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A KINEMATIC AND KINETIC ANALYSIS
OF THE OVERGRIP GIANT SWING ON
THE UNEVEN PARALLEL BARS

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Winifred Witten

has been accepted towards fulfillment
of the requirements for

Ph. D degree in Exercise Science

Eugene W. Brown
Major professor

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A KINEMATIC AND KINETIC ANALYSIS OF THE OVERGRIP GIANT SWING ON THE UNEVEN PARALLEL BARS

By

Winifred Witten

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Physical Education and Exercise Science

1990

ABSTRACT

A KINEMATIC AND KINETIC ANALYSIS OF THE OVERGRIP GIANT SWING ON THE UNEVEN PARALLEL BARS

By

Winifred Witten

This study investigated selected kinematic and kinetic variables of the overgrip giant swing on the uneven parallel bars. The subjects were 15 club gymnasts, who ranged in age from 10 to 16 years. Four judges ranked the 15 overgrip giant swings. Based on the judges' rating, three groups were formed. Group 1, the highly skilled, and Group 3, the lower skilled, were compared on kinematic and kinetic variables.

The top rail of the bars was instrumented with strain and torque gages to measure forces and torques directly on the bar. Joint reaction forces and net muscle moments were calculated for the elbow and shoulder joints. Comparisons between the two groups were made on absolute and temporal occurrences of events within the skill, body segment orientations, joint angles, body segment velocities and acceleration patterns and the path of the total body center of gravity.

There were significant differences between highly skilled and less skilled gymnasts for the horizontal velocity of the total body center of mass (4.9 and 4.4

m/sec, respectively) and the relative time of occurrence of the maximum vertical velocity of the center of mass. Significant differences were shown between the groups for peak velocity of the ankle and hip. Group 1 had a velocity of 11.0 m/sec for the ankle and 6.2 m/sec for the hip. Group 3 showed velocities of 9.6 and 5.6 m/sec, respectively. There were also significant differences for several segmental velocities and accelerations (foot, shank and arm), which were due to body position changes as the gymnasts completed the descent phase of the skill.

There were no significant differences between the groups on the kinetic variables. The total group mean maximum resultant force on the bar was 3.1 times body weight, which occurred in the second quadrant of the skill. The maximum mean torque on the bar was 41.3 Nm. Mean elbow joint reaction forces were 1.6 times body weight for the vertical force and 0.7 times body weight for the horizontal force. The shoulder joint calculations were 1.6 and 1.3 times body weight for the vertical and horizontal forces respectively.

ACKNOWLEDGEMENTS

The completion of this dissertation is the result of the support, advice and help from a number of individuals. I would like to formally thank each of them here.

First, I would like to express my gratitude to Dr. Eugene W. Brown, Dr. V. Dianne Ulibarri, Dr. Crystal F. Branta and Dr. Michael Kasavana for their time and help as members of my doctoral committee. Additional thanks to Dr. Brown and Dr. Ulibarri for their biomechanics expertise and advice in designing and implementing the study.

Second, I would like to thank three important people, who provided the technical help necessary to implement the study. In addition to the moral support given over the years, Dr. Charles X. Witten, Eastern Michigan University, applied the strain gages to the bar. Robert Wells from the Center for the Study of Human Performance provided the electronic support to gather the force data and convert the data to the computer for analysis. Dr. Witten and Mr. Wells spent many hours designing the hardware and calibrating the instruments for use in this study. Dr. Mohammed Usmann, who was in the Department of Engineering at MSU at the time of the study, provided computer support for changes in the analysis program as well as providing many of the graphs used in the study.

Third, I would like to give special thanks to the American Athletic Institute and Mr. Larry Fie for the donation of the graphite uneven parallel bar for use in this study.

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CHAPTER I

Introduction

The uneven parallel bar event is one of the most dynamic and exciting events in women's gymnastics. The event requires hanging, swinging, circling, kipping, and supporting movements (Bowers, Fie, & Schmidt, 1981). In recent years, large swinging movements, movements through the handstand position, and releasing movements have been added to the gymnast's requirements for success in this event (Federation of International Gymnastics, 1985). In addition, a routine is composed of movements that are performed on both bars, change direction, and show flight. The routine contains a minimum of ten skills, that come from four difficulty groups ("A", "B", "C", and "D"). Age group competitors are required to have a minimum of three "A" , three "B", and two "C" skills. A "D" level skill is from the most difficult group. It is not a requirement of competition until a gymnast reaches the elite level.

Prior to 1950, both men and women performed on the parallel bars. Women could narrow and lower the bars to accommodate their smaller frames (Tonry, 1980). The two wooden rails were oval-shaped and relatively stiff in comparison with the modern apparatus. The uneven parallel bars first appeared in Olympic competition in 1952 at Helsinki (Bonniwell, 1983). In the early years of competition on the uneven parallel bars, it was common to see static pose handstands, leg circling, and climbing movements interspersed with kipping and swinging movements. More recently, the inclusion of releasing and large swinging movements and the common practice of maintaining continual movement during the routine has resulted in a more dynamic character to the event.

The evolution of the skills on the uneven parallel bars were accompanied by changes to the apparatus itself. In the 1950's and continuing into the late 1960's, the uneven parallel bars were composed of one bar from the men's parallel bars and an extension bar to achieve the appropriate height for the second bar. Because the modified parallel bars were not designed to be stable under large lateral forces, many of the swinging movements performed by the female gymnast would lift the base of the bars off the floor. It was common to see gymnasts sitting on the base of the modified parallel bars to stabilize the apparatus during competition. The current practice of either cabling the bars to the floor or structuring wide and weighted free standing bases began in the 1970's. The rails themselves have become more flexible and rounder. The material for the bars has evolved from wood to a wood laminate over fiberglass and, more recently, to a bar constructed from a graphite and fiberglass composite with a wood laminate. With the inclusion of the larger swinging and releasing movements, the bars are being adjusted farther apart. This has caused the impact skills, characterized by the hips hitting the bars, to disappear from most modern uneven bar routines.

There has been very little research conducted on the uneven parallel bars event. The majority of studies that have been conducted have analyzed skills that are not currently being used and/or utilize college women as subjects (Landa, 1974; Hay, Putnam & Wilson, 1979; and Evans, 1984). The current investigation examined the overgrip giant swing. This skill has become a necessary movement for the repertoire of the gymnast as it is the basis for many large release movements so popular today. This study used young female gymnasts, between the ages of 10 and 16, the age group that has the highest participation rate in this country.

Statement of the Problem

The problem in this study was to investigate and compare selected kinematic and kinetic characteristics associated with the overgrip giant swing performed on the uneven parallel bars by female, age group, Class I and Elite gymnasts. A subproblem in this study was to develop a technique for measuring forces generated on the bar and on selected joints of the body by gymnasts circling the bar.

Purpose of the Study

The primary purpose of this study was to compare selected kinematic and kinetic parameters obtained from two groups of gymnasts who performed the overgrip giant swing on the uneven parallel bars. A panel of Class I and Elite judges identified one group as "highly skilled" and the other group as "less skilled". By comparing the highly skilled and less skilled performers, it was the intent of this study to identify critical factors that will aid the teacher/coach in understanding this skill.

Need for the Study

The need for the study arose from the paucity of quantitative research found in the literature on women's gymnastics. Many of the studies that are available are outdated because of the frequent changes in the sport, especially in the uneven parallel bars event. Two studies (Hay, et al., 1979; and Landa, 1974) analyzed skills that are not frequently used today. Other studies (Sands, 1982; 1985a; 1985b; Bentham, 1987; and Hay, et al., 1979) used either single subjects or very small populations. Still other studies (Bovinet,1979; Evans, 1984; Hay,et al., 1979; and Landa, 1974) used college aged women as subjects. While this is a convenient population to draw from for university research, it is not the age group with the majority of participants. According to the United States Gymnastics

Federation (USGF) statistics, 86 percent of registered gymnasts are between the ages of 10 and 16, with the average being 12 years old (J. Clair, personal communication, June 26, 1990).

Equipment changes, such as the use of a graphite bar on the uneven parallel bars, also necessitate further investigation. Along with changes in equipment has come an evolution of the type of skills that are being performed. With additional stability to the apparatus, the movements on the uneven parallel bars have become more similar to horizontal bar skills performed by male gymnasts.

The overgrip giant swing was chosen for study because it is a skill that has been widely performed in recent years. It is being viewed as a basic prerequisite for more advanced, large swinging, and releasing movements that characterize today's uneven parallel bars routine. Quantitative investigations are necessary to generate knowledge about technique for teaching the overgrip giant swing to young girls. The technique of the skill is different from the same skill performed by men on the horizontal bar. The proximity of the low bar of the uneven parallel bars, places constraints on the execution of this skill, with which the male gymnast does not have to contend. Data concerning the optimal body position during the descent phase of the circle need to be collected.

There is a paucity of research using young girls as subjects. Information concerning the forces that young girls experience while performing skills on the uneven parallel bars is nonexistent. In order to understand injury potential, there is a need to generate data on joint forces experienced by subjects performing on the uneven parallel bars.

Hypotheses

Three hypotheses were established to study the overgrip giant swing as performed on the uneven parallel bars. These hypotheses were:

1. There will be no difference, at the .10 level of significance between the highly skilled and less skilled groups in selected kinematic parameters. These parameters include:
   a. path and angular velocity of the gymnast′s whole body center of mass around the bar,
   b. body position characteristics in each phase of the overgrip giant swing, and
   c. linear velocity and acceleration histories of selected joints and angular velocity and acceleration histories of selected body segments.
2. There will be no differences at the .10 level of significance in the force histories experienced at

the bar and at the elbow and shoulder joints between and among the two skill level groups.

3. There will be no differences at the .10 level of significance in the net moments about the elbow and shoulder joints between and among the two skill level groups.

Limitations

The study used:

1. Class I or Elite gymnasts in the state of Michigan,
2. volunteer subjects ranging in age from 10 to 16 years, and
3. four Class I or Elite judges, who are members of the National Association of Women's Gymnastics Judges (NAWGJ).

The results of the study were interpreted with the following limitations:

1. Data were collected on overgrip giant swings performed in a noncompetitive environment.
2. The use of Dempster's (1955) segmental data for young girls, may have introduced a source of error.

3. The model developed for joint reaction forces assumed that the force of the bar acted at the center of the wrist joint.
4. Digitization of high speed film may have introduced a source of error.
5. The use of accelerations, generated from position data, introduced a source of error.
6. The analysis performed was two-dimensional. It was assumed that the gymnasts circling the bar would remain in the sagittal plane.
7. The friction forces between the gymnasts' hands and the bar were ignored.

Definitions of Terms

1. Overgrip giant swing - This movement is initiated from a handstand position on top of the upper bar. The gymnast rotates with the chest leading the movement, one revolution around the bar, returning to the handstand position. Sometimes, but not consistently, this movement is called a backward giant swing (See Figure 3.1, p. 35-36).
2. Tap - This is a term used to denote a small, quick body position change from an arch to a pike that aids the gymnast in accelerating the upswing phase of a movement.

3. Force transducer - This is a device that measures the force exerted by the gymnast on an external body and gives an electrical signal proportional to the applied force. The applied force causes a small amount of strain in the transducer, resulting in an unbalance of voltages proportional to the force (Winter, 1979).
4. Strain gage - This is a small instrument that measures the amount of deformation in a material and translates this deformation into a measure of force.
5. Age group gymnast - This is a gymnast who participates in the USGF national program, subscribing to the rules and regulations of that governing body.
6. Class I gymnast - At the time of this study, the Class I gymnast was the highest level of age group competition in the United States.
7. Elite gymnast - This is a gymnast who has been tested on compulsory elements and has achieved scores that indicate her to be capable of international level competition.
8. Shoulder angle - The angle calculated between the arm and trunk. Shoulder extension is a decrease in the shoulder angle with full flexion being at 180 deg.

9. Hip angle - The angle calculated between the trunk and thigh. Hip flexion is a decrease in the hip angle with full extension being at 180 deg.

CHAPTER II

Review of Literature

Kinematic descriptions of various gymnastic activities have appeared in the gymnastics and biomechanics literature since Cureton's (1939) early work on cinematographical techniques for skill analysis. These studies have contributed a great deal of knowledge about the angles of joints during specific phases of movements, angles of take-off from the floor and apparatus, and the velocities of body segments. Vaulting appears to be the most frequently analyzed gymnastic event. Skills on the horizontal bar appear to be the second most frequently analyzed. There is a lack of research for the pommel horse, balance beam, and uneven parallel bars (Kreighbaum, 1983). The review of literature that follows is organized in five parts:

1. gymnastics studies that have used instrumented equipment,
2. biomechanical studies of skills on the uneven parallel bars,
3. studies of the overgrip giant swing on the horizontal bar,
4. studies of the overgrip giant swing on the uneven parallel bars, and
5. summary of the review of literature.

Gymnastics Studies that have Used Instrumented Equipment

In studying gymnastics movements, the direction and magnitude of forces applied to the performer gives the researcher important information concerning the skills to be analyzed. Several methods of directly measuring the horizontal and vertical forces exerted on gymnastics equipment and indirectly on the performer have been reported in the literature. Force transducers have been used in several studies. The strain gage is the most common type of transducer used to instrument gymnastics equipment. A variety of skills on various pieces of apparatus have been analyzed via strain gage technology.

In a study of women side horse vaulters, Kreighbaum (1974) applied eight strain gages in a Wheatstone bridge circuit to the bottom of a vaulting board. Deflections of the board were recorded on photosensitive paper by a galvanometric type of oscillograph. Results of the force data, combined with kinematic data collected by filming the vaulters, gave the researcher information concerning force-time parameters of the vaulter-board interaction during take-off and the mechanical responses of the board during impact.

Wilkerson (1978) examined mean forces and impulses of 11 female gymnasts performing back handsprings on a balance beam that had been instrumented with specially constructed force platforms placed between the balance beam upright supports and the beam. The force platform instrument consisted of two mini-platforms that were bridged together by steel for stabilization. Each mini-platform contained strain gages for measuring pressure sensitivity in three orthogonal planes.

Robertson, Paul, and Nicol (1985) studied "kip" actions on the parallel bars, high bar, and rings. The authors constructed instruments to measure the loads transmitted through the hands to the respective apparatus so that the overall pattern of resultant forces and resultant moments at each major articulation could be assessed. For the rings, the authors applied strain gages to a "proving ring" that was mounted at ceiling level so it could rotate into the line adopted by the cables at any instance. For the parallel bars, the force measuring equipment was a custom made six-quantity force transducer placed between the bar attachment and the frame at each end of the bars. For the high bar, strain gages were directly applied to the bar.

Several researchers have investigated a variety of skills on rings that have been instrumented to collect force data. Sale and Judd (1974) developed a method for directly measuring the force developed on the still rings and for synchronizing the force and cinematographic records. Since force exerted on the rings is transmitted by the ring cables to the suspension points, the authors connected a load cell in series between the ring cable and the suspension point. The load cell consisted of a 3/16" thick aluminum diaphragm welded to an external ring. Eight strain gages were attached to the diaphragm, four per side at 90 degree intervals. Nissinen (1983) placed two Kistler force transducers inside the metal framework of the rings just above the attachment of the ring cables. The force signals were recorded and stored on magnetic tape and then sent to a computer for analysis. The author investigated reaction forces, displacements of the total body center of gravity, and segmental velocities and accelerations of subjects performing giant swings on the rings. Cheetham, Mizoguchi, and Sreden (1987) placed transducers in series with the cables of the rings. They examined the forces on thirteen 10 to 12 year-old-male gymnasts performing dislocates on the rings. The forces of the gymnasts were displayed on a storage oscilloscope. The storage oscilloscope and gymnasts were simultaneously video taped at 200 frames/sec via split screen capability. This system offered immediate feedback to the gymnast and coach.

The men's horizontal bar has been a frequently instrumented piece of equipment. In 1976, Zinkovsky, Vain and Torm reported the use of strain gages in conjunction with cinematography and electromyography. The authors also attached an accelerometer to the back of their subject in order to study the long underswing upstart (kip) on the horizontal bar. The authors were interested in the patterns of kinetic energy and muscular contractions. Kopp and Reid (1980) compared the forces and torques applied to the horizontal bar by gymnasts during the performances of two styles of giant swings. Four gages were bonded to both ends of the bar in such a manner that the resultant strain measurement would be independent of the point of application of force along the bar. Four torque gages were placed in a similar manner. The vertical and horizontal forces and torques were amplified on three channels of a Grass Polygraph. A fourth channel was used to monitor the internal timer from a LOCAM 16mm camera. This allowed the synchronization of film analysis data with the strain and torque gage output. A stroboscope was used to synchronize the exact start and end of each trial. The force and torque data were stored on a tape recorder for later analog to digital conversion and computer analysis. Ishii and Komatsu (1987) used strain gages applied to a horizontal bar and cinematography to examine performances of the overgrip giant swing. The four gages were placed 20 cm from each end of the bar to collect horizontal and vertical forces on the performances of overgrip giant swings by five gymnasts.

Two studies reported in the literature used strain gages to examine forces generated on the uneven parallel bars. Hay, et al. (1979) applied strain gages to a Nissen wood laminate bar to investigate maximum forces exerted by women performing typical uneven parallel bar skills. These strain gages were applied along the neutral axis at a distance of 56 cm from one end of the bar to measure horizontal and vertical bending . Evans (1984) studied performances of the clear back hip circle on the uneven parallel bars. In addition to film data, strain gages were attached along the neutral axis of the bar 56 cm from each end. The strain gages were connected to a galvanometric type oscillograph, which measured bar deflections by means of a light tracing on photosensitive paper. Evans (1984) reported five prominent deflections in the horizontal direction. The data for the vertical deflections was unreported due to failure of the strain gages for this direction.

General Calibration Procedures

Several researchers have documented the methods that they used to calibrate their instrumentation. Kreigbaum (1974) calculated a calibration curve by vertical static loading of a vaulting board for nine positions, four inches apart. The forces were determined by relating the position of the vaulters' metatarsophalangeal joint on the board to the calibration curve. Wilkerson (1978) calibrated a strain gage type force platform, constructed for the balance beam, by statically loading the beam in the vertical, horizontal, and lateral directions. The static loading on the horizontal and vertical axes was performed by manually pulling on the beam in each respective direction. The force of pull was determined by an electric cable tensiometer. The author performed a series of tests to statically and dynamically validate the instrument. A summary of the findings from instrumentation studies reviewed in this section are found in Table 2.1

Calibration Procedures for Instrumented Bars

In calibrating the horizontal bar, Kopp and Reid (1980) applied known weights in the horizontal and vertical directions and known clockwise and counterclockwise torques. For each calibration, linear force-voltage and torque-voltage relationships were found. The authors also found that there was no interaction between the horizontal and vertical force components and that the transducer output was independent of the position of application of the load. In order to determine the relationship between the strain and electric signals, Ishii and Komatsu (1987) statically loaded the bar in the middle and at 30 cm to the right and left of center. The readings of these signals produced a calibration curve. Hay, et al. (1979) statically loaded an uneven parallel bar at the geometric center of the bar and found the system to respond linearly throughout the full range of force from zero to failure. The authors derived a correction

Table 2.1 Summary of Instrumentation Studies

Author (Date)	Event/ Skill	Instrumentation Type	Calibration Method/ Validation Test	Number of Subjects
Sale, Judd (1974)	Rings/ Giant swing	Load cell	Static	4
Zinkovsky, et al.(1976)	*HBar/ Kip	Strain	**NR	NR
Wilkerson (1978)	Beam/ Handspring	Force platforms	Static/ Dynamic	11
Hay, et al. (1979)	† UBars/ Kips,beats	Strain gage	Static	3
Kopp,Reid (1980)	HBar/ Giants	Strain, torque gages	Static	6
Krieghbaum (1983)	Vault/ Handspring	Strain gage	Static	8
Nissinen (1983)	Rings/ Giant swing	Transducer	NR	60
Evans (1984)	UBars/ Clear hip circle	Strain gage	NR	4
Robertson, et al. (1985)	†† PBars,Rings, HBar/ Kip	Strain gage, transducers	Static	NR
Cheetham, et al. (1987)	Rings/ Dislocate	Transducer	NR	13
Ishii, Komatsu (1987)	HBar/ Giant	Strain gage	Static	5

*HBar - Horizontal bar.
**NR - Not reported.
† UBars - Uneven parallel bars.
†† PBars - Parallel bars.

factor to enable the magnitudes of the recorded forces to be adjusted whenever the bars were loaded eccentrically.

Biomechanical Studies of Skills on the Uneven Parallel Bars

There is a paucity of research on skills performed on the uneven parallel bars. This is apparent from the number of studies found in the literature (see Table 2.1). Also, the studies that have been conducted investigated skills that are seldom seen today (Landa, 1974; Hay, et al., 1979) or are single subject studies of high level gymnasts (Sands, 1982, 1985a, 1985b; Bentham, 1987). Other studies (Landa, 1974; Hay, et al., 1979; Evans, 1984) have been conducted on university women gymnasts, even though, most participants in the sport of gymnastics today are below the age of 17 years.

The majority of the studies on skills performed on the uneven parallel bars have used cinematography as the primary method of data collection. In these studies frame rates varied considerably. The lowest frame rate reported (Bovinet, 1979) was 30 frames per second and the highest was 150 frames per second (Bentham, 1987). The most frequently reported frame rates were 80 and 100 frames per second (Sands, 1982, 1985a, 1985b 1987; Evans, 1984; Daniels, 1983).

In order to analyze movements on the uneven parallel bar, several authors have divided the skills into subcategories or phases. Sands (1985a) studied one gymnast performing a low bar kip and release to a catch of the high bar. The skill was divided into four phases:

1. from extension below the low bar to hip flexion,
2. from hip flexion to hip extension,
3. from release of the low bar to grasp of the high bar, and
4. from the grasp of the high bar to the top of the backswing.

Sands (1985b) used a similar procedure for his analysis of a straddle back to handstand. Daniels (1983) and Evans (1984) also subdivided the skills that they analyzed into phases. Table 2.2 summarizes the research reviewed for skills performed on the uneven parallel bars.

The identification of factors critical to the performance of a skill is often the first step to the biomechanical analysis of movement. Sands (1985b) identified the hip extension and foot velocity as the critical factors in good kip performance. Bovinet (1979) used three ability groups with three subjects per group and identified the critical factors of the glide kip as forceful hip extension and the timing of the leg thrust. Daniels (1987) compared two ability groups that performed a Stalder on the uneven parallel bars. The performances of the groups were compared through a one-way analysis of variance to identify the critical factors. The author concluded that performance was

Table 2.2 Summary of Uneven Parallel Bar Research

Author		Skills	Number of Subjects
Landa (1974)	-	Squat on LB* from long hang	4
	-	Squat on LB from jump-cast swing	
Bovinet (1979)	-	Glide kip on LB	9
	-	Short kip to HB**	
Hay, et al. (1979)	-	Short kip, front hip circle, cast wrap, hecht dismount	3
	-	Short kip, front hip circle, cast handstand, pirouette, short beat, cast over LB	
Daniels (1983)	-	Stalder to handstand	14
Daniels (1987)	-	Stalder to handstand	
Evans (1984)	-	Clear hip circle to handstand	4
Sands (1982)	-	Reverse hecht	1
Sands (1985a)	-	Kip to catch HB	1
Sands (1985b)	-	Straddle back to handstand	1
Sands (1987)	-	Giant, giant to dismounts	6
Bentham (1987)	-	Clear hip circle to handstand	1

* LB - Low bar.
** HB - High bar.

enhanced by a starting position that was at or near a handstand. According to Daniels, this position maximized the distance between the axis of rotation and the total body center of mass. Furthermore, Daniels indicated that the straddle-in action should be delayed as long as possible and should be performed with a narrow straddle to maximize the moment of inertia. To maximize further the radius of rotation, Daniels suggested that shoulder extension should be minimal and the hips should always be kept farther from the rail than the shoulders. The straddle-out action should be timed with the recoil of the rail on the upswing. Extension of the legs should occur throughout the straddle-out phase as it will have less effect on the path of the total body center of mass with respect to the rail than a faster, shorter opening.

In studying movements on the uneven parallel bars, a number of authors have been concerned with the forces exerted on a performer. Daniels (1987) calculated forces indirectly from cinematographic data. The mean force applied to the rail by a female gymnast performing the Stalder to handstand was 2.2 times body weight, with a maximum force of 3.3 times body weight. Smith (1981) presented theoretically determined "centrifugal" force values of a gymnast performing two skills on the uneven parallel bars. In the first skill, the gymnast swung from a handstand to a short beat on the low bar. According to Smith's calculations, the resultant bar reaction force immediately before the gymnast contacts the low bar ranged from 4.2 to 4.7 times body weight, depending on the height of the gymnast. For the second skill analyzed, a long beat from a handstand, Smith concluded that the maximum bar reaction force occurred at the bottom of the swing and may be as great as five times body weight.

Another topic investigated in uneven parallel bar studies was that of bar deflection. Daniels (1987) compared the pattern of bar deflections for each of her two groups. The author concluded that the rail deflections were directly related to the amount of angular momentum produced during the performance of Stalder circles. Overall deflections of the bar were greater in a more highly skilled group. Sands (1987) reported a technique for recording bar deflections and at the same time giving immediate feedback to coaches and gymnasts concerning technique corrections. A computer "joystick" was attached to the upper rail of the uneven parallel bars. A computer program "read" the bar deflections in x-y coordinate form. The data were then graphically represented on the computer screen for immediate viewing. Sands attempted to develop models of bar deflections for several skills, including the giant swing. The author concluded that the deflection pattern of good giant swings had two major bar movements and that his method of analysis could identify giant swings in which the performer did not "tap" well or arched excessively.

Two studies have directly measured force through the application of strain gages on uneven parallel bars. Evans (1984) reported a horizontal force of six times body weight for the clear hip circle to handstand, while Hay, et al.(1979) reported a maximum resultant force of 3500 N (5.7 times body weight) for an impact type skill on the low bar and 2140 N (3.6 times body weight) for a swinging skill from the high bar.

Studies of the Overgrip Giant Swing on the Horizontal Bar

Giant swings are a basic skill in men's horizontal bar progressions and have been described in various gymnastics texts. Taylor, Bajin and Zivic (1972) describe the skill as follows:

> In the handstand position the gymnast stretches from the shoulders with the center of gravity held as far away from the center of the bar as possible. From this position the gymnast begins the swing forward and just before reaching the vertical line under the bar, the leg swing is slowed so the back is slightly arched as it passes the vertical. Once past the vertical, a short, quick swing of the legs, finished approximately 45 degrees after the vertical line, lifts the body in a slightly piked position, decreasing the angle between the arms and the body.
>
> This position is maintained until the gymnast is 45 degrees over the horizontal at which time the body stretches, the head moves backward and the chest is lifted upward over the bar. (Taylor, et al., 1972, p. 218).

Hay (1985) added:

> Passing through the horizontal once again and into the fourth quadrant of the circle, the gymnast arches his back and does further work against gravity by pressing downward with the arms. This downward pressing is usually preceded by a shift in the grip to place the hands more nearly on top of the bar than they were before - a shift that makes it easier to press downward a moment later. Ideally this hand shift takes place at a time when the centripetal force required to maintain the angular motion is equal to the component of the

> gymnast's weight acting along a line joining the center of gravity to the axis. Under such circumstances, the pressure between the gymnast's hands and the bar is at a minimum, and movements of the hands about the bar are relatively easy to make. (Hay, 1985, pp.320-321).

For many years and from different perspectives, biomechanists have studied men performing the giant swing on the horizontal bar. Cureton (1939) calculated "centrifugal" forces and the velocities of the total body center of mass about the bar. According to Cureton, peak forces occurred at about 135 deg from the handstand position on top of the bar and equaled 4.9 times body weight. Kopp and Reid (1980) directly measured the forces applied by gymnasts during giant swings on an instrumented horizontal bar and reported a range of 3.5 to 3.7 times body weight in the subjects they tested. The peak force consistently occurred in the third quadrant, just past the bottom of the swing.

Herrmann (1968) produced velocity-time diagrams and calculated hip angles for overgrip giant swing on the horizontal bar. The author concluded that the changes in the body position during the upswing phase resulted in the reduction of the moment of inertia and thereby increased the speed of rotation of the body about the center of the bar. In 1976, Borms, Moers, and Hebblelinck studied performances of forward and backward giant swings. Angular changes in body segments and angular velocities of the feet, center of mass, and chest were examined. This study showed that the maximum velocity of the center of mass of the body was 6.0

m/sec and of the shoulder was 3.5 m/sec. Both velocities occurred during the third quadrant of the giant swing or .83 sec from the handstand position on top of the bar. The maximum velocity of the feet, however, was 12.5 m/sec and occurred at 1.03 sec from the beginning of the circle.

