	0.16	0.18
Thigh	0.40	0.46	0.44
Leg	0.45	0.48	0.40
Foot	0.15	0.15	0.14

*Measurements were taken on the right side of the body.

Rotational Kinetic Considerations

The rotational inertia of the body at the end of the pushoff phase for each subject appears in Table 2. SM had the largest absolute rotational inertia, while JW had the largest normalized rotational inertia and SM had the smallest.

Table 2. Rotational inertia of the body at the end of the pushoff phase.

| | Subject | | |
	JW	SM	HT
Absolute	7.060 kgm^2	7.690 kgm^2	5.610 kgm^2
Normalized	0.090 m^2	0.078 m^2	0.082 m^2

During the pushoff section of the kick, JW had the greatest distance between the right and left metatarsal-phalangeal joints of the right and left feet, absolute and normalized (Table 3). HT had the smallest absolute and normalized distances between m-p joints.

Table 3. Distance between right and left metatarsal-phalangeal joints during pushoff phase.

| | Subject | | |
	JW	SM	HT
	<---------- meters ---------->		
Absolute	0.82	0.76	0.57
Normalized	0.96	0.82	0.68

Subjects JW and HT delayed turning the head at the beginning of the kick (Figure 5). These two subjects started to turn the shoulders and hips as the left foot was moved forward into support foot plant. This delayed head turn was very obvious in HT. HT also had more hip turn than shoulder or head turn by the time the support foot was planted (Figure 5). The back of HT's pelvis was facing the target, while the head was also facing the target and the shoulders were parallel to the y-axis. By the end of the pushoff phase, JW had turned the head until it was perpendicular to the line of the shoulders. JW maintained this head-to-shoulder position throughout most of the remaining portion of the kick. SM turned the head earlier than the shoulders and hips (Figure 5). By the time of support foot plant, SM's head was facing away from the target. During the pushoff phase and the remainder of the kick, SM continued to look over the right shoulder. During the pushoff, both JW and SM turned the shoulders and head as one unit ahead of the hips, but this difference appeared to be small. HT, however, showed an extreme difference in shoulder and hip turn. HT turned the hips well in advance of the rest of the body until the end of the pushoff phase. After the kicking foot left the floor, HT turned the head and shoulders well in advance of the rest of the body.

Full knee extension occurred earliest in subject HT's kick, 0.073 seconds before foot/target contact. For JW and SM, 180° of knee extension occurred 0.040 and 0.051 seconds before foot/target contact.
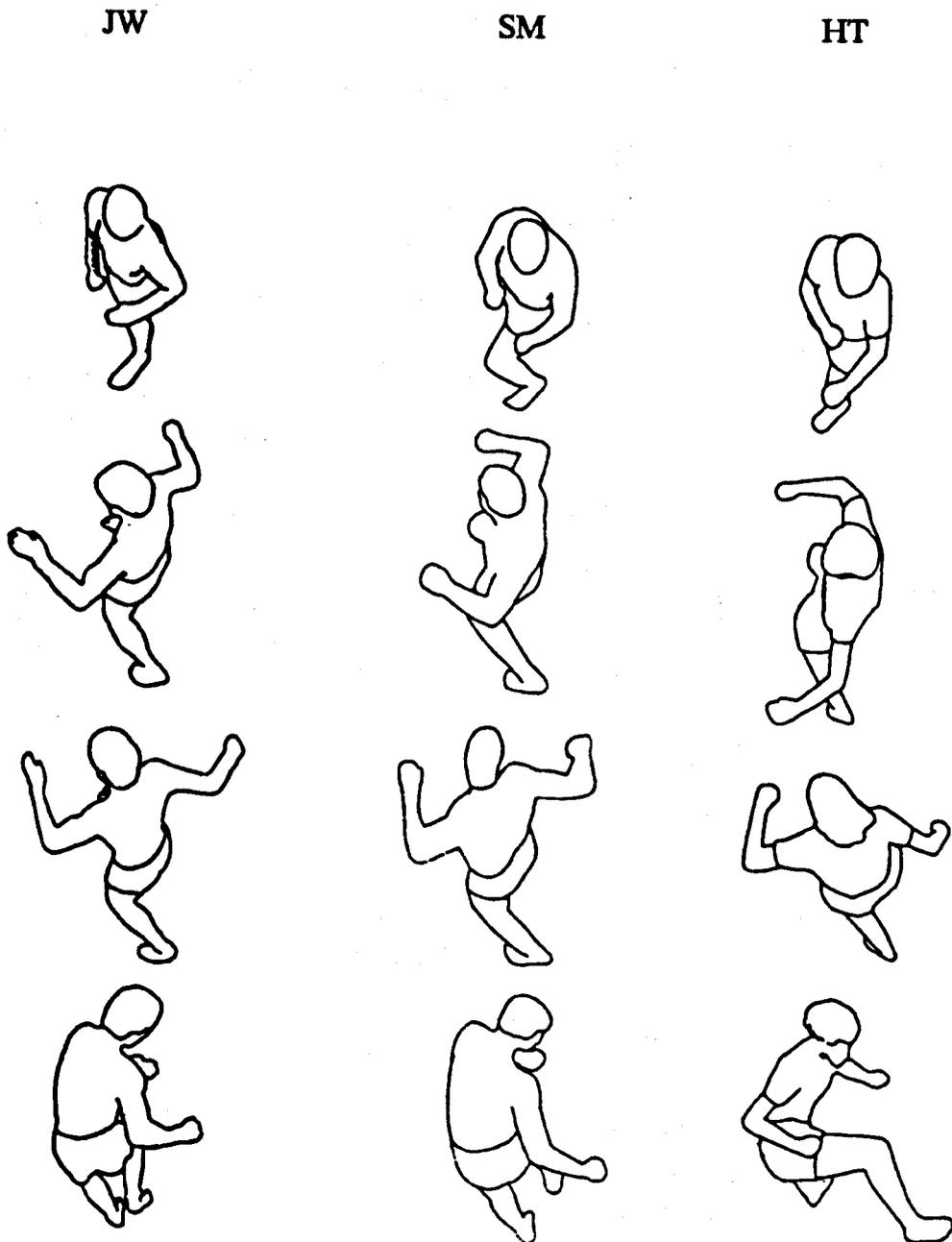
JW   SM   HT

Figure 5. Differential turning of the head, shoulders, and hips.

Sequencing of the Lower Extremity Kinematics

For all subjects, the x-velocity curves of the centers-of-gravity of the thigh and leg increased in the negative direction together until the maximum negative value for the thigh was reached (Figures 6, 7 and 8). The negative x-velocity of the leg continued to increase as the negative x-velocity of the thigh decreased in magnitude. For JW (Figure 6), the x-velocity of the thigh increased again in the negative direction from -1.12 meters per second 0.027 seconds before foot/target contact to -1.48 meters per second at contact. For HT (Figure 8), the x-velocity of the thigh had a section of nearly constant value starting 0.033 seconds before foot/target contact. The x-velocity of the thigh center-of-gravity of SM (Figure 7) smoothly approached a small negative value.

The maximum negative x-acceleration (toward the target) of the leg center-of-gravity occurred before the maximum positive x-acceleration (away from the target) of the thigh center-of-gravity for all subjects (Figures 9, 10 and 11). When the x-acceleration of the thigh became positive, the negative x-acceleration of the leg began to decrease in magnitude.

The y-velocities and accelerations of the thigh and leg centers-of-gravity were fairly synchronous for SM (Figures 14 and 15) and HT (Figures 16 and 17). For JW (Figures 12 and 13), however, the y-velocity and acceleration of the thigh maintained small values after 0.07 seconds before foot/target contact. The y-velocity of the leg of JW had a large positive value, 2.88 meters per second, while

those of SM and HT had small negative values, -0.617 and -0.0805 meters per second respectively.

The hip of JW (Figures 18 and 19) was flexing at foot/target contact (Table 4). The knee of JW (Figures 20 and 21) was also flexing at contact. Peak angular velocity for the knee in flexion occurred after foot/target contact. The hip angle of SM (Figures 22 and 23) was nearly constant just prior to and at foot/target contact. The knee of SM (Figures 24 and 25) was almost fully extended at foot/target contact and was beginning to flex. Peak angular knee velocity for SM occurred after contact. HT (Figures 26 and 27) was extending the hip at foot/target contact. The knee of HT (Figures 28 and 29) was flexing at peak angular velocity at foot/target contact.

Table 4. Hip and knee angular displacements and velocities at foot/target contact.

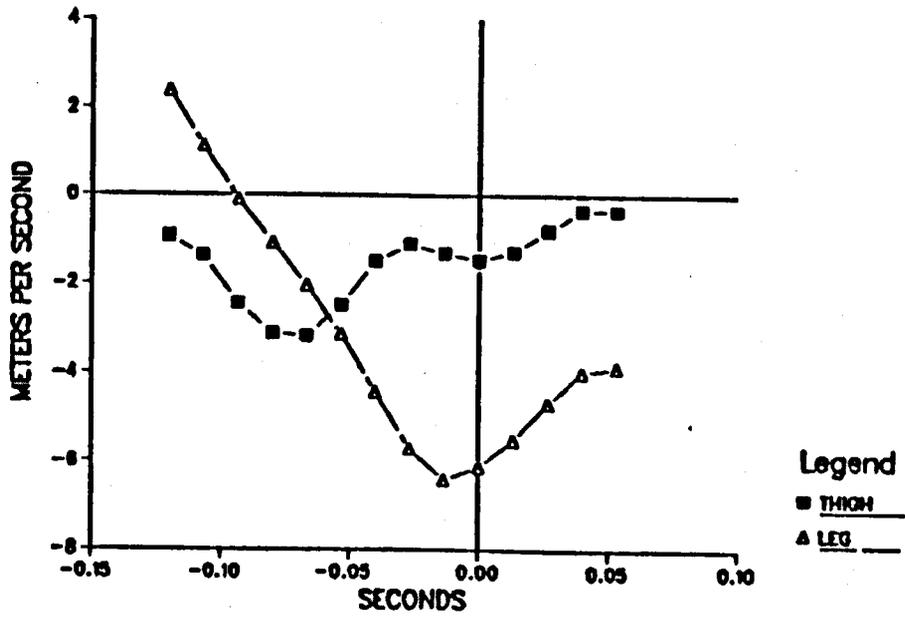| Subject		Hip	Knee
JW	Displacement	249 degrees	163 degrees
	Velocity	357 deg/sec	-924 deg/sec
SM	Displacement	219 degrees	177 degrees
	Velocity	105 deg/sec	-402 deg/sec
HT	Displacement	266 degrees	145 degrees
	Velocity	-308 deg/sec	-1078 deg/sec

