A BIOMECHANICAL ANALYSIS OF THE AERIAL CARTWHEEL

A THESIS

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The science of gymnastics is born in a man
and grows right along with him
- Philostratus

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

ORIENTATION TO THE STUDY

Introduction

In a sport such as gymnastics, particularly competitive gymnastics, success and proper mechanics of performance are inseparable. Because of the emphasis on detail and technique in skill execution, it is essential that those interested in gymnastics analyze skills scientifically in order to accurately describe proper technique. These findings must then be reported to the coaches so that practical application can occur.

Frederick (1969) stated "The body of literature dealing with the problems and techniques of gymnastic analysis and related areas has developed very slowly from the late 1930's" (p. 234). Frederick reported that it was not until the sixties that a true interest was recognized.

At the 1969 International Gymnastic Symposium held in Macalen, Switzerland, several speakers pointed out the need for scientifically based research. In a review of the symposium by Aronson (1969), he quoted Abe from Japan as saying, "The Japanese federation has set up basic principles to follow and will seek future development in research of mechanical analysis" (p. 23). Aronson (1969) also quoted Appelt from Czechoslovakia as saying,

> Continued research with mechanical analysis along with the use of science and psychology is of prime importance in Czech gymnastics. Psychology, sociology, and biomechanics are all playing a role in developing the all-around gymnast. The coach and gymnast must consider a wider variation of combinations and do continued research of human movement. (p. 24)

Another speaker from Czechoslovakia, Karas, had a great deal to say about biomechanical research in gymnastics. His basic premise was that an understanding of the mechanics of human movement is a prerequisite to good coaching. Because of the complexity of gymnastic movements, there seems to be no end to what can be analyzed. Aronson (1969) quoted Karas as follows, "Time, space, Newton's laws, moments of force, acceleration, vectors, are all important in determining the correct movements for gymnastics" (p. 26).

The present investigation involved a biomechanical analysis of an aerial cartwheel. The aerial cartwheel was chosen for three reasons:

1. It is a movement that is basic to women's floor exercise.

2. A female gymnast wishing to excel in tumbling should include the aerial cartwheel in her repertoire.

3. Little scientifically based knowledge is available on the aerial cartwheel.

Nelson (1976) pointed out that little research has been done concerning optimal performances of aerial cartwheels. He stated, "Most of the information which could be found was based on authoritative opinions and little agreement existed among them" (p. 75).

For the most part, any information which could be found pertaining to the proper execution of the aerial cartwheel is contained in gymnastic skill instruction books (Cooper, 1979; Drury, 1977; Murray, 1979). These publications give limited information concerning the improvement of performance once the basic movements are learned.

In a study under the direction of Nelson (1976), the aerial cartwheel was analyzed in an attempt to quantify and compare selected mechanical factors which vary with different performance levels. It should be noted here that even though this study was entitled "A Biomechanical Analysis of the Aerial Cartwheel" (Nel, 1976, p. 76), Biesterfeldt (1976), in a review of the study stated, "Despite the title, this paper contains no biomechanics. It is a statistical analysis of correlation between scores awarded by 'experts' and features of performances as obtained from films of the performers" (p. 75).

Nelson (1976) recommended that,

> three dimensional cinematography should be implemented in order to more accurately analyze the motions of the body, specifically, the arms and shoulders, which can not be satisfactorily studied using only one camera. (p. 77)

In order to see all phases, body positions, and body segments, a multiple camera system was used in this investigation.

Purpose of the Study

The primary purpose of this study was to determine through the use of cinematography, selected biomechanical variables involved in the performance of an aerial cartwheel. It was hoped that the information obtained could provide the gymnastic coach/teacher with a better understanding of the skill.

Statement of the Problem

The study entailed a biomechanical analysis of the aerial cartwheel as performed by a highly skilled female gymnast. According to the rating system of the United States Gymnastic Federation, the subject was ranked eleventh in the United States just prior to the XX World Gymnastic Championships.

The study involved the filming of the subject utilizing a multiple camera system to record the front and side views of the aerial cartwheel. Through analysis of the film, the investigator attempted to determine the critical mechanical factors in the performance of the aerial cartwheel.

Research Questions of the Study

For this investigation, the following questions will be addressed.

1. What angles of push-off knee flexion and extension are exhibited in the take-off phase of the aerial cartwheel?

2. What is the velocity of the thigh of the push-off leg extension, after maximum push-off knee flexion?

3. What are the forces applied to the ground during the take-off phase?

4. What velocities of the thigh of the kicking leg are exhibited in the take-off phase of the aerial cartwheel?

5. What hip positions are exhibited in relation to the push-off and landing foot during the aerial cartwheel?

6. What path does the center of gravity follow throughout the skill?

Definitions and/or Explanations

For the purpose of clarification the following terms are defined:

Cinematography: "Cinematography is the study of human performance through the use of motion picture film" (Northrup, Logan & McKinney, 1974, p. 221).

Biomechanics: "Mechanics is the study of forces and their effects. The application of these mechanical principles to human and animal bodies in movement and at rest is biomechanics" (Leveau, 1977, p. 1).

Aerial Cartwheel:

This is a leg skill (requiring power from the legs); therefore, from the lunge position (stride position, first or front leg bent, second or rear leg straight, shoulders directly over the hips, arms relaxed at the sides), the gymnast lifts her rear leg up and over. She passes through the side plane as if performing a cartwheel without the hands. The gymnast then lands the skill foot after foot. (Murray, 1979, p. 46)

Push-off leg: The leg (the front or lead leg) which thrusts the body upward during the take-off phase.

Take-off phase: The period of time which begins with the first frame in which the kicking leg is in contact with the mat, and ends at the first frame in which the push-off leg leaves the mat.

Take-off: The action shown in the last frame in which the push-off leg is in contact with the mat.

Flight phase: The period of time when no part of the gymnast's body is in contact with the mat.

Landing: The contact of the kicking leg (the lead leg) with the mat after the flight phase.

P-1: The camera used to record the front view of the aerial cartwheel at 300 frames per second. The 16mm P-1 camera was manufactured by Photo-Sonics, Inc.

Locam: The camera used to record the side view of the aerial cartwheel at 300 frames per second. The 16mm Locam, model number 51-0003, was manufactured by the Redlake Corporation.

Limitations and Delimitations of the Study

The study was subject to the following limitations and delimitations:

1. The investigation was delimited to one subject who was selected by the investigator on the basis of the subject's ability and national ranking.
2. The investigation was delimited to the use of a two-camera system.
3. The investigation was limited to the ability of the panel of experts to select the aerial cartwheel that was best in terms of correct execution and technique, and to the reliability of the investigator in analyzing the films.

Review of Literature

A survey of the related literature revealed no previous research which was identical to this investigation. The information presented in this section includes studies which were deemed pertinent to the investigation. Although biomechanical studies of gymnastic skills have been done, little research has been reported which was applicable to this investigation. Most of the review represents a sample of authoritative opinions that exist concerning the aerial cartwheel. This review will be divided into two parts: (a) Research Studies Related to the Aerial Cartwheel, and (b) Authoritative Opinions Related to the Aerial Cartwheel.

Studies Related to the Aerial Cartwheel

Splithoorn (1973) studied the single foot take-off for various tumbling skills. The take-off phase included the run, the hurdle, and the beginning of the skill. Splithoorn stated, "These three parts were the subject of this scientific and comparative study, because it had been determined that success of a move is largely determined by the introductory part" (p. 34). This is true in the aerial cartwheel.