Boone (1977) filmed two male gymnasts of different skill levels and subsequently examined angular velocity and centripetal force at specific points in the giant swing on the horizontal bar. In this study, the giant swings with a higher angular velocity were associated with poorer performances. This led to the conclusion that those gymnasts who perform the giant swings with a higher angular velocity must hold on tighter to the bar to counteract the "centrifugal" forces. Cheetham (1984) also examined angular velocity and the trajectory of the center of gravity of the body and the beat characteristics of three types of giant swings (overgrip giant, dismount giant, and wind-up giant). He concluded that the path of the center of mass of the body was different for each type of giant swing.

Several authors have attempted to model the overgrip giant swing. Dainis (1975) used a three link model (arms, trunk, and legs) to describe the differences between an "ideal" and a "poor" overgrip giant swing. In his model, the bar was considered as inflexible and grip friction was neglected. The author concluded that a relaxed body on the downswing caused a hyperextension of the hips in the first quadrant of movement and this was indicative of poor technique. A good overgrip giant swing should have coordinated action between the shoulder and the hip resultant forces. In a less skilled performance of the overgrip giant swing, these forces do not act in unison and do not produce as smooth a movement. Dainis (1974) also used a four link system (arms, trunk, thighs, and shanks) in developing a model from Lagranges's equations of motion. Torques acting between the segments and the time increments of torque applications were used as input into a computer program. In developing the model, Dainis used two performers, a skilled and an unskilled performer. The skilled performer required 1.9 sec for completion of the skill as compared with 1.8 sec for the less skilled gymnast. At the completion of the skill, the gymnasts' angular velocities were -101 deg/sec and -151 deg/sec, respectively. Duck (1978) developed a three link model (arms, trunk, and legs) based on Newtonian mechanics. Input variables consisted of body segments, a friction constant of proportionality, angular velocity and acceleration of the shoulder and hip, and the initial velocities and accelerations of the arms. Bauer (1983) used the equations of a pendulum of variable length to construct a model for various gymnastics movements including the giant swing. From this model, the author could input anthropometric variables for individual performers and predict performance.

Studies of the Overgrip Giant Swing on the Uneven Parallel Bars

The information in the literature concerning the overgrip giant swing on the uneven parallel bars is sparse. Gluck (1982) described the overgrip giant swing on the uneven parallel bars as being mechanically more difficult than the same skill on the horizontal bar. When comparing the performance of an overgrip giant swing on the uneven parallel bars by a female gymnast to the same skill performed by a male gymnast on the horizontal bar, it is evident that the female has to execute a skill of greater difficulty. The female gymnast must contend with the physical constraint of the low bar and rotate about a bar of greater cross sectional area. This difference in bar size may partially account for the skill being given a higher difficulty rating, a "C", in women's gymnastics and only an "A" rating in men's gymnastics. Piking and straddling are the two methods for clearing the low bar on the downswing. According to Gluck (1982), the pike method was preferred because in this approach rotational inertia did not decrease as much as in the straddle method and the bar deformed more in the pike when compared to the straddle method.

George (1980) emphasized the importance of the starting position and the fully stretched handstand, in order to maximize the amplitude of the descent phase of the overgrip giant swing. The second factor emphasized was the distance of the center of mass of the body from the bar during the descent phase. The greatest distance, according to George, is realized by extending the shoulder-trunk angle and flexing at the hips to miss the bar. Sands (1987) emphasized that the completion of the overgrip giant swing with an arched body position was related to the performer not executing a "tap" at the appropriate time in the overgrip giant swing.

Summary of the Review of Literature

A review of the literature concerning instrumentation of gymnastics equipment indicated that this method of data collection gives the researcher important information concerning forces applied by the gymnast. Studies have been conducted in which the vaulting board, balance beam, parallel bars, high bar, rings, and horizontal bar had been instrumented. (Kreigbaum, 1974; Wilkerson, 1978; Sale & Judd, 1974; Zinovsky, et al., 1976; Kopp & Reid, 1980; Nissinen, 1983; Robertson, et al., 1985; Ishii & Komatsu, 1987; Cheetham, et al., 1987). Force transducers have been used to instrument the equipment, with strain gages being the most frequently used transducer. Calibration of the instrumented equipment is generally performed by statically loading the equipment with known weights.

Two studies (Hay, et al., 1979; Evans, 1984) have specifically instrumented the uneven parallel bars with strain gages applied along the neutral axis for horizontal and vertical bending. Each study synchronized the force data with images from film and analyzed the following uneven parallel bars skills: clear hip to handstand, kips, front hip circle, cast wraps, long beats, and Hecht dismounts. The number of subjects used in these studies were small. Hay, et al. (1979) reported data for three subjects and Evans (1984) reported analyzing four subjects.

The amount of force exerted by gymnasts on the uneven parallel bars in the studies reviewed varied with the type of skill being studied and the method of estimating the force. The highest reported horizontal force was six times body weight (Evans, 1984) and was directly collected from the uneven parallel bars while the gymnast was performing a clear hip circle. The lowest reported force was 2.2 times body weight (Daniels, 1987) and was calculated indirectly from film data of a gymnast performing a Stalder on the uneven parallel bars.

Several studies of the overgrip giant swing on the horizontal bar have been conducted. This skill is similar to the overgrip giant swing on the uneven parallel bars, but the female gymnast must change body position on the downswing to compensate for the position of the low bar. These studies reported variable force values. Cureton (1939) calculated the peak force to be 4.9 times body weight, while Kopp and Reid (1980) directly measured the forces to be 3.5 to 3.7 times body weight. There was also disagreement as to the portion of the circle where the maximum force was generated. Ishii and Komatsu (1987) reported the peak force occurred during the third quadrant, just past the bottom of the swing. Cureton (1939) and Kopp and Reid (1980) reported the maximum force occurring during quadrant two, just prior to the bottom of the swing.

Other variables reported in studies of the overgrip giant swing on the horizontal bar included the hip and shoulder angle and velocities and accelerations of body segments, joints, and the total body center of mass as the gymnast rotates about the bar (Borms et al., 1976; Boone, 1977; Herrmann, 1980; Cheetham, 1984).

CHAPTER III

Experimental Procedures

The purpose of this study was to compare selected kinematic and kinetic parameters between two groups of gymnasts performing the overgrip giant swing on the uneven parallel bars. By comparing two skill groups, Group 1 (highly skilled) and Group 3 (less skilled), it was postulated that critical factors would be identified that could aid teachers and coaches in understanding the skill. Subjects were assigned to the skill groups based on judges' ratings of their overgrip giant swing performances.

This chapter is divided into the following sections: general procedures, instrumentation and calibration of the bar, cinematographic techniques for data collection and analysis, kinematic analysis, kinetic analysis, and statistical analysis.

General Procedures

Subjects

The subjects for this study were 15 volunteer Class I age group or Elite level gymnasts, who ranged from 10 to 16 years of age. Coaches from ten clubs throughout the state of Michigan were asked to suggest subjects for this study.

Twenty gymnasts were invited to participate in the study and 17 actually arrived on the day of filming. Two more were eliminated from the study because they were unable to perform the required skill. The requirement for entry into the study was that the gymnast must be able to perform an overgrip giant swing on the uneven parallel bars without the assistance of her coach. The subjects came from five different gymnastics clubs in central and southeastern Michigan. Prior to data collection, each subject, her parents, and her coach were informed about the purposes of the study and the requirements of participation. After informing the subjects and their parents about the study, the investigator asked them to sign an informed consent form (see Appendix A).

For each subject, a brief history of their years in the sport, their age, and place of participation was taken. Percent body fat was determined by hydrostatic weighing and height, weight, thigh length, calf length, shoulder-elbow length, elbow-wrist length, hand length, biacromial diameter, and biiliac diameter were measured. The anthropmetric measurements were taken at the Center for the Study of Human Performance at Michigan State University and followed the standards set by Lohman, Roche, and Martorell (1988). This information was collected to compare the groups, after they were formed on the basis of the judges' ratings. It was the intent to show that the groups were different because of the technique of skill performance and not because of the above characteristics. The information sheet used during data collection is shown in Appendix B.

Filming of Performance Sequence

Subjects were prepared for filming by placing joint markers on the right side of the body on the following landmarks: ankle, knee, hip, shoulder, elbow, and wrist. In order to ensure as safe and familiar an environment for the gymnasts as possible, the filming was performed in a gymnastics facility. The bars were properly cabled into the floor and there were numerous safety mats available. The gymnasts' own coaches accompanied them on the day of filming and were available to spot the gymnast if necessary.

Figure 3.1 shows the four skill sequence performed by the gymnasts for this study. Because skills are linked together in competition on the uneven parallel bars, each gymnast was asked to perform a sequence of skills. The skills occurred in the following order: kip, cast, clear hip to handstand, overgrip giant swing, and flyaway dismount. Since these skills are used commonly as transition skills and are used frequently in compulsory routines, it was expected that the gymnasts who volunteered for this study could perform them in sequence.

a. long hang kip

b. cast, clear hip to handstand

Figure 3.1 Skill Sequence on the Uneven Parallel Bars

Judges and Ratings of Performance

In order to limit the judges' evaluations to the skill of interest in this study, a video tape from each filmed sequence was made of the overgrip giant swing isolated from the other skills performed. The video tape was shown to three Elite and one Class I NAWGJ judges, who were asked to rate the performances of the gymnasts on the basis of criteria established by the investigator. The criteria were selected to correspond to deductions judges use to evaluate performance of an overgrip giant swing on the uneven parallel bars. Each criteria was assigned a score from 1.0 to 2.0, depending on the seriousness of the error. Each judge was asked to score each criteria based on the number assigned. The highest total score that a judge could award was a 10. The judging criteria and score sheet appear in Appendix C. Based on the judges' ratings, the top five gymnasts were classified as the "highly skilled" group (Group 1), the middle five were classified as intermediate (Group 2), and the bottom five gymnasts were considered the "less skilled" group (Group 3). Since it was the intent of this study to differentiate skill groups that were diverse in performance characteristics, group 2, the intermediate group, was dropped from further study. Groups 1 and 3 were compared on selected kinematic and kinetic variables. Figures 3.2 and 3.3 show film tracings of two subjects, one from each skill level group performing the overgrip giant swing. Subject 16 was typical of Group 1, the highly skilled group, while Subject 6 displayed a performance typical of Group 3, the less skilled group. Both subjects used the pike technique of clearing the low bar during the overgrip giant swing.

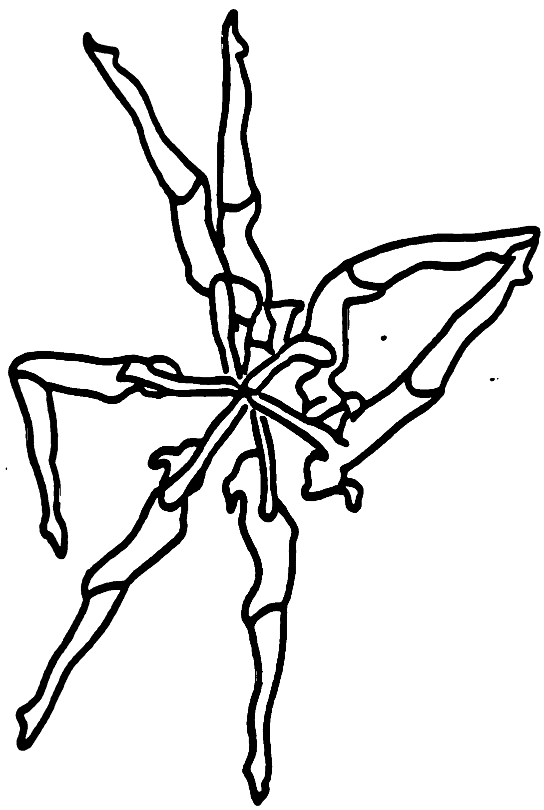


Figure 3.2 Skilled Performance of an Overgrip Giant Swing on the Uneven Parallel Bars (Subject 16)

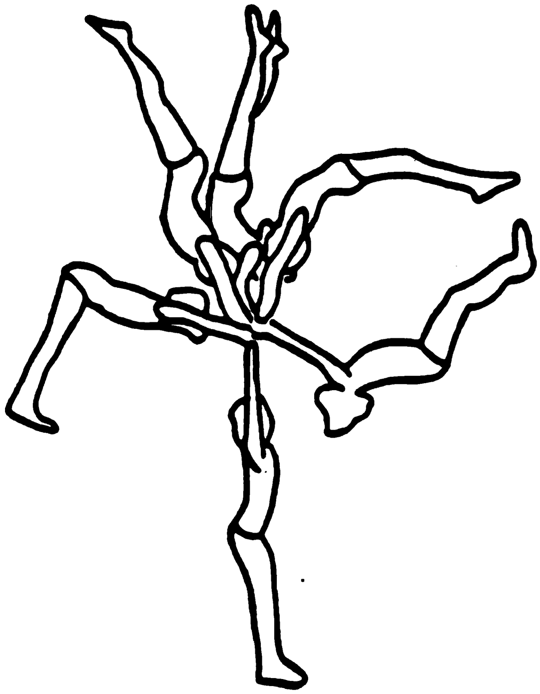
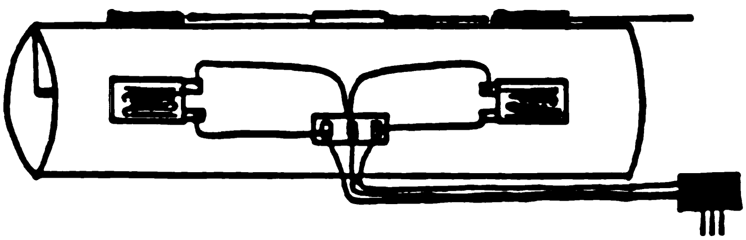


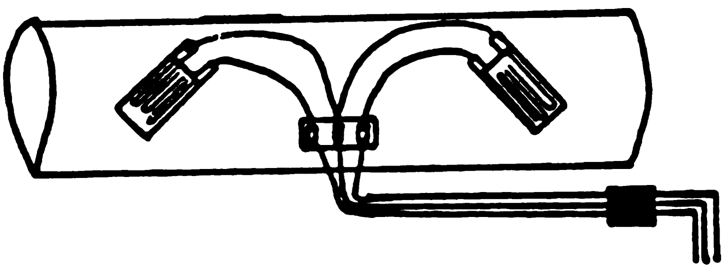
Figure 3.3 Unskilled Performance of an Overgrip Giant Swing on the Uneven Parallel Bars (Subject 6)

Instrumentation and Calibration of the Bar

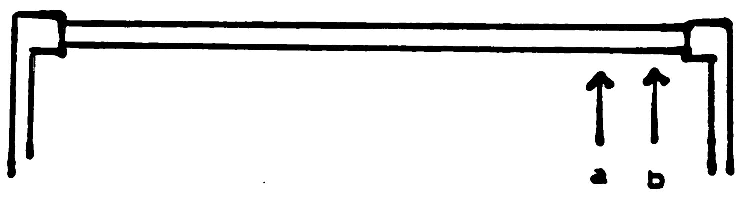
One 233.7 cm American Athletic Institute Graphite X bar with a wood laminated surface was instrumented for this study. The 40 mm diameter bar was constructed from a composite material consisting of graphite and fiberglass. This is the latest bar produced and it has replaced the wood laminated fiberglass bar that was oval in shape, measuring 45 mm by 40 mm. Four Measurements Group CEA-06-250UWw-350 electrical resistance strain gages (see Figure 3.4) were bonded to the surface of the bar in a differential



a. strain gages to collect horizontal and vertical forces



b. strain gages to collect torques

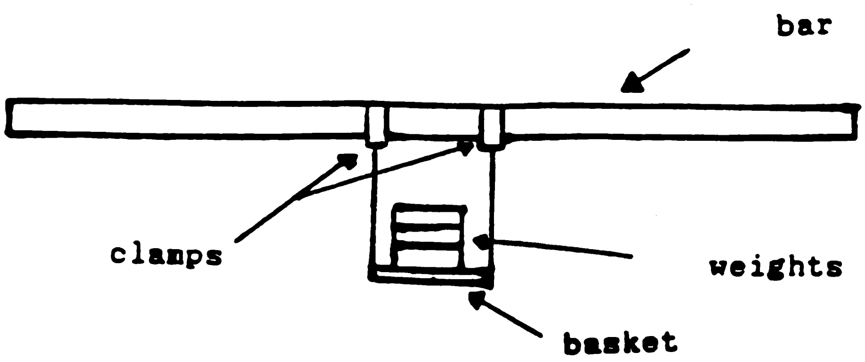


c. placement of gages on the bar

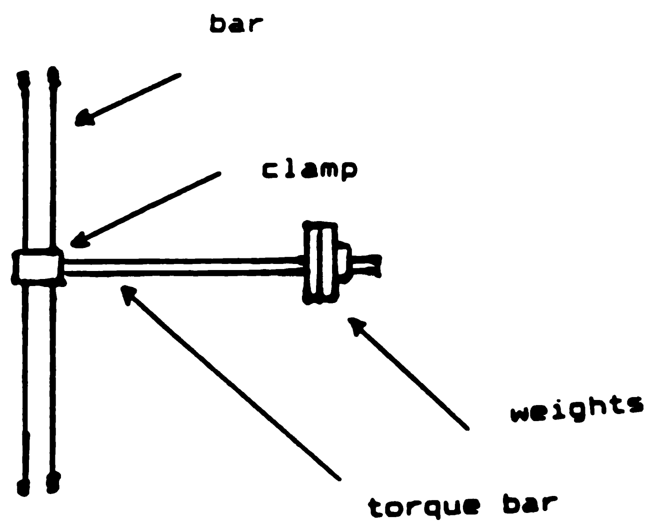
Figure 3.4 Strain Gage Configuration

configuration. This configuration allowed the resultant strain measurement in the vertical and horizontal direction to be independent of the point of application of force along the bar. The gages had a resistance of 350 ohms and a gage factor of 2.075. One set of gages was placed on the top of the bar to collect vertical strain values and another set was placed orthogonally to the first set of gages to collect horizontal strain values (see Figure 3.4 a). An additional pair of gages were placed at a 45 deg angle to the long axis of the bar for the purpose of collecting torque data (see Figure 3.4 b). Figure 3.4 c shows the relative placement of the pairs of gages along the top bar of the uneven parallel bars.

A series of calibration tests were performed prior to data collection. The bar was calibrated statically by suspending known loads, ranging from 9.8 to 133.7 kg, from the bar in the vertical and horizontal directions. It was felt that this range of loads was sufficient since the maximum weight of the subjects was 61.3 kg. A metal device was constructed to hold the weights during calibration. The device was constructed so that two clamps could be placed on the uneven parallel bar and hold weights placed in a basket suspended from the clamps (see Figure 3.5). The bar support was modified to allow the bar to be rotated 90 deg for the purpose of calibrating strain gages that measured the horizontal forces. The calibrations included an analysis for linearity and independence of vertical and horizontal outputs. The strain gages applied at 45 deg, that measured



a. device suspended from uneven parallel bar rail to hold weights



b. weights applied to bar for torque calibrations (viewed from above)

Figure 3.5 Calibration Device

torque, were calibrated by applying known torques to a torque fixture mounted to the bar. Through these tests it was found that the force varied depending on how far from the gages the force was applied. As a result of this finding, a second camera was used to determine the position of each gymnast along the bar. Based on the gymnast's position on the bar, calibration correction factors were applied to the strain gage data.

Prior to filming, the bars were set at the farthest distance apart and not adjusted for individual gymnasts. By positioning the bars at the widest setting, the danger of a gymnast striking the low bar was reduced. This approach also provided a consistency to the data collection process. With the bars in this position, the upright support was at an eight degree tilt from vertical, which meant that the strain gages were also rotated by eight degrees. A correction for the eight degree rotation was included in the data analysis software.

The strain gages were positioned to minimize channel interactions (crosstalk). To verify this, experiments were conducted by applying horizontal and vertical forces to the bar. Results of these experiments showed nearly zero interaction between the vertical and horizontal channels.

Based on the torque values obtained by Kopp and Reid (1980), it was estimated that the maximum torques were relatively small. This required the strain gages for measuring torque to be about ten times the sensitivity as the strain gages for measuring force. Because of this, crosstalk on the order of 10% was experienced between the horizontal force and torque. This interaction was corrected to within 2-3% in the hardware by subtracting a portion of the horizontal channel output from the torque channel output. Final correction of the crosstalk was made in the software. During the pre-filming calibration, loads were applied first to the strain gages set to measure vertical force, then to the strain gages set to measure the horizontal force. As the forces were measured, variations produced in the torque records were also measured. The software then calculated a correction factor to be applied to all subsequent torque outputs when forces were simultaneously present.

The three pairs of strain gages that comprised half of three Wheatstone bridge circuits were connected to three pre-amplifiers. Included in the bridge circuits were three pairs of fixed resistors to establish the reference side of the bridge. In addition, three zero adjustments were used to ensure that bridge outputs under zero conditions were near the center of the pre-amplifier ranges. Final zero was determined in software, prior to data collection for each trial. The actual outputs of all three channels were sampled and used as baselines.

During filming, the three pre-amplifier outputs were sampled at a rate of 100 times/sec in sequence along with synchronizing pulses from the timing lights to coincide with the film images collected. The sampled data were converted to digital form by an analog-to-digital converter (ADC) and read by an IBM Model 9000 dedicated computer. A trigger button, activated by this experimenter, started a 10 sec software timer. During this period, incoming data were stored in the computer's memory and then transferred to floppy disk for storage.

Cinematographic Techniques for Data Collection and Analysis

Film data were collected by two LOCAM 16 mm high speed pin registration motion picture cameras. Kodak Ektachrome Video News Film with an ASA rating of 400 was used in this study. One camera, with a focal length of 30 mm and an f/stop of 5.6, was placed perpendicular to the side of the uneven parallel bars at a distance of 20.2 m from the center of the bars. A second camera, with a focal length of 17 mm and an f/stop of 4.0, was used to record the position of the hands and was placed 10.6 m from the base of the bars. The center of the lens of each camera was 2.3 m from the floor. Both cameras had a shutter angle of 120 deg and were set at 100 frames/sec. The actual filming speed was calculated by timing lights located in each field of view. The timing lights had an effective frequency of 1000 cycles/sec and were used as an aid in synchronizing the film and kinetic data. A schematic of the filming area appears in Figure 3.6.

Prior to filming, a meter stick was held in the field of view at a location where it was projected that the side of the gymnast closest to the camera would form a sagittal plane during the performance of the overgrip giant swing. A second meter stick was placed in the field of view for camera two for the frontal view of the gymnast. From these reference measures a linear multiplier scale factor was

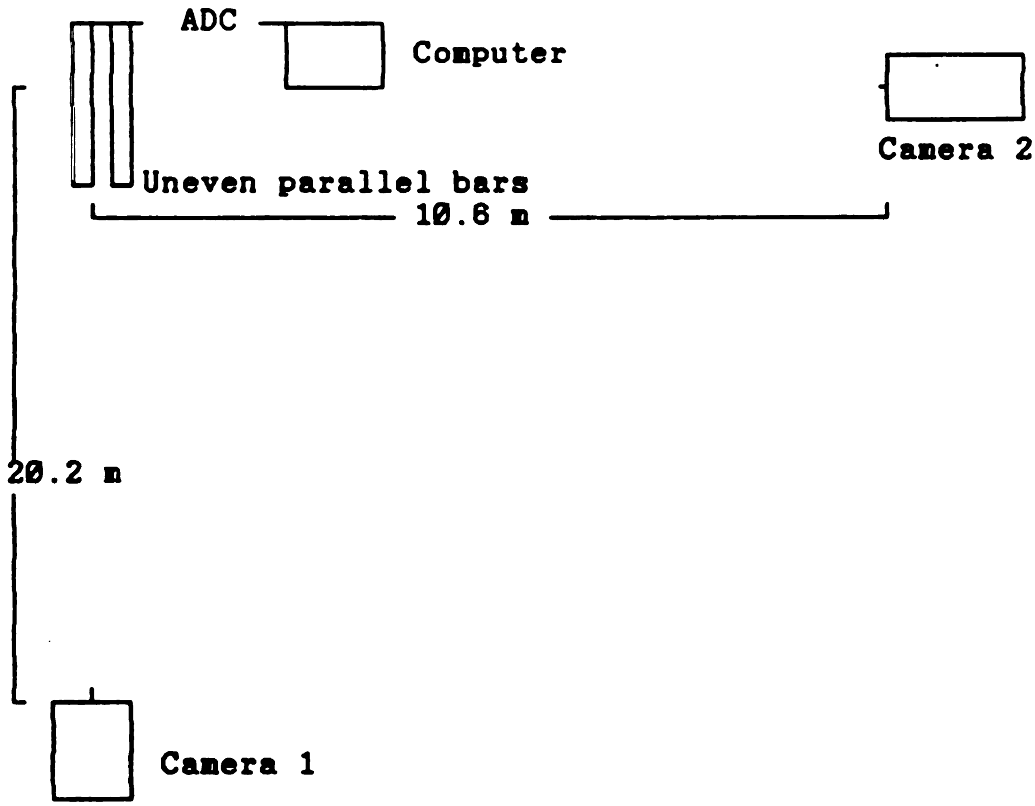


Figure 3.6 Filming Area and Equipment Set-up

obtained. This scale factor was used in converting projected film distances into actual distances. A plumb line was also filmed in the field of view of both cameras as a vertical reference for determining spatial orientation.

For analysis, the film was projected onto a drafting table by a Vanguard Overhead Motion Analyzer (Brown, 1983). With this set-up, the image size was controlled for clarity with the intent of increasing the accuracy of data point identification. X-Y Cartesian coordinates were obtained by digitizing the film images with a Sonic Graf/Pen system. The digitizing system was interfaced with an IBM-PC Computer and an interactive data acquisition computer program. A FORTRAN data analysis program, Bioanalysis, was used to analyze the kinematic parameters selected. This program utilized a fourth order Butterworth filter to smooth the raw data points.

Kinematic Analysis

The overgrip giant swing on the uneven parallel bars was divided into four phases following the convention established in several studies of men's giant swings on the horizontal bar (Kopp & Reid, 1980; Borms, et al., 1976; Dainis, 1975). The quadrant location of the gymnast was determined by the location of the subject's total body center of mass calculated by the Bioanalysis computer program. The four quadrants (see Figure 3.7) were defined as follows:

Quadrant 1: the frame of film in which the center of mass of the subject was closest to being vertical over the bar to the frame of film where the center of mass was located at 180°,

Quadrant 2: from the frame of film where the center of mass of the subject was located closest to 180° to the frame where the center of mass of the subject was closest to being vertically (270°) below the bar,

Quadrant 3: from the frame of film where the subject's center of mass was located closest to 270° to the frame of film where the center of mass of the subject was located closest to horizontal (360°) on the upswing phase of the skill, and

Quadrant 4: from the frame of film where the subject's center of mass was located closest to 360° to the frame of film where the subject's center of mass again arrived over the bar to the 90° location.