Figure 6. JW: X-velocities of the thigh and leg centers-of-gravity.
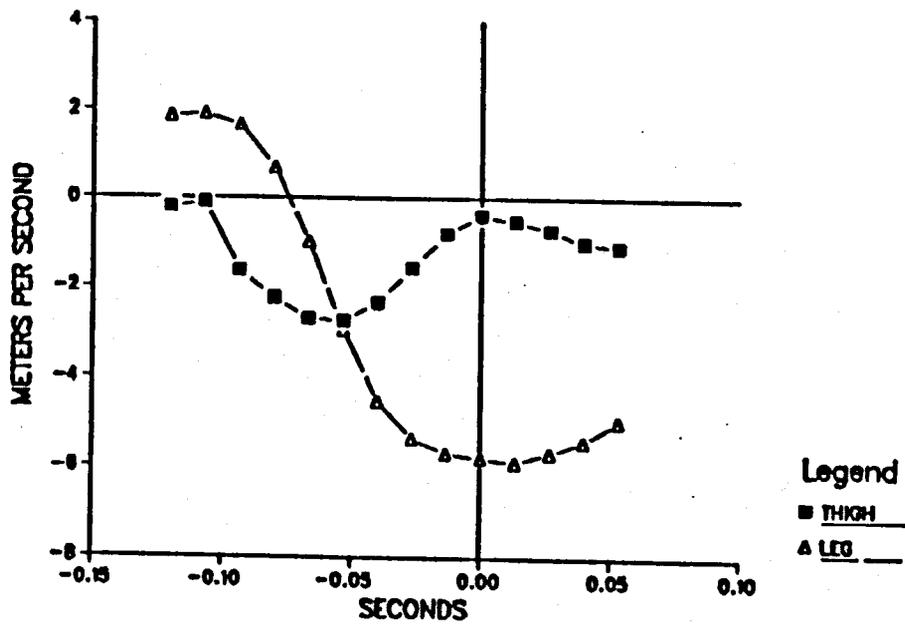
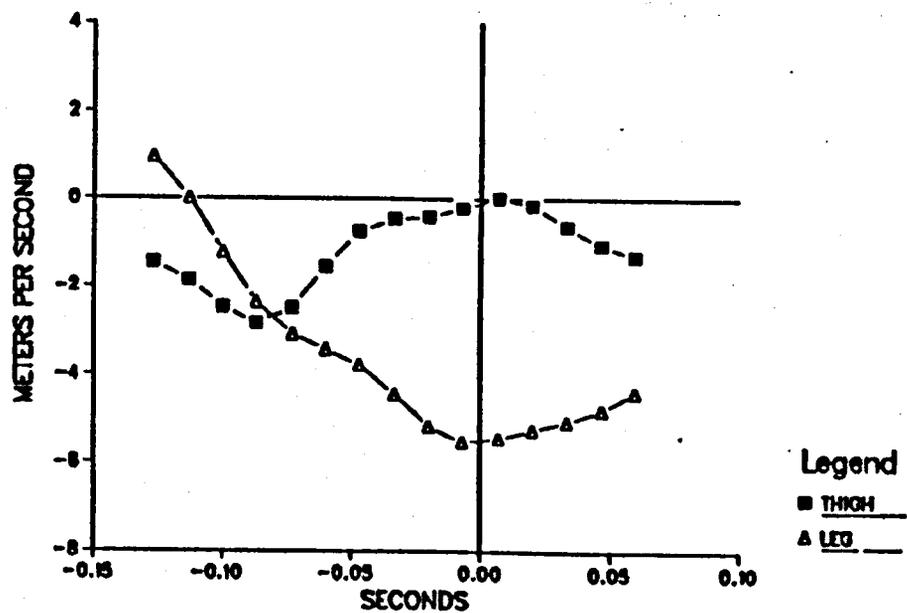Figure 7. SM: X-velocities of the thigh and leg centers-of-gravity.

Figure 8. HT: X-velocities of the thigh and leg centers-of-gravity.
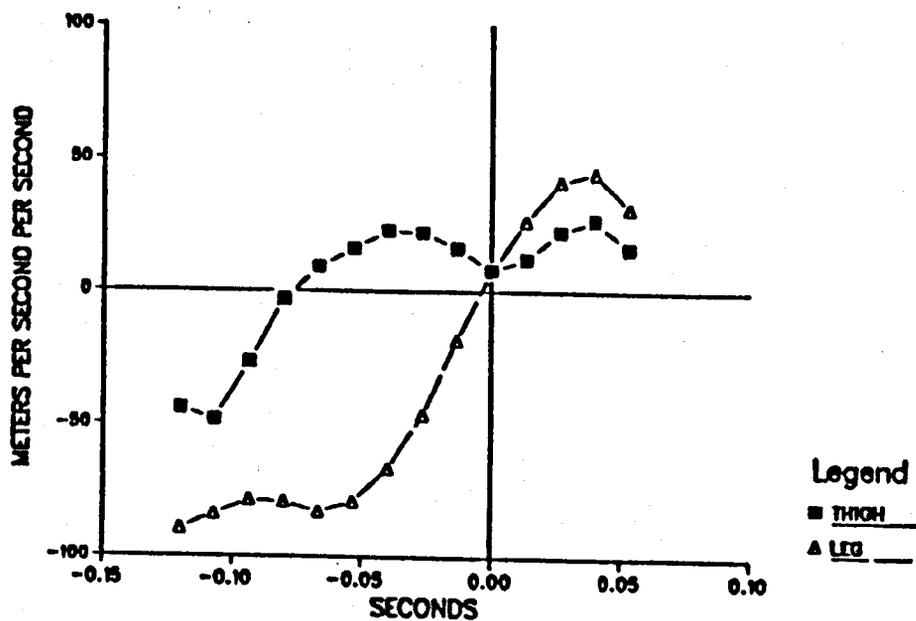

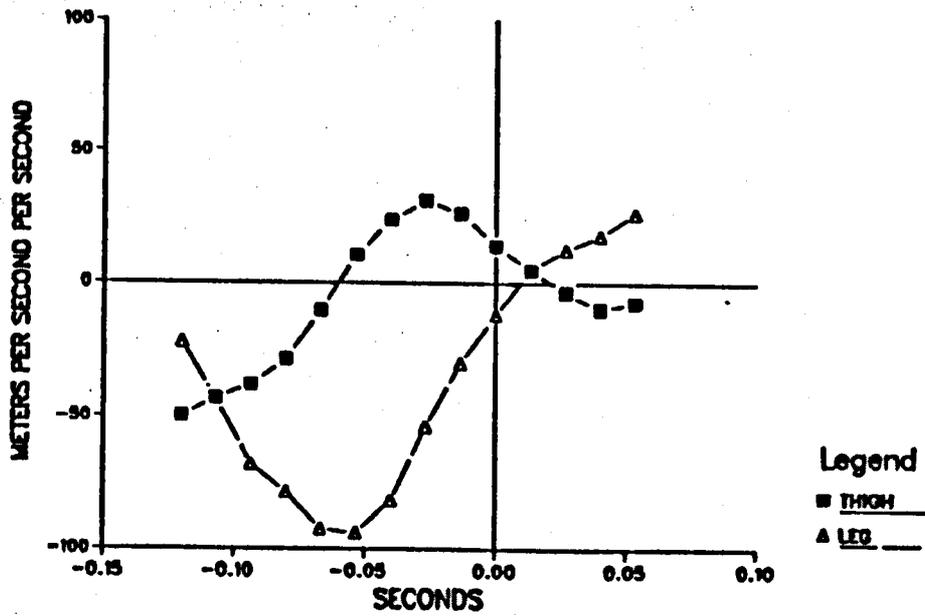Figure 9. JW: X-accelerations of the thigh and leg centers-of-gravity.

Figure 10. SM: X-accelerations of the thigh and leg centers-of-gravity.
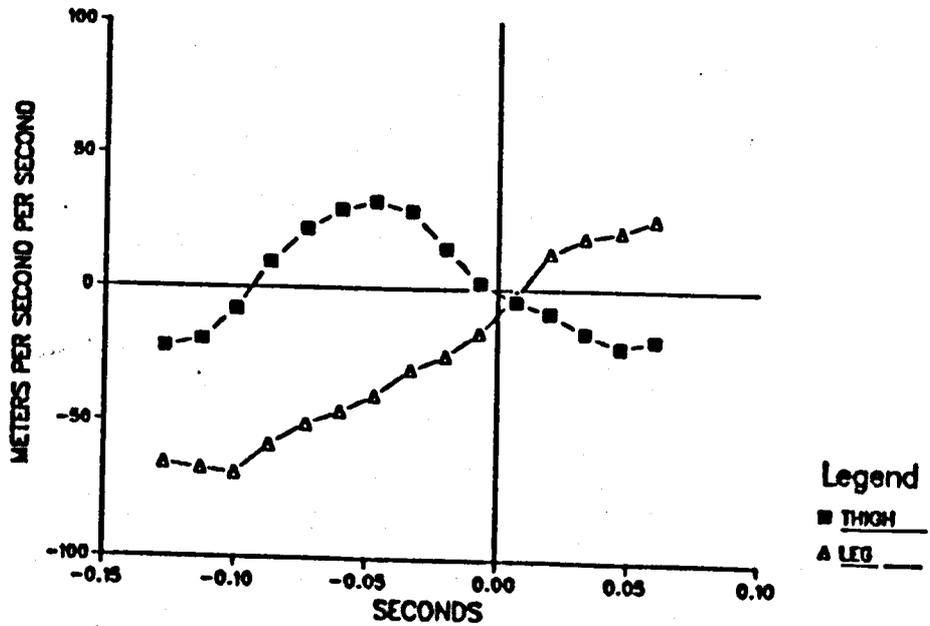

Figure 11. HT: X-accelerations of the thigh and leg centers-of-gravity.