The films were taken in the sporthall of the Higher Institute of Physical Education of the Free University of Brussels. Two subjects were studied, both of whom were Belgian champions. Each subject was filmed performing the various single foot take-off gymnastic skills. These films were then compared to the most recent films of world and Olympic champion gymnasts. The analysis consisted of a qualitative observation of the films. Following this, various mechanical factors of each skill were discussed.

It was found that in somersaults and tumbling moves with a floating period, such as the aerial cartwheel, the body leaves the floor completely after the take-off. In the aerial cartwheel, however, the rotation must be completed without the use of the hands. Splithoorn concluded that the take-off phase has much to do with the successful rotation of the aerial cartwheel.

Splithoorn cited several mechanical factors associated with the hurdle and take-off phase of the aerial cartwheel:

> During the hurdle, the gymnast swings the arms more forcefully upward. This will give him the opportunity to use the arms to their best advantage. The forward inclination, due to speed, is not lessened, but causes a hyperextension in the hips and shoulders. The stretched position allows both arms to be pulled down quicker and the hips to be flexed more forcefully. For the aerial cartwheel, a good gymnast often chooses the more aesthetic form with the stretched arms. The pushing leg, the swinging leg, and the arms, are elements to gain height and rotation in the aerial cartwheel. (p. 37)

Splithoorn felt the extension of the pushing leg is a factor in determining the height of the skill, while the arms accentuate the rotation. He believed that the center of gravity has already passed the pushing foot at this point, so that the extension of the pushing leg and the movement of the swing leg act solely in favor of rotation.

Nelson (1976) conducted a study of the aerial cartwheel. The primary purpose of the study was to quantify and compare selected mechanical factors of the aerial cartwheel with the intent being to identify the factors which vary with differing levels of performance.

Subjects for this study were 17 female gymnasts, ranging in age from 15 to 24 years. The subjects were videotaped performing the aerial cartwheel. A Vanguard Motion Picture Analyzer was used to collect X and Y coordinates from the film. Following the film analysis, a computer program calculated time, distance, angles, and velocities based on the X and Y coordinates.

Based on the results of the study, the investigator indicated that the hurdle length, hip position, angle of maximum knee flexion, and the average velocity of extension after maximum knee flexion were the most critical factors in determining the performance quality of the aerial cartwheel.

Nelson stated:

> Based upon the findings and within the limitations of this study, successful aerial cartwheels are characterized by a long preliminary step, a marked velocity of extension of the pushing leg, and the mid-hip being horizontially proximal to the push-off ankle at take-off. (p. 77)

It should be noted that both studies focused primarily on the take-off phase of the aerial cartwheel. Little attention was given to the mechanics of the upper body (head, arms and shoulders), and the landing. In order to have successfully reported the data on the upper body, a two-camera system would need to have been employed. Only one camera was used in the previously mentioned studies.

Authoritative Opinions Related to the Aerial Cartwheel

Cooper (1973) gave the following advice and directions on performing the aerial cartwheel:

> From the hurdle, step forward, keep the head and chest high, and not allowing the chest to go forward of the foot position. Forcefully swing the right leg back-upward; then immediately push very strongly with the left foot.

> Put arms up on the hurdle, and as the swing leg action is started, swing them down to the sides of the body. The arms may keep moving with the body or may be brought to the side of the body and bend and remain in this position throughout. As the right foot lands on the mat, followed by the left foot, lift the head and chest. (p. 42)

In addition to this explanation, Cooper listed some common errors that can be associated with a poor performance of the aerial cartwheel.

1. Uncoordinated hurdle.

2. Allowing the shoulders and head to drop too far forward or move forward of the feet.

3. Insufficient swing, push of the leg, or both.

4. Not allowing the body to make a quarter turn as the push foot leaves the mat.

5. Failure to continue lifting head and chest upon landing. (p. 43)

Schmid and Drury (1977) described the aerial cartwheel in a simplified manner, neglecting the hurdle and take-off. Their directions were simplified by explaining how to perform a cartwheel, without the use of the hands. The authors mentioned that the arms (straight or bent) may be used to increase rotation. No mention was made of the take-off leg as an aid in rotation.

Murray (1979) gave a more thorough description of the aerial cartwheel in her gymnastic textbook. The description is as follows:

> The gymnast stands in a lunge position and extends her rear leg and then her front leg. She maintains the position of her shoulders over her hips while she lifts fore-upward from the floor. From the lunge position and using her legs to get as much lift as possible without piking, the gymnast performs a cartwheel. (p. 48)

Following this explanation, Murray presented a list of corrections the gymnast could make if problems are encountered while performing the aerial cartwheel. Several errors in body position were discussed. Again, arms were mentioned, but they were not described as being necessary for rotation. "This is a leg skill, and because the arms are not necessary for rotation, they usually create and exaggerate improper technique" (Murray, 1979, p. 48). The author indicated that the arms should be held loosely at the sides.

Murray believed a tucked head would cause the rotation to be lower. Thus, the head position should be up throughout the skill. Finally, a change of position of the shoulders over the hips (piking at the waist) would cause a poor performance of the aerial cartwheel; thus, a straight body position should be maintained throughout the skill.

Murray also believed the aerial should be taught from a standing position with no run before the hurdle step. It was her belief that this particular teaching technique needed to be reinforced by the teacher/coach as the student starts to learn this skill. If a run was added before the gymnast understood that her take-off leg must be bent at take-off, the possibility of performing the skill from a straight front leg could result. "Erroneously, the gymnast thinks she can get enough power and lift to rotate her body from ankle extension" (Murray, 1979, p. 48).

Murray stated,

> A well-bent knee in the first or front leg of the lunge is essential. The gymnast must use all the leg strength available. The quadriceps and hamstrings are the major muscle groups involved. This error often occurs when a run precedes the skill. (p. 48)

Finally, she explained that a loose body in the air could cause the force from the impetus to dissipate and a poor aerial cartwheel would result.

As one can see, most of the descriptions are very sketchy; each author has developed the teaching techniques for the aerial cartwheel without regard for the specific mechanics required for a good performance. Each author seemed to emphasize different aspects of the skill, with the specifics of how, when, where, and why left unanswered.

The use of a multiple camera system in this investigation has allowed the collection of data not possible by a single camera. Because of the limitations of single camera data, the recommendation of such investigators as Bergemann (1974), Hall (1978), and Miller and Petak (1973), have been followed. All support the three-dimensional analysis of film.

CHAPTER II

PROCEDURES IN THE DEVELOPMENT OF THE STUDY

The purpose of this investigation was to examine through the use of cinematography, selected kinematic and kinetic aspects of the aerial cartwheel. The present chapter entails the procedures used. The preliminary procedures, selection and description of the subject, selection and description of the instruments, procedures followed in collection of the data, procedures followed in the analysis of the data, and the preparation of the final written report are included.

Preliminary Procedures

Prior to initiating the study, several preliminary procedures were followed. Since a human subject was involved, approval was obtained from the Texas Woman's University Human Subjects Review Committee.

The investigator surveyed information from documentary and human sources which was related to the investigation. A tentative outline of the study was formulated and approved by the thesis committee. A prospectus of the approved study was filed in the Graduate School at the Texas Woman's University. Arrangements were made to use the necessary equipment and facilities.