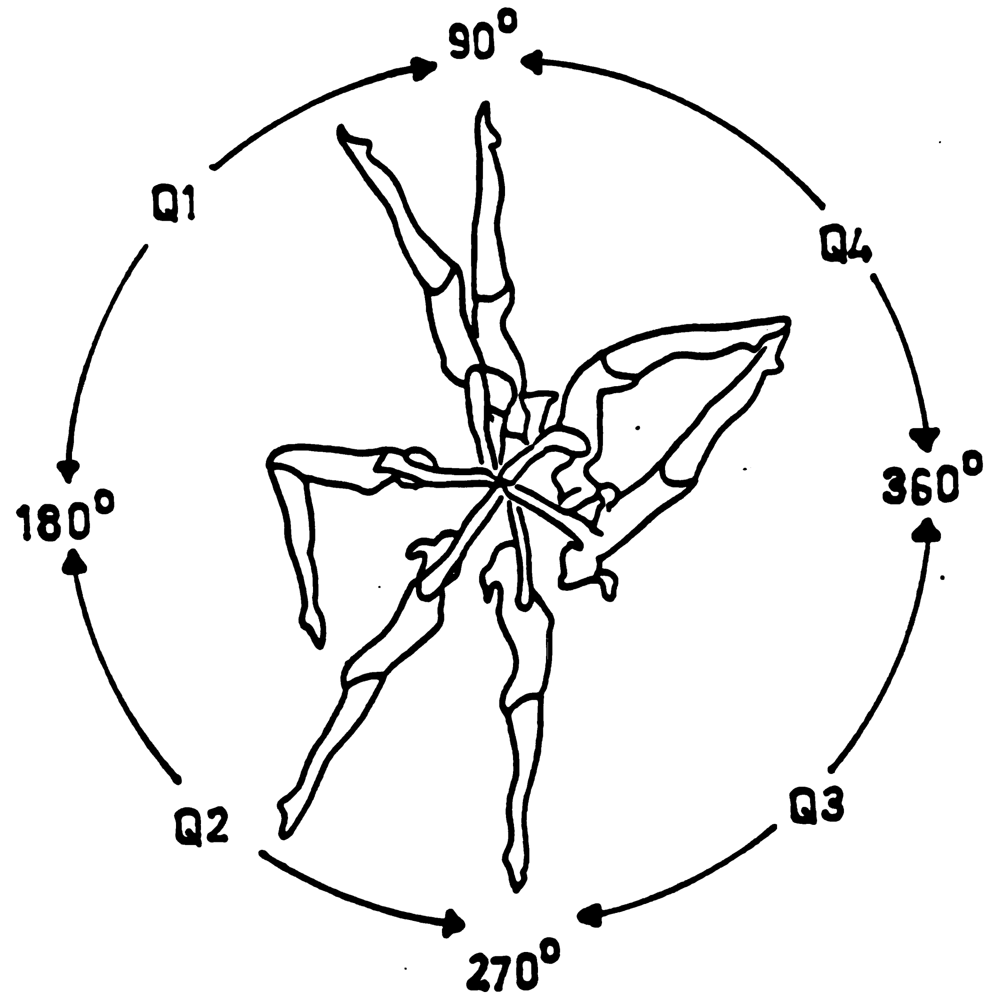


Figure 3.7 Performance of an Overgrip Giant Swing Showing Quadrants (Subject 16)

In order to compare the two skill level groups and to compare the overgrip giant swing on the uneven parallel bars with men's performances of this skill on the horizontal bar, the following kinematic parameters were investigated:

1. Positions of selected body segments. (The segments of interest in this study included the forearm, arm, trunk and head, thigh, shank, and foot).
2. Angles between specific body segments. (The angles of interest in this study were the shoulder angle, and the hip angle).
3. Linear velocity of the center of gravity of individual segments, individual joint centers, and total body center of gravity.
4. Linear acceleration of the center of gravity of segments, joint centers, and total body center of gravity.
5. Time to perform the entire overgrip giant swing and a temporal analysis of the individual quadrants.

Kinetic Analysis

Data collected by the strain and torque gages were transmitted to a computer program developed at the Center for the Study of Human Performance at Michigan State University. Force-time curves, normalized by body weight, and torque-time curves were generated as well as vertical and horizontal forces and moments. The resultant force and the angle of the resultant force were calculated. By synchronizing the kinetic data with the film data, relationships could be drawn between kinematic and kinetic variables in the performance of the overgrip giant swing.

Anthropometic, kinematic, and kinetic data were input variables in a FORTRAN computer program developed by the author to calculate joint forces and net muscle moments. Figure 3.8 shows a link segment model of a gymnast's forearm and arm that was used to calculate the joint forces and muscle moments. The following assumptions were made with respect to the model:

1. The gymnast and the bar were bilaterally symmetrical and a two-dimensional model in the sagittal plane was valid.
2. The arm and forearm could be treated as rigid bodies.
3. The joints, that link the segments together, could be treated as frictionless and pinned.
4. Each segment had a fixed mass located as a point mass at its center of gravity.
5. The location of the center of gravity of each segment remained fixed within the segment during the movement.
6. The moment of inertia of each segment about its mass center was constant during the movement.
7. The forces and torques between the bar and hand were considered to be transmitted directly to the center of the wrist and forearm, respectively.

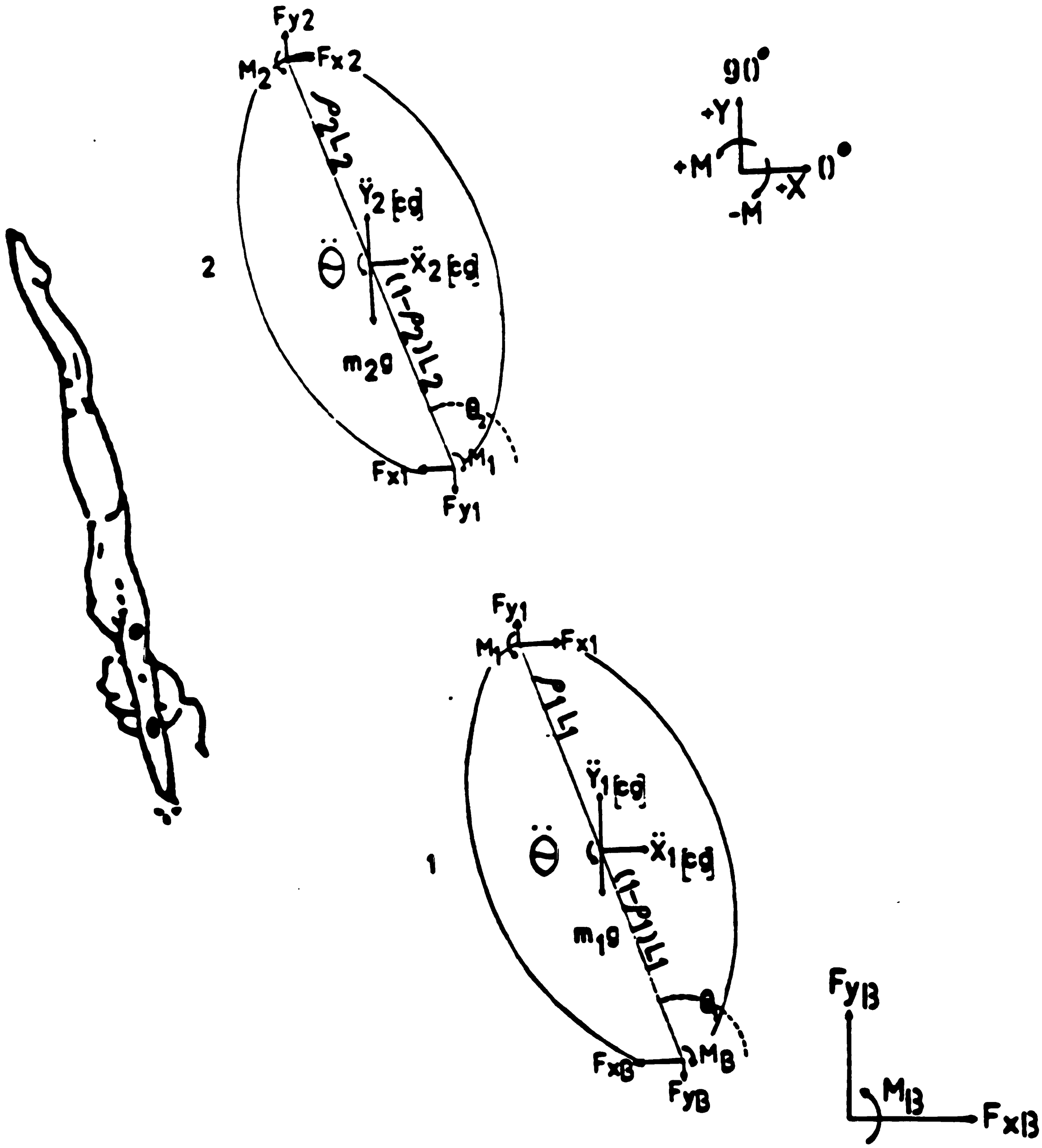


Figure 3.8 Link Segment Model of Forearm and Arm

Model Nomenclature

(1) Forearm
(2) Arm
B Bar and hand
g acceleration due to gravity (-9.8 m/s^2)
m mass (kg)
M Torque (Nm)
F Force (N)
L Segment length (m)
p Percent of segment length to center of gravity
cg Center of gravity
X Horizontal acceleration (m/s^2)
Y Vertical acceleration (m/s^2)
θ Angular acceleration (rad/s^2)

Figure 3.8 (Continued)

8. The use of Dempster's (1955) data to represent the segment mass proportions and center of gravity locations on female gymnasts did not substantially alter the magnitude of kinematic and kinetic parameters from their true values.

Linear equations of each segment's mass center may be expressed as:

$$\Sigma F = ma, \text{ where } a = \text{acceleration } (m/sec^2)$$

$$\Sigma F_X = mX\ (cg) \qquad \Sigma F_Y = mY\ (cg)$$

$$F_{X1} - F_{XB} = m_1X_1(cg) \qquad F_{Y1} - F_{YB} - m_1g = mY_1(cg)$$

$$(1)\quad F_{X1} = F_{XB} + m_1X_1(cg) \qquad (3)\quad F_{Y1} = F_{YB} + m_1g + m_1Y_1(cg)$$

$$F_{X2} - F_{X1} = m_2X_2(cg) \qquad F_{Y2} - F_{Y1} - m_2g = m_2Y_{Y2}(cg)$$

$$(2)\quad F_{X2} = F_{x1} + m_2X_2(cg) \qquad (4)\quad F_{Y2} = F_{Y1} + m_2g + m_2Y_2(cg)$$

Angular equations of motion of the forearm and arm may be expressed as:

$$\Sigma M = I\theta, \text{ where } I = \text{moment of inertia (kg m}^2\text{)}$$

$$(5) \quad M_1 = I_1\theta_1 + F_{YB}\ (1-p_1)\ L_1 \cos\theta_1 - F_{XB}\ (1-p_1)\ L_1 \sin\theta_1 + F_{Y1}\ (p_1L_1 \cos\theta_1) + F_{X1}\ (p_1L_1 \sin\theta_1) + M_B$$

$$(6) \quad M_2 = I_2\theta_2 + F_{Y1}\ (1-p_2)\ L_2 \cos\theta_2 - F_{X1}\ (1-p_2)\ L_2 \sin\theta_2 + F_{Y2}(p_2\ L_2 \cos\theta_2) + F_{X2}\ (p_2\ L_2 \sin\theta_2) + M_1$$

Statistical Analysis

The judges' ratings of the subjects' giant swings were used to divide the subjects into two groups, highly skilled and less skilled. The objectivity of the judges' ratings was obtained by calculating an intraclass correlation coefficient as described by Safrit (1976) and Wilkerson (1978). The selected kinematic and kinetic variables for each group were compared by using a one way analysis of variance (ANOVA). One way ANOVA was used to determine if the groups were significantly different ($p < .05$) in height, weight, segment lengths, and percent body fat; parameters which could account for differences in kinematic or kinetic variables. A $p < .05$ level of significance was used because a more stringent test was desired to show group comparability than was used to show skill performance differences.

The analysis of variance technique was used to compare the two groups on the following variables:

1. temporal comparisons of the two skill groups;
2. peak resultant, horizontal and vertical velocities and accelerations of segments;
3. peak resultant, horizontal and vertical velocities and accelerations of the center of mass;
4. peak resultant velocities of joint centers (ankle, knee, hip, shoulder, and elbow);
5. shoulder, elbow, and hip joint angles;
6. peak resultant, horizontal, and vertical forces generated on the bar by each group; and
7. horizontal and vertical forces and moments exerted on the elbow and shoulder joints.

This statistical treatment, calculated by the Statistical Package for the Social Sciences (SPSSX) on a VAX computer was used to determine if performance differences between the two groups were significant at the .10 level to identify critical features associated with skillful execution of the overgrip giant swing on the uneven parallel bars.

CHAPTER IV

Results and Discussion

The data for this study of the overgrip giant swing on the uneven parallel bars were collected from two sources: cinematographic records of performance and strain gage records of force and torque applied to the top bar of the uneven parallel bars. The results are presented in this chapter under the headings of general characteristics of the subjects, group placement and characteristics, objectivity of the judges' ratings, reliability of digitized data, kinematic analysis, and kinetic analysis.

General Characteristics of the Subjects

The performance of the overgrip giant swing on the uneven parallel bars by 15 female, Class I and Elite gymnasts were filmed for possible inclusion in this study. The gymnasts were from five clubs located in Michigan. Gymnasts ranged in age from 10 years and 6 months to 16 years and 5 months, in weight from 29.5 kgs to 61.3 kgs, and in height from 134.3 cm to 167.3 cm. The means for age, weight, and height were 13 years and 3 months, 41.1 kgs, and 149.3 cm, respectively. The subjects had participated from four to 10 years in gymnastics with a total group mean of 6.7 years.

The subjects were weighed hydrostatically and their percent body fat calculated. The total group body fat ranged from 13 to 22 percent with a mean of 17.5 percent. The following anthropometric measurements were taken: biiliac diameter, biacromial diameter, hand length, elbow-wrist length, shoulder-elbow length, calf length, and thigh length (see Table 4.1).

Table 4.1 Means and Ranges of Selected Anthropometric Measurements

	Entire Group		
Measurement	Mean (cm)	Minimum (cm)	Maximum (cm)
Biiliac Diameter	23.7	21.0	28.1
Biacromial Diameter	33.5	28.3	39.0
Hand Length	16.2	14.5	17.5
Elbow-wrist Length	23.2	19.5	26.0
Shoulder-elbow Length	31.3	27.4	34.9
Calf Length	34.3	30.0	38.4
Thigh Length	36.5	31.0	45.0

Group Placement and Characteristics

A panel of four Michigan judges, three elite and one Class I, independently rated the 15 gymnasts based on the following characteristics that had been predetermined by this researcher: bent arms, arched body position, bent legs, separated legs, forced return to handstand, and general impression. A sample judging sheet and a summary of the judges scores appear in Appendix C. A weighted scale was devised that associated with each characteristic a set number of points, resulting in a total of 10 points. Each judge awarded a score out of 10.0 for each gymnast after having viewed the subjects' individual video tapes of their overgrip giant swing isolated from the other skills in the sequence. The judge was given three times to view each trial before awarding a score. The ranking of the gymnasts was obtained by averaging the two middle scores of all judges. Subjects with the five highest scores were assigned to Group 1 - the highly skilled group. Subjects with the lowest five scores were assigned to Group 3 - the less skilled group. Group 2 was the intermediate skilled group and subjects in this group were not analyzed further.

A one way analysis of variance (ANOVA) was used to determine if there was any significant difference between the groups on the following variables: age, height, weight, years in gymnastics, percent body fat, thigh length, calf length, shoulder-elbow length, elbow-wrist length, hand length, biacromial diameter, and biiliac diameter. While there are individual differences between the subjects in this study, the ANOVA results revealed that there were no significant differences at the $p < .05$ level between Groups

1 and 3 on the above variables. Table 4.2 gives a summary of selected group characteristic.

Table 4.2 Selected Comparisons by Group

Variable	Group	Mean	Minimum	Maximum
Age (yrs)	1	13.35	12.17	15.33
	2	12.20	10.50	14.58
	3	14.19	10.50	16.42
Years in gymnastics	1	7.20	4.00	9.00
	2	5.70	4.00	7.50
	3	6.67	4.00	10.00
Height (cm)	1	151.00	145.50	155.70
	2	143.00	134.30	155.00
	3	153.84	136.00	167.30
Weight (kg)	1	39.90	34.60	44.06
	2	36.24	29.46	45.09
	3	47.15	31.70	61.34
Body Fat (%)	1	17.53	13.00	22.00
	2	18.14	16.00	20.30
	3	16.83	13.50	21.33

Objectivity of Judges' Ratings of Performances

The procedure for evaluating the objectivity of the judges ratings was taken from Safrit (1976) and Wilkerson (1978). A two-way analysis of variance was obtained through the latest version of the Statistical Package for the Social Sciences (SPSSX) program on a VAX mainframe computer and the intraclass correlation coefficient was manually calculated. The analysis of variance summary table and objectivity calculation appear in Table 4.3. The objectivity score was .935. This supported the technique of using judges ratings to assign gymnasts to skill level groups.

Table 4.3 Analysis of Variance Summary Table and Objectivity Calculation

Source of Variation		dF	SS	MS
Between Subjects	(n-1)	13	106.09	8.16
Between Judges	(1-1)	3	53.20	17.73
Interaction	(n-1)(1-1)	39	20.55	.53
Total		55	179.84	

$$O = \frac{\sigma^2_s}{\sigma^2_s + \frac{\sigma^2_{sxJ}}{1} + \frac{\sigma^2_J}{1}} = \frac{MS_s - MS_{sxJ}}{MS_s} = \frac{8.16 - .53}{8.16} = .935$$

Reliability of Digitized Data

Two of the subjects' trials were digitized twice and each trial was analyzed by the Bioanalysis computer program. A Pearson product-moment correlation was calculated by the SPSSX program for the linear velocity of the toe, ankle, knee, and hip for Subjects 1 and 4. In addition, correlations were performed on acceleration values calculated from displacement data for both subjects for the arm, and forearm. The results, which appear in Table 4.4, show that the reliability for the velocities were very high, ranging from .969 for the hip of Subject 1 to .997 for the knee of Subject 4. The reliability coefficients for the accelerations, however, are much more varied. The lowest correlation coefficient was .315 for the vertical acceleration of Subject 1's arm, while the highest coefficient was .883 for the horizontal acceleration for Subject 4's arm. The acceleration values are subject to variability, since there is error introduced due to the digitizing process as well as from calculating accelerations from position data. Since the arm and forearm accelerations and masses are relatively small compared to the magnitude of

Table 4.4 Reliability Correlation Coefficients of Selected Variables

Velocity:	Toe	Knee	Ankle	Hip
Subject 1	.994	.983	.989	.969
Subject 4	.987	.997	.996	.995
Accelerations:	Arm X	Arm Y	Forearm X	Forearm Y
Subject 1	.765	.315	.367	.553
Subject 4	.883	.862	.787	.686

the forces exerted and the mass of the whole body, it is assumed that the variable accelerations would not substantially alter the joint reaction force and muscle moment calculations.

Kinematic Analysis

The digitized cinematographic data files were transferred to a mainframe VAX computer and analyzed by a FORTRAN program (Bioanalysis), that was developed at Michigan State University. The Bioanalysis program used the digitized, position data to calculate velocities and accelerations of the total body center of mass, the body segments, and the selected joint centers (ankle, knee, hip, shoulder, and elbow) for each subject. For each of the previously mentioned variables, peak values, peak values per quadrant, and the time of occurrence of peak values expressed as a percent of total time for the cycle of the overgrip giant swing were calculated. Statistical analysis consisted of a one way analysis of variance on each variable to determine if a significant difference existed between Group 1 (highly skilled) and Group 3 (less skilled). In this section, the results will be presented under the following sub-headings: temporal analysis, position data for shoulder and hip angles, center of mass analysis, joint analysis, and body segment analysis.

Temporal Analysis

The giant swing from handstand to handstand took a mean time of 2.26 seconds for the total group. The range for the total group was 1.80 to 2.87 seconds. Table 4.5 gives the mean times for each group and the relative proportions for each quadrant. The mean total times and times for individual quadrants for Groups 1 and 3 showed no statistical difference ($p < .10$).

Although not statistically different at $p < .10$, there was an indication of a trend between the groups in the first and fourth quadrants. The gymnasts in Group 3 frequently did not end the previous skill in a vertical handstand position and therefore began the overgrip giant swing from a lower starting position. This in turn, created a shorter time

Table 4.5 Temporal Data for Giant Swings for the Total Group, Group 1, and Group 3

	Total Time (sec)			
	Mean	S.D.	Min	Max
Total Group	2.280	.324	1.80	2.87
Group 1	2.304	.355	1.97	2.87
Group 3	2.256	.332	1.80	2.65
	Relative Time/Quadrant (% of total cycle time)			
	Quad 1	Quad 2	Quad 3	Quad 4
Total Group	42.68	15.48	16.18	25.66
Group 1	44.44	15.71	16.06	23.78
Group 3	40.87	15.25	16.31	27.57

period for Quadrant 1. Consequently, in Quadrant 4, the less skilled gymnasts averaged a longer time to bring their center of mass over the high bar to complete the overgrip giant swing.

Men's overgrip giant studies reveal similar temporal data. Boone (1977) recorded times of 2.40 and 2.04 sec for his two male subjects to complete the overgrip giant swing, while Ishii and Komatsu (1987) reported a time of 2.2 sec for their subject. The slightly longer period of time for the overgrip giant swing on the uneven parallel bars reported in the current study as compared to those reported for men on the horizontal bar, may be accounted for by the difference in the size of the bars and the obstacle presented by the low bar.

Hip and Shoulder Angles

Hip angle. Figure 4.1 shows a graph of the hip and shoulder angles of Subject 16, who was typical of the higher skill level (Group 1) and Figure 4.2 shows Subject 6, who was typical of the less skilled gymnasts (Group 3). These graphs show shoulder and hip angles throughout the overgrip giant swing. The vertical lines on the graph separate the quadrants, each quadrant being labeled Q1, Q2, Q3, or Q4. A horizontal line was drawn at 180 deg to indicate when either the hip or shoulder was fully extended. The graphs of the hip angles for the two gymnasts show a similar shape, although Subject 6 began the skill in a hyperextended hip position. Both gymnasts showed maximum hip flexion on the downswing phase of the circle. Subject 16 reached maximum hip flexion (88.7 deg) just prior to the end of Quadrant 1, while Subject 6 reached her maximum pike (110.2 deg) just after the beginning of Quadrant 2. Studies of men's giant

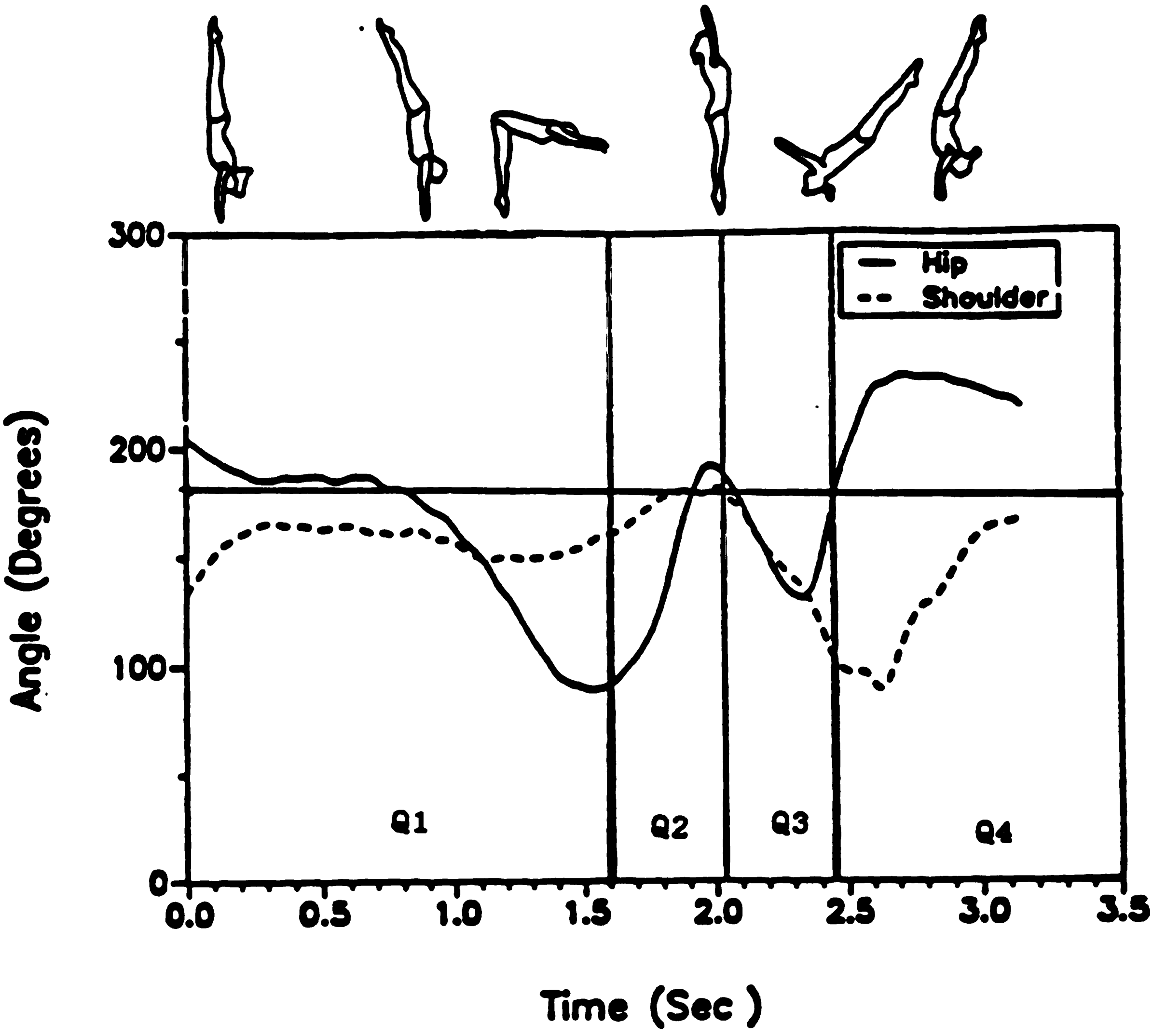


Figure 4.1 Hip and Shoulder Angles (Subject 16)

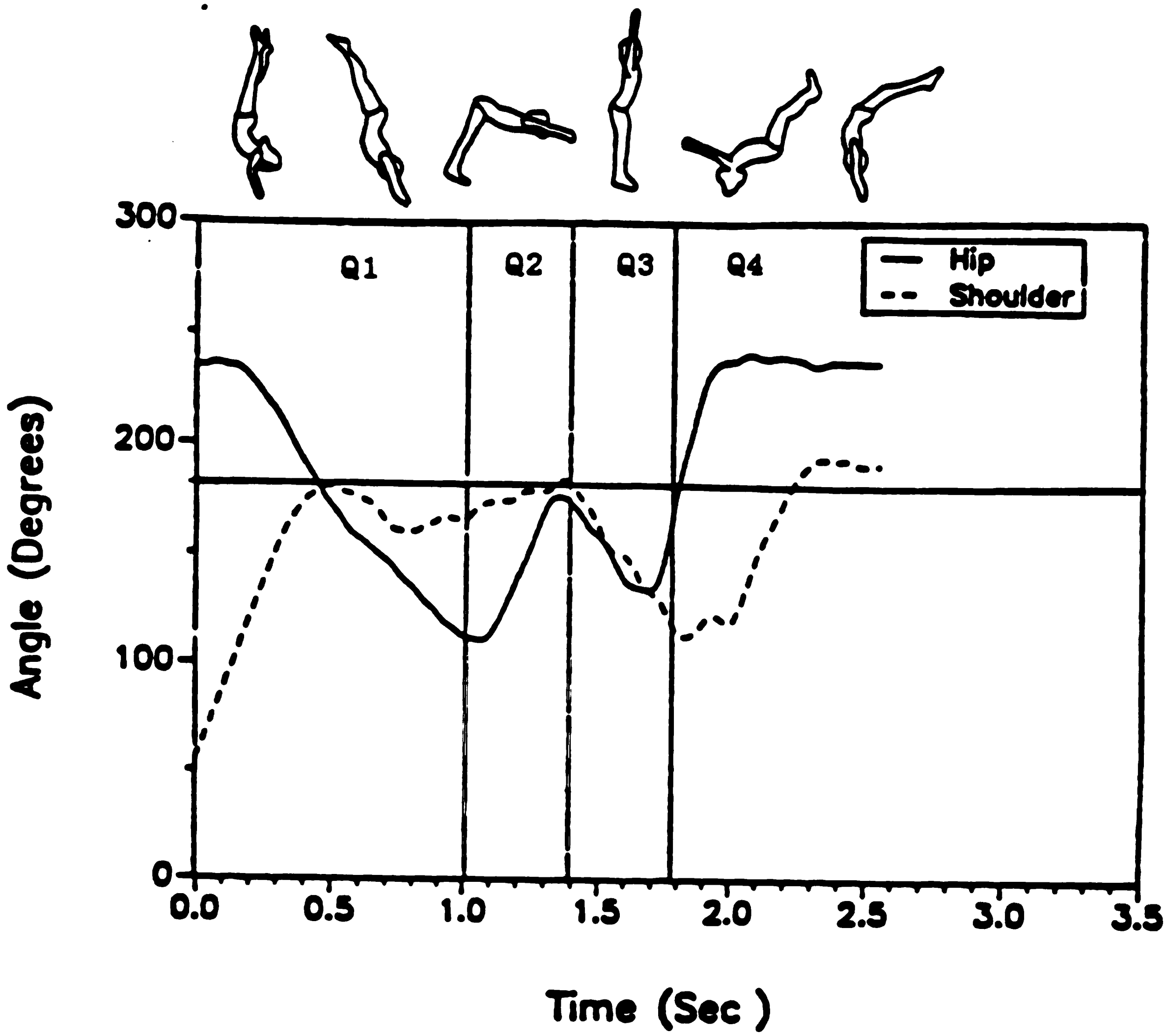


Figure 4.2 Hip and Shoulder Angles (Subject 6)

swings have shown a different pattern during this quadrant. Men do not have the physical constraint of the low bar on the descent phase. Borms, Moers and Hebblelinck (1976) reported that their male subjects were slightly hyperextended at the end of Quadrant 1.