Figure 12. JW: Y-velocities of the thigh and leg centers-of-gravity.
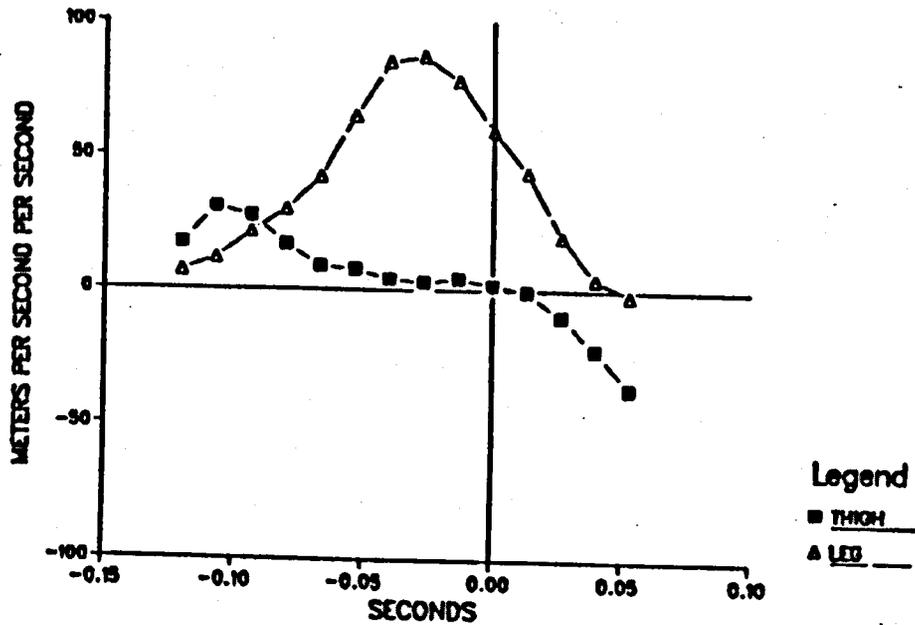
Figure 13. JW: Y-accelerations of the thigh and leg centers-of-gravity.
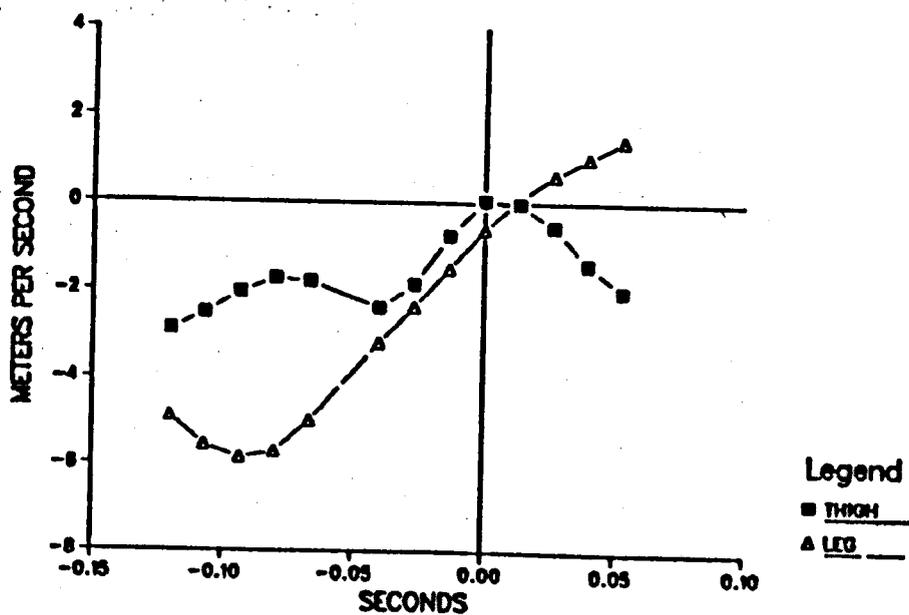
Figure 14. SM: Y-velocities of the thigh and leg centers-of-gravity.