Procedures in the Selection of the Subject

Since this study was to be descriptive in nature, it was deemed necessary to obtain the best possible performance of the aerial cartwheel. While the XX World Gymnastic Championships were being held in Fort Worth, Texas, December, 1979, several American coaches were contacted for permission to film their gymnasts. Of those coaches who gave permission, the investigator chose the one gymnast with the highest national standing according to the United States Gymnastic Federation Ranking System. The subject selected agreed to participate in the study and signed a consent form permitting the investigator to use the film data for educational purposes. The subject's resume appears in the appendix.

Procedures in the Collection of Data

Preparation of the Subject

Personal data including height, weight, age, years of gymnastic experience and honors or awards received, were provided by the subject. The subject was instructed to wear a regulation competition leotard for the filming session.

One practice session was held to instruct the subject as to the protocol to be followed in the filming of the aerial cartwheel. Several practice aerial cartwheels were performed to ensure proper filming procedures.

Preparation of the Filming Site

An outdoor area on the Texas Woman's University campus was chosen as the site for data collection. Two cameras were arranged at 90 degrees to each other, in order to collect film data from both the front and side views. Each camera was loaded, positioned, leveled, and focused. Measurements were taken from camera lens to the ground, and from camera to the center of the performance area. A black marker was put in the field of view of both cameras to serve as the focal point. The distances from each camera to the focal point were recorded. A piece of tape was placed on the mat to mark the take-off point of the aerial cartwheel. A complete description of the instrumentation used to collect the data may be found in Table 1.

Graduate students who were enrolled in the Department of Physical Education during the fall of 1979 volunteered to serve as members of the film crew for the study. The crew members were oriented to the study and the instrumentation to be used. Each assisted in the set up of the filming site and operated the cameras during the data collection process.

Table 1

Description of Instruments Used for Data Collection

16mm Camera	Lens	Operating Speed	Shutter Opening	Distance in feet from lens to ground	Distance in feet from camera to origin	Distance in feet from camera to subject
P-1 Photosonics	Angenieux Zoom F12-75mm	300 fps	1/3	3' 9"	49' 1/4"	42' 4"
Model 51 Redlake Locam	Angenieux Zoom F12-120mm	300 fps	1/3	3' 9"	26' 2"	31' 6"

Collection of the Data

Immediately prior to the data collection, the procedures were simulated with the subject and film crew members. Necessary adjustments were made before the actual filming took place.

In order to provide a known measure, film data were recorded by both cameras of a meter stick held at waist level by the subject. Data from the frontal view were recorded at 300 frames per second with a P-1 Photosonic motion picture camera. Data from the sagittal view were collected with a Model 51 Locam motion picture camera; it was also set at an operating speed of 300 frames per second. The film used in the study was Kodak TRI-X Reversal Film 7278.

Several trials of the aerial cartwheel were recorded. As a means of documenting the research process, color slides were taken. The film data were submitted to PSI Film Laboratories, Dallas, Texas, for processing.

Procedures in Analyzing the Film Data

The following steps in analyzing the film data were taken: (a) selection of the aerial cartwheel to be analyzed, (b) synchronization of the front and side view data, and (c) selection of mechanical procedures in analyzing of the data.

Selection of the Aerial Cartwheel to be Analyzed

After the films were processed, all trials of the aerial cartwheel were shown to a panel of judges who were rated by the United States Gymnastic Federation. After viewing all trials (6), the judges selected the trial which, to their standards, was mechanically and asthetically the best performed trial. After tabulation of the ballots, it was found that all judges agreed on the same trial as being the best. This was the trial analyzed by the investigator.

Synchronizing the Front and Side View Data

The Locam and P-1 cameras were equipped with a built-in timing light generator which flashed at the rate of 100 times per second. It was possible to verify that the cameras were operating at 300 frames per second by counting the number of frames within 100 strobe marks on the film.

There were three points clearly evident in each filmed view: (a) when the push-off foot contacted the mat, (b) when the push-off foot left the mat, and (c) when the kicking leg contacted the mat (landing). With the use of an F & B CECO/SOS Magnasync Moviola 16mm table viewer, the frames between these points in time were manually counted. By matching the three reference points, it was possible to synchronize both views for digitizing. Beginning with the frame showing the push-off foot contacting the mat, every tenth frame was digitized to the completion of the skill. This yielded 36 frames per view for analysis.

Analyzing the Data

Preliminary to analysis of the film data, attention was given to the percentage of error inherent in the digitizing process. The accuracy of the Numonics Graphic Digitizer used to obtain the data points is listed as plus or minus .020". The reliability of the investigator in digitizing the film was found to be .999981, as determined through the intraclass method (Safrit, 1973).

The film data were projected by a Lafayette Stop Action Projector via a system of three angled 45 degree mirrors via a glass top table. This system was adjusted to yield images of approximately 1/5 life size. The Numonics Graphic Digitizer was interfaced with DEC-system 2050 computer for recording the X and Y coordinates.

Data for every tenth frame, from both views, were recorded in the following order: (a) the toe touching the ground, (b) the ankle, (c) the knee, (d) the hip (same side), (e) the hip (other side), (f) the knee, (g) the ankle, (h) the toe, (i) shoulder (same side as original leg), (j) the elbow, (k) the wrist, (l) the finger tips, (m) opposite shoulder, (n) the elbow, (o) the wrist, and (p) the finger tips. These data were submitted to a program entitled DIG2C (Kelly, 1980). The output was then formulated into 3 separate link systems, each containing X and Y coordinates in a form acceptable for the program KNMTC2.FOR.

The KNMTC2.FOR program (Long, 1980) is an interactive program designed to read X and Y coordinates from two separate data files and merge them together into a single output file. This output file contained segment lengths, and absolute and relative angular displacements for each position.

LAMB.FOR, a version of the program found in Plagenhoef's Patterns of Human Motion: A Cinematographic Analysis (1971) revised by Kelly, (1980), was run on each of the three link system outputs of KNMTC2FOR. The output of LAMB.FOR contained velocities, accelerations, vertical and horizontal forces, moments of force, and location of the total body center of gravity.

The final step of this process was use of the program entitled MAKLNK.FOR (Odom, 1980); it combined the three output files of LAMB into one complete link system. This link was run through LAMB.FOR for a final time to produce the final output.

Procedures in the Preparation of the Final Written Report

The final written report was prepared by developing chapters in accordance with the tentative outline. The document was submitted to members of the thesis committee for suggestions. A summary of the research was prepared; the findings were presented, interpreted and discussed; recommendations for further studies were suggested; and appendices and references were developed.

CHAPTER III

PRESENTATION OF THE FINDINGS

The primary purpose of the study was to determine selected kinematic and kinetic aspects of an aerial cartwheel. An outdoor area on the Texas Woman's University campus was chosen as the site for data collection. Two cameras were arranged at 90 degrees to each other in order to collect data from the front and side views.

The computer program used in the analysis of the data was designed to yield data based on two-dimensional input. Data from the front and side views of the aerial cartwheel were merged to obtain a theoretical third view. Data obtained from this program should be viewed not as absolute in value, but in a relative sense because the computer program was validated on a motion which maintained ground contact. Because of the massive volume of raw data resulting from the study, the data are not reproduced in this document.

In this chapter the findings of the investigation are presented and discussed under the following headings: (a) Description of the Subject, (b) Knee Flexion and Extension of the Push-off Leg, (c) Velocity of the Thigh of the

Push-off Leg, (d) Pattern of Force Applied to the Ground, (e) Velocity of the Thigh of the Kicking Leg, (f) Hip Position Relative to the Take-off and Landing Foot, and (g) Excursion of the Total Body Center of Gravity

Description of the Subject

One female gymnast was selected on the basis of ability and national ranking. At the time of data collection, the subject was ranked 12th in the United States. Table 2 presents descriptive data relative to the subject.