During Quadrant 2, the hips again extend to reach a nearly straight position as the body passes under the bar. Subject 16 reached an angle of 191.8 deg at the end of Quadrant 2, while Subject 6 achieved a maximum angle of 176.1 deg during this quadrant. George (1980) emphasized the importance of achieving a straight body position before the end of Quadrant 2. Subject 16 achieved this goal, but Subject 6 did not. Subject 6 began an extending movement, but did not achieve a fully extended position during Quadrant 2.

During Quadrant 3, Subject 16 and Subject 6 again piked to 130.6 deg and 133.3 deg, respectively. Cheetham (1984) reported that there was very little pike necessary during this phase for the overgrip giant swing on the horizontal bar and Borms (1976) reported that his subjects only showed a 10 deg change from a straight body position during the same phase of the giant swing on the horizontal bar. The female gymnasts pike much more during this phase to compensate for the inability to maintain a long body position during the descent phase of the skill due to the proximity of the low bar. Both Subjects 16 and 6 extended their hips to arrive on top of the bar in a handstand position. Both gymnasts hyperextended their hips in Quadrant 4, with Subject 6 showing slightly more hip hyperextension during this phase of the skill.

Shoulder angle. The graphs of the shoulder angle also show similarities in the two representative subjects' patterns (see Figures 4.1 and 4.2). Since the gymnasts performed a sequence of skills, the beginning position of the overgrip giant swing was dependant upon the finishing position of the previous skill. Both gymnasts began the overgrip giant swing with the shoulders in an extended position. Subject 16 showed a beginning shoulder angle of 132.9 deg, while Subject 6 had a shoulder angle of 55.2 deg. Both gymnasts rapidly began to flex at the shoulder joint so that maximum flexion (181 deg and 183 deg, respectively) did not fluctuate very much until the end of Quadrant 2. George (1980) emphasized the importance of maintaining an open shoulder angle in order to achieve a longer radius of rotation of the center of mass of the body during the descent phase. Subject 16 came closer to achieving this goal than Subject 6.

During Quadrants 3 and 4, the shoulders of Subjects 16 and 6 extended again until the gymnasts began to return to the handstand position on top of the bar. Kopp and Reid (1980) indicated that this shoulder extension during Quadrants 3 and 4 served to decrease the moment of inertia of the gymnast to generate an increase in angular velocity. These factors contribute to the gymnast being able to complete the overgrip giant swing.

Center of Mass Analysis

Path of the center of mass. Figures 4.3 and 4.4 show the path of the center of mass of the two representative gymnasts, as they performed the overgrip giant swing. The horizontal and vertical lines were drawn to depict the occurrences of the quadrants. The smaller closed figure

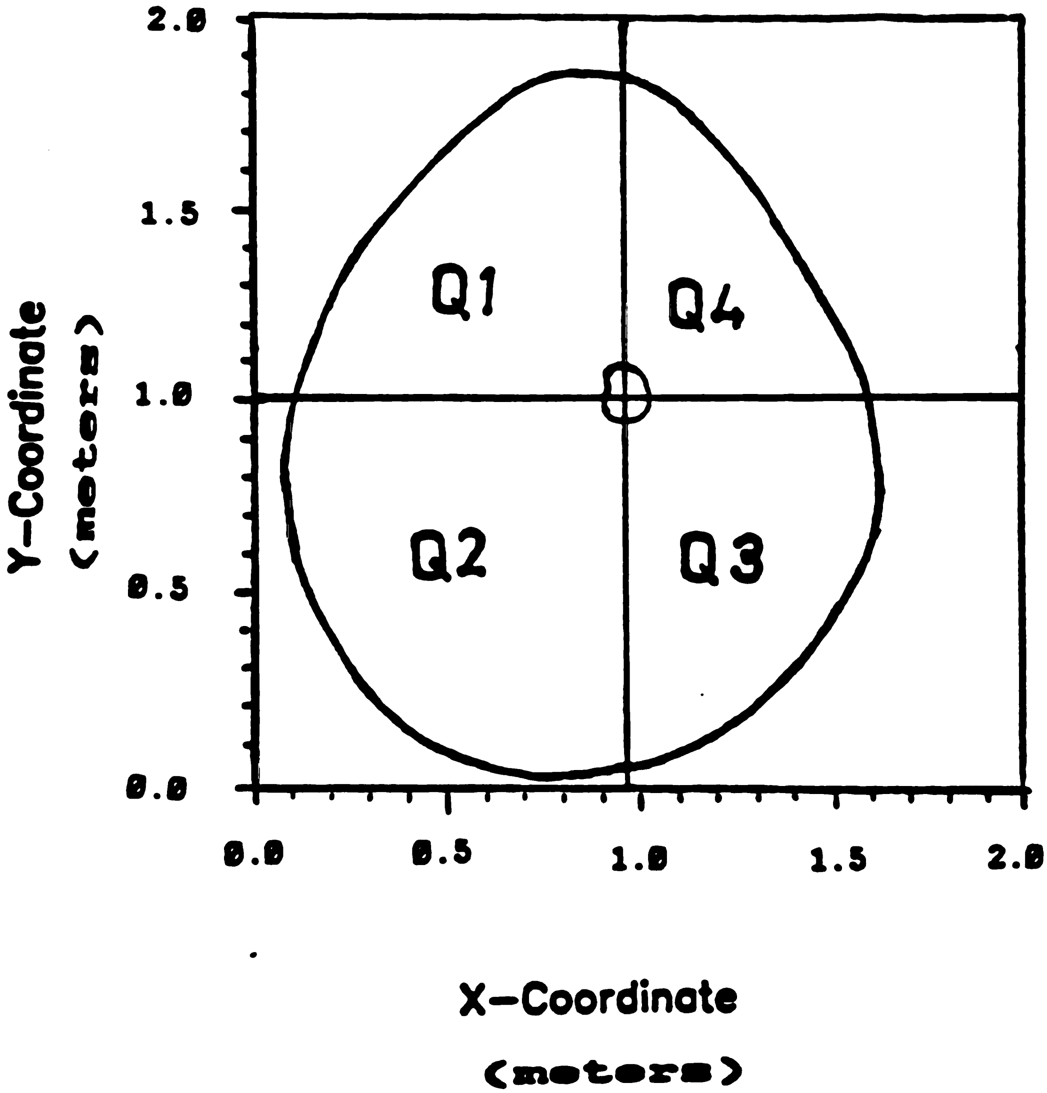


Figure 4.3 Path of Center of Mass (Subject 16)

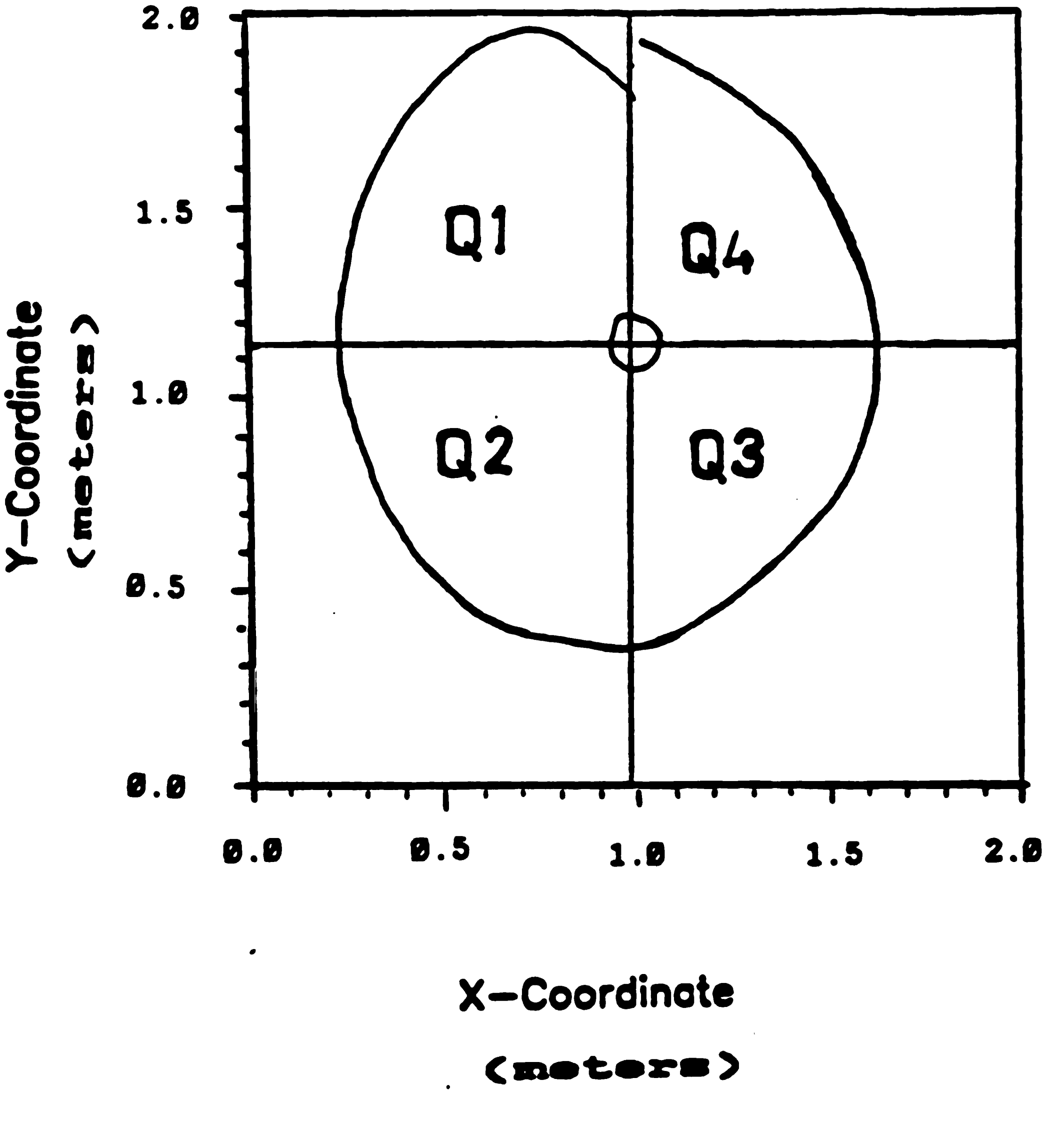


Figure 4.4 Path of Center of Mass (Subject 6)

shows the path of the wrists around the bar during the performance of the skill. The larger closed figure shows the path of the total body center of mass. While a difference in height of the two gymnasts, (154.3 cm for Subject 16 and 137.5 cm for Subject 6) may have influenced the relative size of the paths of the center of mass as the gymnast performed the overgrip giant swing, the pattern of the path was quite different and was of interest in this investigation. It can be seen by these figures that Subject 16, the more highly skilled gymnast, had a higher relative starting position of the center of mass, as recommended by George (1980), and the ending position of the circle was the same as the beginning position. In Figure 4.4, the center of mass of Subject 6 was closer to the bar at the beginning of the cycle. Then, on the downswing, the center of mass moved farther from the bar which enabled the gymnast to complete the skill. The ending position, however was lower than the highest position of the center of mass of Subject 6 during Quadrant 1. For both subjects, note that the position of the center of mass is farther from the bar during Quadrants 1 and 2, the descent phase, than Quadrants 3 and 4, the ascent phase.

Peak resultant velocity of the center of mass. The mean peak resultant velocity (m/sec) of the center of mass was calculated for each subject and the groups were compared for the mean peak resultant velocity, mean peak resultant velocity per quadrant, and the time of occurrence of peak values expressed as a percent of total time. The mean peak resultant velocity for the total group was 5.60 m/sec, the means were 6.15 and 5.05 m/sec for Group 1 and Group 3, respectively. Borms, et al. (1976) reported a maximum resultant velocity of the center of mass to be 6.0 m/sec for the male subjects in their study and the maximum resultant velocity occurred in Quadrant 2. The mean peak values for the velocities in the horizontal and vertical directions can be seen in Table 4.6. There was a significant difference ($p < .10$) between the groups for mean peak horizontal velocity and the relative time of occurrence for the mean peak vertical velocities. (See Appendix D, Table D.1)

The mean peak horizontal velocity was 4.63, 4.89, and 4.38 m/sec for the Total Group, Group 1, and Group 3, respectively. The mean peak vertical velocity for Group 1 was .3 m/sec. and occurred 57.9 percent through the cycle. For Group 3, the mean peak vertical velocity of -2.9 m/sec occurred 40 percent through the skill.

Table 4.6. Mean Peak Resultant Velocity of the Center of Mass

	V_X* (m/sec)	V_Y (m/sec)	V_R (m/sec)
Total Group	+4.63 (.46)	-1.30 (5.40)	5.60 (1.41)
Group 1	4.89 (.37)	.30 (6.64)	6.15 (1.91)
Group 3	4.38 (.42)	-2.90 (3.89)	5.05 (0.23)

+Mean (S.D).
* $p < .10$.

Examining the mean peak velocity of the center of mass per quadrant (see Appendix D. Table D.2) revealed a significant difference ($p < .10$) between the groups for horizontal velocity in Quadrant 3. The mean peak horizontal velocity for Group 1 was 4.3 m/sec and 3.6 m/sec for Group 3. A significant difference ($p < .10$) was found for the mean peak resultant velocity in Quadrant 4. These results indicated that the more highly skilled gymnasts, as compared to the less skilled, had a greater increase in velocity of the center of mass during this critical, upswing phase of the skill.

Acceleration of the center of mass. The accelerations (m/sec^2) were also calculated (see Appendix D, Table D.4). Mean peak resultant accelerations of the total movement of the overgrip giant swing were 766.8, 1068.4, and 465.3 m/sec^2 for the total group, Group 1, and Group 3, respectively. There were no significant differences in the mean peak resultant accelerations of the center of mass about the bar. In Quadrant 4, a significant difference ($p < .10$) was found between the groups for the relative time of occurrence of mean peak resultant accelerations for the center of mass. Appendix D (Tables D1-D.6) contains summary tables of the statistical comparisons for peak velocity and acceleration.

Angular velocity and angular acceleration. Angular velocity (deg/sec) and angular acceleration (deg/sec^2) of a line segment connecting the center of the bar and the center of mass of the gymnast were calculated. The mean peak angular velocity for the total group was 262.3 deg/sec and occurred at 73.6 percent of the time of the cycle. The representative graph of the angular velocity for Subject 16 appears in Figure 4.5. The angular velocities reported in

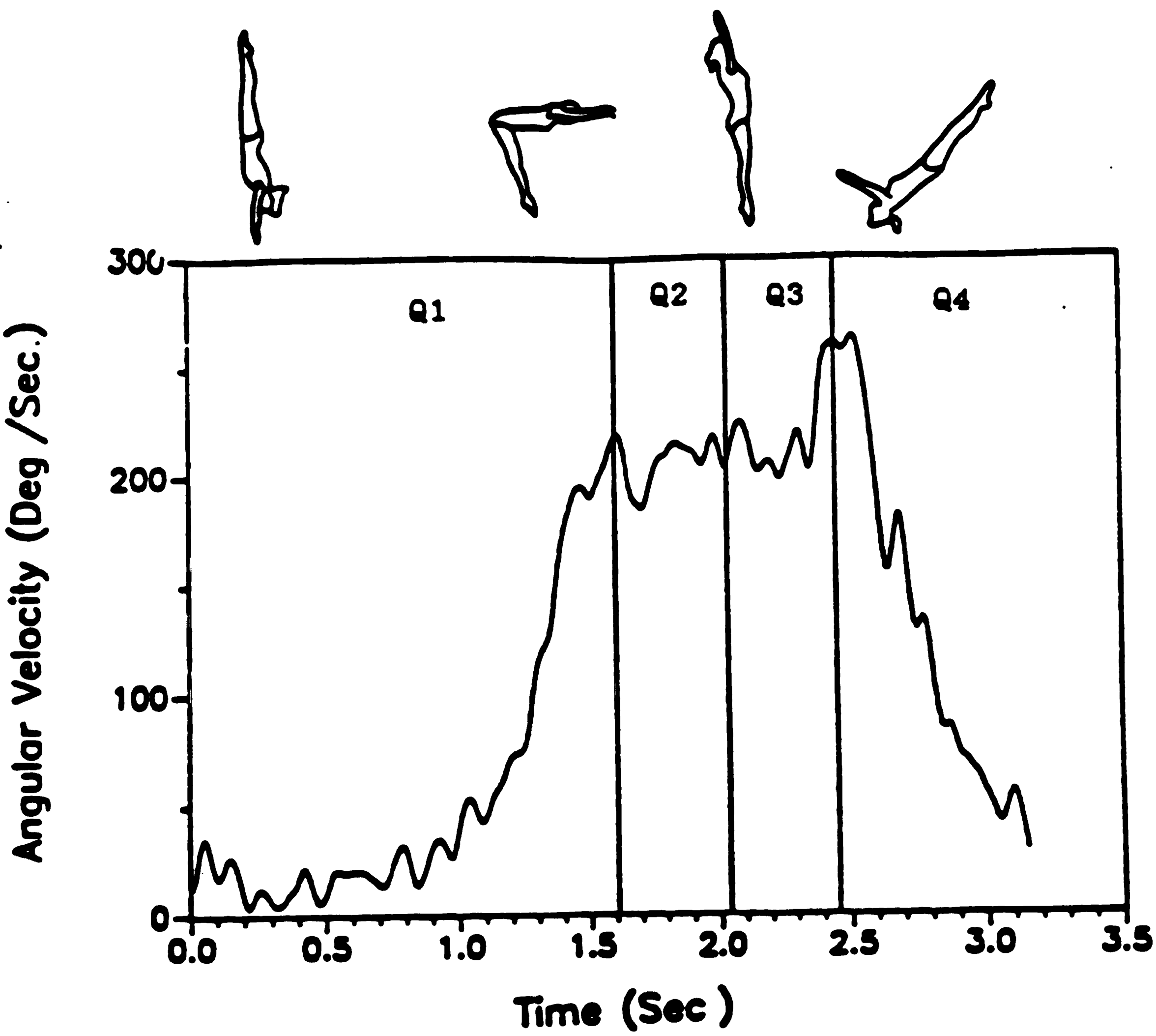


Figure 4.5 Angular Velocity of Center of Mass of the Whole Body (Subject 16)

this investigation were somewhat lower than those reported in other research on men's overgrip giant swings. Cheetham (1984) reported a mean peak angular velocity of 318 deg/sec, which occurred at the end of Quadrant 3. Boone calculated angular velocities of 291.0 deg/sec and 304.9 deg/sec for the two male subjects in his study. The female gymnasts lower maximum angular velocity may be related to their use of a larger size bar and to the technique of piking on the downswing.

The mean peak angular acceleration of the total group was 1159.60 deg/sec^2 and occurred in Quadrant 1, 33.0 percent into the cycle. There were no significant differences between the groups on these variables.

Joint Analysis

Mean peak resultant velocity and acceleration values were calculated for selected joints of the body (ankle, knee, hip, and shoulder) and compared using a one way ANOVA. A significant difference ($p < .10$) was found between Group 1 and Group 3 on mean peak resultant velocity of the ankle, knee, and hip. Table 4.7 summarizes the mean peak velocities of selected joints. The total group mean peak resultant velocity for the ankle was 10.47 m/sec, while Group 1 was 11.03 m/sec and Group 3 was 9.64 m/sec. For the hip, the mean peak resultant velocities were 5.96, 6.22 and

5.57 m/sec. for the Total Group, Group 1, and Group 3, respectively.

Table 4.7 Mean Peak Resultant Velocity of the Selected Joints

	Ankle*** (m/sec)	Knee* (m/sec)	Hip*** (m/sec)	Shoulder (m/sec)	Elbow (m/sec)
Total Group	+10.47	7.16	5.76	3.64	2.66
	(.793)	(.323)	(.427)	(.657)	(.359)
Group 1	11.03	7.30	6.22	3.91	2.64
	(.372)	(.191)	(.326)	(.751)	(.235)
Group 3	9.64	6.95	5.57	3.24	2.68
	(.338)	(.389)	(.186)	(.071)	(.543)

+Mean
(S.D.).
* $p < .10$ *** $p < .01$.

There also was a significant difference ($p < .10$) between the groups for the time of occurrence of peak velocities of the ankle and shoulder expressed as a percent of total time. Tables D.7 and D.8 in Appendix D give the complete statistical information for the peak velocities and their relative times of occurrence.

When examining the mean peak resultant velocities per quadrant, a significant difference ($p < .10$) was found between the groups for the hip and elbow in Quadrant 2; for the ankle and shoulder in Quadrant 3; and for the knee, hip, and shoulder in Quadrant 4. Tables D.9 and D.10 in Appendix D show the statistical data for mean peak resultant velocities per quadrant and the times of occurrence of peak values expressed as a percent of total time.

Figures 4.6 and 4.7 show the resultant linear velocity of the hip and ankle joints for Subject 16 and Subject 6, typical of Group 1 and Group 3, respectively. The graphs are

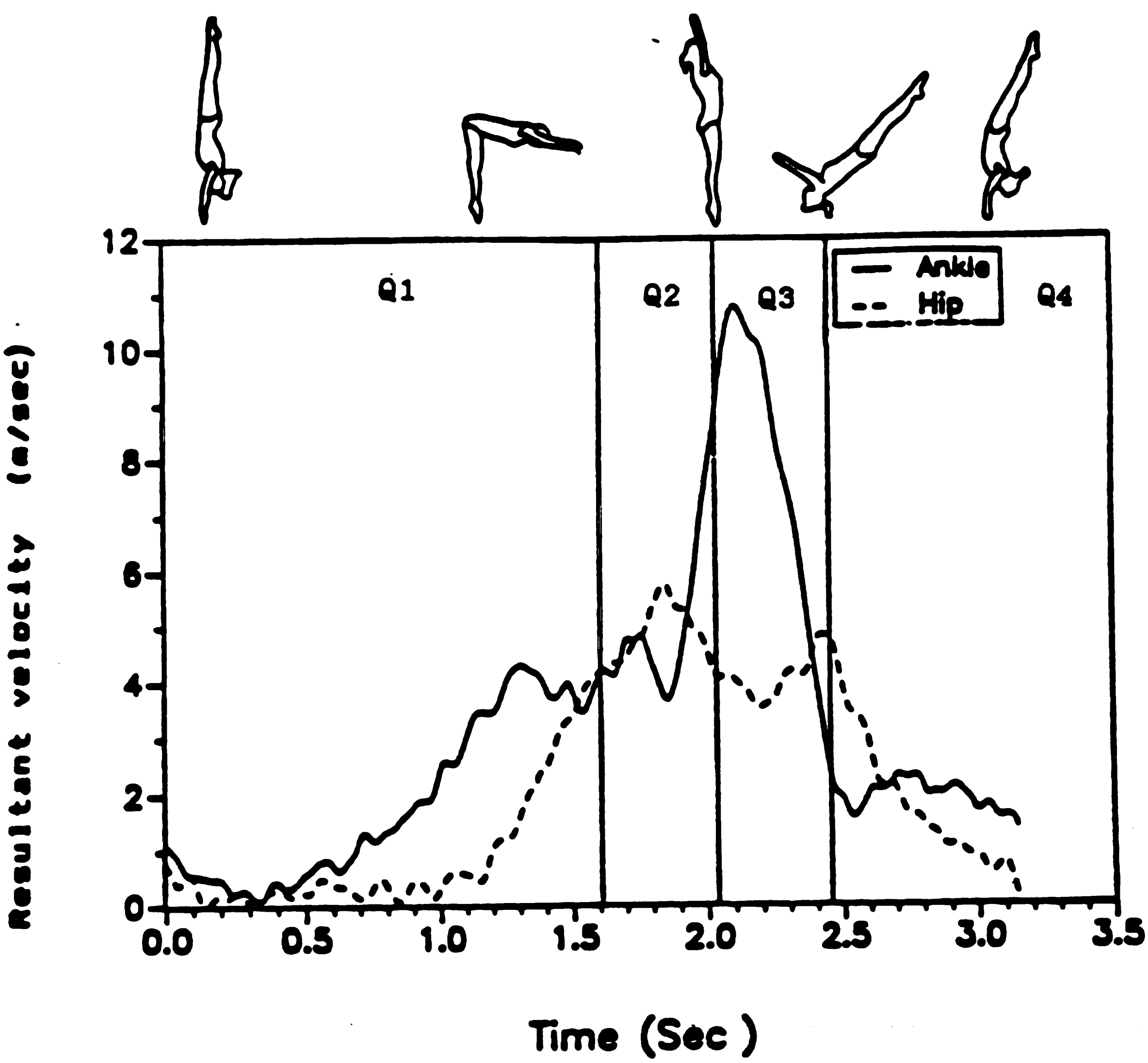


Figure 4.6 Resultant Velocity of Ankle and Hip
(Subject 16)

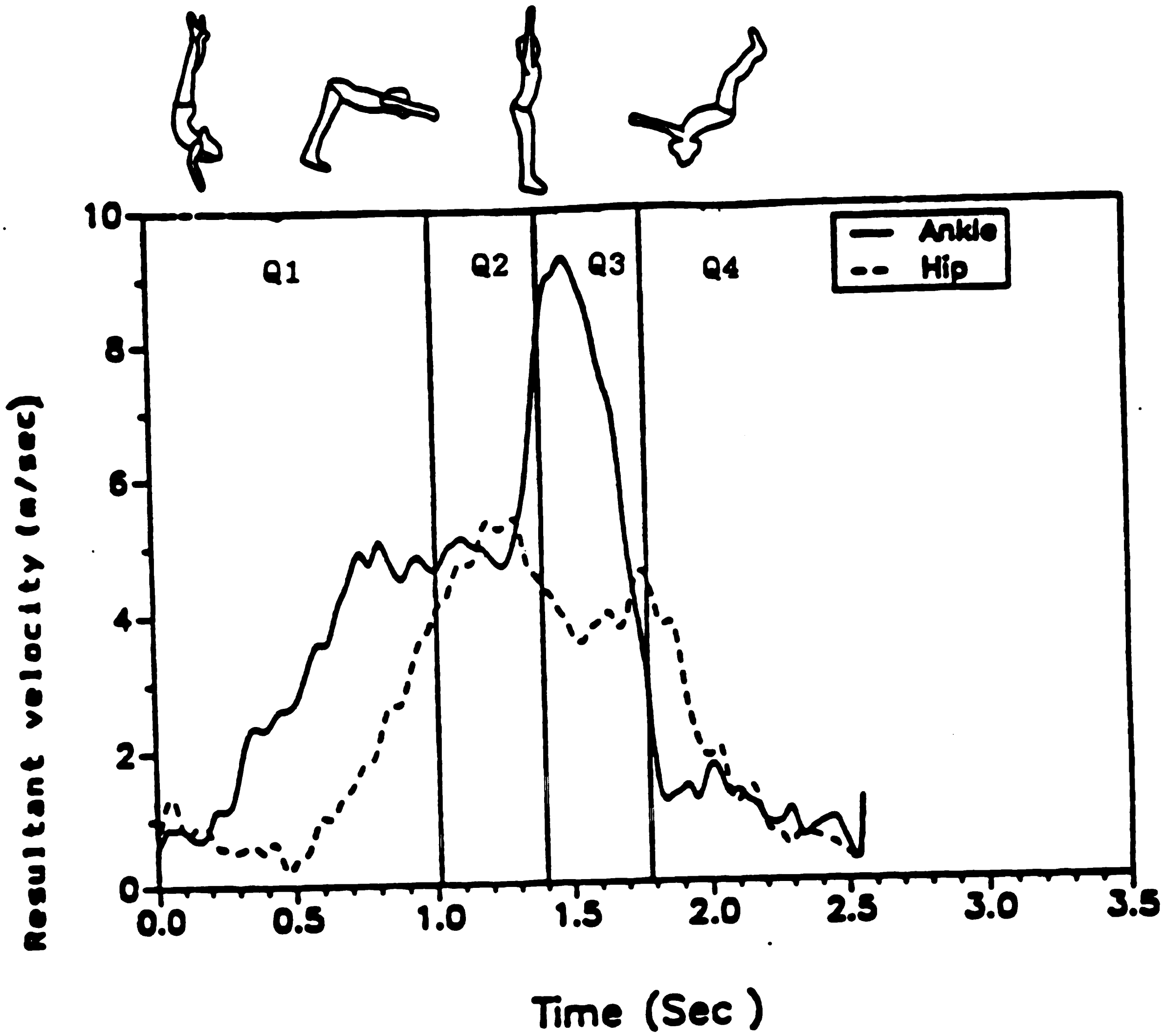


Figure 4.7 Resultant Velocity of Ankle and Hip
(Subject 6)

similar, but Subject 16 had a larger peak resultant velocity for the ankle (10.77 m/sec) and hip (5.73 m/sec) than Subject 6 for the ankle (9.0 m/sec) and the hip (5.40 m/sec). For all gymnasts, the peak resultant velocity of the ankle occurred in Quadrant 3, as the gymnast began the upswing phase of the skill. The timing of the maximum velocity of the ankles agrees with the results of Borms, et al. (1976), although his gymnasts showed a larger resultant velocity (12.5 m/sec). In the graph of Subject 16, there was a slowing of the ankles at the end of Quadrant 1. Following an increase in velocity, the ankles slowed to 3.67 m/sec in Quadrant 2 before the rapid rise to the peak velocity in Quadrant 3. During a similar time of performance, Subject 6 did not show the same pattern of slowing. The velocity of the ankle of Subject 6 remained relatively constant. This slowing of the ankle of Subject 16 in Quadrant 2, was the beginning of the "tap" that is emphasized by coaches when they teach the overgrip giant swing. The gymnast is asked to reach her feet back under the low bar after she clears that bar. This extends the gymnast at the hips and delays the feet in their cycle around the bar. When the total body center of mass travels under the high bar, the gymnast is encouraged to be in an extended or slightly hyperextended hip position. During Quadrant 3, the gymnast then begins the piking action and the velocity of the feet is greatly enhanced. Subject 16 has managed to "tap" during her performance of the overgrip giant swing, whereas Subject 6 did not demonstrate this technique. Subject 6 maintained a slight pike at the hips throughout Quadrants 1 and 2. Therefore, she did not have sufficient range of motion in the lower extremities to gain the velocity necessary to carry her to a handstand above the bar with a minimum of body position errors.