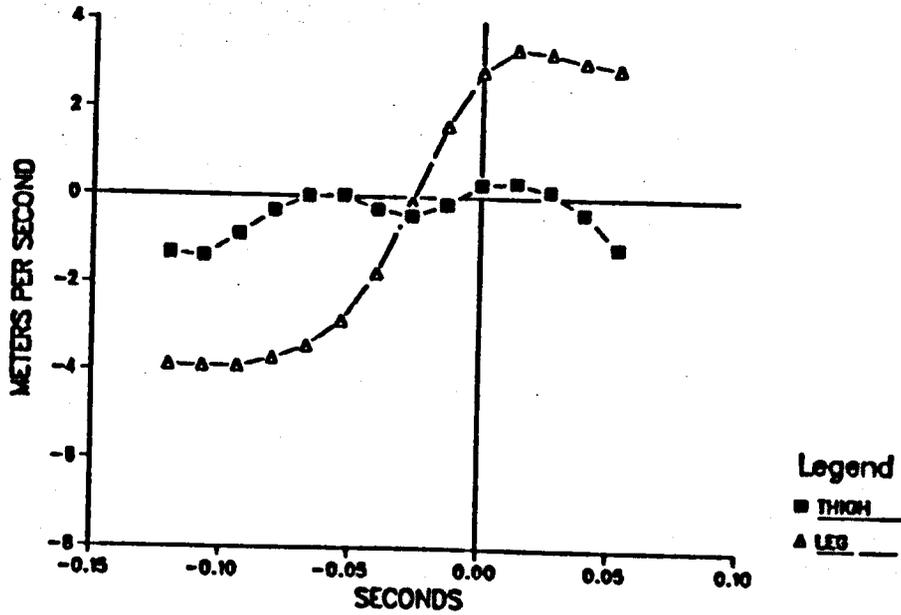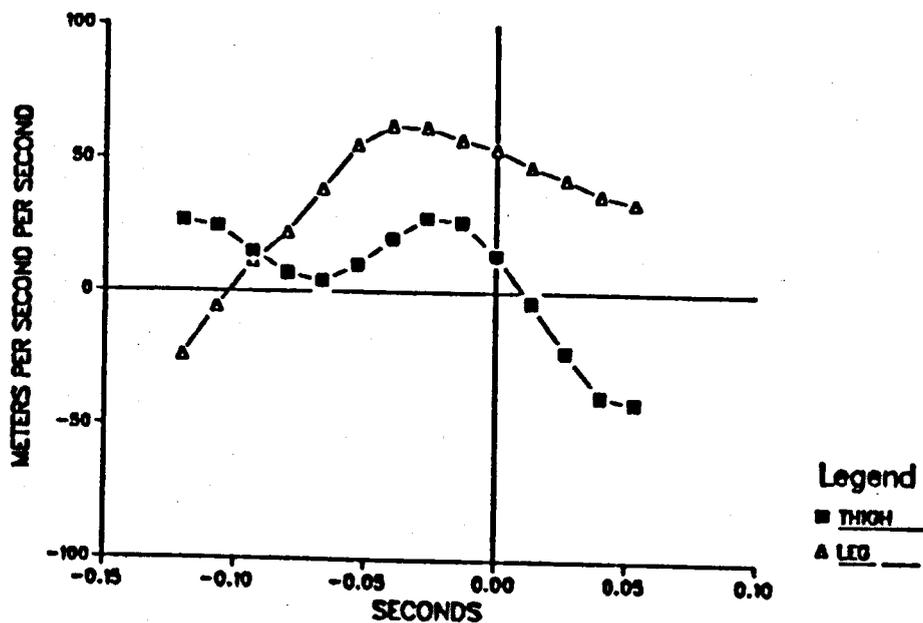Figure 15. SM: Y-accelerations of the thigh and leg centers-of-gravity.
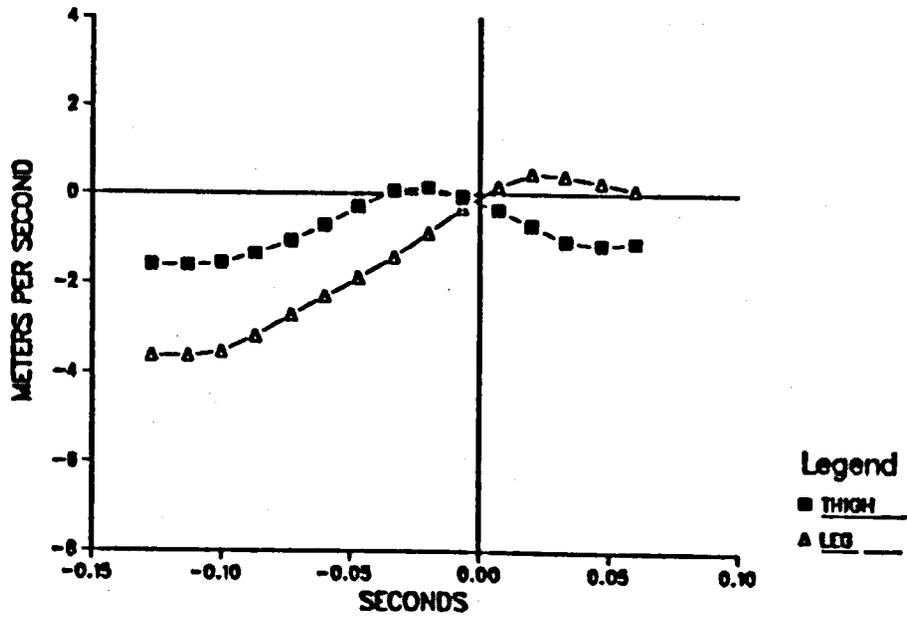
Figure 16. HT: Y-velocities of the thigh and leg centers-of-gravity.
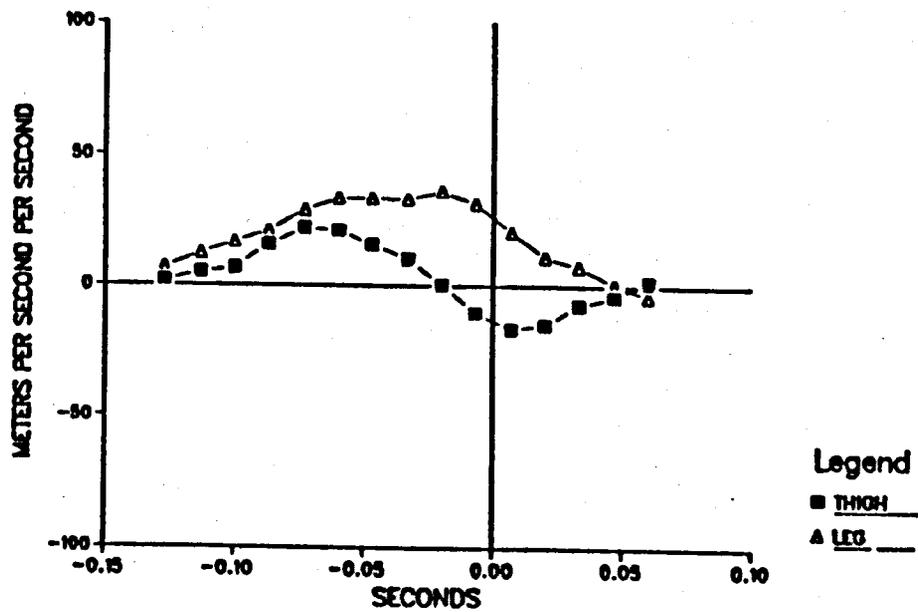
Figure 17. HT: Y-accelerations of the thigh and leg centers-of-gravity.
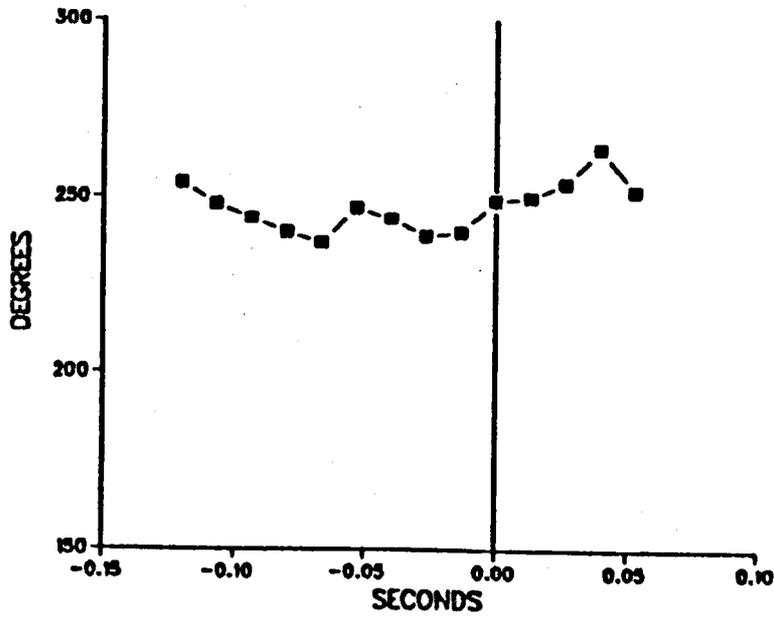
Figure 18. JW: Angular displacement of the hip.
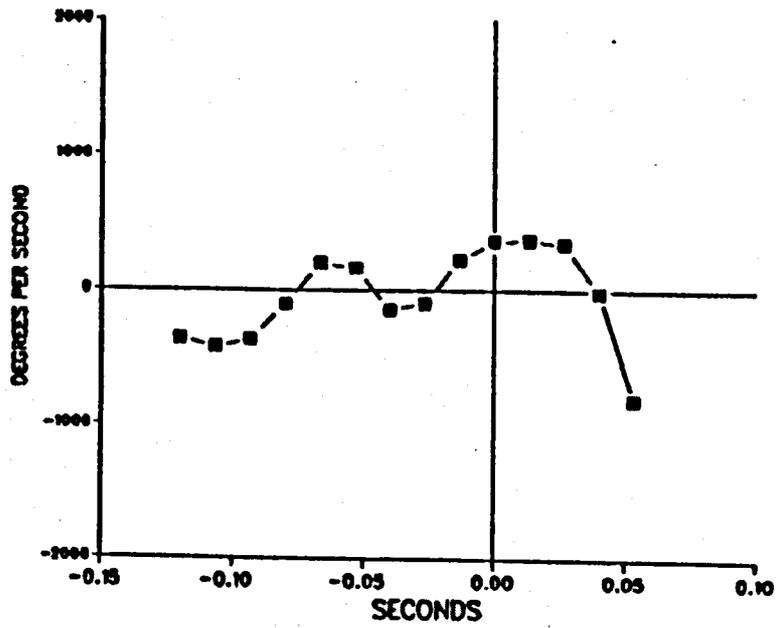
Figure 19. JW: Angular velocity of the hip.
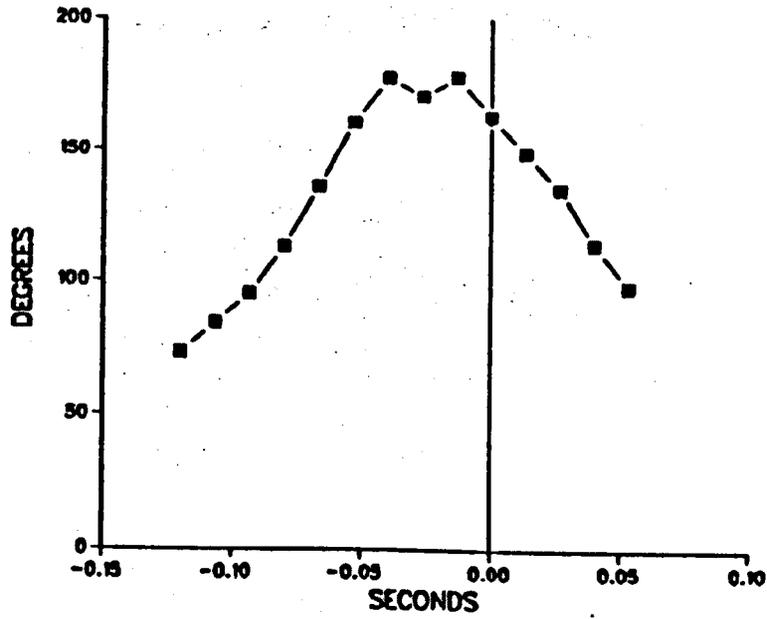
Figure 20. JW: Angular displacement of the knee.
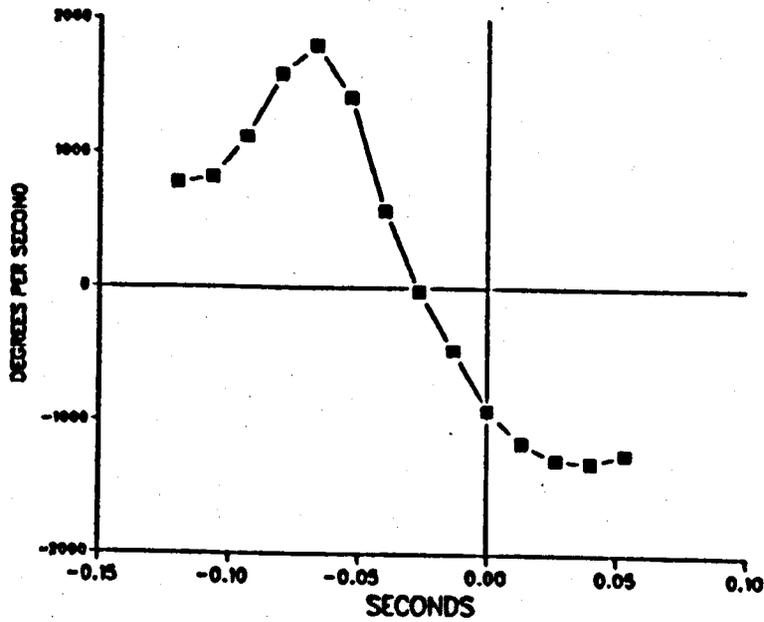
Figure 21. JW: Angular velocity of the knee.
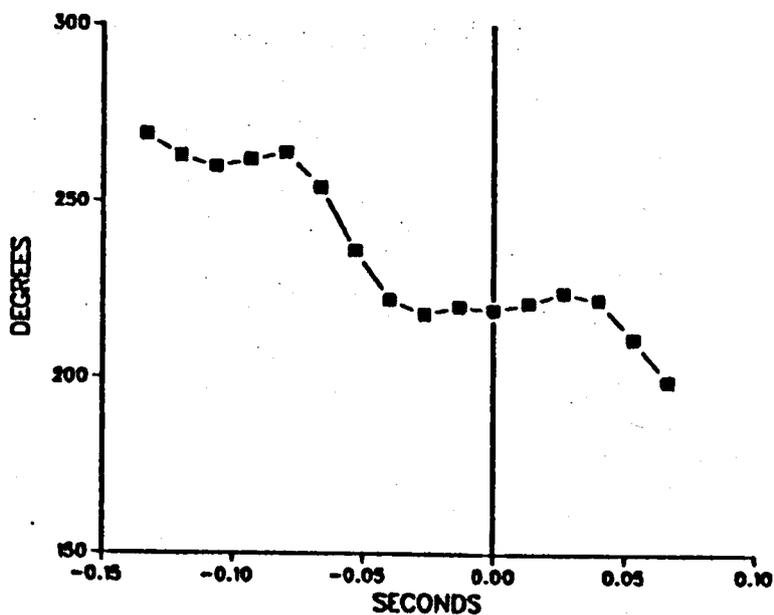
Figure 22. SM: Angular displacement of the hip.
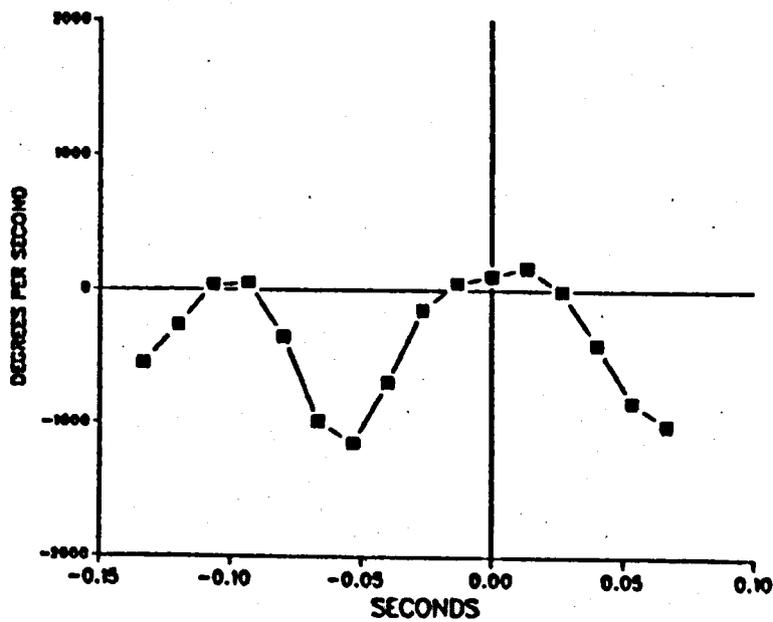
Figure 23. SM: Angular velocity of the hip.
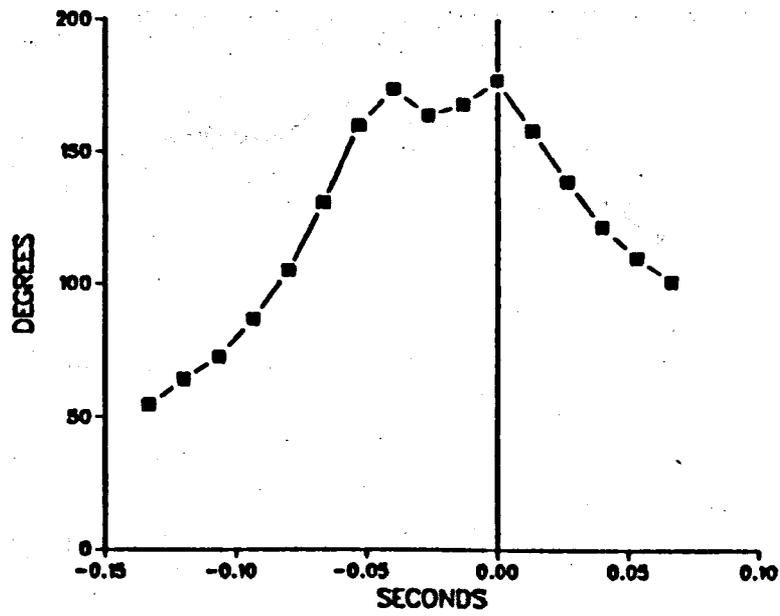
Figure 24. SM: Angular displacement of the knee.
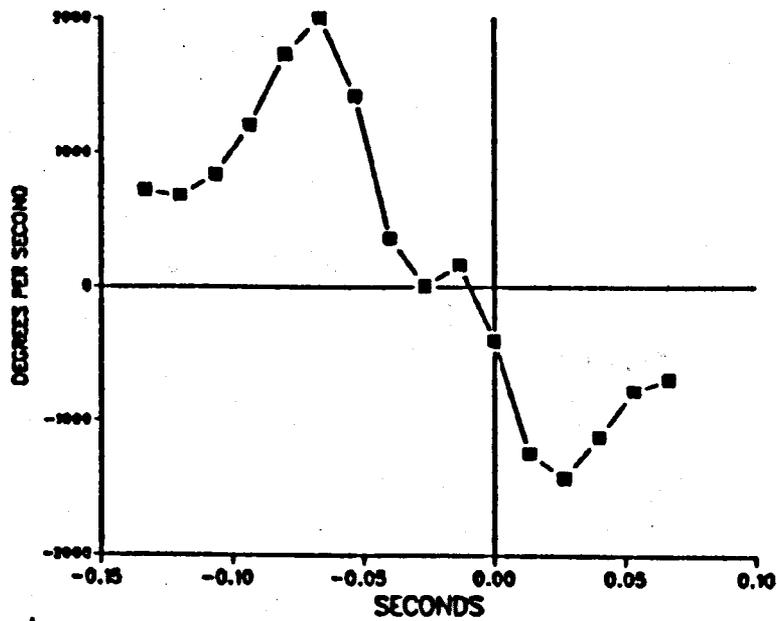
Figure 25. SM: Angular velocity of the knee.
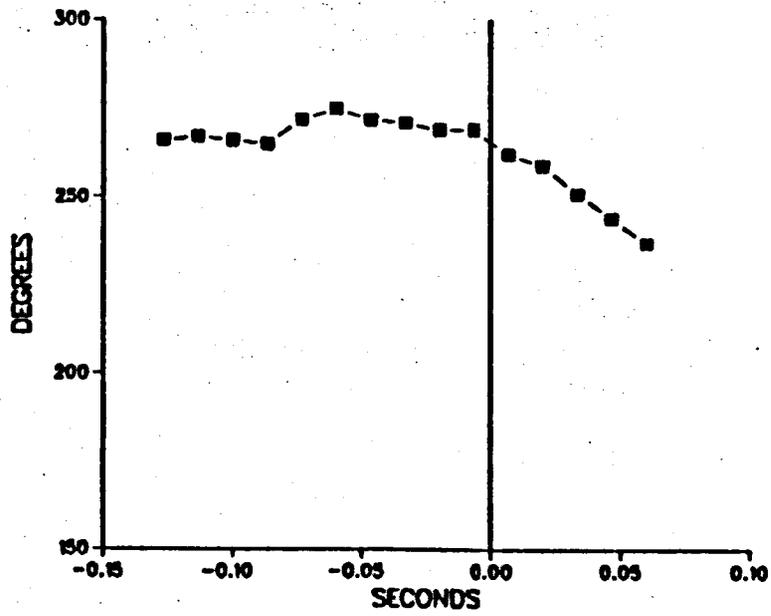
Figure 26. HT: Angular displacement of the hip.
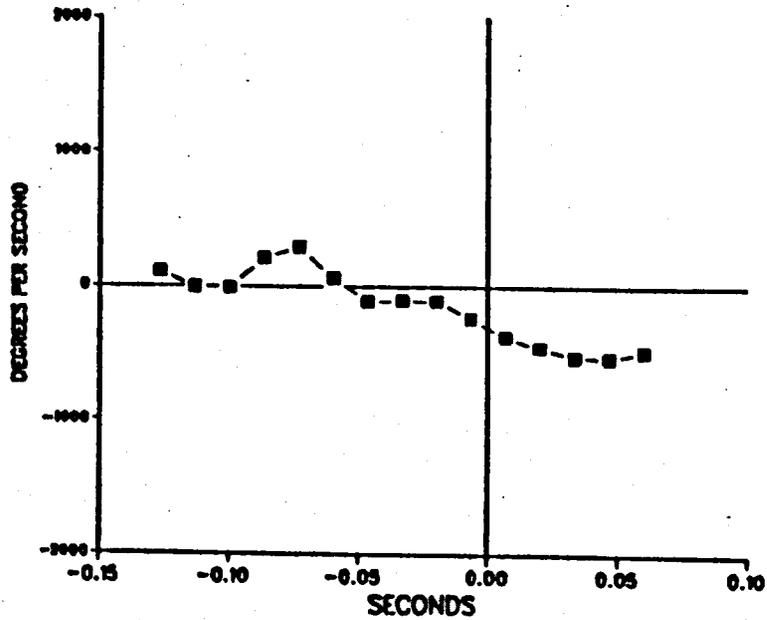
Figure 27. HT: Angular velocity of the hip.
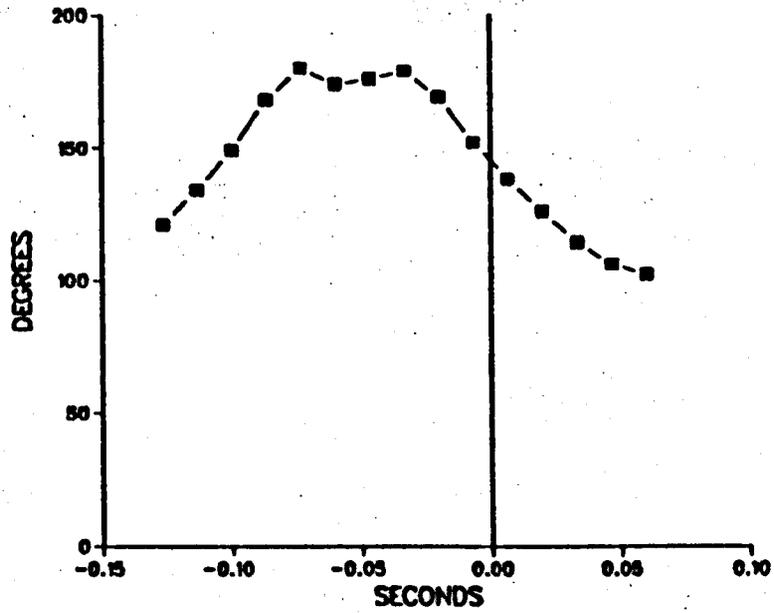
Figure 28. HT: Angular displacement of the knee.
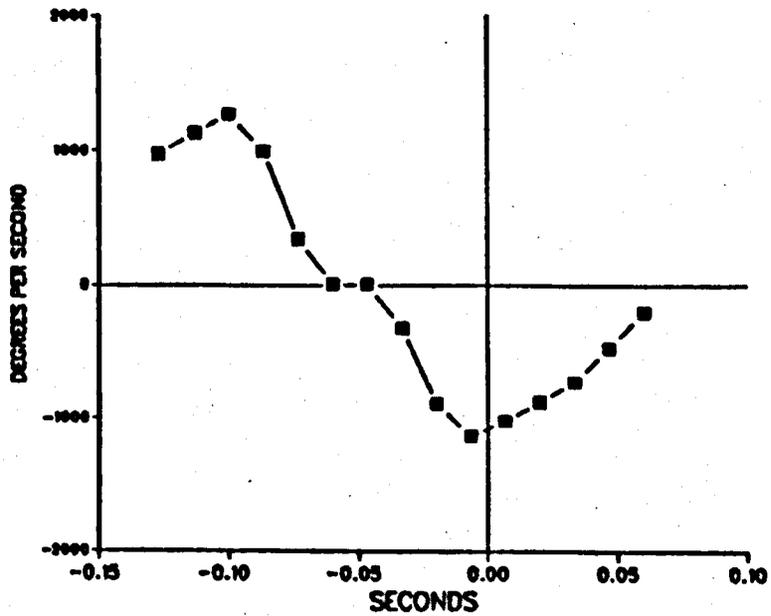
Figure 29. HT: Angular velocity of the knee.