Table 2

Descriptive Data of the Subject

Age	Height	Weight	Years of Experience
15	5' 1/2"	98 Lbs.	6

The subject had 6 years of gymnastic experience and had competed in several national and international meets. The subject's height was 5 feet, 1 and 1/2 inches, and she weighed 98 pounds.

Knee Flexion and Extension of the Push-off Leg

Of interest to the investigator was the amount of knee flexion and extension exhibited by the push-off leg during the take-off phase. Table 3 presents the angles of knee flexion and extension exhibited by the subject during the take-off phase of the aerial cartwheel.

Table 3

Knee Flexion and Extension of the Push-off Leg During the Take-off Phase

Position	Angle[a] (in degrees)		Movement of the Knee
1	140	(2.44)	Flexion
2	126	(2.19)	Flexion
3	123	(2.14)	Flexion
4	122	(2.12)	Maximum Flexion
5	122	(2.12)	
6	122	(2.12)	
7	124	(2.16)	Extension
8	130	(2.26)	Extension
9	164	(2.86)	Extension
10	180	(3.14)	Maximum Extension

Note. Position 1 is initial ground contact. Ten frames of film exist between each position analyzed.

[a]The angle represented is the angle between the shank and thigh of the push-off leg, measured behind the knee.

Values in parentheses are expressed in radians.

As shown in Table 3, at initial ground contact, the knee of the subject's lead leg was positioned at an angle of 140 degrees. Table 3 also reveals that the deepest degree of knee flexion (122 degrees) was maintained over a longer time span than any other position. This enabled the rear leg to develop sufficient speed and momentum to assist in rotation.

It can also be seen that the knee of the subject's lead leg reached a position of complete extension (180 degrees) while still maintaining ground contact. This extension to 180 from the exhibited position of maximum knee flexion enabled the subject to utilize 100% of the thrust initiated by the push-off leg.

Velocity of the Thigh of the Push-off Leg

The calculated angular velocities of the thigh of the push-off leg from maximum knee flexion to extension are presented in Table 4. Values were determined using the hip as the axis.

Table 4

Angular Velocity of the Thigh of the Push-off Leg From Maximum Knee Flexion to Extension

Position	Displacements (Radians)	Velocity (Radians/Sec.)
4	.01	.33
5	.06	2.00
6	.10	3.30
7	.13	4.30
8	.17	5.60
9	.24	8.00
10	.40	13.33

Average Angular Velocity = 6.38

Note. Position 4 is maximum knee flexion; position 10 is maximum knee extension.

Table 4 reveals that a steady increase in angular velocity occurred beginning at the point of maximum knee flexion and continued to maximum leg extension. The last two positions of leg extension exhibited the highest velocity. The average angular velocity from maximum knee flexion to extension was found to be 6.38 radians/second.

Figure 1 graphically illustrates the velocity of the thigh of the push-off leg following maximum knee flexion. At maximum knee flexion, the angular velocity of the thigh

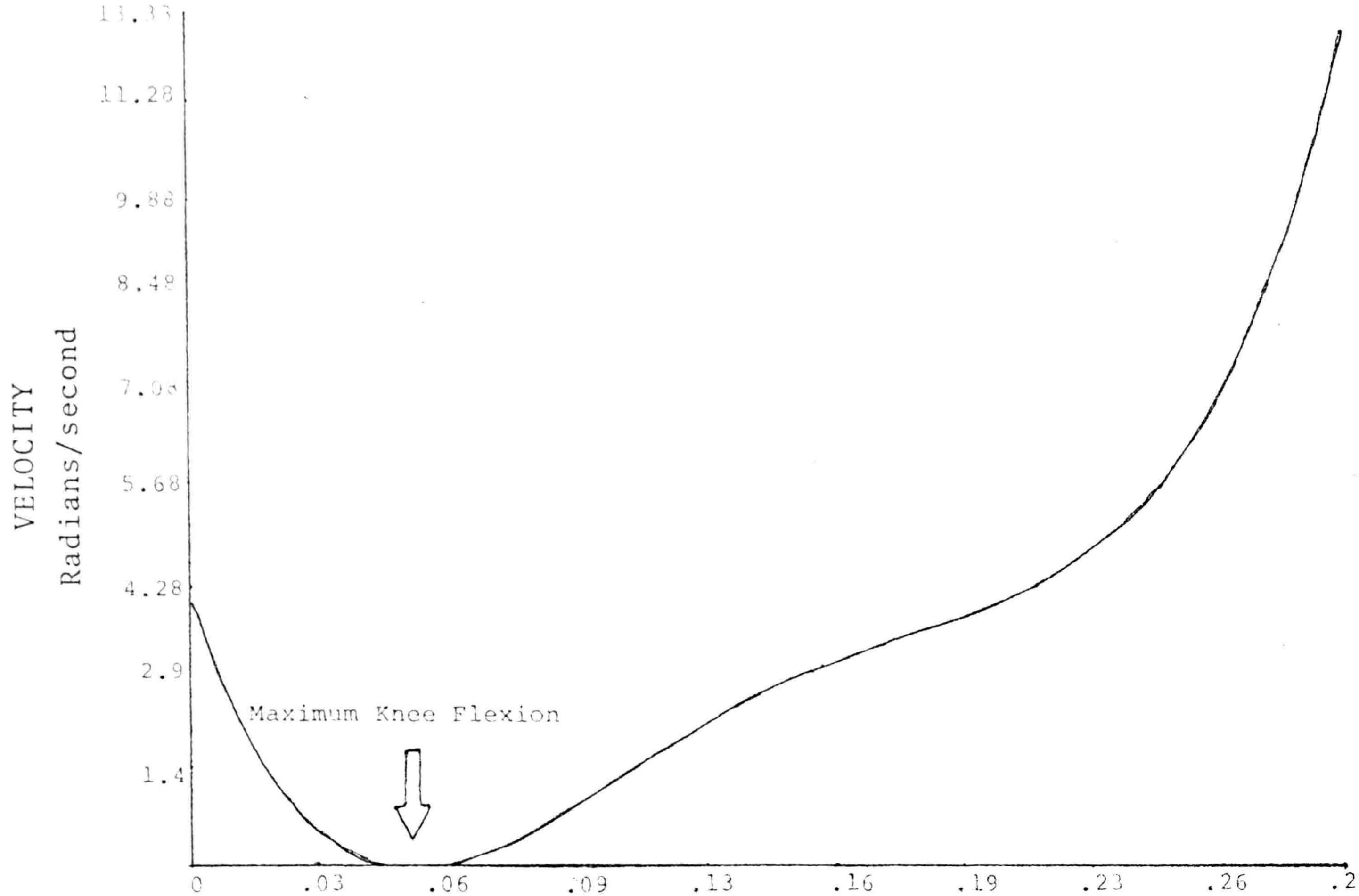

Figure 1. Velocity of the thigh of the push-off leg.

approached zero. As the push-off leg extended, a steady rate of velocity was seen.

Just prior to take-off, knee extension and velocity of the thigh of the push-off leg increased greatly. Figure 1 illustrates that this was the period of time of the highest velocity of the thigh.

Pattern of Force Applied to the Ground

Figure 2 graphically presents the force curve of the take-off phase of the aerial cartwheel. As the knee of the push-off leg moves toward maximum flexion, a steady increase in force production is seen. The force curve reveals a slight decrease in force during maximum flexion, indicating that a hesitation prior to extension took place at this time. This slight hesitation enabled the kicking leg to begin movement, hence developing sufficient speed in order to coordinate lift along with extension of the push-off leg.