Both gymnasts showed two peaks in resultant velocity of the hip; one occurred midway through Quadrant 2 and a lesser peak occurred at the end of Quadrant 3. This pattern indicated that the maximum resultant velocity of the hip occurred before the body passed under the bar, slowed somewhat while passing under the bar, then increased again as the body began the upswing phase of the skill. These occurrences indicated that the increase in resultant velocity of the feet, during Quadrant 3, successfully transferred some momentum to the hips to increase the resultant velocity of the hips for the upswing phase of the skill.

The mean peak resultant velocity of the shoulder of the total group in this investigation agreed with the results of Borms, et al. (1976). The mean peak resultant velocity of the shoulder in this study was 3.6 m/sec, while Borms reported a resultant velocity of 3.5 m/sec. The peak resultant velocity of the shoulder in both studies occurred in Quadrant 2.

Peak resultant acceleration values for the ankle, knee, hip, shoulder, and elbow for the Total Group, Group 1, and Group 3 appear in Table 4.8, with more detailed statistical information appearing in Appendix D, Table D.11. There were no significant differences in the peak resultant acceleration values for these joints, but there was a statistical difference ($p < .10$) between the groups in the the time of occurrence of peak values expressed as a percent of total time. Appendix D, Table D.12 contains maximum and

Table 4.8 Mean Peak Resultant Accelerations of the Selected Joints

	Ankle (m/sec^2)	Knee (m/sec^2)	Hip (m/sec^2)	Shoulder (m/sec^2)	Elbow (m/sec^2)
Total	91.02+	67.67	46.71	74.89	51.58
	(13.4)	(16.9)	(8.1)	(75.1)	(20.3)
Group 1	94.78	65.72	49.56	99.54	44.12
	(16.6)	(16.4)	(9.02)	(91.9)	(4.8)
Group 3	85.39	70.58	42.45	37.90)	62.77
	(3.4)	(19.6)	(4.63)	(3.4)	(30.2)

+Mean.
(S.D).

minimum values for mean peak resultant acceleration, as well as mean and standard deviation values for the relative times of occurrence of peak accelerations.

Body Segment Analysis

Mean peak resultant, horizontal, and vertical velocities and accelerations were calculated for the trunk, thigh, shank, foot, arm, and forearm. There were significant differences ($p < .10$) between the groups for the resultant velocity of the trunk, foot, arm, and shank; the vertical velocity of the shank and foot; and horizontal velocity of the foot. Table 4.9 gives a summary of mean peak resultant velocities for the body segments. Table D.13 in Appendix D shows the complete data for horizontal and vertical velocities for each of the body segments. Also in Appendix D, Table D.14 gives the time of occurrence of peak velocities of each body segment expressed as a percent of total time.

The differences between the groups in linear velocity of the body segments seemed to indicate that the velocities of the foot, shank, trunk, and arm are critical features of the overgrip giant swing. By quickly rotating these segments around the bar, fewer body position errors occur and fewer deductions are seen by the judges. This is especially true in the case of the trunk and arms. Both gymnasts show hip hyperextension and arm flexion during Quadrant 4. However, the more highly skilled gymnast (Subject 18) was able to minimize the time interval in which these errors occurred. This shorter time interval perhaps caused less severe deductions from the judges since it is more difficult to see errors in performance when done for a shorter period of time.

The mean, maximum, and minimum horizontal, vertical, and resultant accelerations for each body segment were calculated. While there was a significant difference ($p < .10$) for the mean peak vertical accelerations of the foot and trunk and resultant acceleration of the foot, it was

Table 4.9 Mean Peak Resultant Velocities of the Selected Body Segments

	Total Group (m/sec)	Group 1 (m/sec)	Group 3 (m/sec)
Trunk**	4.64+	4.86	4.45
	(.33)	(.32)	(.19)
Thigh	5.80	5.88	5.73
	(.34)	(.37)	(.33)
Shank***	8.56	8.94	8.18
	(.50)	(.20)	(.41)
Foot**	9.72	10.33	9.12
	(.92)	(.48)	(.86)
Arm*	3.08	3.42	2.74
	(.64)	(.77)	(.17)
Forearm	1.94	2.07	1.82
	(.27)	(.22)	(.28)

+Mean.
(S.D.).
*$p < .10$ ** $p < .05$ *** $p < .01$.

felt that the means were misleading due to acceleration sign changes. Therefore, ranges of the peak accelerations are reported. The peak resultant accelerations of the foot for Group 1 ranged from 89.2 deg/sec^2 to 122.2 deg/sec^2, while for Group 3, the resultant accelerations ranged from 72.7 deg/sec^2 to 95.3 deg/sec^2. The highly skilled gymnasts were able to accelerate their feet to a greater magnitude than the less skilled group. This greater acceleration of the feet at the bottom of the swing again showed the existence of a "tap" in the highly skilled group. Complete statistical information is located on Table D.15, Appendix D.

Graphs of the angular velocity of the trunk and shank are shown in Figures 4.8 and 4.9. The plots of the trunk and shank velocities were similar for both subjects. The angular velocity of the trunk increased throughout Quadrants 1 and 2, reached a maximum at the end of Quadrant 3, and was of similar magnitude for Subjects 16 and 6 (458.92 deg/sec² and 448.00 deg/sec², respectively). Subject 16 showed a higher

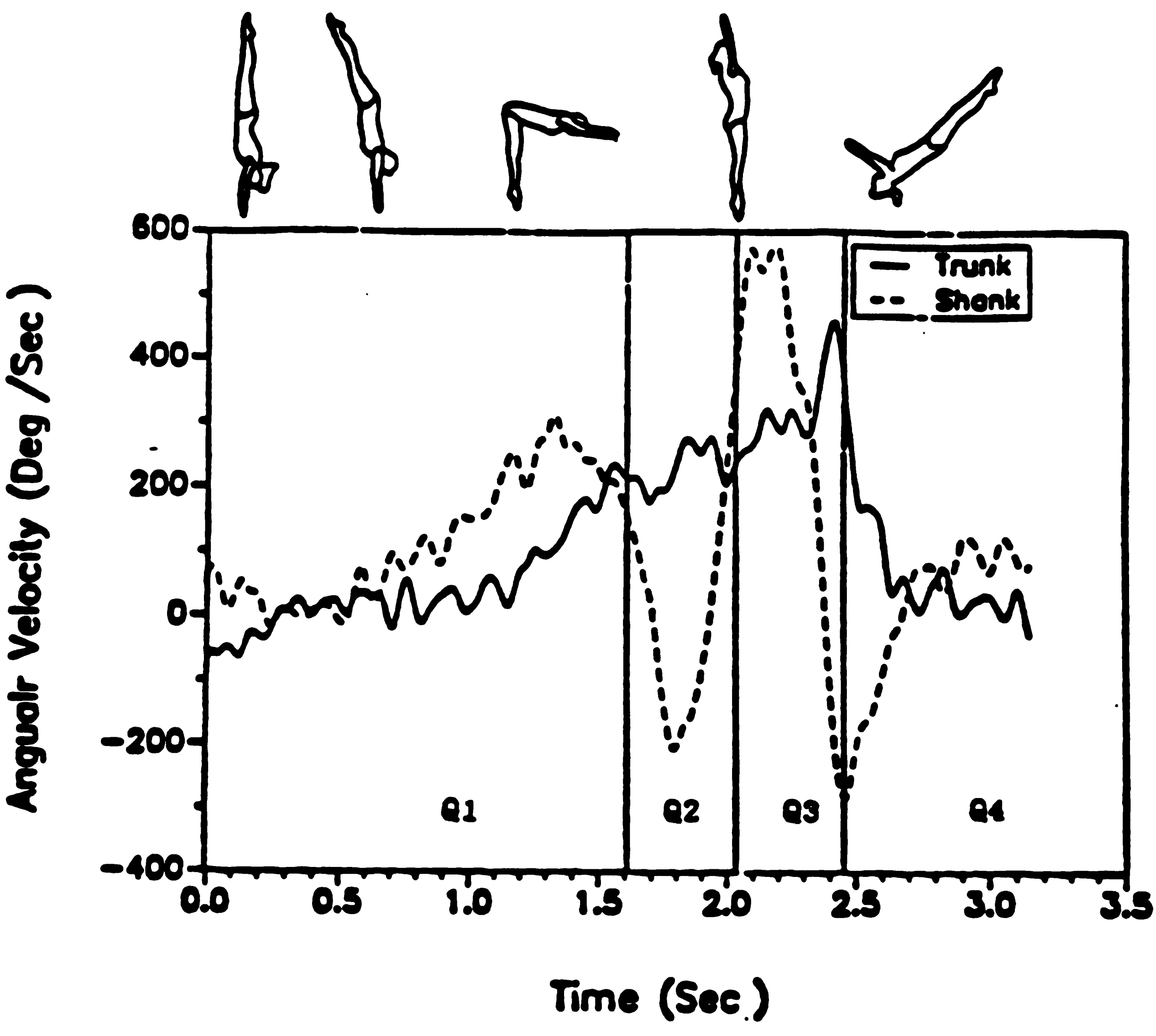


Figure 4.8 Angular Velocity of Trunk and Shank
(Subject 16)

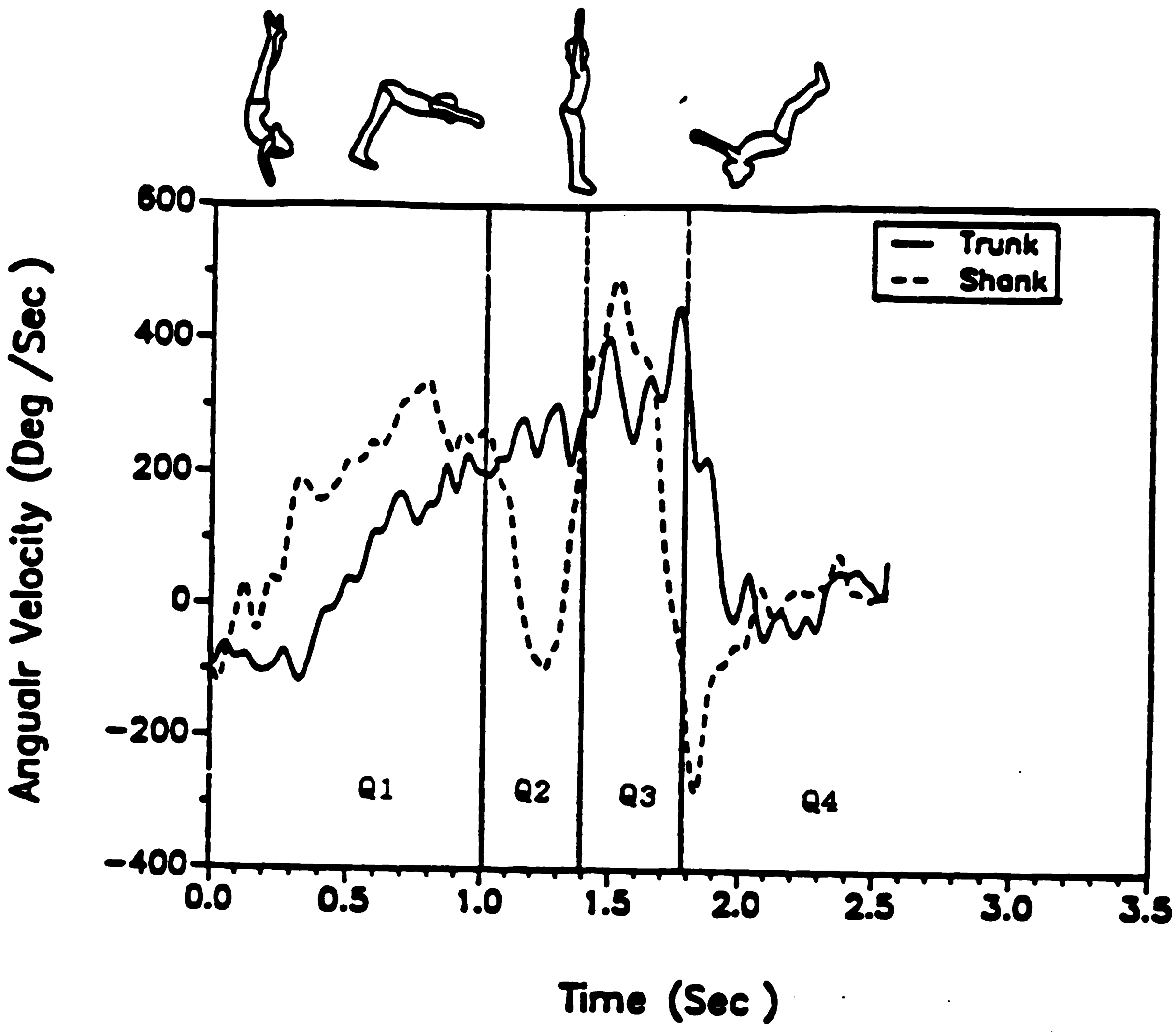


Figure 4.9 Angular Velocity of Trunk and Shank (Subject 8)

positive angular velocity (577.31 deg/sec) than Subject 6 (490.13 deg/sec) for the shank in Quadrant 3 and a greater negative value (-208.87 deg/sec and -98.46 deg/sec, respectively) for the first negative peak in Quadrant 2.

The plots of the angular velocities of the trunk and lower limb of a male gymnast analyzed by Ishii and Komatsu (1987) showed a different pattern than shown in the current study. In their investigation, the angular velocity of both limbs increased constantly until midway through Quadrant 2. The authors concluded that the segments were accelerating due to gravity. They further showed that the angular velocity of lower limb continued to increase constantly until midway through Quadrant 3 where it began to decrease gradually until the completion of the skill. The angular velocity plots for the female gymnasts in the current study were very different from those reported by Ishii and Komatsu for male gymnasts. The female gymnasts showed a bimodal path, which corresponds to the body position change necessary to clear the low bar on the downswing.

Kinetic Analysis

This section on kinetic analysis is divided into two main headings: forces applied to the bar and joint forces and moments.

Forces Applied to the Bar

The force data were collected by applying strain gages to the upper bar of the uneven parallel bars. The sampled data were changed to digital form by an analog-to-digital converter and then transmitted to a IBM 9000 dedicated computer. A computer program was written to generate force-time and torque-time histories. Figures 4.10 and 4.11 show the resultant force (normalized by body weight) applied to the bar by Subjects 16 and 6, respectively. Subject 16

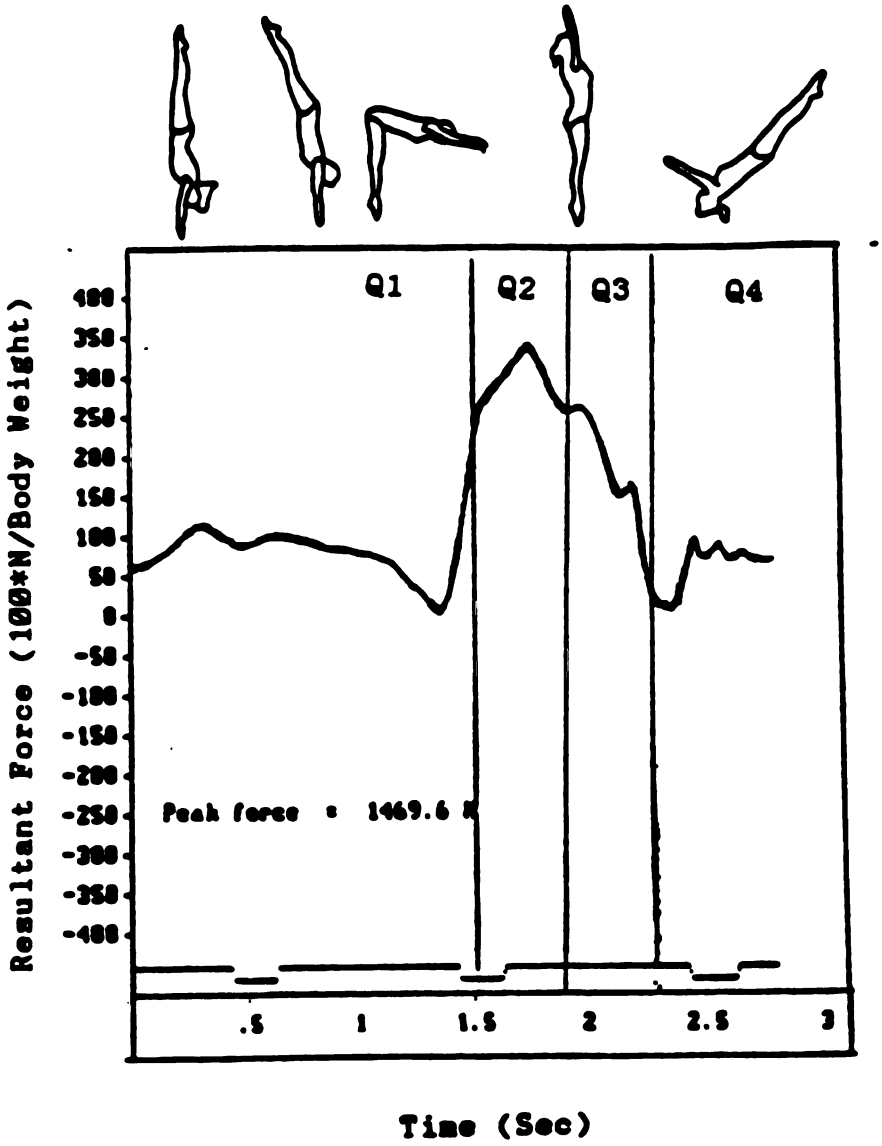


Figure 4.10 Resultant Force Applied to the Bar (Subject 16)

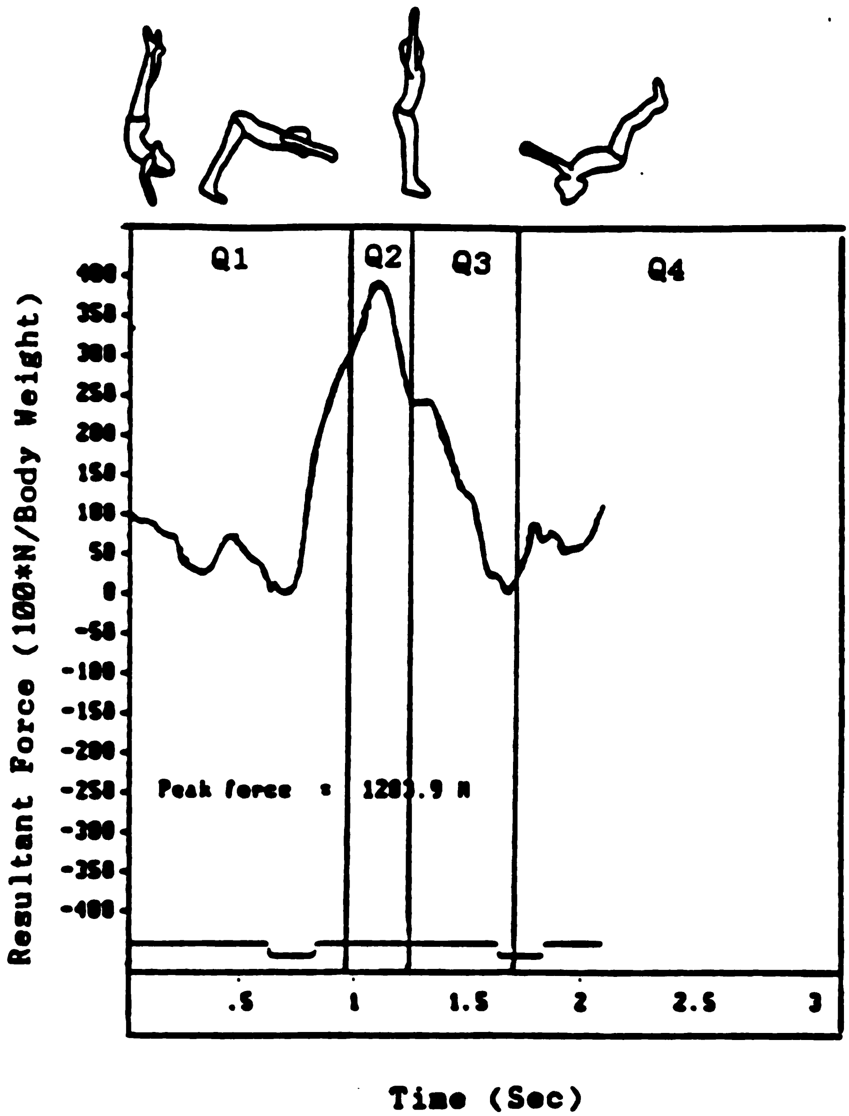


Figure 4.11 Resultant Force Applied to the Bar (Subject 6)

produced a peak resultant force of 1469.6 N or 3.40 times body weight. Subject 6 produced a peak resultant force of 1203.9 N or 3.94 times body weight. The peak resultant force occurred midway through Quadrant 2 for all gymnasts. The force on the bar then began to decrease and level off as the gymnast's center of mass passed under the high bar at the beginning of Quadrant 3. The force continued to decrease for Subject 6. However, another small peak occurred for Subject 16 prior to the end of Quadrant 3. It was hypothesized that this peak represented a grip change or sliding of the hands around the bar by the highly skilled gymnasts timed to correspond with a recoil action of the bar. Sands (1987) noted a deflection of the bar at this point and he concluded that this was related to the "tap" the gymnast performed earlier in the overgrip giant swing. The "tap" may allow the gymnasts to accelerate their feet and eventually result in an unweighting of the hands so that the gymnast may slide the hands around the bar in order to secure a better grip for the upcoming handstand position.

Resultant forces reached a minimum near the beginning of Quadrant 4. For Subject 16, this minimum resultant force occurred just after the center of mass passed the height of the bar (the beginning of Quadrant 4) while for Subject 6 this minimum occurred just before the end of Quadrant 3. During Quadrant 4, another small force was applied to the bar. At this point in the overgrip giant swing, the gymnast pulled with the arms to help bring her body over the bar into a handstand position. Ishii and Komatsu (1987) also noted an application of a small force near the end of the overgrip giant swing and concluded that it was due to body position changes or an application of force to the bar in order to increase the rotational velocity.

Figures 4.12 and 4.13 show the vertical forces on the

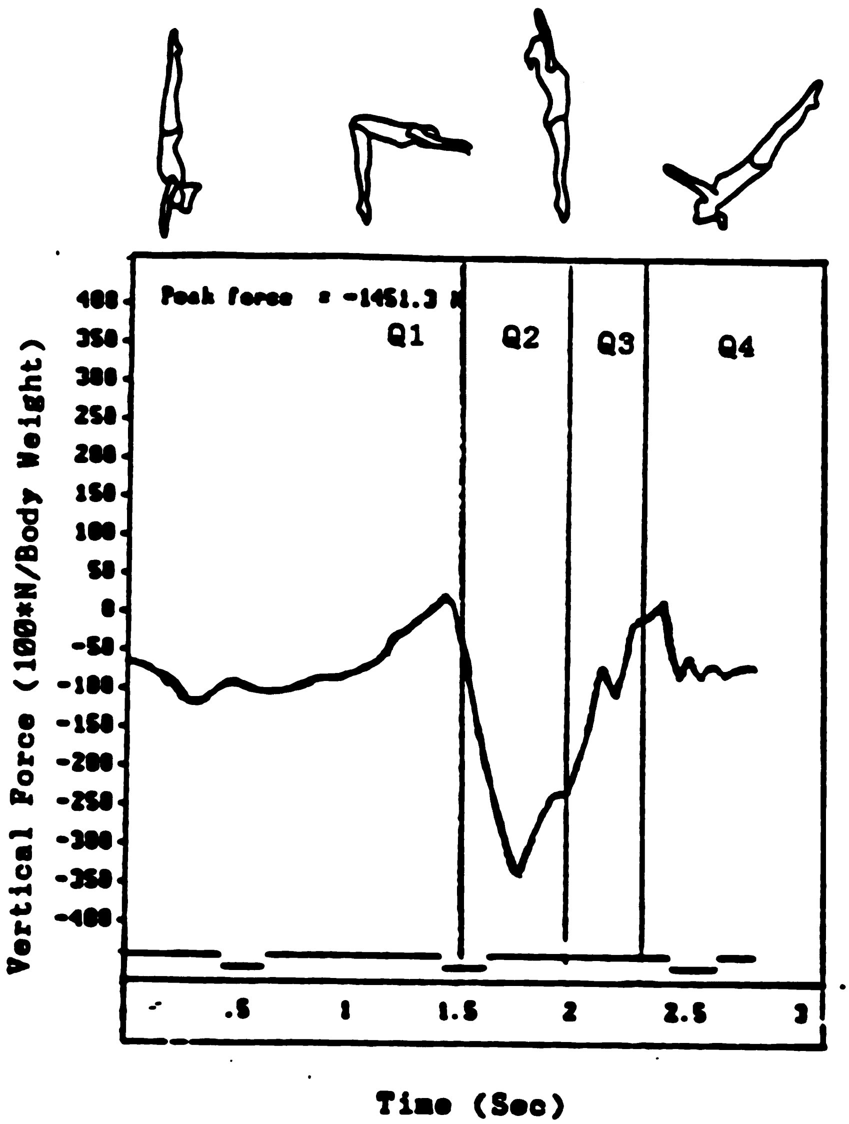


Figure 4.12 Vertical Force Applied to the Bar (Subject 16)

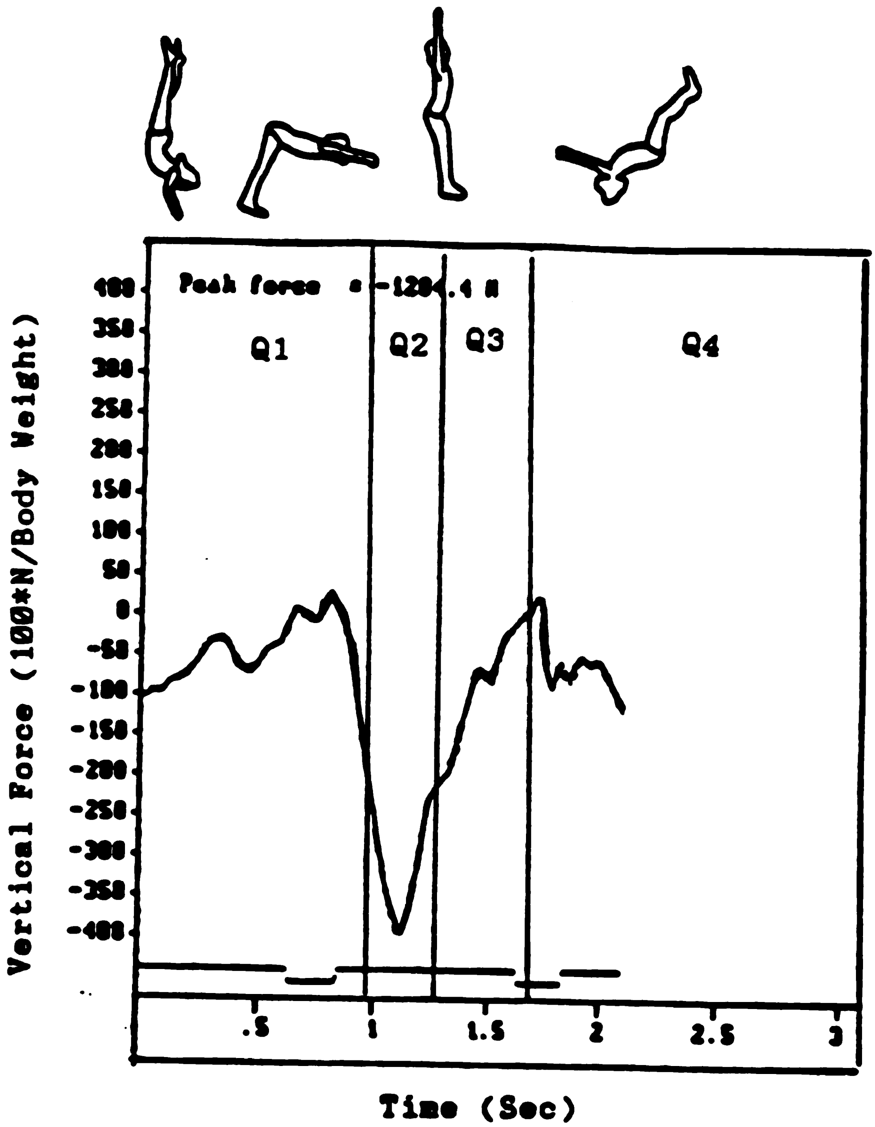


Figure 4.13 Vertical Force Applied to the Bar
(Subject 6)

bar produced by Subject 16 and Subject 6, respectively. A negative force on the graph represents force being applied to the bar in a downward direction. Subject 16 produced a maximum vertical force of 1451.3 N directed downward or 3.4 times body weight, while Subject 6 produced a maximum vertical force of 1204.4 N or 3.9 times body weight. Ishii and Komatsu (1987) found that the peak vertical velocities of his five male subjects ranged from 3.5 to 4.9 times body weight, with the unskilled gymnast producing the lowest force. This peak force occurred midway through Quadrant 2 for the female gymnasts in this study, while the male gymnasts in Ishii and Komatsu's (1987) study produced their maximum vertical force just after passing under the high bar (at the beginning of Quadrant 3). Other studies (Cureton, 1939; Boone, 1977) reported that the maximum force occurred at the bottom of the swing. As the force on the bar decreased, Subject 16's plot showed a short period of time where the force was constant just as the center of mass passed under the bar at the end of Quadrant 2. This short period of constant force, being applied as the gymnast's center of mass passed under the bar, may be related to the "tap" observed by Sands (1987). The force for Subject 6, however, continued to decrease.