Metatarsal-Phalangeal Velocities

The time histories of the x-, y-, and z-velocities of the metatarsal-phalangeal joints of the kicking feet of the subjects appear in Figures 30, 31 and 32. The x-velocities of the m-p joints of JW (Figure 30) and SM (Figure 31) increased negatively at a greater rate than did that of HT (Figure 32). The x-velocities for JW and SM also became negative temporarily closer to foot/target contact than did the x-velocity of HT. The peak negative x-velocity occurred slightly after contact for all subjects. JW's y-velocity of the m-p had a small positive peak shortly before contact. The y-velocities for the m-p's of SM and HT remained negative before foot/target contact, although they did approach zero as the x-velocities became negative. The z-velocities of SM and HT decreased at a much greater rate than did that of JW.

Calculated correction factors for the x- and y-velocities of the metatarsal-phalangeal joint were 0.87, 0.88, and 0.89 for JW, SM, and HT respectively. The linear velocities of the metatarsal-phalangeal joint after being adjusted with the correction factors appear in Table 5. The z-velocity of the m-p for JW was more than 3.5 times larger in magnitude than the m-p z-velocity for the other two subjects. The y-velocity of the m-p for SM was more than 4.5 times larger than that for the other two subjects. The differences in the heights of the right shoulder of the subjects between kicking foot liftoff and foot/target contact were 0.17 meters for JW, 0.07 meters for SM, and 0.02 meters for HT.

Table 5.   Velocities of the metatarsal-phalangeal joint at foot/target contact.

