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

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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Scot Gerald Wohlin

This thesis has been read by each member of the graduate committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

6/15/89
Date

Ellen Knighton
Chairperson, Graduate Committee

Approved for the Major Department

6/15/89
Date

Head, Major Department

Approved for the College of Graduate Studies

July 12, 1989
Date

Henry L Parsons
Graduate Dean

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Date June 15, 1989

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES--Continued

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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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.

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

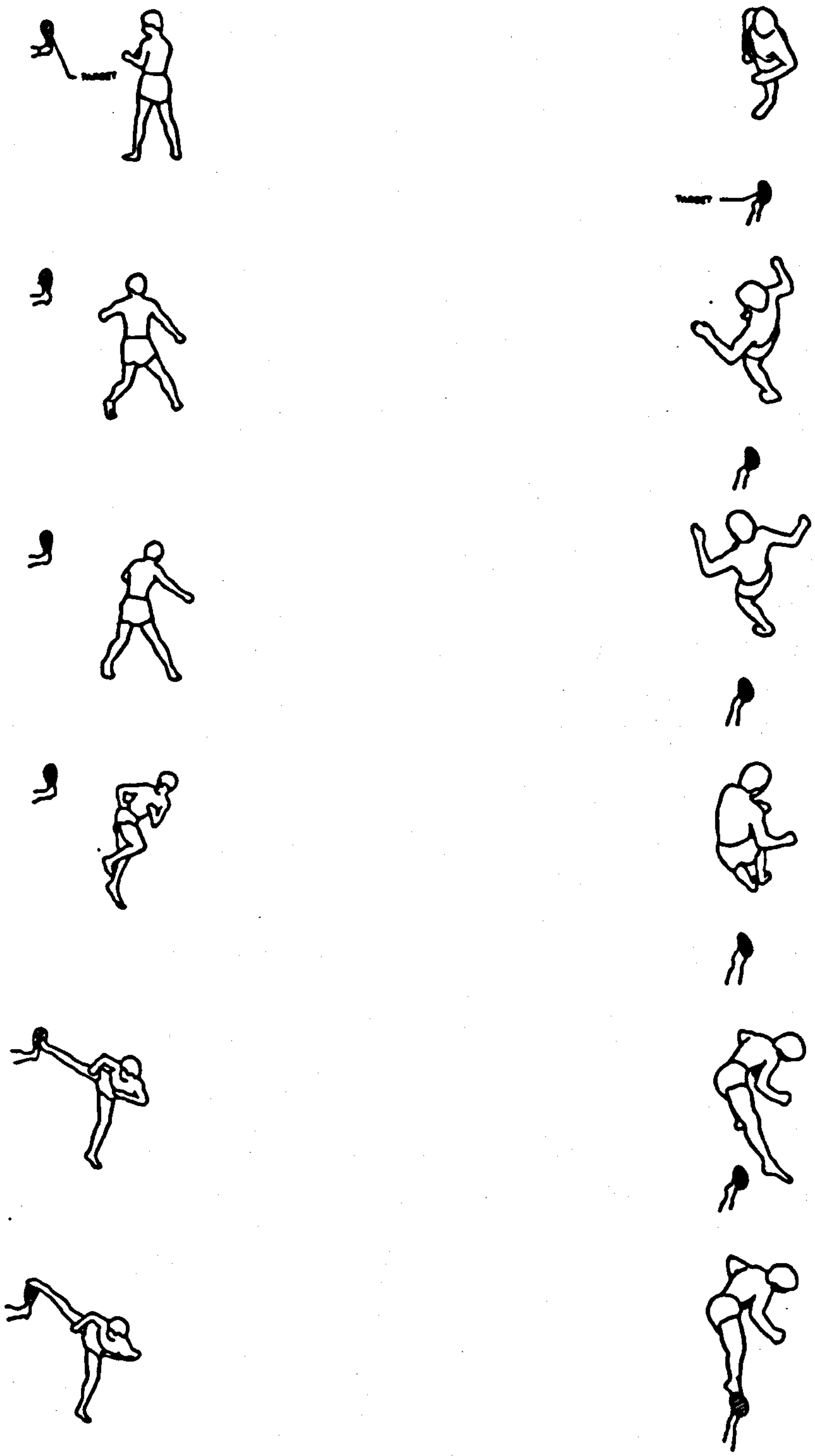

Figure 1. The turning hook kick from initial stance to foot/target contact: Side and top views.

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.

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

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

(3) Support leg: 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) Torque: 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.

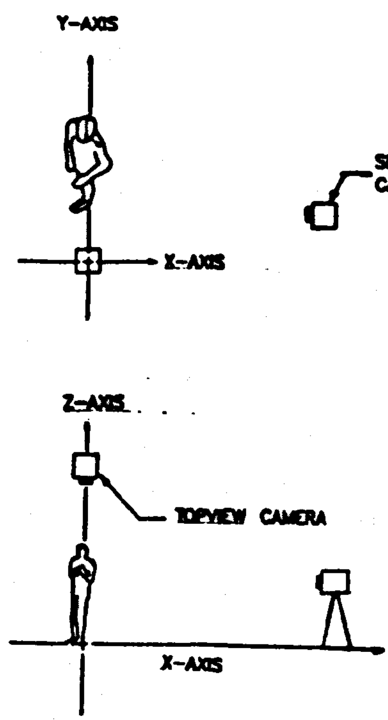

Figure 2. Filming schematic.