As the push-off leg resumed extension, the pattern of force increased. When the push-off leg reached maximum extension, the line of the center of gravity moved to a position perpendicular to the push-off foot. This shift accounted for the large amount of force needed to complete maximum extension. Figure 2 indicates that the amount of force exerted at take-off was 242.5 pounds.

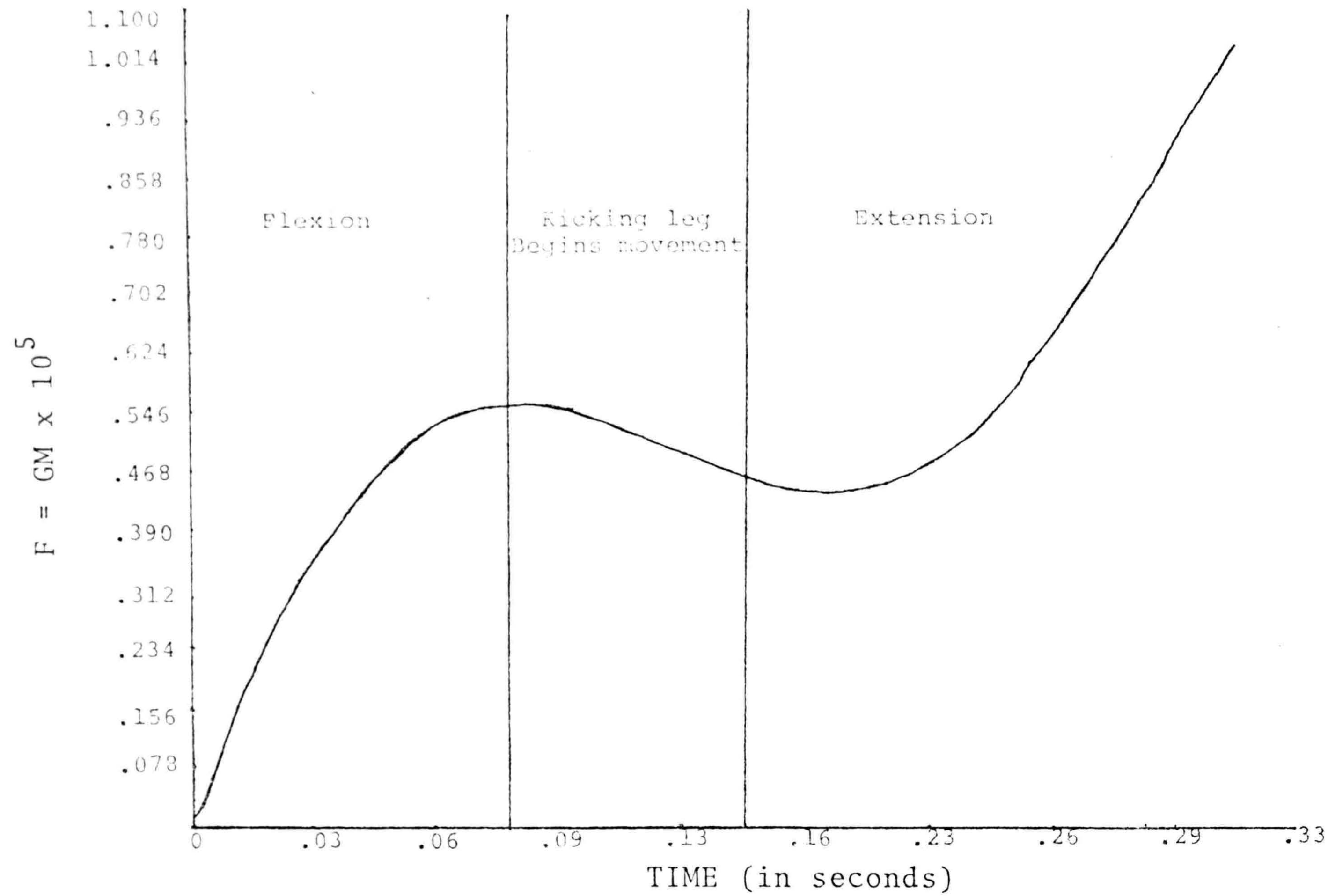

Figure 2. Force curve of the take-off phase.

Velocity of the Thigh of the Kicking Leg

Table 5 presents the calculated angular velocities of the thigh of the kicking leg during the take-off phase of the aerial cartwheel. Values were determined using the hip as the axis.

Table 5

Angular Velocity of the Thigh of the Kicking Leg in the Take-off Phase

Position	Displacement (Radians)	Velocity (Radians/Sec.)
2	.03	1.16
3	.15	5.00
4	.24	8.00
5	.26	8.72
6	.27	9.30
7	.31	10.50
8	.33	11.05
9	.36	12.21
10	.38	12.79
Average Angular Velocity = 7.97		

The greatest change in velocity occurred directly after the thigh began moving. A steady increase in velocity was seen as the thigh continued to move in an upward direction. The average angular velocity from ground contact to maximum height was found to be 7.97 radians/second.

Figure 3 graphically illustrates the velocity of the thigh of the kicking leg during the take-off phase of the aerial cartwheel. The greatest increase in velocity occurred just after the thigh began its movement. A steady increase in velocity was exhibited at subsequent positions.

Hip Position Relative to the Take-off and Landing Foot

The hip position in relation to the push-off foot during the take-off phase of the aerial cartwheel was investigated. Figure 4 presents these position data in graphic form. As can be seen in the figure, the hips were behind the ankle of the push-off foot at the beginning of the take-off phase. At maximum knee flexion, the hips had moved forward, closer in with the foot; they remained behind the ankle. At take-off, the hips were directly in line with the foot. This position allowed the force from the extension of the push-off leg to be exerted most efficiently. This may have aided in the production of the most efficient lift and rotation.

The positions of the hips in relation to the landing foot during the landing phase are shown in Figure 5.