Component	Subject		
	JW	SM	HT
x	-13.100 m/s	-13.500 m/s	-12.200 m/s
y	-0.783 m/s	-3.800 m/s	0.655 m/s
z	8.160 m/s	2.150 m/s	2.190 m/s
Total	15.500 m/s	14.200 m/s	12.400 m/s
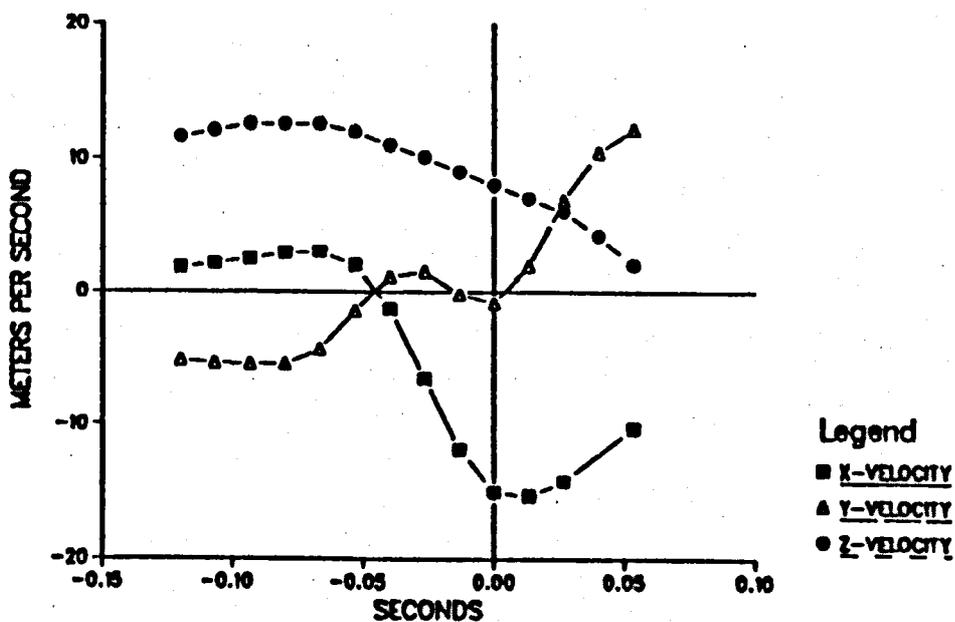
Figure 30.   JW: Velocity of the metatarsal-phalangeal joint.
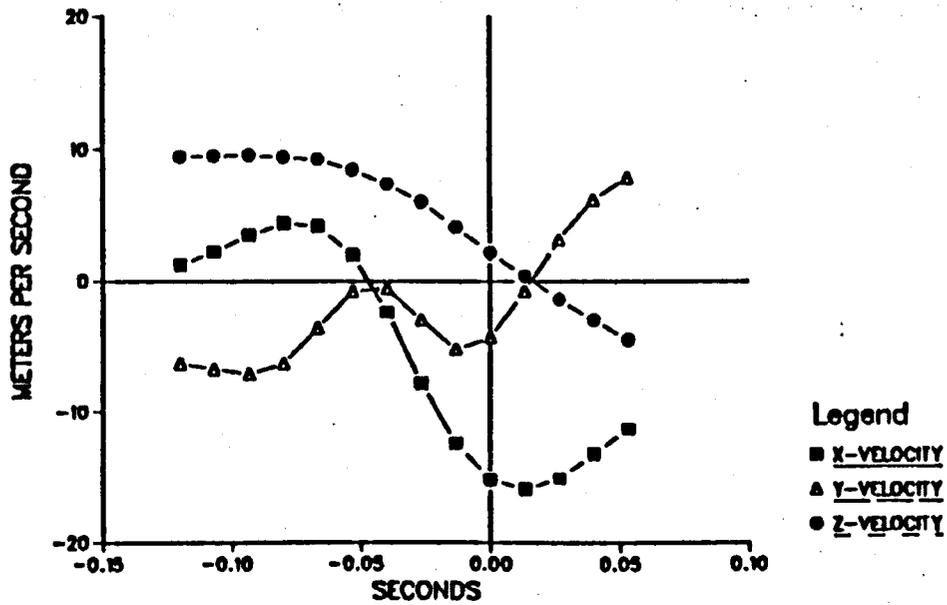
Figure 31. SM: Velocity of the metatarsal-phalangeal joint.
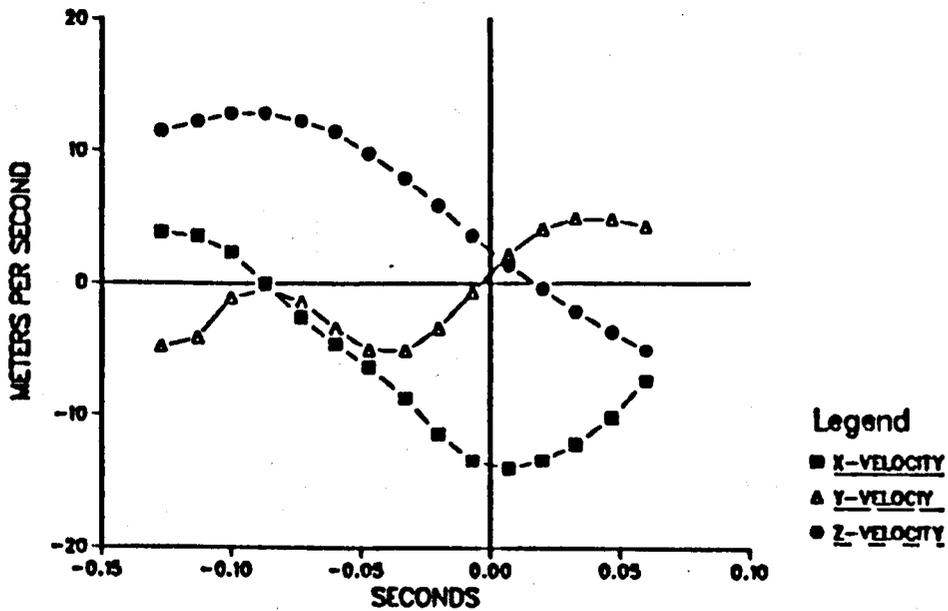
Figure 32. HT: Velocity of the metatarsal-phalangeal joint.

The resultant x- and y-accelerations of the metatarsal-phalangeal joint for JW, SM, and HT appear in Figures 33, 34 and 35. The peak resultant acceleration of the m-p for all subjects coincided with the beginning of knee flexion, the positive x-acceleration peak of the thigh that occurred prior to foot/target contact, and the maximum positive y-acceleration of the leg. The resultant accelerations of the m-p's of JW (Figure 33) and SM (Figure 34) decreased to a local minimum at foot/target contact. The resultant acceleration of the m-p of HT (Figure 35) reached a local minimum before foot/target contact and then increased until contact.
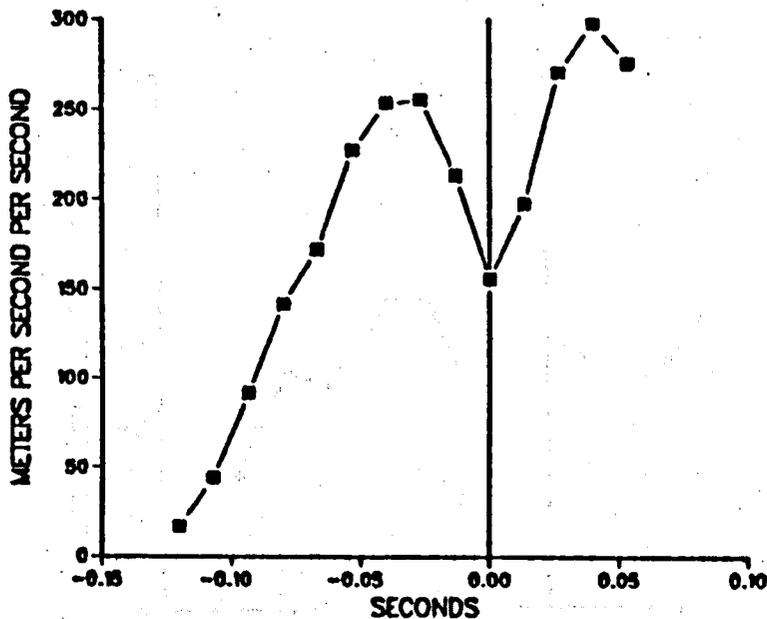
Figure 33. JW: Resultant acceleration of the metatarsal-phalangeal joint.
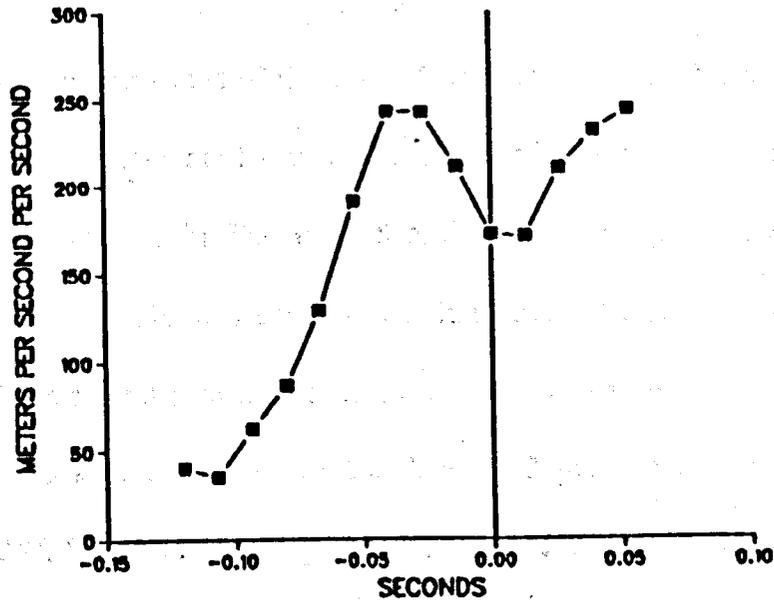
Figure 34. SM: Resultant acceleration of the metatarsal-phalangeal joint.
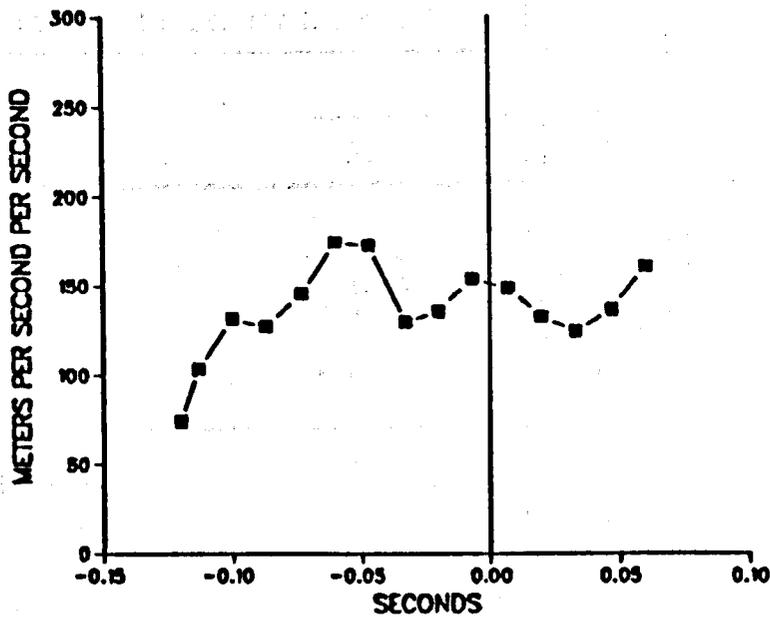
Figure 35. HT: Resultant acceleration of the metatarsal-phalangeal joint.

Movement Times

The movement times of the three first sections of the kicks appear in Table 6. The average movement times with standard deviations for all kicks for the three subjects appear in Tables 7, 8 and 9. Thirty-eight percent of the total movement time of JW was spent in section one. SM and HT spent 44 and 36 percent of their total movement times in section one respectively. The pushoff section of the kick amounted to 14, 8, and 12 percent of the total movement times for JW, SM, and HT respectively. Both JW and SM spent 48 percent of the total movement time in the third section of the kick, while HT spent 52 percent of total movement time in this section.

Table 6. Movement times for the selected kicks.

Section	Subject		
	JW	SM	HT
1	0.22 s	*	0.24 s
2	0.10 s	0.09 s	0.12 s
3	0.31 s	0.28 s	0.35 s
Total	0.63 s	*	0.71 s

*Not available

Table 7. Average movement times for JW.

Section	Average	Std. Deviation
1	0.24 s	.021 s (n=6)
2	0.09 s	.019 s (n=6)
3	0.30 s	.013 s (n=6)
Total	0.63 s	.026 s (n=6)

Table 8. Average movement times for SM.

Section	Average	Std. Deviation
1	0.31 s	.013 s (n=3)
2	0.07 s	.015 s (n=6)
3	0.33 s	.027 s (n=6)
Total	0.71 s	.009 s (n=3)

Table 9. Average movement times for HT.