Both graphs show a small peak of vertical force being produced midway through Quadrant 3, which perhaps was a recoil of the bar, then a minimum was reached shortly after entering Quadrant 4. The application of a small force during Quadrant 4, as previously discussed, was especially evident on the vertical force graphs.

Figures 4.14 and 4.15 are plots of the horizontal force applied to the bar by Subjects 16 and 6, respectively. As seen in Figures 4.14 and 4.15, a negative horizontal value indicated a force that tends to displace the bar to the left

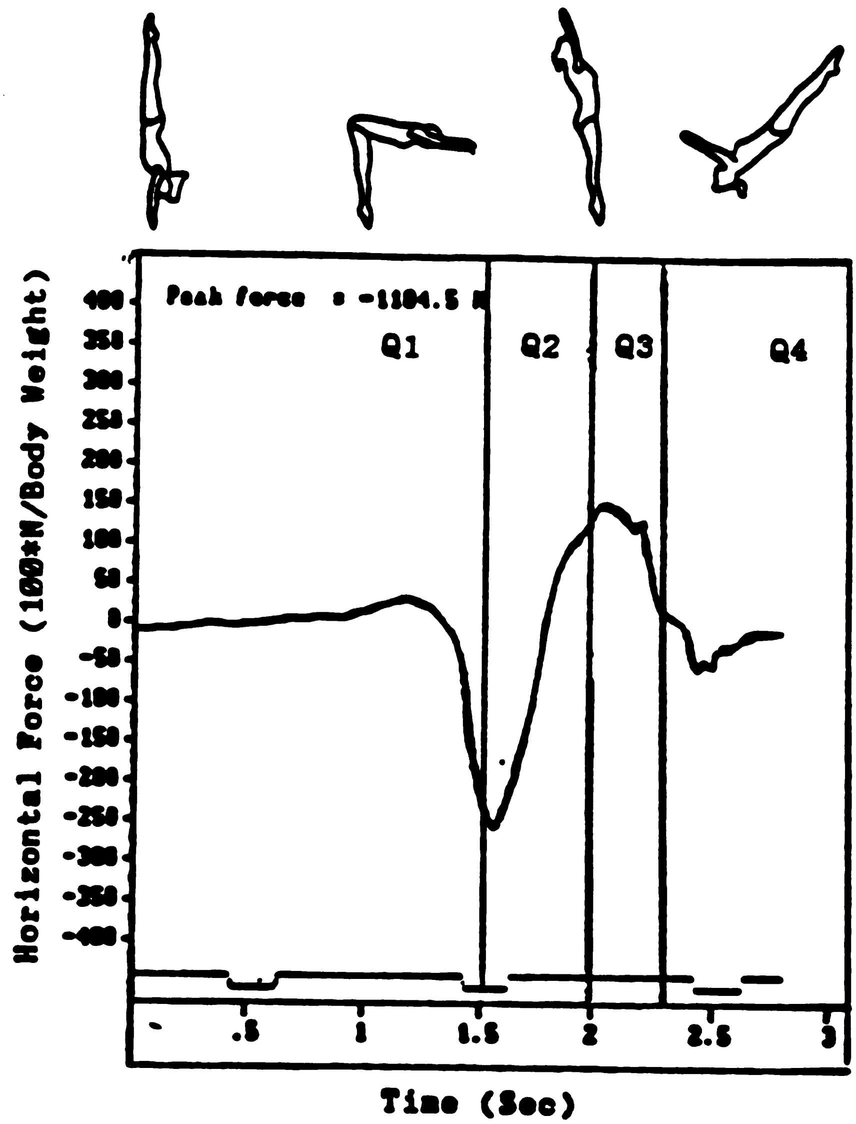


Figure 4.14 Horizontal Force Applied to the Bar (Subject 16)

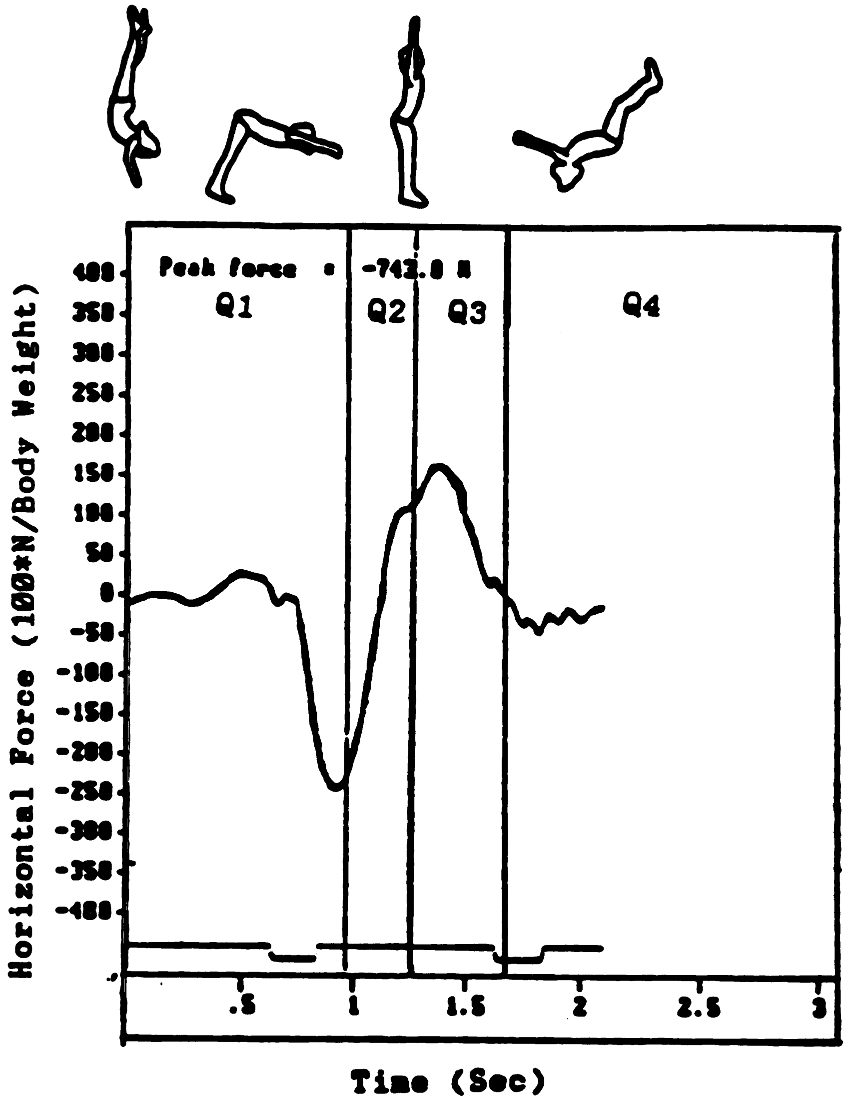


Figure 4.15 Horizontal Force Applied to the Bar (Subject 8)

and a positive value to the right. Subject 16 produced a maximum of -1104.4 N or 2.6 times body weight. This occurred at the beginning of Quadrant 2, on the subject's downswing phase of the skill. A second, positive peak of horizontal force occurred at the beginning of Quadrant 3, just after the gymnast's center of mass passed under the bar. This peak was 664.7 N or 1.5 times body weight. Figure 4.15 shows a similar pattern for Subject 6, who had a maximum horizontal force of -743.0 N or 2.4 times body weight. The occurrence of this peak force was at the end of Quadrant 1 and was slightly sooner than observed for Subject 16. The second peak, which was 503.1 N or 1.7 times body weight, occurred at the beginning of Quadrant 3. During the upswing phase of the skill, the horizontal force gradually decreased until the giant swing was completed.

Figures 4.16 and 4.17 are graphs of the moment applied to the bar by the gymnasts performing the overgrip giant swing. Subject 16 (see Figure 4.16) had a peak moment of 39.43 Nm. Subject 6 (see Figure 4.17) had a peak moment of 31.17 Nm. The peak moments for both gymnasts occurred midway through Quadrant 2 and decreased until the beginning of Quadrant 4. The peak moment of force corresponded to the peak vertical and resultant forces produced by the gymnasts in this study.

No statistical differences were found between the groups on peak moments or peak resultant, vertical, or horizontal forces applied to the bar or on the relative times of occurrences of the peak forces or moments. Table 4.10 contains a summary of the Total Group, Group 1, and

Group 3 peak moments and peak resultant, vertical, and horizontal forces. In addition, the relative time of the occurrences of each peak force and torque is reported in

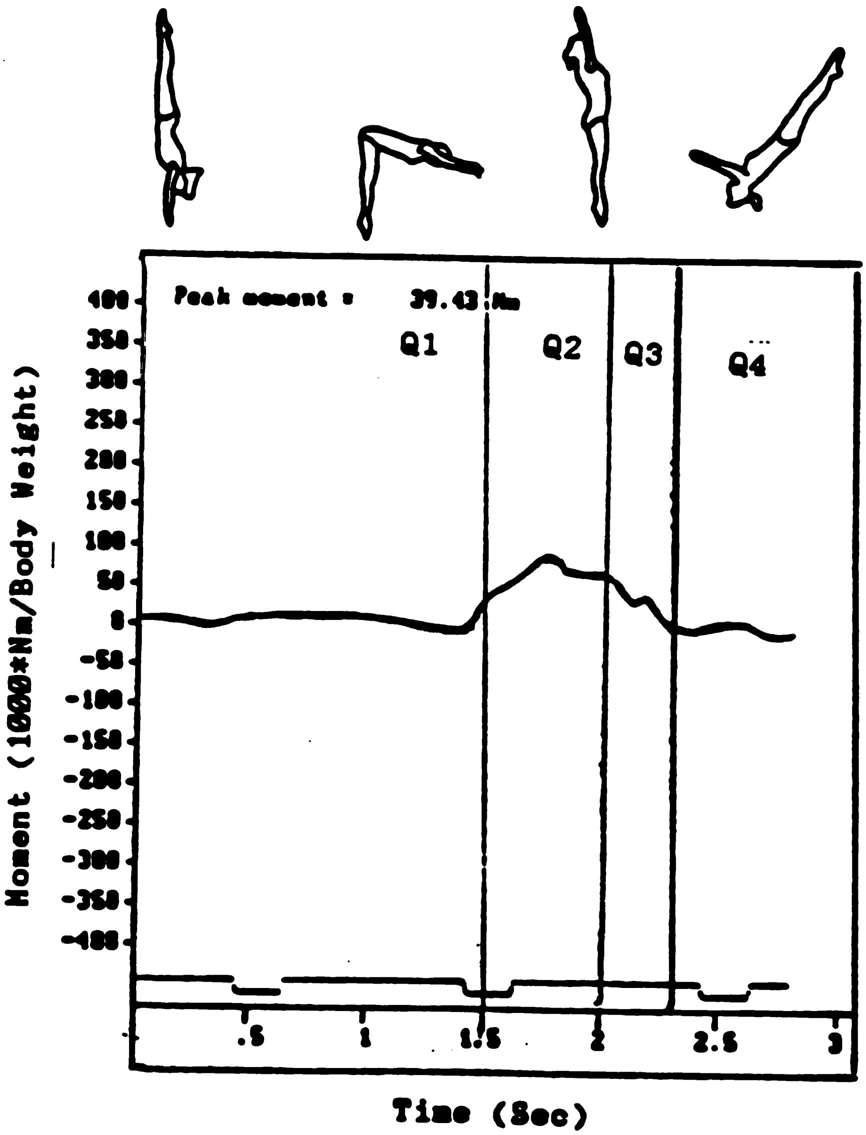


Figure 4.16 Moment Applied to the Bar
(Subject 16)

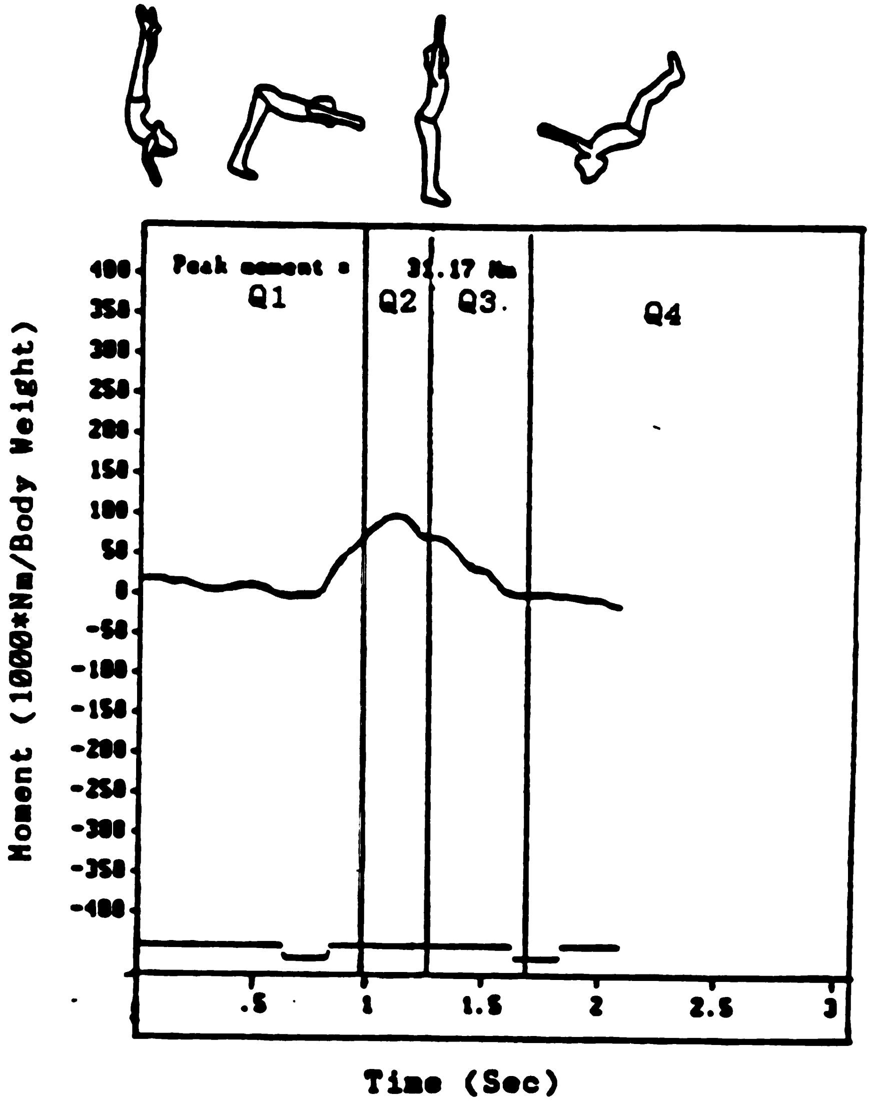


Figure 4.17 Moment Applied to the Bar (Subject 6)

Table 4.11. For each of the above variables, the mean, standard deviation, and range were shown in Tables 4.10 and 4.11.

Table 4.10 Forces and Moments Applied to the Bar

	Total	Group 1	Group 3	Total	Group 1	Group 3
	Vertical Force+			Horizontal Force+		
Mean	3.082	2.288	3.872	1.979	1.532	2.426
SD	2.598	3.687	0.107	1.638	2.352	0.065
Min	-4.280	-4.280	3.710	-2.660	-2.660	2.380
Max	4.170	4.170	3.990	2.790	2.790	2.540
	Moment (Nm)			Resultant Force+		
Mean	-41.3	-44.0	-38.6	3.090	2.294	3.886
SD	9.3	6.2	11.7	2.596	3.683	0.118
Min	-55.5	-49.1	-55.5	-4.270	-4.270	3.710
Max	-29.5	-35.5	-29.5	4.160	4.160	3.980

+Normalized by body weight.

Table 4.11 Times of Occurrences of Peak Forces+

	Total	Group 1	Group 3	Total	Group 1	Group 3
	Vertical Force			Horizontal Force		
Mean	56.26	58.66	53.86	48.27	51.42	45.12
SD	4.96	4.40	4.64	6.35	6.40	50.19
Min	48.00	54.30	48.00	41.00	45.30	41.00
Max	65.50	65.00	60.40	61.70	61.70	53.60
	Moment			Resultant Force		
Mean	56.71	58.94	54.48	56.33	58.68	53.98
SD	5.06	4.30	5.18	5.26	4.54	5.30
Min	48.00	54.30	48.00	47.50	54.30	47.50
Max	65.50	65.50	61.90	65.90	65.90	61.50

+ expressed as a percent of total time

The force data obtained in this study showed lower resultant, vertical, and horizontal forces compared to forces reported in studies of the overgrip giant swing performed by men on the horizontal bar. Kopp and Reid (1980) reported a resultant force of 3.6 times body weight while in the current study the same variable was found to be 3.1 times body weight. Ishii and Komatsu (1987) found a mean horizontal force of 2.5 times body weight and a mean vertical force of 4.3 times body weight. The current investigation found these variables to be 2.0 and 3.1 times body weight, respectively. The peak torques found by Kopp and Reid (1980) were 23.3 Nm while in the current study the peak torque on the bar was reported to be 41.29 Nm. It was hypothesized that this difference in torques can be explained by the larger bar size for the women. Since the female gymnasts' hands are smaller in relation to the bar size, they must grip the bar more tightly, as compared to the men gripping the horizontal bar. In the study by Ishii and Komatsu (1987), the peak resultant force occurred just after the gymnast passed under the high bar, or at the beginning of Quadrant 3. Kopp and Reid (1980) reported that the maximum force occurred just before the gymnast reached the bottom of the swing, or at the end of Quadrant 2. For the current study, the peak resultant force occurred midway through Quadrant 2. The body position change, during the descent phase, necessary to clear the low bar also changed the timing of the maximum force.

Joint Forces and Moments

The forces and moments measured at the bar and accelerations calculated from film data were read into a FORTRAN computer program written by this researcher. The program used equations (1) - (6), expressed in Chapter 3, to calculate the muscle moments and joint forces at the elbow and shoulder. Each of the forces and moments were halved to represent the forces on one side of the body.

No significant differences between the groups on the mean peak joint forces, moments, or relative time of occurrence of the peak forces were found. Table 4.12 reports the mean peak forces and moments of the total group for each joint. Table D.16 and D.17 in Appendix D reports the forces and the relative times of occurrence for the individual groups.

When examining the mean peak joint reaction forces per quadrant, (see Appendix D, Table D.18), there was a significant difference ($p < .10$) between the groups for the horizontal force for the shoulder in Quadrant 1. The forces were -0.5, -0.4 and -0.6 times body weight for the Total Group, Group 1, and Group 3, respectively. The less skilled gymnasts in this investigation experienced significantly more horizontal force at the shoulder joint than the more highly skilled gymnasts. This may be due to the less skilled gymnasts piking earlier during the descent phase of the overgrip giant swing. There was also a significant difference ($p < .10$) between the groups for the time of occurrence of peak moments expressed as a percent of total time.

For the elbow joint there were significant differences ($p < .10$) between the groups for the vertical force in Quadrant 4. This force occurred as the gymnast attempted to attain the handstand position above the bar. The less skilled gymnasts experienced a higher vertical force at the elbow during this phase. This could be due to the slower vertical movement of the hips and feet.

Table 4.12 Mean Peak Joint Forces and Moments at the Elbow and Shoulder for the Total Group

	Mean	SD	Min	Max
FY Elbow+	-1.56	1.33	-2.09	2.22
FX Elbow+	-0.74	1.11	-1.44	1.36
Moment Elbow (Nm)	-54.11	55.28	-97.80	96.80
FY Shoulder+	1.62	1.28	-2.01	2.17
FX Shoulder+	-1.28	.09	-1.41	-1.14
Moment Shoulder (Nm)	97.04	27.24	50.80	134.30

+Normalized by body weight.

There was a significant difference ($p < .10$) between the groups for the relative time of occurrence of the vertical force in Quadrant 1, for the relative time of occurrence of the moments, and the relative time of the mean peak horizontal force in Quadrant 2. Complete analysis for the individual groups appear in Tables D.18 - D.21 for the forces per quadrant and relative time of occurrences for the forces for the shoulder and elbow joints.

CHAPTER V

Summary and Conclusions

Summary of Procedures

The purpose of this study was to identify critical elements of the performance of the overgrip giant swing on the uneven parallel bars by comparing highly skilled and less skilled gymnasts on selected kinematic and kinetic parameters. The kinematic variables included temporal analysis; position data for shoulder, hip, and center of mass; velocity and acceleration of the center of mass; angular velocity and acceleration of a line segment connecting the center of the bar and the center of mass; linear velocity and acceleration of the ankle, knee, hip, shoulder, and elbow joints; and velocity and acceleration of the center of mass of the trunk, thigh, shank, foot, arm, and forearm. The kinetic data, which were collected by instrumenting the high bar with strain and torque gages, included the following analyses: resultant, vertical, and horizontal forces; moments applied to the bar; and calculated joint reaction forces for the elbow and shoulder joints. A comparison was made between the results obtained in this study with the results obtained from investigations of male gymnasts performing an overgrip giant on the horizontal bar.

The subjects for this study were 15 female gymnasts ranging in age from 10 to 16 years. They were all Class I or Elite gymnasts from five gymnastics clubs in Michigan. Anthropometric data and hydrostatic weight were collected at the Center for the Study of Human Performance at Michigan State University on the day that kinematic and kinetic data were collected. The subjects were then transported to a local gymnastics club where they were prepared for filming. The preparation included placing joint markers on the right side of their bodies (center of the wrist, elbow, shoulder, hip, knee, and ankle joints) as reference points for digitizing. Following a practice trial, the gymnasts were asked to perform a sequence of four skills (long hang kip, cast clear hip to handstand, overgrip giant swing, and flyaway dismount) on the uneven parallel bars. The sequence of skills were filmed with two LOCAM 16mm pin registration motion picture cameras, one perpendicular to the plane of movement of the gymnast and the other placed to record a frontal view. The cameras were set at 100 frames/sec and the filming speed was calibrated from timing lights placed in the field of view. Kodak Video News high speed film with an ASA of 400 was used in this investigation.

The film was transferred to video tape, which was edited so that the overgrip giant swings were the only skill left on the tape. Four Elite and Class I judges then independently evaluated the 15 overgrip giant swings and awarded a score to each gymnast based on criteria set by the experimenter. These criteria were similar to deductions that judges use in evaluating uneven parallel bar routines. Skill groups were then determined on the basis of the judges' ratings. The top five scoring gymnasts were placed in Group 1 (highly skilled) and the five lowest scoring gymnasts were placed in Group 3 (less skilled). In order to compare diverse performance, Group 2, the intermediate group was omitted from further study.

After processing, the high speed film was projected from overhead onto a drafting table by a Vanguard Motion Analyzer and digitized using a Sonic Graf/Pen system. The digitizing system was interfaced with an IBM-PC, which collected the X and Y coordinates in a data acquisition computer program. A FORTRAN Bioanalysis program, developed at Michigan State University, was used to analyze the kinematic data.

Summary of Findings for the Kinematic Variables

Center of Mass Analysis

This study found a significant difference ($p < .10$) between Group 1 and Group 3 for the mean peak horizontal velocity of the total body center of mass, which was 4.89 and 4.38 m/sec, respectively. There was also a significant difference ($p < .10$) for the timing of the peak vertical velocity of the total body center of mass. The peak vertical velocity occurred at 57.9 and 40.3 percent of the way through the giant swing for Group 1 and Group 3, respectively. The highly skilled gymnasts were able to generate a significantly ($p < .10$) higher horizontal velocity of the total body center of mass (4.9 and 4.4 m/sec for Groups 1 and 3, respectively) and that mean peak velocity occurred later in the cycle. This enabled the gymnast to complete the overgrip giant swing without major form breaks.

When the peak velocity data of the total body center of mass for each quadrant were examined, there was a significant difference ($p < .10$) between the groups for the horizontal velocity in Quadrant 3. The velocities were 4.33 and 3.64 m/sec for Group 1 and Group 3, respectively. There was also a significant difference ($p < .10$) between the groups for the mean peak resultant velocity during Quadrant 4. These velocities were 3.87 m/sec for Group 1 and 3.21 m/sec for Group 3.

Joint Analysis

There were significant differences ($p < .10$) between the groups for the mean peak resultant linear velocities of the ankle, knee, and hip joints. Group 1 had a mean peak resultant velocity of 11.03 m/sec for the ankle while Group 3 showed a mean peak resultant velocity of 9.64 m/sec. The mean peak resultant velocities for the knee were 7.30 m/sec for Group 1 and 6.95 m/sec for Group 3. The mean peak resultant velocities for the hip were 6.22 and 5.57 m/sec for Group 1 and Group 3, respectively. There was a significant difference ($p < .10$) between the groups for the time of occurrence of peak values of the ankle expressed as a percent of total cycle time. The mean peak resultant velocity of the ankle occurred at 65.1 and 58.4 percent through the cycle of the overgrip giant swing for Groups 1 and 3, respectively. There were also significant differences ($p < .10$) between the groups for the time of occurrence of peak values of the hip and shoulder expressed as a percent of total time. The mean peak resultant velocity occurred at 55.3 and 48.6 percent of the cycle for the hip and at 61.0 and 48.5 percent for the shoulder for Groups 1 and 3, respectively.

When examining the mean peak resultant velocity of the joints by quadrant, significant differences ($p < .10$) were found between the groups in Quadrant 2 for the hip and elbow; in Quadrant 3 for the ankle, shoulder and hip; and in Quadrant 4 for the knee, hip, and shoulder.

The mean peak resultant velocities of the ankle, knee and hip joints were of greater magnitude and occurred later in the performance of the overgrip giant swing of the more highly skilled gymnasts when compared to the less skilled group. It was concluded that the gymnasts who "tapped" at the appropriate time were able to achieve greater mean peak resultant velocities and achieve them later in the overgrip giant swing, thereby arriving in the handstand position on the top bar without severe form breaks.