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 estimated. 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.

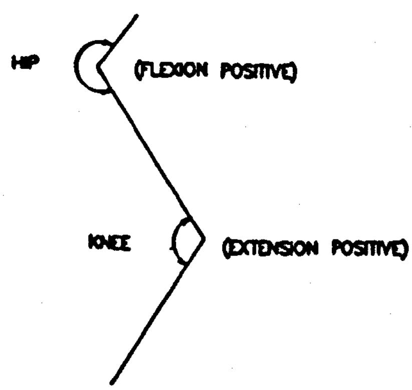

Figure 3. Hip and knee angles.

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.

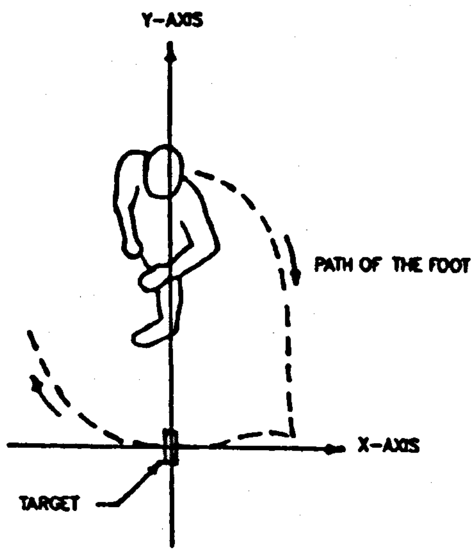

Figure 4. Coordinate system convention.

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.

	Subject		
Characteristics	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.