Section	Average	Std. Deviation
1	0.24 s	.016 s (n=5)
2	0.08 s	.020 s (n=5)
3	0.35 s	.015 s (n=5)
Total	0.67 s	.021 s (n=5)

CHAPTER 5

DISCUSSION

The purpose of this study was to describe the turning hook kick in mechanical terms as executed by three United States national-level competitors. The results presented in Chapter 4 are discussed in this chapter through a comparison of the three subjects and as they relate to the literature. The subtopics of this chapter are as follows:

(1)   Rotational kinetic considerations of the body.

    (a)   Rotational inertia of the body at kicking foot liftoff.

    (b)   Distance between the right and left metatarsal-phalangeal joints at kicking foot liftoff.

    (c)   Differential turning of the hips, shoulders, and head.

(2)   Sequencing of lower extremity kinematics.

(3)   Velocity of the metatarsal-phalangeal joint at foot/target contact.

(4)   Movement time.

Rotational Kinetic Considerations of the Body

Rotational Inertia of the Body at Kicking Foot Liftoff

Laws (1978) noted that at the beginning of a turn the dancer's arms were abducted while exerting a torque against the floor with the feet. Abduction of the

arms created a larger rotational inertia than if the arms were close to the body or held overhead. The larger the rotational inertia of the body, the smaller the angular velocity required for the dancer to develop the same angular momentum. Once the dancer's gesture leg leaves the floor, the angular momentum will remain relatively constant if the friction between the floor and the support foot is small. Adjustments in the rate of rotation are possible through positioning of the body mass about the axis of rotation. Extending the arms and leg as in the arabesque turn will slow rotation, while holding the arms and gesture leg in to the body will produce more rapid turning rates.

For an effective kick, the kicker would want to produce a large amount of angular momentum in a short period of time in order to reduce the amount of time during which the back is turned to the opponent and to increase the velocity of the kicking foot. By abducting the arms, the mass of the body would be moved further from the axis of rotation and would increase the rotational inertia of the body. The increased rotational inertia would allow the kicker to create angular momentum with a smaller angular velocity of the body. The kicker might also choose a smaller rotational inertia with an accompanying larger angular velocity in order to generate angular momentum. Ballet dancers use the former method in order to create the illusion of rising up on the support foot toe and then turning as the rotational inertia of the body is reduced. The kicker may want such an illusion in order to conceal the onset of the turning hook kick. However,

if the kicker chose the latter method, then perhaps the turn would be executed too quickly for the opponent to react.

The subjects of this study used a relatively large rotational inertia, with the arms held away from the body and the feet at least 0.56 meters apart, though the arms could have been held further from the body, thereby increasing the inertia. At the moment that the kicking foot left the floor at the end of the pushoff phase of the turning hook kick, the rotational inertia of SM was the largest of the three subjects. The normalized rotational inertia, however, was largest for JW and smallest for SM. These results were indicative of how the subjects distributed the mass of their bodies during the pushoff phase. An optimal rotational inertia configuration probably exists for each subject and is dependent on that subject's ability to generate torque quickly.

Distance Between the Right and Left Metatarsal-Phalangeal Joints at Kicking Foot Liftoff

Laws (1978) stated that the torque applied to the floor by a dancer initiating a turn was produced by the feet pushing in opposite directions at some distance apart, in effect forming a force couple. The turns that were begun with the feet further apart required less force to execute due to a larger torque arm.

The distances between the metatarsal-phalangeal joints at kicking foot liftoff were 0.82 meters for JW, 0.76 meters for SM, and 0.57 meters for HT. Thus, JW had a greater torque arm between the feet than did the other two subjects. If the

subjects had applied the same forces at the same rate to the floor, then JW would have produced a greater torque than the other two subjects. If the rotational inertia of the subjects were the same during the pushoff phase, then JW would have developed angular momentum at a more rapid rate than the other two subjects due to a larger angular acceleration resulting from a larger torque applied to the floor. However, the subjects did not have the same rotational inertias. JW had the largest normalized rotational inertia of the three subjects and, thus, needed to use more torque to turn the body. HT had the second largest rotational inertia, but had the smallest distance between m-p joints. HT compensated for the smaller torque producing configuration of the feet by turning the hips and legs during the plant section of the kick and then turning mainly the head and shoulders during the pushoff phase.

Differential Turning of the Hips, Shoulders, and Head

Laws (1978) noted that after the angular momentum had been produced, turning the head at a more rapid rate than the rest of the body resulted in reducing the rate at which the body was turning because the head absorbed some of the angular momentum of the system. Turning the head and shoulders first while the feet were in contact with the ground would result in angular momentum being stored in these body parts and would add to the total body angular momentum once the gesture foot left the ground.

During the plant phase of the kick, JW and HT delayed the turn of the head until after that of the shoulders and hips, while SM turned the head before the rest of the body. Angular momentum could have been stored in the head of SM during the plant and pushoff phases while the feet were in contact with the floor. The angular momentum of the head could then be transferred to the rest of the body after kicking foot liftoff. Turning the head opposite to the direction of rotation of the rest of the body would increase the turning rate of the rotating body. SM did not counter-rotate the head, and therefore was not taking advantage of stored angular momentum, but was more likely attempting to see the target over the right shoulder as the body turned. The advanced head turn of SM may have slowed the turning of the rest of the body during the plant phase. The average time for the plant phase was the largest for SM. This large plant phase time may also have been due to SM concentrating on turning the head at the expense of turning the body. The delayed head turn for JW and HT could have hastened the plant phase turning of the shoulders and hips in the case of JW or just the hips in HT's case, since HT also delayed turning the shoulders. Delaying the turning of the head would reduce the amount of mass being turned and, therefore, reduce the rotational inertia being turned. JW and HT did have smaller average plant phase times than SM. However, the subjects were probably increasing the amount of time that they could see the target rather than attempting to increase the initial turn of the rest of the body.

By the middle of the pushoff phase, JW and HT had brought the head perpendicular to the shoulders. Some additional time may have been required during the pushoff phase in order to bring the head to this position. JW and HT had larger average pushoff phase times than did SM, but SM also had a smaller normalized rotational inertia during this phase. After kicking foot liftoff, JW and SM turned the body more as a unit than did HT. HT turned the shoulders well in advance of the hips, which delayed the movement time of the kicking foot from the floor to the target. HT had the largest third section movement time.

The large movement time of the third section for HT was probably also due to the early extension of the knee. HT extended the kicking leg longer before foot/target contact than did JW or SM. Once the kicking leg is extended, the rotational inertia of the body is increased and the body turns at a slower angular velocity. Thus, HT was turning at a slower rate for a greater amount of time than were the other subjects. The longer the duration spent turning at a slower rate, the greater the movement time of the third section.

To summarize, JW had the largest normalized rotational inertia at kicking foot liftoff, the greatest distance between the left and right metatarsal-phalangeal joints, the second longest pushoff and third section times, and the smallest time between full knee extension and foot/target contact. SM had the smallest normalized rotational inertia at kicking foot liftoff, the second largest distance between m-p joints, the shortest pushoff and third section times, and the second smallest time between full knee extension and foot/target contact. HT had the second

largest normalized rotational inertia, the smallest absolute and normalized distances between the m-p joints, the longest pushoff and third section times, and the greatest time between full knee extension and foot/target contact.

JW had data indicative of the largest torque and angular momentum production of the three subjects. However, the pushoff time appeared to be critical for JW. Perhaps eliminating the delayed head turn would hasten the pushoff of JW. Also, JW's rotational inertia at the end of pushoff may have been too large, requiring time for the subject to achieve a low inertia position quickly after pushoff. SM probably reduced the amount of angular momentum that could have been produced by having a small rotational inertia, but also reduced the time spent in pushoff and third section. SM did have the largest x- and y-velocities of the m-p at foot/target contact. SM had the largest average plant phase time. Eliminating or reducing the advanced head turn might reduce this first section time. For HT, the distance between the m-p joints during pushoff could perhaps be increased in order to provide better torque producing capabilities. Reducing the difference in turning of the torso and hips and the time between full knee extension and foot/target contact would reduce the third section time for HT.

Sequencing of Lower Extremity Kinematics

The slowing of the thigh in the turning hook kick as executed by the subjects of this study did not appear to accelerate the lower leg into the target in the x-direction. When the thigh began to decelerate, the acceleration of the leg

toward the target was also reduced. Peak deceleration of the thigh occurred after the peak x-acceleration of the leg. The peak positive y-acceleration of the leg did correspond with the peak deceleration of the thigh. Positive y-acceleration of the leg would cause it to travel toward the kicker and away from the target or else "hooking" into the target from behind. The motions of the thigh and leg corresponded with accelerating the metatarsal-phalangeal joint maximally at peak positive acceleration of the thigh and peak positive y-acceleration of the leg. Thus, deceleration of the proximal segment, the thigh, appeared with acceleration of the distal point of the most distal segment, the foot.

Roberts et al. (1968), Plagenhoef (1971), and Phillips et al. (1983) predicted that in a sequential motion such as kicking, one would expect to see deceleration of the thigh accompanied by acceleration of the leg. The kicking motions that were investigated by Plagenhoef and Roberts et al. were forward kicking motions. The mechanics of the hook kick, a backward kick, apparently follow the same sort of pattern as the forward kicking motion. The thigh probably slowed due to the increase in the rotational inertia created when the kicking leg was extended. Whether or not the thigh was slowed in order to accelerate the foot or the active flexion of the knee caused the thigh to decelerate could not be determined.

Both JW and SM were flexing at the hip at foot/target contact, though this was small for SM. Because the thigh was moving slowly at this time, the hip flexion was largely due to movement of the pelvis and trunk. Such motion of the trunk was in the same direction as the rotation of the body and would absorb

some of the angular momentum, momentum that should remain in the thigh. Extending the hip, however, would increase the rotational inertia of the body and might also place the kicker in an anatomically uncomfortable position.

Peak angular velocity of the knee occurred after the peak metatarsal-phalangeal joint and foot/target contact for JW and SM. Peak angular knee velocity occurred at foot/target contact and peak m-p velocity for HT. The thighs of SM and HT were moving slowly at foot/target contact; therefore, knee flexion must have been necessary to maintain velocity of the foot. SM had the lowest knee flexion velocity at contact, but also had the longest leg and foot lengths, which may have accounted for this subject having a greater velocity of the m-p at foot/target contact than HT. JW had a larger thigh velocity than did the other subjects. Perhaps JW achieved velocity at the m-p because of the velocity of the thigh. HT extended the knee a longer time period before foot/target contact than did JW or SM, and this earlier extension may have allowed HT to attain peak angular velocity at the knee by the time of foot/target contact, but would also increase the time of the third section of the kick.

Velocity of the Metatarsal-Phalangeal Joint at Foot/Target Contact

The velocity of the metatarsal-phalangeal joint at foot/target contact showed some major differences among the styles of the three subjects. JW's m-p was travelling in an upward (positive z) and sideward (negative x) direction when it

struck the target. SM's m-p was travelling into the target (negative y) and across it (negative x) at foot/target contact. HT's m-p was moving across the target (negative x) at foot/target contact. SM had the largest m-p x- and y-velocities at foot/target contact, but the z-component of the velocity of JW's m-p was so large that the total velocity of the m-p was greater for JW than for SM.