Segment Analysis

An examination of the mean peak velocities of the segments of the body revealed a significant difference ($p < .10$) between the groups for the mean peak vertical velocity of the foot and mean resultant velocity of the shank. Group 1 had a mean peak vertical velocity of the foot of 10.4 m/sec, while Group 3 had a velocity of 9.0 m/sec. For the mean peak resultant velocity of the shank, Group 1 had 8.9 m/sec and Group 3 had 8.2 m/sec. There was also a significant difference ($p < .10$) between Groups 1 and 3 for the mean peak resultant velocity of the trunk (4.9 and 4.5 m/sec, respectively), mean peak vertical velocity of the shank (7.7 and 7.1 m/sec, respectively), and mean peak horizontal velocity (10.3 and 9.1 m/sec, respectively) and mean peak resultant velocity (11.7 and 10.4 m/sec, respectively) of the foot. There was also a significant difference ($p < .10$) in mean peak resultant velocity of the arm for Groups 1 and 3 (3.4 and 2.7 m/sec, respectively).

There were significant differences ($p < .10$) between the groups for the relative time of occurrence of the mean peak resultant velocity for the shank; the mean peak vertical velocity of the shank; and the mean peak resultant velocity of the trunk. The examination of the mean peak horizontal, vertical, and resultant acceleration data showed the following significant differences ($p < .10$): in the mean peak resultant and vertical acceleration of the foot; and the mean peak vertical acceleration of the trunk.

Summary of Findings for the Kinetic Variables

Forces Applied to the Bar

While there were no significant differences between the groups for the horizontal, vertical and resultant forces applied to the bar, it was interesting to compare the forces obtained in this study with forces reported in the literature available for the overgrip giant swing and other similar skills. The current study found that the mean peak resultant force on the bar was 3.1 times body weight. Kopp & Reid (1980) recorded a mean peak resultant force of 3.6 times body weight. Hay et al. (1976) found a resultant force of 3.6 times body weight for a long swing type movement on the uneven parallel bars. Each of these studies, in which the researchers directly measured forces by instrumenting the bar resulted in force values considerably lower than those reported in studies that indirectly calculated the force. Smith (1981) theoretically determined a force of 5.0 times body weight applied to the bar for a skill similar to the overgrip giant swing. In his early work, Cureton (1939) estimated that the peak force on the bar to be 4.9 times body weight for a male gymnast performing an overgrip giant swing.

The present investigation found the mean vertical and horizontal forces to be 3.1 times body weight for Group 1 and 2.0 times body weight for Group 2. Ishii and Komatsu (1987) found the mean peak vertical and horizontal forces for men to be 4.3 and 2.5 times body weight, respectively. Ishii and Komatsu (1987) reported that the occurrence of the peak resultant force was at the beginning of Quadrant 3, just after the gymnast passed under a vertical line projected by the bar. Kopp and Reid (1980) reported the peak force occurred at the end of Quadrant 2, just before the body passed under the bar. In the present study, the mean peak resultant force occurred earlier, just after the gymnast had cleared the low bar on the descent phase of the skill. It was hypothesized that since a body position change was necessary in order for the gymnast to clear the low bar during the descent phase of the skill, the expected pattern of the peak force occurring at the bottom of the swing was altered. The gymnast must pike during Quadrant 1 in order to clear the low bar. Having cleared the low bar, the gymnasts again extended at the hips during Quadrant 2. This extension of the hips may account for the earlier production of the mean peak resultant force as compared with the men's overgrip giant swing on the horizontal bar.

The mean peak torque found in the current study was 41.3 Nm with a range of 30.3 to 55.5 Nm. The mean peak torque reported by Kopp and Reid (1980) was 23.3 Nm. It was hypothesized that the larger bar of the uneven parallel bars was the factor that created this difference. Since the female gymnasts' hands are smaller in relation to the bar size, they must grip the bar more tightly, as compared to the men gripping the horizontal bar.

Joint Forces

Using the equations (1)-(6) reported in Chapter 3, joint reaction forces were calculated for the elbow and shoulder joints. There were no significant differences between the groups for mean peak vertical or horizontal force or for moments at the elbow and shoulder joints. The total group mean peak vertical force on the elbow joint was 1.6 times body weight. The range of vertical forces was 1.2 to 2.0 times body weight. The total group mean peak horizontal force on the elbow was 0.7 times body weight, with a range of 0.2 to 1.2 times body weight. The vertical force for the shoulder joint for the total group was 1.6 times body weight with a range of 1.3 to 2.0 times body weight. The horizontal force of the shoulder joint was 1.3

times body weight for the total group with a range of 1.1 to 1.4.

When examining the joint reaction forces per quadrant, a significant difference ($p < .10$) occurred in the horizontal force of the shoulder and in the moment of the elbow in Quadrant 1.

Conclusions

Gymnastics is a sport that has aesthetic qualities, which are reinforced by the rules. The table of deductions in the Federation of International Gymnastics Code of Points (1985) emphasizes that the aesthetics of the sport require straight body lines, straight arms, and straight legs even though the ease of execution may be enhanced by the athlete performing a skill with one or more deviations from the ideal. Often, when a new skill is performed, a less than perfect body line is acceptable, until gradually the execution improves with each succeeding generation of gymnast. This is the case with the overgrip giant swing being performed on the uneven parallel bars. When first performed, it was executed with a very large arch in the back during the ascent phase. This arch helped to compensate for the relatively small radius of rotation due to the gymnasts' necessity to clear the low bar. The giant swing was looked at as being a very difficult, high level skill on its own. As time went on, some gymnasts began to execute the skill with noticeably less deviations in body line. They had an excellent model to follow as the skill has been performed by men on the horizontal bar for a very long time. Like the men, the female gymnasts also started to use the overgrip giant swing as a means of generating speed for the execution of large release movements. The goal today is not only to execute the skill, but to execute it with speed and force to be able to use the skill to lead into more difficult movements.

The female gymnast has one very large constraint placed upon her that her male counterpart does not have. That constraint is the proximity of the low bar of the uneven parallel bars. The male gymnast is fully extended, even hyperextended slightly, during the descent phase of the skill in order to maximize the velocity of the downswing. Due to gravitational and relatively constant frictional forces and air resistance, the velocity of the ascent phase of the circle is always less than the descent phase. The gymnast usually compensates for this decrease in velocity by decreasing the length of the radius of rotation during the ascent phase. The most acceptable method for accomplishing this decrease in length of the radius for men on the horizontal bar is to decrease the shoulder and hip angles after passing under the bar (Gluck, 1982). Cheetham (1984) has stated that for regular overgrip giant swings, these angular decreases are very slight. When the gymnasts on the horizontal bar want to increase the angular and linear velocity of the giant swing for large release moves and dismounts, they decrease the hip and shoulder angles even more than for the regular overgrip giant swing.

The female gymnasts performing the overgrip giant swing on the uneven parallel bars produced slightly less linear and angular velocities during the descent phase than their male counterparts. In the current study, the total group mean peak resultant velocity was 5.6 m/sec and occurred during Quadrant 2. Borms (1976) reported a peak resultant velocity of 6.0 m/sec., which also occurred in the second quadrant. While the differences were not statistically significant, it was interesting to note the trends between the groups on this variable. Group 1 achieved mean peak resultant velocity of 6.2 m/sec at the end of Quadrant 2, while Group 3 only had a mean peak resultant velocity of 5.1 m/sec, which occurred earlier in Quadrant 2. There was a significant difference ($p < .10$), however, between the groups in the horizontal velocities, which were 4.9 and 4.4 m/sec for Group 1 and Group 3, respectively. Even more interesting was the difference in the timing of the peak vertical velocity, which showed a significant difference ($p < .10$) between the groups. The mean peak vertical velocity occurred slightly before the end of Quadrant 2 for Group 1, but at the end of Quadrant 1 for Group 3. The highly skilled gymnasts were better able to increase the peak vertical velocity by starting in a higher position on the bar, as recommended by George (1980), and by keeping the shoulder angle more flexed during the descent phase. In addition, the highly skilled gymnasts resumed a more extended hip position earlier in the cycle, after clearing the low bar. Achieving this extended hip position well before reaching the bottom of the swing has an important function. Sands (1987) discussed the importance of a "tap" when the body is positioned below the bar. He suggested that the "tap" was used to achieve greater velocity of the body on the ascent phase of the swing.

In the present study, there was a significant difference ($p < .10$) between Groups 1 and 3 on the mean peak resultant velocity of the ankle joint. The velocities were 11.0 and 9.6 m/sec, respectively. There was also a significant difference between the groups on the timing of this peak velocity. Group 1 was able to produce the peak velocity later in Quadrant 3 than was Group 3. It was observed that the highly skilled gymnasts were able to achieve a straighter body position before the bottom of the swing, while the less skilled gymnasts maintained a slight pike throughout Quadrant 2.

Sands (1987) studied rail movement of several skills, including the overgrip giant swing. He determined patterns of bar movements of gymnasts performing the overgrip giant swing and observed that gymnasts who did not "tap" effectively at the bottom of the bar showed a smoother curve on the upswing phase of the skill. This was also seen to be true for this investigation. The highly skilled gymnasts showed a second peak in force on the graphs of the resultant force. This second peak indicated that the bar was in the process of recoiling and that another force had been added. This was likely the result of the gymnast pulling on the bar to aid in the upswing phase of the skill. Borms, et al. (1976) observed this phenomenon in men's giant swings, stating that the forceful arm pull resulted in an upward and forward movement of the shoulders. In their study this forceful arm pull occurred in Quadrant 4. In the present study, this second peak occurred in Quadrant 3 indicating that the female gymnast must exert this force earlier, since she has less velocity coming through the bottom of the swing.

The phase of the giant swing that receives the most deductions from the judges is the ascent phase. Large deductions (up to .3 for each error) are incurred for bending the arms, bending the legs, and arching the body. None of the gymnasts in this study performed deduction free giant swings. Those who were rated the highest, however, were gymnasts who maintained straighter body positions for a longer period. Subject 16, who performed the best overgrip giant swing on the uneven parallel bars, did show some arch at the end of the overgrip giant swing, but for a very brief period of time. It should be emphasized that the ascent phase is dependent upon the descent phase.

The gymnasts in this study applied a mean peak resultant force to the bar of slightly more than three times their body weight. This figure was slightly lower than that reported in the literature for men's giant swings. The maximum force for the subjects in this study, also occurred sooner, in Quadrant 2, than was reported in the studies on the horizontal bar. It was hypothesized that this difference was due to the body position change in order to clear the low bar during the descent phase.

The stress placed on the elbow and shoulder joints of the total group was of interest in this investigation. The gymnasts in this study experienced a mean peak vertical force of 1.6 times body weight on each elbow and shoulder. The mean peak horizontal forces were 0.7 and 1.3 respectively. These figures agree with Robertson et al. (1985) who found that a performer experienced 1.5 times body weight on one arm while performing swinging skills on the rings.

Recommendations for Coaches

The purpose of this study was to identify critical elements of the overgrip giant swing on the uneven parallel bars. Based on the findings of this study, the author would recommend the following suggestions to coaches for teaching the overgrip giant swing:

Instruct gymnasts to:

1. Start in as high a body position on the bar as possible.
2. Extend the handstand, so the body is completely straight with the shoulders elevated.
3. Keep the extended body position as long as possible on the downswing.
4. Pike the hips and keep the shoulder joints as straight as possible, when clearing the low bar.
5. Extend the hips as quickly as possible, as soon as the low bar is cleared. This will put the gymnast into position to perform a "tap".
6. Shorten the radius of rotation during the ascent phase by decreasing the angles of the shoulder and hip joints, rather than by hyperextending (arching) the hips. Once gymnasts learn the recommended technique for shortening the radius, they will be able to increase their velocity during the ascent phase to set up more advanced skills.

Recommendations for Further Research

There has been a paucity of research in women's gymnastics especially on recently evolving skills on the uneven parallel bars. This author encourages others to conduct additional research on high level skills performed by highly skilled gymnasts as well as skills performed by developing gymnasts. The largest percentage of participants in the sport of gymnastics is children between the ages of 10 and 16. More research needs to be done to determine the effects of gymnastic skills on the development of those participants.

There needs to be additional data analyzed on joint reaction forces and muscle moments. Also the long term effects of forces and torques applied to the joints of young gymnasts needs to be studied. In addition, because of the inordinate amount of back problems in this population, there need to be methods developed for studying the forces and torques applied to the lower back of gymnasts.

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APPENDIX A

APPENDIX A

Informed Written Consent Form

For Parents/Participants in a Study of Giant Swings on the Uneven Parallel Bars

The purpose of this study is to examine the biomechanics of a giant swing on the uneven parallel bars. Volunteer subjects between the ages of 10 and 16 will be filmed performing a previously learned sequence of skills, including the giant swing, on the uneven parallel bars. The top bar of the uneven parallel bars will be instrumented with strain gages to directly measure the forces and torques on the bar while the gymnast performs. Data obtained from the film and instrumented bar will be used to identify critical factors in performing good giant swings and to calculate typical forces and torques on the elbow and shoulder joints while performing the skill. The study will be conducted at the Human Performance Laboratory at Michigan State University and at Great Lakes Gymnastics Club, Lansing Michigan.

1. I have freely consented to allow my child to take part in a scientific study being conducted by Winifred Witten, a doctoral candidate in the School of Health Education, Counseling Psychology and Human Performance at Michigan State University.

2. The study has been explained to me and to my child. We understand the explanation that has been given and what participation in the study will involve.

3. My child and I understand that she is free to discontinue her participation in the study at any time without penalty.

4. I understand that my child will be performing skills that she has previously learned on the uneven parallel bars and that proper safety procedures and matting will be provided.

5. I understand if my child is injured as a result of participation in this study, Michigan State University will provide emergency medical care if necessary, but these and any other medical expenses must be paid from my own health insurance program.

6. I understand that my child's name will not be associated with any publication and/or presentation of the data collected in this study.

7. I understand that film and other measurement data will be collected and may be used for demonstrations, instruction and/or study.

8. I understand that my child's participation in this study does not guarantee any beneficial results for her.

9. I understand that, at our request, my child and I can receive additional explanation of the study after participation is completed.

Signature of Parent	Signature of Witness
Date	Date
Signature of Gymnast	Signature of Witness
Date	Date

APPENDIX B

APPENDIX B

INFORMATION SHEET FOR DATA COLLECTION

Biomechanical Study of Giant Swings

A. General Information:

Name:____________________________________

Address:____________________________________

____

Phone Number:_________________________

Date of Birth:____________________

Height:____________________

Weight:____________________

Age:_____________________

B. Gymnastics History:

Years of participation in gymnastics?________________

Class I or Elite? ____________________________________

Coach ____

C. Anthropometric Data:

Thigh length_____________________________

Calf length______________________________

Shoulder-elbow length____________________

Elbow-wrist length ______________________

Hand length______________________________

Biacromial diameter______________________

Biiliac diameter ________________________

D. Underwater weighing data:

Body density (g/ml)____________________

Relative fat (%)____________________

Lean body mass (kg)____________________

D. Filming Record

Location____________________

Camera____________________ Film rate____________________

Shutter angle____________________ f/stop____________________

Lens____________________ Focal length____________________

Type of film____________________

Camera height____________________

Camera-subject distance____________________

Shooting details (trials, etc) Comments

APPENDIX C

APPENDIX C

C.1 Judging Sheet for Giant Swings on the Uneven Parallel Bars

Subject #____________________

Arms Bent 2.0 ____________________

Body Position:
Arch 2.0____________________

Leg Position:
Legs Bent 2.0____________________

Legs Apart 1.5____________________

Arriving to Handstand:
Using Force 1.5____________________

General Impression: 1.0____________________

Judge____________________

Comments:

____

C.2 Summary of Judges' Ratings

Subject Number	JI	J2	J3	J4	Ave.
16	9.2	9.3	9.4	8.4	9.25
4	8.7	8.9	9.1	8.4	8.80
1	8.5	9.0	9.5	8.1	8.75
7	7.5	8.8	8.9	8.6	8.70
5	5.8	8.4	8.2	8.6	8.30
12	5.0	8.0	8.4	8.0	8.00
10	5.0	6.8	7.7	6.7	6.75
14	4.9	6.5	7.6	6.5	6.50
3	4.9	8.1	8.9	6.0	7.05
2	4.7	6.7	7.9	6.0	6.35
17	4.4	7.0	7.8	5.5	6.30
6	4.3	6.3	7.4	6.0	6.15
11	3.6	6.6	8.4	5.0	5.70
9	3.1	7.3	7.8	5.2	6.25
8	2.5	4.2	6.0	4.0	4.10

APPENDIX D

APPENDIX D

Statistical Summary Tables

Table D.1 Mean Peak Velocities of Total Body Center of Mass and the Times of Occurrences of Mean Peak Velocities Expressed as Percents of Total Time

	Mean	SD	Min	Max
V_X * (m/sec)				
Total Group	4.633	.460	3.880	5.450
Group 1	4.886	.371	4.550	5.450
Group 3	4.380	.423	3.880	4.960
V_Y (m/sec)				
Total Group	-1.301	5.401	-5.110	9.070
Group 1	.298	6.641	-4.850	9.070
Group 3	-2.900	3.891	-5.110	4.020
V_R (m/sec)				
Total Group	5.601	1.410	4.580	9.470
Group 1	6.152	1.912	4.580	9.470
Group 3	5.050	.239	4.780	5.320
% Time V_X				
Total Group	57.65	6.500	49.20	71.50
Group 1	60.92	6.958	53.90	71.50
Group 3	54.38	4.464	49.20	61.10
% Time V_Y **				
Total Group	49.07	12.87	27.30	73.10
Group 1	57.86	10.352	44.30	73.10
Group 3	40.28	8.493	27.30	48.30
% Time V_R				
Total Group	55.95	10.28	36.40	73.10
Group 1	60.42	8.81	49.80	73.10
Group 3	51.48	10.50	36.40	61.80

*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.2 Mean Peak Velocities+ of Total Body Center of Mass Per Quadrant

	Total	Group 1	Group 3		Total	Group 1	Group 3
	Quadrant 1				Quadrant 2		
V_X				V_X			
Mean	-1.98	-2.03	-1.92		4.57	4.77	4.38
SD	.39	.47	.36		.47	.48	.42
Min	-2.84	-2.84	-2.53		3.88	4.22	3.88
Max	-1.63	-1.63	-1.70		5.45	5.45	4.96
V_Y				V_Y			
Mean	-3.84	-3.97	-3.72		-4.74	-4.96	-4.51
SD	.74	.63	.89		.87	1.16	.46
Min	-5.11	-5.02	-5.11		-6.95	-6.95	-5.02
Max	-2.91	-3.44	-2.91		-3.95	-3.95	-3.97
V_R				V_R			
Mean	3.20	2.41	3.99		5.39	5.90	4.91
SD	2.63	3.63	.90		1.26	1.69	.34
Min	-4.00	-4.00	3.16		4.39	4.58	4.39
Max	5.13	5.02	5.13		8.83	8.83	5.32
	Quadrant 3				Quadrant 4		
V_X **				V_X			
Mean	3.99	4.33	3.64		-2.04	-2.04	-2.03
SD	.48	.43	.18		.14	.16	.14
Min	3.43	3.74	3.43		-2.20	-2.18	-2.20
Max	4.82	4.82	3.81		-1.81	-1.81	-1.85
V_Y				V_Y			
Mean	4.45	5.20	3.71		3.18	3.37	2.98
SD	1.83	2.36	.75		.52	.67	.25
Min	3.04	3.52	3.04		2.56	2.59	2.56
Max	9.07	9.07	4.90		4.39	4.39	3.22
V_R				V_R *			
Mean	5.00	5.68	5.33		3.54	3.87	3.21
SD	1.70	2.25	.54		.56	.51	.42
Min	3.84	3.84	3.88		2.75	3.47	2.75
Max	9.47	9.47	5.27		4.74	4.74	3.90

+ m/sec.
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.3 Times of Occurrences of Mean Peak Velocities of Total Body Center of Mass Per Quadrant Expressed as Percents of Total Time

	Total	Group 1	Group 3		Total	Group 1	Group 3
		Quadrant 1				Quadrant 2	
% Time V_x				% Time V_x			
Mean	36.03	36.88	35.88		57.08	59.22	54.94
SD	7.39	8.07	7.50		5.15	4.18	5.56
Min	26.90	26.90	28.30		49.20	53.90	49.20
Max	47.40	45.20	47.40		64.60	64.60	63.90
% Time V_y				% Time V_y			
Mean	41.41	43.58	39.24		49.23	52.98	45.48
SD	6.79	6.34	7.21		7.74	6.69	7.41
Min	34.00	38.60	34.00		37.30	44.30	37.30
Max	52.00	52.00	51.90		60.00	60.00	57.50
% Time V_R				% Time V_{xR}			
Mean	41.62	43.58	39.66		52.86	55.50	50.22
SD	6.70	6.34	7.16		7.55	7.01	7.85
Min	34.00	38.60	34.00		43.80	47.70	43.80
Max	52.00	52.00	51.90		64.60	64.60	61.40
		Quadrant 3				Quadrant 4	
% Time V_x				% Time V_x			
Mean	60.37	62.88	57.86		83.58	86.58	80.58
SD	6.05	5.84	5.70		6.52	3.09	7.98
Min	51.60	57.00	51.60		69.30	83.80	69.30
Max	71.50	71.50	66.70		91.70	91.70	90.60
% Time V_y				% Time V_y			
Mean	68.29	70.02	66.56		76.59	78.02	75.16
SD	6.08	5.19	6.98		4.01	2.79	4.83
Min	60.70	61.00	60.70		69.30	74.70	69.30
Max	75.60	73.80	75.60		82.20	82.20	80.60
% Time V_R				% Time V_R			
Mean	63.97	66.12	61.82		76.07	77.50	74.64
SD	6.47	6.90	5.91		4.04	2.15	5.19
Min	52.90	57.00	52.90		69.30	74.60	69.30
Max	73.10	73.10	69.50		80.60	80.20	80.60

$*p < .10$, $**p < .05$, $***p < .01$.

Table D.4 Mean Peak Accelerations+ of Total Body Center of Mass and Relative Times of Occurrences

	Mean	SD	Min	Max
A_X				
Total	-20.39	475.73	-475.73	1047.31
Group 1	46.13	634.79	-475.73	1047.31
Group 3	-86.90	308.54	-340.61	293.46
A_Y				
Total	237.45	964.89	-496.81	2578.88
Group 1	600.39	1238.71	-496.81	2578.88
Group 3	-125.49	480.68	-370.94	732.33
A_R				
Total	766.84	716.11	286.37	2522.39
Group 1	1068.38	947.56	286.37	2622.39
Group 3	465.30	189.17	296.17	734.35
% Time A_X				
Total	54.71	21.92	16.80	90.10
Group 1	62.00	27.53	16.80	90.10
Group 3	47.42	13.78	35.90	68.90
% Time A_Y				
Total	59.32	14.57	35.90	78.10
Group 1	62.60	16.07	36.70	78.10
Group 3	56.04	13.88	35.90	69.40
% Time A_R				
Total	61.48	12.91	35.90	76.50
Group 1	66.26	10.36	51.60	76.50
Group 3	56.70	14.51	35.90	69.40

+(m/sec^2).
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.5 Mean Peak Accelerations^{+} of Total Body Center of Mass Per Quadrant

	Total	Group 1	Group 3	Total	Group 1	Group 3
	Quadrant 1			Quadrant 2		
A_X						
Mean	- 92.39	-19.02	-165.75	75.13	10.36	139.89
SD	296.16	374.94	208.12	253.66	303.78	204.96
Min	-359.33	-359.33	-340.61	-262.24	-262.24	-220.50
Max	456.67	456.67	183.45	356.26	356.26	293.46
A_Y						
Mean	-30.97	222.35	-284.29	-110.03	-309.77	89.71
SD	405.15	448.99	85.51	531.57	665.32	305.57
Min	-370.94	-290.63	-370.94	-1423.59	-1423.59	-236.86
Max	773.52	773.52	-189.70	432.97	203.67	432.97
A_R						
Mean	407.12	474.74	339.50	439.09	550.94	327.24
SD	182.68	229.50	104.81	367.22	509.67	111.23
Min	242.52	285.67	242.52	264.46	286.37	264.46
Max	852.90	852.90	503.60	1460.28	1460.28	523.05
	Quadrant 3			Quadrant 4		
A_X						
Mean	-11.46	43.67	-66.59	-17.10	43.49	-77.70
SD	439.42	613.14	255.67	233.71	255.47	220.12
Min	-475.73	-475.73	-277.42	-284.17	-253.18	-284.17
Max	1047.31	1047.31	208.94	300.75	300.75	165.46
A_Y						
Mean	264.63	612.81	-83.54	85.11	79.66	90.55
SD	948.52	1227.81	462.31	349.39	265.26	241.09
Min	-496.81	-496.81	-353.21	-282.50	-282.50	-214.95
Max	2578.88	2578.88	732.33	792.30	792.30	324.42
A_R						
Mean	721.25	1048.18	394.32	333.90	399.45	268.36
SD	743.45	968.01	198.38	198.20	246.51	95.07
Min	222.75	232.49	222.75	200.33	236.72	200.33
Max	2622.39	2622.39	734.35	832.77	832.77	431.28

$^{+}$(m/sec^2).
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.6 Times of Occurrences of Mean Peak Accelerations of Total Body Center of Mass Per Quadrant Expressed as Percents of Total Time

	Total	Group 1	Group 3		Total	Group 1	Group 3
		Quadrant 1				Quadrant 2	
% Time Ax				% Time Ax			
Mean	32.39	30.54	34.24		51.35	54.08	48.62
SD	6.58	8.45	4.17		8.64	10.18	6.75
Min	16.80	16.80	29.90		37.30	42.50	37.30
Max	40.40	38.90	40.40		64.20	60.00	64.20
% Time Ay				% Time Ay			
Mean	31.44	33.02	29.86		51.63	54.32	48.94
SD	13.37	11.85	15.99		8.38	7.63	9.05
Min	8.60	16.80	8.60		40.60	42.60	40.60
Max	51.60	46.90	51.60		60.00	64.20	62.00
% Time AXr				% Time Ar			
Mean	29.99	27.32	32.66		51.63	54.32	48.94
SD	11.02	10.25	12.28		8.38	7.60	9.06
Min	16.80	16.80	19.30		40.60	42.60	40.60
Max	51.60	39.10	51.60		64.20	62.00	64.20
		Quadrant 3				Quadrant 4	
% Time Ax				% Time Ax *			
Mean	67.49	69.38	65.60		86.48	92.28	80.68
SD	7.21	6.16	8.37		10.01	8.34	8.47
Min	58.30	60.50	58.30		68.90	79.30	68.90
Max	79.00	76.10	79.00		99.50	99.50	91.10
% Time Ay				% Time Ay			
Mean	68.50	68.50	68.50		85.65	88.92	82.38
SD	6.13	7.12	5.82		9.69	8.74	10.39
Min	60.50	60.50	61.40		68.90	76.90	68.90
Max	76.60	76.60	77.20		99.50	99.50	97.20
% Time Ar				% Time Ar			
Mean	67.34	68.38	66.30		86.34	87.14	85.54
SD	6.16	5.53	7.22		9.90	9.97	10.94
Min	58.30	60.50	58.30		68.90	76.50	68.90
Max	76.80	73.10	76.80		99.50	99.50	97.20

*p < .10, ** p < .05, ***p < .01.

Table D.7 Mean Peak Resultant Velocities+ of Selected Joints

	Mean	SD	Min	Max
Ankle ***				
Total	10.47	.793	9.29	11.70
Group 1	11.03	.372	10.62	11.70
Group 3	9.64	.338	9.29	9.97
Knee *				
Total	7.16	.323	6.60	7.53
Group 1	7.30	.191	7.01	7.53
Group 3	6.95	.389	6.60	7.47
Hip ***				
Total	5.96	.427	5.40	6.70
Group 1	6.22	.326	5.73	6.70
Group 3	5.57	.186	5.40	5.75
Shoulder				
Total	3.64	.657	3.04	5.00
Group 1	3.91	.751	3.04	5.00
Group 3	3.24	.071	3.18	3.33
Elbow				
Total	2.66	.359	2.19	3.33
Group 1	2.64	.235	2.45	3.13
Group 3	2.68	.543	2.19	3.33

+ (m/sec).
*p < .10, ** p < .05, ***p < .01.