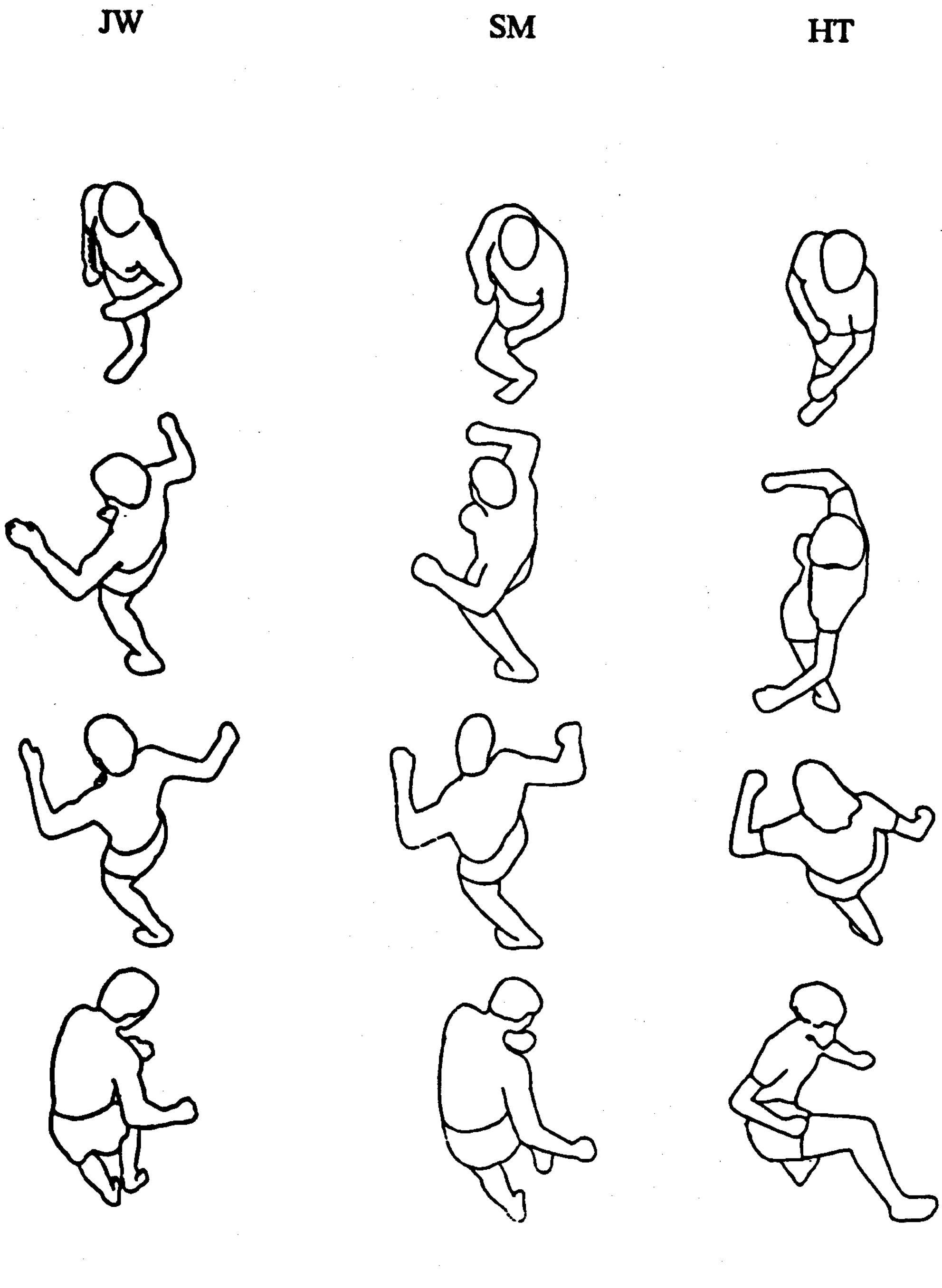

Figure 5. Differential turning of the head, shoulders, and hips.

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

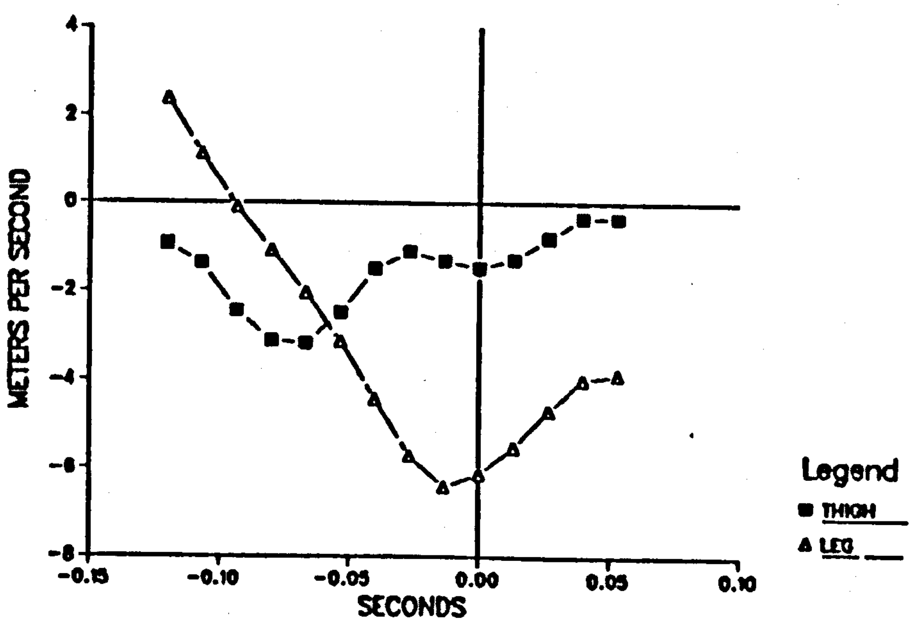

Figure 6. JW: X-velocities of the thigh and leg centers-of-gravity.

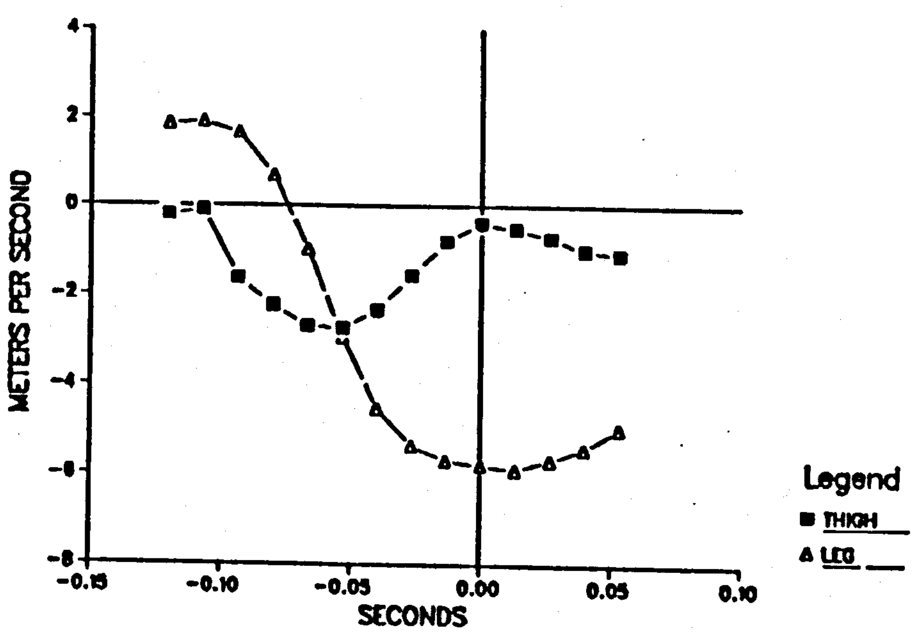

Figure 7. SM: X-velocities of the thigh and leg centers-of-gravity.