Movement Times

The total average movement time of the subjects was shorter than that reported for the subjects of the study by Joon et al. (1987). Fifteen one-hundredths of one second was the largest difference between the average total movement times of the subjects in the present study and those performing the spin back kick to the face in the research of Joon et al. However, the movement time used by Joon et al. included reaction time, whereas the movement time for the subjects of this study was begun at the first noticeable movement. The average reaction time for the subjects of the study by Joon et al. was 0.21 second. The reaction time would account for the discrepancy in movement times between these studies. The time spent in pushoff was shorter, almost half the time, than that reported for a ballet dancer executing pirouettes (Laws, 1978). The subjects did use the plant phase to produce some angular momentum; however, some turning of the body did occur during this section of the kick and this may account for the differences in pushoff times between the dancers and the kickers.

Thirty-six (HT) to 44 (SM) percent of the total movement time was spent in the plant phase. This amount of time is quite large and is probably not generating a great deal of angular momentum. Forty-eight (JW and SM) to 53 (HT) percent of the movement time was spent in the third section of the kick. Reducing the time spent in these two sections might prove very beneficial to reducing the total movement time. Reduction in the first section time might be accomplished by practicing the execution of this first step as quickly as possible. Reduction in the third section might be accomplished by maximizing the angular momentum generated during the first two sections and maintaining a small rotational inertia as long as possible during the third section.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The present study was intended to provide a biomechanical description of the turning hook kick in Taekwondo as performed by three subjects. It was hoped that the information gained from this study would provide a data base for future studies of this technique and would aid coaches and performers in learning and improving this kick.

Two national-level competitors and one Olympic competitor from the Bozeman Taekwondo team served as subjects. These subjects were between the ages of 25 and 31 years and were capable of using the turning hook kick in national competition. Two of the subjects were male and one subject was female.

The subjects were filmed performing the kick. Two separate camera views were used. A Photec IV was placed over the target and a Beaulieu was placed to the side. Filming took place at Montana State University in the Shroyer Gymnasium. The film records of the kicks were analyzed with the software *FILMDATA* on the Honeywell CP6 computer at Montana State University. The kick with the greatest total velocity of the metatarsal-phalangeal joint at foot/target impact was selected for detailed study.

Graphs of the linear velocities and accelerations of the centers-of-gravity of the thigh and leg and of the metatarsal-phalangeal joint were made from the kinematic data using *CUECHART* and *TELLAGRAF* on the VAX network at Montana State University. Angular displacements and velocities of the hip and knee joints of the kicking leg were also graphed. The relative turning of the heads, shoulders, and hips of the subjects were studied by observation of the film records. In discussing the turning hook kick, the researcher divided the turning hook kick into four sections: the plant section, the pushoff section, the third section, and the recovery section. The study was concentrated on the first three sections. Movement times for each of the first three sections were calculated from the film records.

The kinematic data indicated that the deceleration of the thigh prior to foot/target contact may be causally related to the acceleration of the metatarsal-phalangeal joint and to the y-acceleration of the leg. From observations of the turning of the head, shoulders, and hips, it was concluded that differential turning of these parts of the body may have the effect of slowing the turning of the total body. The majority of the movement time was spent in the first and third sections of the kick. Investigation into the reduction of the movement times of these two sections might prove very beneficial to reducing the total movement time of this kick and improving the performance of the kick as a whole.

Conclusions

Due to the nature of the cameras, synchronizing them was impossible. Montana State University had no software capable of three-dimensional cinematographical analysis at the time of the study. Thus, a comprehensive three-dimensional description of the turning hook kick which was adjusted for problems in perspective was beyond the means of this study. Also, because the number of subjects was only three, generalizations for the rest of the population were not made. However, the following conclusions seem justified:

(1) The sequencing of the thigh and lower leg accelerations did follow those found in typical forward kicking motions (Plagenhoef, 1971; Zernicke & Roberts, 1978; and Phillips et al., 1983).

(2) Flexion of the knee immediately prior to and through foot/target contact was important for attaining a high velocity of the kicking foot. However, the time required to achieve a high angular velocity of the knee may be too long for use in a turning hook kick.

(3) Reducing the movement time of the plant phase and third section of the kick might help reduce the total movement time for these subjects.

(4) An optimum rotational inertia configuration during the plant and pushoff phases likely exists based on the subjects' ability to apply torque rapidly to the floor and to assume a low inertia position after pushoff.

Recommendations

For future study, the researcher recommends the following:

(1) EMG recordings of subjects performing the turning hook kick should be taken; of particular interest would be the gluteal hip extensors, knee extensors, and knee flexors of the legs.

(2) Force plate measurements should be taken, particularly during the plant to liftoff time and at the end of unweighting through foot/target contact.

(3) Three-dimensional cinematographical equipment and methods should be used. EMG, forceplate, and film data should be synchronized.

(4) A larger population of kickers should be used in order to permit the determination of generalizable and statistically significant conclusions.

(5) A mathematical model of a person performing the turning hook kick could be used or developed in order to explore the effects of changing various variables on rotational inertia, movement time, and foot velocity at foot/target contact.

Performance in the turning hook kick could likely be improved by developing exercises designed to increase the kicker's ability to generate torque explosively while maintaining a large rotational inertia configuration. Exercises could also be developed to increase the ability to assume a low rotational inertia position about a vertical axis quickly from a large inertia position. Finally, rapid knee flexion

immediately after full knee extension may be critical and should probably be exercised.

REFERENCES CITED

REFERENCES CITED

Ahn, B. (1985). Kinematic and kinetic analyses of Tae Kwon Do kicking motions. Unpublished master's thesis, University of Oregon, Eugene, OR.

Feld, M.S., McNair, R.E., & Wilk, S.R. (1979). The physics of Karate. Scientific American, 240, 150-158.

Joon, S.N., Guk, L.S., Jong, P.H., & Kyu, J.S. (1987). An analysis of the basic Taekwondo kicks. U.S. Taekwondo Journal: Official Magazine of the United States Taekwondo Union, Inc., 6(2), 10-15.

Kreighbaum, E., & Barthels, K.M. (1985). Biomechanics: A qualitative approach to human movement. Minneapolis, MN: Burgess.

Laws, K. (1978). An analysis of turns in dance. Dance Research Journal, 11, 12-19.

Laws, K. (1984). The physics of dance. New York: Schirmer.

Phillips, S.J., Roberts, E.M., & Huang, T.J. (1983). Quantification of intersegmental reactions during rapid swing motions. Journal of Biomechanics, 16, 411-417.

Plagenhoef, S. (1971). Patterns of human motion. Englewood Cliffs, NJ: Prentice-Hall.

Putnam, C.A. (1983). Interaction between segments during a kicking motion. In H. Matsui & K. Kobayashi (Eds.), International series on biomechanics, Vol. 4B, Biomechanics VIII-B: Proceedings of the Eighth International Congress of Biomechanics (pp. 688-694). Champaign, IL: Human Kinetics.

Roberts, E.M., & Metcalfe, A. (1968). Mechanical analysis of kicking. In J. Wartenweiler, E. Jokl, & M. Hebbelinck (Eds.), Medicine and sport, Vol. 2: Biomechanics, techniques of drawings of movement and movement analysis (pp. 315-319). Baltimore, MD: University Park Press.

Roberts, E.M., Zernicke, R.F., Youm, Y., & Huang, T.C. (1974). Kinetic parameters of kicking. In R.C. Nelson & C.A. Morehouse (Eds.), <u>International series on sport sciences, Vol. 1, Biomechanics IV: Proceedings of the Fourth International Seminar on Biomechanics</u> (pp. 157-162). University Park, PA: University Park Press.

Steiner, M. (1987). [Biomechanical analysis of the turning hook kick.] Unpublished raw data.

Warwick, J. (1987, October). [The turning hook kick.] Unpublished interview.

Zernicke, R.F., & Roberts, E.M. (1978). Lower extremity forces and torques during systematic variation of non-weight bearing motion. <u>Medicine and Science in Sports, 10</u>, 21-26.

APPENDICES

APPENDIX A:

INFORMED CONSENT FORM

INFORMED CONSENT FORM:

Analysis of the Taekwondo Turning Hook Kick

Biomechanical research in the sport area of the martial arts has been scant. The turning hook kick in Taekwondo has been selected for this study as a taking-off point for analysis in this field. We are asking your permission to film you performing a series of ten turning hook kicks. Filming will be done from directly above you and from one side with 16mm high speed motion picture cameras. We are asking male subjects to wear only shorts and female subjects shorts and a tank top so that the motions of your limbs and joints are not concealed by overlying clothing. Adhesive markers will be affixed to you at the wrists, elbows, shoulders, top of the pelvis (iliac crests), hips, knees, ankles, and balls of the feet. These markers will aid in analyzing the films.

All film records will be the property of the Montana State University Department of Health and Human Development. Since the films are full body films, subjects will be able to be identified. However, film records will be completely confidential. Any use of the films for publication or presentation to professionals will not contain the names or addresses of the subjects.

Subjects of the films are invited to view the films in order to evaluate their own technique. A full account of the results of the study will be provided to the subjects.

In the event your participation in this research directly results in injury to you, assistance to the nearest emergency medical services will be available, but there is no compensation for such injury. Further information about this treatment may be obtained by calling Ellen Kreighbaum at 994-6341.

Authorization: I have read the above and understand the discomforts, inconvenience, and risk of this study. I, _____,
agree to participate in the research. I understand that I may refuse to participate or that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed:_____

Witness:_____

Investigator:_____

Date:_____

APPENDIX B:

SUBJECT DATA SHEETS

SUBJECT DATA SHEET

Subject: SM

Height: 6'3½" (191.8 cm)

Weight: 218# (969.7 N)

Segment Lengths (centimeters):

Biacromial Width: 47

Upper Arm (right):   36   (left):

Lower Arm (right):   27   (left):

Trunk: 43

Biiliac Width: 33

Pelvis: 16

Thigh (right):   46   (left):

Leg (right):   47½   (left):

Foot (right):   15   (left):

Other (e.g., injuries, illness):

SUBJECT DATA SHEET

Subject: HT

Height: 5'9" (175.3 cm)

Weight: 150# (667.2 N)

Segment Lengths (centimeters):

Biacromial Width: 31

Upper Arm (right):   32½   (left):

Lower Arm (right):   27   (left):

Trunk: 39

Biiliac Width: 31

Pelvis: 18

Thigh (right):   43½   (left):

Leg (right):   40   (left):

Foot (right):   14   (left):

Other (e.g., injuries, illness):

SUBJECT DATA SHEET

Subject: JW

Height: 6'1" (185.4 cm)

Weight: 173# (769.5 N)

Segment Lengths (centimeters):

Biacromial Width: 47

Upper Arm (right):   34   (left):   33½

Lower Arm (right):   27   (left):

Trunk: 43

Biiliac Width:

Pelvis: 18

Thigh (right):   40   (left):

Leg (right):   45   (left):

Foot (right):   15   (left):

Other (e.g., injuries, illness):

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