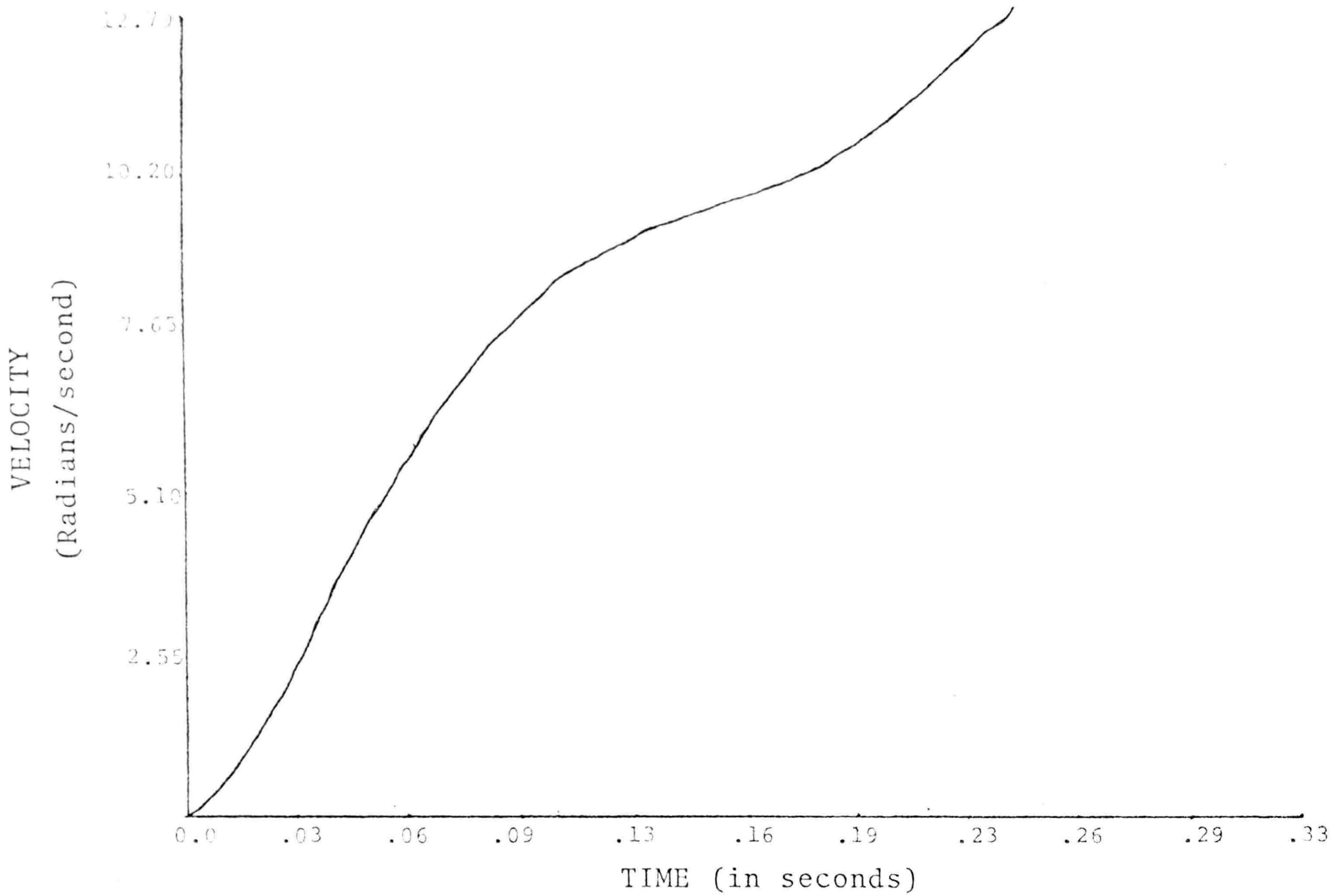

Figure 3. Velocity of the thigh of the kicking leg.

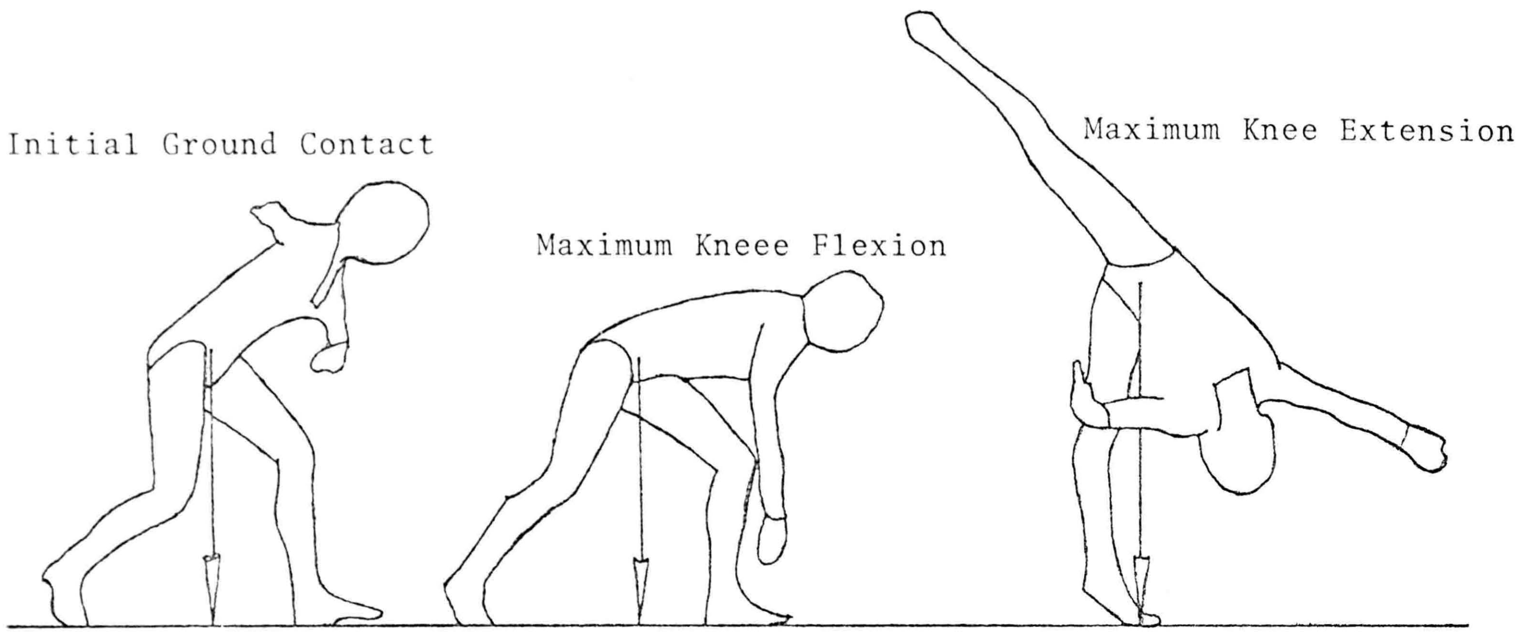

Figure 4. Hip positions relative to the take-off foot.

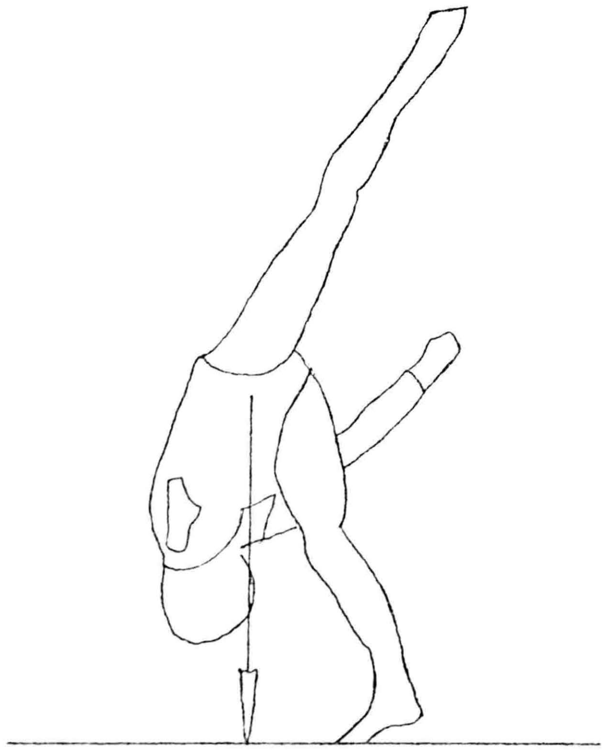

Figure 5. Hip positions relative to the landing foot.

The hips were found to be in front of the landing foot at initial ground contact. The subject's total weight had not yet been placed on the landing leg at this time. This allowed the performer to absorb the force of the landing most effectively. As the hips moved toward the landing foot, more weight was placed on that foot. If, for instance, the hips were directly over the landing foot at initial ground contact, a greater amount of force would be encountered by the leg. This could result in injury, as the performer would have a more forceful landing.