Table D.8 Times of Occurrences of Mean Peak Resultant Velocities Expressed as Percents of Total Time

	Mean	SD	Min	Max
% Time Ankle ***				
Total	62.45	4.454	53.30	67.30
Group 1	65.13	2.018	62.40	67.30
Group 3	58.43	4.090	53.30	63.30
% Time Knee				
Total	59.34	9.703	34.40	67.60
Group 1	59.57	12.686	34.40	67.60
Group 3	59.00	3.733	54.90	63.30
% Time Hip **				
Total	52.64	4.700	44.70	58.50
Group 1	55.32	3.622	50.20	58.50
Group 3	48.63	2.927	44.70	51.10
% Time Shoulder **				
Total	55.95	11.156	40.60	82.70
Group 1	60.95	11.413	48.90	82.70
Group 3	48.53	5.725	40.60	53.90
% Time Elbow				
Total	74.26	12.709	49.30	84.70
Group 1	77.20	13.745	49.30	84.70
Group 3	69.85	11.245	53.90	78.60

+ (m/sec).
*p < .10, ** p < .05, ***p < .01.

Table D.9 Mean Peak Resultant Velocities+ of the Selected Joints Per Quadrant

	Mean	SD	Min	Max		Mean	SD	Min	Max
	Quadrant 1					Quadrant 2			
Ankle					Ankle				
Total	5.71	1.06	4.33	7.49		8.23	.69	6.97	9.22
Group 1	6.26	1.27	4.33	7.49		8.50	.71	7.33	9.22
Group 3	5.15	.41	4.73	5.70		7.95	.62	6.97	8.65
Knee					Knee				
Total	4.54	.31	4.08	4.95		6.33	.27	5.82	6.59
Group 1	4.62	.32	4.09	4.88		6.39	.32	5.82	6.59
Group 3	4.46	.33	4.08	4.95		6.28	.22	5.91	6.49
Hip					Hip *				
Total	4.42	.33	4.02	4.98		5.96	.43	5.40	6.71
Group 1	4.45	.39	4.02	4.98		6.21	.36	5.73	6.71
Group 3	4.39	.30	4.08	4.85		5.70	.34	5.40	6.24
Shoulder					Shoulder				
Total	2.62	.29	2.19	3.10		3.62	.64	3.04	5.00
Group 1	2.64	.16	2.41	2.80		3.91	.81	3.04	5.00
Group 3	2.59	.40	2.19	3.10		3.32	.19	3.18	3.65
Elbow					Elbow *				
Total	1.45	.23	1.17	1.89		2.13	.23	1.86	2.50
Group 1	1.49	.27	1.17	1.89		2.27	.22	1.94	2.50
Group 3	1.41	.20	1.17	1.60		2.00	.16	1.86	2.27
	Quadrant 3					Quadrant 4			
Ankle ***					Ankle				
Total	9.90	.88	9.00	11.00		2.98	.42	2.33	3.69
Group 1	10.60	.55	10.00	11.00		2.98	.52	2.33	3.69
Group 3	9.20	.45	9.00	10.00		2.97	.38	2.39	3.27
Knee					Knee **				
Total	7.16	.32	6.60	7.53		3.50	.62	2.62	4.66
Group 1	7.31	.21	7.01	7.53		3.90	.58	3.34	4.66
Group 3	7.01	.36	6.60	7.47		3.11	.39	2.62	3.53
Hip ***					Hip *				
Total	4.86	.32	4.45	5.47		4.44	.71	2.71	5.45
Group 1	4.12	.24	4.48	5.47		4.84	.38	4.48	5.45
Group 3	4.61	.12	4.45	4.75		4.30	.78	2.71	4.7

Table D.9 (Continued)

	Mean	SD	Min	Max		Mean	SD	Min	Max
	Quadrant 3					Quadrant 4			
Shoulder ***					Shoulder **				
Total	2.62	.78	2.02	4.59		3.01	.34	2.43	3.59
Group 1	3.09	.93	2.02	4.59		3.23	.29	2.92	3.59
Group 3	2.21	.15	2.04	2.37		2.97	.24	2.43	3.05
Elbow					Elbow				
Total	1.81	.71	1.40	3.79		2.57	.34	2.19	3.30
Group 1	2.11	.95	1.53	3.79		2.72	.36	2.37	3.30
Group 3	1.52	.10	1.40	1.61		2.43	.29	2.19	2.91

+ (m/sec).
*p < .10, ** p < .05, ***p < .01.

Table D.10 Times of Occurrences of Mean Peak Resultant Velocities Expressed as Percents of Total Time

	Mean	SD	Min	Max	Mean	SD	Min	Max
	Quadrant 1				Quadrant 2			
% Time Ankle					% Time Ankle			
Total	37.88	6.13	29.90	48.10	58.62	4.98	50.40	65.70
Group 1	39.30	5.50	33.50	46.70	60.68	3.81	56.10	65.70
Group 3	36.46	7.03	29.90	48.10	56.56	5.55	50.40	65.30
% Time Knee					% Time Knee *			
Total	42.43	6.83	35.30	53.30	57.95	4.65	50.40	65.70
Group 1	43.88	6.93	36.00	52.40	60.68	3.81	56.10	65.70
Group 3	40.98	7.20	35.30	53.30	55.22	4.65	50.40	61.40
% Time Hip					% Time Hip			
Total	42.97	6.41	35.30	53.30	53.15	5.36	44.70	61.40
Group 1	44.86	5.73	39.60	52.40	55.12	3.98	50.20	59.50
Group 3	41.08	7.12	35.30	53.30	51.18	6.25	44.70	61.40
% Time Shoulder					% Time Shoulder			
Total	42.82	6.58	35.30	53.30	52.37	6.11	40.60	61.80
Group 1	44.86	5.73	39.60	52.40	53.56	4.23	48.90	59.50
Group 3	40.78	7.37	35.30	53.30	51.18	7.73	40.60	61.80
% Time Elbow					% Time Elbow			
Total	42.70	6.24	35.30	52.60	51.90	6.95	39.30	62.60
Group 1	44.30	6.05	39.60	52.40	53.56	5.61	48.70	62.20
Group 3	41.14	6.69	35.30	52.60	50.24	8.36	39.30	61.40
	Quadrant 3				Quadrant 4			
% Time Ankle					% Time Ankle			
Total	62.83	4.87	53.30	69.10	83.69	10.91	66.00	98.90
Group 1	65.10	2.27	62.40	68.00	85.10	8.47	76.70	97.30
Group 3	60.56	5.94	53.30	69.10	82.28	13.82	66.00	98.90
% Time Knee					% Time Knee			
Total	62.73	4.71	54.90	69.50	76.28	5.71	66.00	87.20
Group 1	64.30	3.29	60.20	68.40	77.36	1.75	74.70	78.90
Group 3	61.10	5.70	54.90	69.50	75.20	8.21	66.60	87.20
% Time Hip					% Time Hip			
Total	73.18	5.05	60.30	78.30	75.92	5.25	66.00	84.40
Group 1	75.52	2.55	71.50	77.90	77.36	1.75	74.70	78.90
Group 3	70.84	6.94	60.30	78.30	74.48	7.33	66.00	84.40

Table D.10 (Continued)

	Mean	SD	Min	Max		Mean	SD	Min	Max
	Quadrant 3					Quadrant 4			
% Time Shoulder					% Time Shoulder				
Total	64.99	7.66	55.40	78.50		78.70	4.93	69.30	82.70
Group 1	67.80	8.35	58.90	78.50		81.18	1.86	78.30	82.70
Group 3	62.18	6.54	55.40	71.80		76.36	6.06	69.30	83.30
% Time Elbow					% Time Elbow *				
Total	63.63	7.23	55.40	78.50		80.91	4.62	70.10	85.00
Group 1	64.18	8.68	57.00	78.50		83.36	1.13	81.90	84.70
Group 3	63.08	6.44	55.40	71.80		78.46	5.63	70.10	85.00

$^*p < .10$, $^{**}p < .05$, $^{***}p < .01$.

Table D.11 Mean Peak Resultant Accelerations+ of Selected Joints

	Mean	SD	Min	Max
Ankle				
Total	91.02	13.44	74.58	121.21
Group 1	94.78	16.58	74.58	121.21
Group 3	85.39	3.637	82.13	89.06
Knee				
Total	67.67	16.88	49.85	94.69
Group 1	65.72	16.44	49.85	94.69
Group 3	70.58	19.62	53.44	89.65
Hip				
Total	46.71	8.11	37.51	63.52
Group 1	49.56	9.02	39.14	63.52
Group 3	42.45	4.63	37.51	48.60
Shoulder				
Total	74.89	75.08	32.92	231.72
Group 1	99.54	91.20	35.93	231.72
Group 3	37.90	3.44	32.92	40.57
Elbow				
Total	51.58	20.26	37.99	106.46
Group 1	44.12	4.83	37.99	52.40
Group 3	62.77	30.24	39.87	106.46

+(m/sec^2).
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.12 Times of Occurrences of Mean Peak Resultant Accelerations Expressed as Percents of Total Time

	Mean	SD	Min	Max
% Time Ankle				
Total	62.46	4.729	57.00	68.60
Group 1	64.38	4.549	57.10	68.60
Group 3	59.58	3.756	57.00	65.00
% Time Knee				
Total	58.84	3.679	52.10	63.10
Group 1	59.73	2.226	56.60	62.70
Group 3	57.50	5.324	52.10	63.10
% Time Hip **				
Total	53.40	9.823	41.10	75.60
Group 1	59.08	8.155	53.90	75.60
Group 3	44.88	4.176	41.10	50.60
% Time Shoulder *				
Total	57.73	12.637	36.90	78.10
Group 1	63.53	11.839	48.00	78.10
Group 3	49.03	8.781	36.90	57.20
% Time Elbow				
Total	79.31	8.931	62.60	88.30
Group 1	80.08	9.296	62.60	86.40
Group 3	78.15	9.606	65.20	88.30

*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.13 Mean Peak Velocities[+] of the Center of Mass of Selected Segments

	Mean	SD	Min	Max	Mean	SD	Min	Max
				Trunk				
V_X					V_Y			
Total	4.05	.37	3.69	4.74	-4.09	.31	-4.73	-3.76
Group1	4.19	.45	3.72	4.74	-4.24	.35	-4.73	-3.76
Group3	3.91	.22	3.69	4.18	-3.94	.20	-4.27	-3.78
V_R **								
Total	4.64	.33	4.31	5.25				
Group1	4.86	.32	4.39	5.25				
Group3	4.45	.19	4.31	4.76				
				Thigh				
V_X					V_Y			
Total	5.37	.20	5.07	5.72	-2.98	4.37	-5.59	5.60
Group1	5.42	.19	5.19	5.72	-1.00	5.74	-5.45	5.60
Group3	5.31	.20	5.07	5.53	-4.97	.36	-5.59	-4.71
V_R								
Total	5.80	.34	5.39	6.31				
Group1	5.88	.37	5.39	6.31				
Group3	5.73	.33	5.40	6.24				
				Shank				
V_X					V_Y **			
Total	7.55	.48	6.43	8.13	7.44	.48	6.71	8.04
Group1	7.88	.17	7.69	8.13	7.74	.28	7.39	8.04
Group3	7.22	.48	6.43	7.62	7.14	.45	6.71	7.74
V_R ***								
Total	8.56	.50	7.74	9.18				
Group1	8.94	.20	8.73	9.18				
Group3	8.18	.41	7.74	8.71				

Table D.13 (Continued)

	Mean	SD	Min	Max	Mean	SD	Min	Max
Foot								
V_X **					V_Y ***			
Total	9.72	.92	8.06	10.82	9.68	.95	7.91	10.90
Group1	10.33	.48	9.55	10.82	10.40	.38	9.92	10.90
Group3	9.12	.86	8.06	9.92	8.95	.75	7.91	9.67
V_R **								
Total	11.07	.89	9.30	12.07				
Group1	11.70	.31	11.42	12.07				
Group3	10.44	.84	9.30	11.53				
Arm								
V_X					V_Y			
Total	2.60	.39	2.14	3.50	-.001	2.89	-3.33	2.96
Group1	2.76	.53	2.14	3.50	.388	3.27	-3.33	2.96
Group3	2.44	.18	2.28	2.68	-.390	2.78	-2.50	2.75
V_R *								
Total	3.08	.64	2.58	4.70				
Group1	3.42	.77	2.69	4.70				
Group3	2.74	.17	2.58	3.04				
Forearm								
V_X					V_Y			
Total	-.07	1.57	-1.82	1.59	1.44	1.16	-1.78	2.13
Group1	-.33	1.74	-1.82	1.59	1.17	1.66	-1.78	2.04
Group3	.19	1.53	-1.64	1.46	1.71	.26	1.43	2.13
V_R								
Total	1.94	.27	1.64	2.45				
Group1	2.07	.22	1.90	2.45				
Group3	1.82	.28	1.64	2.32				

+ (m/sec).
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.14 Times of Occurrences of Mean Peak Velocities+ of Selected Body Segments Expressed as Percents of Total Time

	Mean	SD	Min	Max		Mean	SD	Min	Max
				Trunk					
V_X					V_Y				
Total	55.0	4.9	45.5	63.4		46.69	5.1	39.33	55.8
Group1	57.2	4.1	52.5	63.4		49.04	4.9	44.3	55.8
Group3	52.7	4.9	45.5	58.9		44.2	4.4	39.3	51.3
V_R **									
Total	4.64	.33	4.31	5.25					
Group1	4.86	.32	4.39	5.25					
Group3	4.45	.19	4.31	4.76					
				Thigh					
V_X					V_Y				
Total	56.5	4.3	50.0	63.4		49.5	10.1	41.0	74.8
Group1	58.3	4.6	52.5	63.4		53.9	12.6	43.9	74.8
Group3	54.7	3.9	50.0	60.8		45.1	4.9	41.0	53.6
V_R									
Total	5.80	.34	5.39	6.31					
Group1	5.88	.37	5.39	6.31					
Group3	5.73	.33	5.40	6.24					
				Shank					
V_X					V_Y **				
Total	60.1	4.6	51.2	65.9		65.0	5.8	55.7	70.4
Group1	62.4	3.2	58.8	65.9		66.2	5.9	56.1	70.4
Group3	57.8	4.9	51.2	64.2		63.7	5.7	55.7	70.2
V_R ***									
Total	8.56	.50	7.74	9.18					
Group1	8.94	.20	8.73	9.18					
Group3	8.18	.41	7.74	8.71					

Table D.14 (Continued)

	Mean	SD	Min	Max	Mean	SD	Min	Max
				Foot				
V_X					V_Y			
Total	60.1	4.7	51.2	65.9	66.1	4.6	54.9	70.0
Group1	62.3	3.4	58.4	65.9	67.6	2.3	64.3	70.0
Group3	57.9	5.1	51.2	64.5	64.5	5.9	54.9	69.4
V_R								
Total	11.07	.89	9.30	12.07				
Group1	11.70	.31	11.42	12.07				
Group3	10.44	.64	9.30	11.53				
				Arm				
V_X					V_Y			
Total	57.8	5.7	46.7	65.2	62.0	19.6	39.1	83.3
Group1	57.2	5.8	49.3	65.2	68.3	18.4	46.6	83.3
Group3	52.3	5.7	46.7	59.3	55.8	20.8	38.1	80.8
V_R *								
Total	3.08	.64	2.58	4.70				
Group1	3.42	.77	2.69	4.70				
Group3	2.74	.17	2.58	3.04				
				Forearm				
V_X					V_Y			
Total	71.2	14.5	51.5	88.3	77.1	10.7	49.3	85.6
Group1	74.0	15.2	54.2	87.3	76.1	15.0	49.3	83.6
Group3	68.4	14.9	51.5	88.3	78.2	5.6	70.1	85.6
V_R								
Total	1.94	.27	1.64	2.45				
Group1	2.07	.22	1.90	2.45				
Group3	1.82	.28	1.64	2.32				

+ m/sec.

*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.15 Mean Peak Accelerations+ of the Selected Body Segments

Segment	Group 1 Min	Group 1 Max	Group 3 Min	Group 3 Max	Total Group Min	Total Group Max
			Horizontal Acceleration			
Trunk	-33.73	40.88	-30.80	34.24	-33.73	40.88
Thigh	-37.15	44.76	-49.46	37.18	-49.46	44.76
Shank	-63.44	-56.47	-76.57	-51.64	-76.57	-51.64
Foot	-94.63	110.03	-78.72	-65.11	-94.63	110.03
Arm	-27.40	107.89	-39.52	23.33	-39.52	107.89
F.Arm	-30.98	21.17	-85.33	25.80	-85.33	25.80
			Vertical Acceleration			
Trunk*	27.33	83.18	-29.70	38.36	-29.70	83.18
Thigh	32.25	67.06	38.21	52.95	32.25	67.06
Shank	59.50	98.57	51.39	67.22	51.39	98.57
Foot **	87.47	99.03	34.47	85.12	34.47	99.03
Arm	-33.18	119.48	-39.21	39.01	-39.21	119.48
F.Arm	-41.18	37.42	-49.44	37.15	-49.44	37.42
			Resultant Acceleration			
Trunk	30.48	84.88	31.90	40.66	30.48	84.88
Thigh	34.78	68.07	38.85	57.78	34.78	68.07
Shank	61.44	104.61	57.76	78.88	57.76	104.61
Foot **	89.20	122.19	72.71	95.32	72.71	122.19
Arm	34.29	134.95	26.45	42.19	26.45	134.95
F.Arm	36.89	42.47	25.62	93.07	25.62	93.07

\+ (m/sec^2).
*p < .10, ** p < .05, ***p < .01.

Table D.16 Mean Peak Joint Reaction Forces

	Mean	SD	Min	Max
		Elbow		
Vertical Force+				
Total Group	-1.56	1.33	-2.09	2.22
Group 1	-1.15	1.89	-2.09	2.22
Group 3	-1.98	0.04	-2.02	-1.94
Horizontal Force+				
Total Group	-0.74	1.11	-1.44	1.36
Group 1	-0.24	1.46	-1.44	1.36
Group 3	-1.24	0.09	-1.39	-1.16
Moment (Nm)				
Total	-54.11	55.28	-97.80	96.80
Group 1	-38.90	76.78	-86.00	96.80
Group 3	-69.32	20.03	-97.80	-53.20
		Shoulder		
Vertical Force+				
Total Group	1.62	1.28	-2.01	2.17
Group 1	1.25	1.82	-2.01	2.17
Group 3	2.00	0.05	1.95	2.08
Horizontal Force+				
Total	-1.28	0.09	-1.41	-1.14
Group 1	-1.31	0.11	-1.41	-1.14
Group 3	-1.25	0.07	-1.35	-1.16
Moment (Nm)				
Total	97.04	27.24	50.80	134.30
Group	110.16	17.79	92.00	134.30
Group 3	83.92	30.38	50.80	124.30

+ Normalized by body weight.
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.17 Times of Occurrences of Mean Peak Joint Forces and Moments Expressed as Percents of Total Time

	Mean	SD	Min	Max
		Elbow		
% Vertical Force				
Total	54.81	5.225	45.10	62.60
Group 1	56.86	3.328	53.20	61.60
Group 3	53.76	2.823	45.10	62.60
% Horizontal Force				
Total	47.12	6.280	39.10	56.00
Group 1	50.22	4.485	45.80	56.00
Group 3	44.02	6.677	39.10	55.10
% Moment				
Total	49.48	5.971	40.10	58.50
Group 1	51.74	5.617	46.80	58.50
Group 3	47.22	5.991	40.10	56.60
		Shoulder		
% Vertical Force				
Total	55.43	5.940	44.20	63.04
Group 1	57.46	4.693	53.20	63.40
Group 3	53.40	6.860	44.20	62.60
% Horizontal Force				
Total	46.72	6.111	38.60	56.30
Group 1	49.88	4.943	44.80	56.30
Group 3	43.56	5.885	38.60	53.20
% Moment				
Total	57.50	5.310	48.90	64.80
Group 1	59.18	5.511	52.00	64.80
Group 3	55.82	5.100	48.90	63.00

*p < .10, ** p < .05, ***p < .01.

Table D.18 Joint Reaction Forces and Moments of the Shoulder Per Quadrant

	Total Group	Group 1	Group 3	Total Group	Group 1	Group 3
		Quadrant 1			Quadrant 2	
			Vertical Force+			
Mean	-0.56	-0.59	-0.53	2.02	2.05	1.98
SD	0.07	0.04	0.08	0.09	0.11	0.07
Min	-0.45	-0.55	-0.45	1.91	1.92	1.91
Max	0.66	0.61	-0.66	2.17	2.17	2.08
			Horizontal Force			
**						
Mean	-0.52	-0.44	-0.60	-1.28	-1.31	-1.25
SD	0.13	0.13	0.07	0.09	0.12	0.07
Min	-0.67	- .65	-0.67	-1.41	-1.41	-1.35
Max	0.30	0.30	-0.51	-1.35	-1.35	-1.16
			Moment (Nm)			
Mean	-24.74	-20.80	-28.68	69.62	108.86	30.38
SD	28.84	41.26	11.39	69.45	19.40	81.40
Min	-54.70	-54.70	-43.20	-78.00	86.10	86.10
Max	51.10	51.10	-16.30	134.30	134.30	124.10
		Quadrant 3			Quadrant 4	
			Vertical Force+			
Mean	1.77	1.08	1.75	0.60	0.59	-0.60
SD	0.23	0.11	0.33	0.06	0.09	0.02
Min	1.21	1.68	1.21	0.49	-0.49	-0.57
Max	2.04	1.20	2.04	-0.71	-0.71	-0.62
			Horizontal Force+			
Mean	0.74	0.97	0.51	0.29	0.48	0.11
SD	0.58	0.11	0.78	0.69	0.60	0.69
Min	-0.88	0.82	-0.88	-0.67	-0.59	-0.67
Max	1.13	1.13	0.87	0.88	0.88	0.66

Table D.18 (Continued)

	Total Group	Group 1	Group 3	Total Group	Group 1	Group 3
		Quadrant 3			Quadrant 4	
			Moment (Nm)			
Mean	94.97	106.00	83.94	-21.13	-27.18	-15.08
SD	25.88	16.67	30.42	21.09	26.15	15.03
Min	50.80	85.50	50.80	-50.10	-50.10	-26.40
Max	124.70	124.70	124.40	17.00	17.00	11.20

+Normalized by body weight.
*$p < .10$, ** $p < .05$, ***$p < .01$.

Table D.19 Times of Occurrences of Joint Reaction Forces and Moments of the Shoulder Per Quadrant Expressed as Percents of Total Time

	Total Group	Group 1	Group 3	Total Group	Group 1	Group 3
	Quadrant 1			Quadrant 2		
	% Vertical Force					
Mean	10.06	11.00	9.12	54.79	56.80	52.74
SD	5.09	4.53	5.96	5.82	3.84	7.14
Min	1.20	3.60	1.20	44.20	53.20	44.20
Max	15.90	15.90	15.30	64.00	61.60	64.00
	% Horizontal Force					
Mean	41.08	43.30	38.86	46.63	49.36	43.90
SD	7.30	7.16	7.51	6.06	4.35	6.59
Min	32.20	36.20	32.20	38.60	44.80	36.60
Max	51.60	51.30	51.60	56.30	56.30	54.90
	% Moment					
**						
Mean	13.69	18.70	8.68	55.18	57.88	52.48
SD	7.81	7.40	4.48	6.61	4.90	7.50
Min	4.70	9.70	4.70	44.50	52.00	44.50
Max	28.50	28.50	15.30	64.40	64.00	64.40
	Quadrant 3			Quadrant 4		
	% Vertical Force					
Mean	58.29	59.46	57.12	91.99	89.72	94.26
SD	3.96	3.75	4.22	4.74	2.38	5.66
Min	54.00	55.60	54.00	86.80	88.10	86.80
Max	64.80	64.80	64.40	98.70	93.90	98.70
	% Horizontal Force					
Mean	68.95	71.16	66.74	78.70	79.08	78.32
SD	6.20	4.09	7.58	7.80	6.33	10.15
Min	57.10	65.80	57.10	64.80	73.50	64.80
Max	77.80	77.10	77.80	90.50	90.00	90.50

Table D.19 (Continued)

	Total Group	Group 1	Group 3	Total Group	Group 1	Group 3
	Quadrant 3			Quadrant 4		
% Moment						
Mean	57.83	59.56	59.10	92.11	91.90	92.32
SD	4.85	3.73	5.61	5.41	2.62	5.41
Min	48.90	55.60	48.90	82.80	88.80	82.80
Max	64.80	64.90	64.40	98.80	94.40	98.80

*p < .10, ** p < .05, ***p < .01.

Table D.20 Joint Reaction Forces and Moments of the Elbow Per Quadrant

	Total Group	Group 1	Group 3	Total Group	Group 1	Group 3
	Quadrant 1			Quadrant 2		
	Vertical Force+					
Mean	-0.31	-0.12	-0.49	-1.57	-1.16	-1.98
SD	0.47	0.63	0.07	1.33	1.89	0.04
Min	-0.63	-0.63	-0.58	-2.09	-2.09	-2.02
Max	0.58	0.58	-0.43	2.22	2.22	-1.94
	Horizontal Force+					
Mean	-0.42	-0.23	-0.61	-0.72	-0.24	-1.21
SD	0.39	0.48	0.14	1.10	1.46	0.11
Min	-0.76	-.54	-0.76	-1.44	-1.44	-1.39
Max	0.62	0.62	-0.46	1.36	-1.11	-1.11
	Moment (Nm)					
Mean	-8.78	-11.62	-5.95	-54.90	-38.89	-69.31
SD	17.64	23.03	12.23	55.27	76.76	20.03
Min	-32.20	-32.20	-17.35	-97.80	-85.99	-97.80
Max	27.89	27.89	7.47	96.80	96.80	-53.16
	Quadrant 3			Quadrant 4		
	Vertical Force+					
				**		
Mean	-1.48	-1.10	-1.85	-0.53	-0.49	-0.57
SD	1.18	1.66	0.13	0.06	0.05	0.02
Min	-2.05	-2.05	-2.01	-0.60	-0.54	-0.60
Max	1.86	1.86	-1.72	-0.41	-0.41	-0.55
	Horizontal Force+					
Mean	0.90	0.95	0.86	0.43	0.48	0.39
SD	0.10	0.11	0.07	0.42	0.49	0.39
Min	0.78	0.78	0.79	-0.37	-0.37	-0.30
Max	1.08	0.97	1.08	0.80	0.80	0.82

Table D.20 (Continued)

	Total Group	Group 1	Group 3	Total Group	Group 1	Group 3
	Quadrant 3			Quadrant 4		
	Moment (Nm)					
Mean	26.03	31.69	20.36	8.83	8.85	9.10
SD	9.56	6.57	9.07	12.71	14.48	12.39
Min	9.10	23.39	9.10	-14.88	-14.88	-10.00
Max	40.66	40.66	30.59	23.43	23.43	22.06

+ Normalized by body weight.
$^{*}p < .10$, $^{**}p < .05$, $^{***}p < .01$.

Table D.21 Times of Occurrences of Joint Reaction Forces and Moments of the Elbow Per Quadrant Expressed as Percents of Total Time

	Total	Group 1	Group 3	Total	Group 1	Group 3
		Quadrant 1			Quadrant 2	
			% Vertical Force			
*						
Mean	9.28	11.76	4.80	55.42	57.32	53.52
SD	6.03	5.36	4.77	6.14	3.79	7.84
Min	.50	3.10	.50	45.10	53.20	45.10
Max	16.90	1.90	12.10	66.40	61.60	66.40
			% Horizontal Force			
Mean	40.69	42.90	38.48	47.11	50.20	44.02
SD	6.67	6.50	6.76	6.27	4.46	6.68
Min	32.20	36.20	32.20	39.10	45.80	39.10
Max	50.70	50.70	49.80	56.00	56.00	55.10
			% Moments			
Mean	21.57	18.96	24.18	49.64	51.74	47.54
SD	11.79	12.14	12.18	5.79	5.62	5.73
Min	1.50	1.50	8.10	40.80	46.80	40.80
Max	34.90	33.50	34.90	58.50	58.50	56.60
		Quadrant 3			Quadrant 4	
			% Vertical Force			
Mean	57.74	60.08	55.40	93.33	92.52	94.14
SD	5.16	4.40	5.19	4.92	3.48	6.39
Min	48.50	55.60	48.50	86.20	89.30	86.20
Max	64.80	64.80	63.00	99.90	97.30	99.90
			% Horizontal Force			
*						
Mean	69.39	72.44	66.34	77.76	79.90	75.62
SD	5.74	3.55	6.20	7.70	5.46	9.59
Min	57.10	69.40	57.10	64.40	74.50	64.40
Max	77.80	77.80	73.60	90.50	88.60	90.50

Table D.21 (Continued)

	Total	Group 1	Group 3	Total	Group 1	Group 3
	Quadrant 3			Quadrant 4		
			% Moment			
**						
Mean	68.28	70.12	62.44	81.79	82.00	81.50
SD	5.59	2.45	5.24	9.68	8.32	11.90
Min	56.20	68.20	56.20	72.50	76.30	72.50
Max	73.80	73.80	69.10	99.40	96.50	99.40

*p < .10, ** p < .05, ***p < .01.

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