Excursion of the Total Body Center of Gravity

The graph of the excursion of the total body center of gravity may be found in Figure 6. During the take-off phase of the aerial cartwheel, vertical displacement of the center of gravity was evident. This was primarily because of flexion of the knee of the take-off leg, flexion of the trunk, and movement of the arms in a downward direction.

At take-off, the center of gravity rose with the marked extension of the push-off leg. As the subject rotated and assumed an inverted position, the center of gravity leveled off (flight), and then dropped vertically in preparation for the landing. The lowest position of the center of gravity was reached as the subject landed.

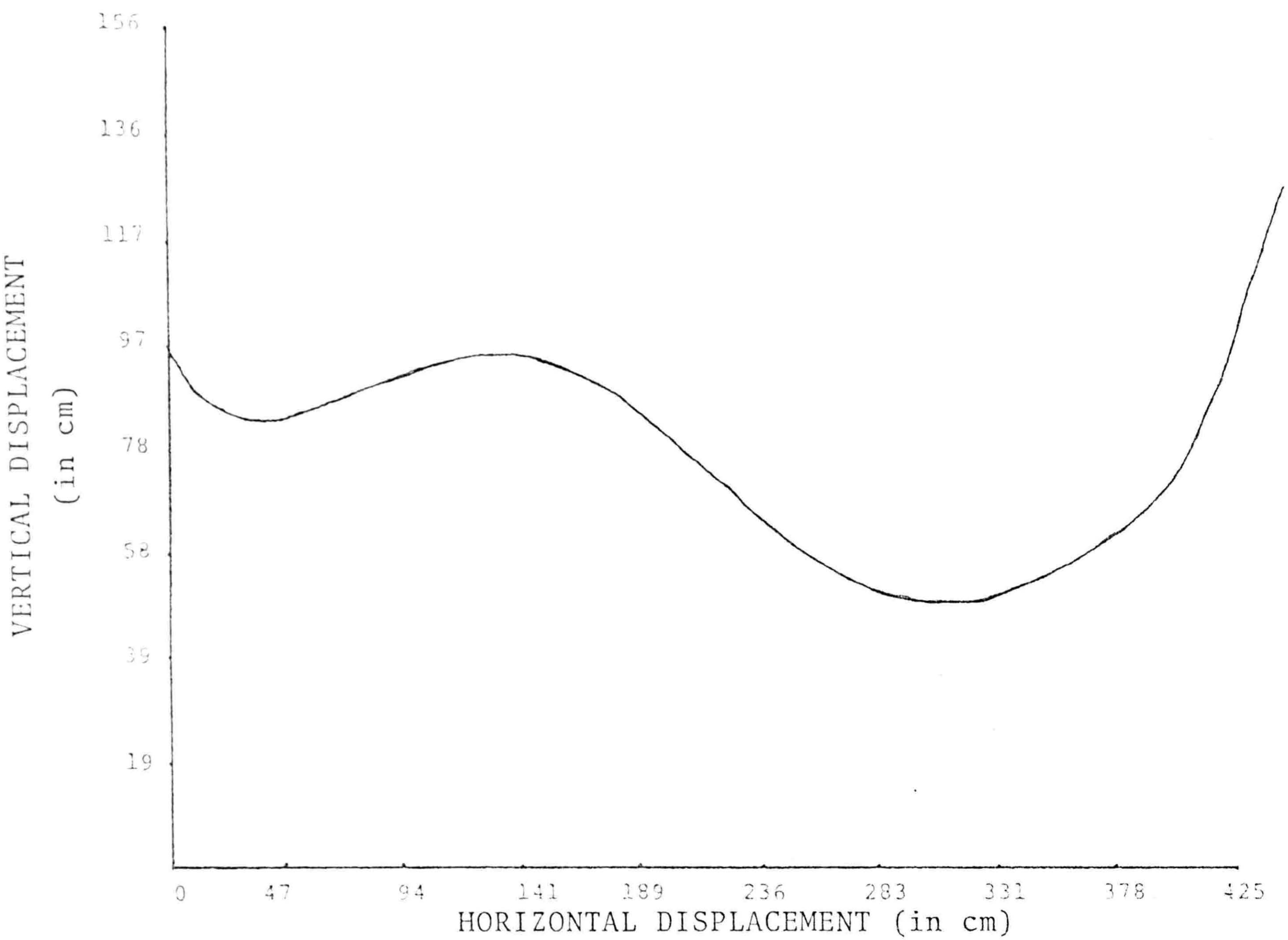

Figure 6. Excursion of the total body center of gravity.

This was because of the extreme flexion of the trunk, flexion of the knee of the landing leg, and the arms positioned at the sides. This low center of gravity assisted in the maintenance of balance. This would be an important factor if the gymnast were to perform the aerial cartwheel on the balance beam.

As the subject completed the skill, the legs and trunk extended. The arms were moved to a position above the head for aesthetic purposes. This accounts for the higher center of gravity at the completion of the skill.

Chapter IV contains a summary of the findings discussion, conclusion, and recommendations for future studies.

CHAPTER IV

SUMMARY, DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

The teacher or coach of gymnastics must be thoroughly aware of the techniques required for the correct performance of gymnastic skills. Having to resort to the available literature for guidance may be a frustrating experience. A survey of the literature indicated that little of what is stated with respect to the aerial cartwheel has been submitted to verification through research.

A review of previous studies disclosed that the present study did not duplicate any known investigation. Most of the information found was based on authoritative opinions.

Cooper (1979), Drury (1977), and Murray (1979) gave descriptions of the aerial cartwheel in their respective gymnastics instruction books. These authors gave limited scientifically based information in their description of the proper techniques of performance of an aerial cartwheel.

Nelson (1976) directed an investigation of the aerial cartwheel. The purpose of the study was to quantify and compare selected mechanical factors which varied with different performance levels.

Splithoorn (1973) studied the single foot take-off for various tumbling skills. The purpose of the study was to determine what mechanical factors were involved in the single foot take-off phase of these skills.

In the present study, film data were collected on a highly skilled gymnast. Judges determined the best aerial cartwheel for analysis. Front and side view film data were synchronized, digitized, and merged for subsequent computer analysis. A computer program entitled LAMB.FOR was utilized to obtain forces, velocities, accelerations, and excursion of the total body center of gravity.

The primary purpose of this study was to determine through the use of cinematography, selected kinematic and kinetic aspects of the aerial cartwheel. The investigator's intent was to answer the following research questions:

1. What angles of push-off knee flexion and extension are exhibited in the take-off phase of the aerial cartwheel?

2. What is the velocity of the thigh of the push-off leg extension, after maximum push-off knee flexion?

3. What are the forces applied to the ground during the take-off phase?

4. What velocities of the thigh of the kicking leg are exhibited in the take-off phase of the aerial cartwheel?

5. What hip positions are exhibited in relation to the push-off foot and landing foot during the aerial cartwheel?

6. What path does the center of gravity follow throughout the skill?

Summary of the Findings

At initial ground contact following the hurdle step, the lead leg (push-off leg) was flexed at 140 degrees. The deepest degree of knee flexion (122 degrees) was maintained over a longer period of time than any other position. The knee of the subject's push-off leg exhibited a range of joint movement from maximum knee flexion (122 degrees) to extension (180 degrees). The movement occurred while the subject still maintained contact with the ground.

The most powerful knee extension of the push-off leg occurred just prior to take-off. Again, this indicates the subject's ability to use the range of motion to gain power from the push-off leg. The greatest amount of vertical force produced by the subject was 242.5 pounds. This was equal to 2.47 times the subject's actual body weight.

The average angular velocity of the thigh (determined from the hip) of the push-off leg after maximum knee flexion was 6.38 radians/second. During the exhibited maximum knee flexion, a slight hesitation occurred. This hesitation allowed the kicking leg to begin its movement and develop sufficient speed and momentum in order to coordinate its lift with the extension of the knee of the push-off leg.

The highest rate of velocity produced by the thigh of the kicking leg occurred just after the leg began its movement. The average angular velocity of the thigh of the kicking leg from ground contact to maximum height was found to be 7.97 radians/second.

During the take-off phase of the aerial cartwheel, the hips remained behind the push-off foot; they moved directly in line with the foot at take-off. The hips were in front of the landing foot at ground contact during the landing phase of the aerial carthweel.

The path of the center of gravity initially dropped vertically because of the flexion of the knee of the take-off leg, flexion of the trunk, and movement of the arms in a downward direction. It then rose slightly with extension of the knee of the push-off leg. A leveling off took place during flight, followed by a sudden drop as the subject landed. The extreme flexion of the trunk, flexion of the knee of the landing leg, and the arms held at the sides contributed to this shift. As the gymnast completed the skill, the center of gravity rose once again.

Discussion

A great misconception often exists as coaches and teachers of gymnastics analyze skills in order to teach them to their students. Many believe that there is one, and only one, correct way to perform a particular gymnastic skill. Coaches and teachers analyzing techniques employed by the great gymnasts of the past and present often try to apply these techniques to their students, many times with disastrous results. The coach must recognize that each and every gymnast is different in body build, strength, and flexibility. These factors alone will have a significant effect on determining the most effective technique for an individual gymnast.

This investigator believes technique is important, but what coaches must first determine are the basic mechanical principles that exist in every gymnastic movement. These basic principles can then be applied so that gymnasts may determine and develop their own technique and style of gymnastics.

The coach and gymnast should strive for efficiency. An efficient movement in gymnastics can be described as that which produces maximum results, with minimum effort. Through application of basic mechanical principles the gymnast can perform movements with less effort. The coach can recognize mistakes more readily and give more effective advice to the performer.

In this section, the findings of the present study are assimilated as an explanation of an aerial cartwheel. Mentioned are some of the basic mechanical principles involved in the successful and efficient performance of the skill. It is hoped that sufficient insight will be gained from the findings of the study and this subsequent explanation.

In the following description, certain phases of the aerial cartwheel are mentioned that were not studied. The descriptions given were taken from the actual film collected for this investigation.

The investigator is in agreement with Murray (1979) in that the aerial cartwheel should be learned from a standing position, thus eliminating the run and hurdle. Also, a spotter should be used in the initial stages of learning this skill.

Starting Position

The arms should be held in an extended position above the head. Proper body alignment should be reinforced at this point as well as at the completion of the skill. It appears that for all intents and purposes, the head should remain in a neutral or natural position throughout the entire skill.

Take-off Phase

Eliminating the run will force the gymnast to step forward with the push-off leg to begin the movement. At ground contact, the leg should begin a slow but steady flexion to an angle of approximately 120 degrees. The position of the hips and shoulders should be facing forward and level. The trunk begins flexion at this point; the arms continue to remain extended above the head. It seems that the arms should not be allowed to move to a position below the shoulders during this phase.

The push-off leg remains flexed as the rear leg or kicking leg begins its upward movement. The kick should be forceful and continuous. Just after the kicking leg begins its movement, the push-off leg should extend forcefully to 180 degrees (full extension). In order for this to occur, the kicking leg must not hinder the push-off leg.

It may be that a lack of flexibility in the "split" position would be such a hindrance.

It appears that if the gymnast can not execute a 180 degree "split" of the legs, lift and rotation of the hips will begin where the range of motion (flexibility) of the kicking leg ends. If there is a lack of flexibility, the push-off leg will not have enough time to reach full extension. Hence, the gymnast will lose the power that comes from the latter stages of leg extension. The more flexible the gymnast is in the "split" position, the better chance of utilizing the push-off leg. This "split" position should also be maintained during the flight phase.

The hips should be located behind the push-off foot during the flexion stage, and move directly over the foot as extension of the leg takes place. This will allow the force from the push-off leg to aid in creating maximum lift. The momentum of the kicking leg is used to contribute to the rotation.

It seems that the arms should follow a natural path and not be forced to create lift. If left to follow a natural path, the arms usually will not hinder lift and rotation. It is here the coach should allow the gymnast to determine the most comfortable and effective arm swing.

Flight

Once the gymnast leaves the ground she becomes a projectile. The flight path of the skill will have already been determined at this point. The velocity of extension and the height of the center of gravity are factors which determine the flight path. Thus, these two factors play a most important role in the successful completion of the skill. With a low center of gravity at take-off, the lesser amount of force will be required in order to create rotation.

Landing

At landing the chest and head should be at its lowest point. This will ensure a lower center of gravity, thus producing greater stability at landing. The kicking leg (now the landing leg) should land in line with the take-off foot. It appears that the foot should be pointed straight ahead.

The hips should be in front of the landing leg. This position allows the gymnast to absorb the force of the landing in a gradual manner. If the hips were directly over the landing foot at initial ground contact, a greater amount of force and weight would be encountered by the landing leg. As a result many injuries might occur. The hips and shoulders should be positioned forward and parallel to the landing surface.

For completion of the skill, the trunk should be brought to an upright position. The arms are brought above the head for balance and asthetic purposes.

Conclusion

Selected kinematic and kinetic aspects of the aerial cartwheel have been determined. Within the limitations of the study, mechanics related to velocities and positions of the push-off and kicking legs; the path of the center of gravity; and the ground reaction forces at take-off have been recorded and can be used to evaluate the performance of this skill. These should be a valuable addition to the existing literature relative to this skill.

Recommendations for Further Studies

For future study concerning gymnastic skills, the investigator proposes the following recommendations:

1. Study other skills frequently performed in gymnastic routines. Most of the skills frequently performed have not been scientifically analyzed.

2. Replicate the study collecting force pattern data.

APPENDIX A

RESUME OF SUBJECT

RESUME

NAME: Gigi Ambandos

AGE: 15 DATE OF BIRTH: 9/4/64

HEIGHT: 5' 1 1/2" WEIGHT: 98 pounds

HOMETOWN: Emmaus, Pennsylvania

TEAM: Parkette Gymnastic Club

COACHES: Bill and Donna Strauss

YEARS OF GYMNASTIC EXPERIENCE: 6

AWARDS OR HONORS:

1977	2nd All-around,	Junior Nationals, Houston, Texas
1978	4th All-around,	Junior Elite Nationals, California
	9th All-around,	CSSR Cup, Czechoslovakia
		3rd place, Uneven Bars
		6th place, Floor Exercise
	12th All-around,	U.S.A. Championships, New York
	9th All-around,	World Game Trials, Oklahoma
	Taiwan Games	1st place, Vault, Floor Exercise
		2nd place, Balance Beam
		4th place, Uneven Bars
1979	9th All-around,	Dial Meet, East Germany
	16th All-around,	U.S.A. Championships, Ohio
	13th All-around,	World Game Trials, Utah
	9th All-around,	Japan Junior Invitational, Japan
		2nd place, Uneven Bars

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