A Cinematographic and Comparative Analysis of National Class Gymnasts Performing Selected Skills on the Horizontal Bar.

Gerald Stephen George

Louisiana State University and Agricultural & Mechanical College

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A CINEMATOGRAPHIC AND COMPARATIVE ANALYSIS OF NATIONAL CLASS GYMNASTS PERFORMING SELECTED SKILLS ON THE HORIZONTAL BAR

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Health, Physical and Recreation Education

by

Gerald S. George
B.S., Louisiana State University, 1966
M.S., Springfield College, 1967
August, 1970
Dedicated to the memory of my father

Ellis G. George, Sr.
ACKNOWLEDGMENTS

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TABLE OF CONTENTS

ACKNOWLEDGMENTS ........................................................... iii
LIST OF TABLES ................................................................. vi
LIST OF COMPOSITE GRAPHS .................................................. viii
LIST OF FIGURES ................................................................. x
ABSTRACT ................................................................................ xi

CHAPTER I

I. INTRODUCTION ................................................................. 1
   Statement of the Problem .................................................. 4
   Purpose of the Study ....................................................... 5
   Definition of Terms ......................................................... 6
   Limitations of the Study .................................................. 13
   Delimitations of the Study ................................................. 14
   Assumptions of the Study ................................................ 15
   Significance of the Study ................................................ 15

II. REVIEW OF THE LITERATURE .............................................. 17
   Literature Related to the Historical Development of
   Cinematography as an Aid to Physical Education Research ....... 17
   Books and Articles Relating Mechanical Principles to Gymnastic
   Activities ................................................................. 24
   Studies Related to Cinematographic Research in the Area of
   Gymnastics ................................................................ 31

III. PROCEDURE FOR THE STUDY ........................................... 39
   Introduction .................................................................. 39
<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection of Subjects</td>
<td>42</td>
</tr>
<tr>
<td>Materials</td>
<td>42</td>
</tr>
<tr>
<td>Reference Points</td>
<td>44</td>
</tr>
<tr>
<td>Cinematographic Procedures</td>
<td>46</td>
</tr>
<tr>
<td>Recording Procedures</td>
<td>47</td>
</tr>
<tr>
<td>Cinematographic and Comparative Analysis</td>
<td>51</td>
</tr>
<tr>
<td>IV. PRESENTATION AND ANALYSIS OF DATA</td>
<td>53</td>
</tr>
<tr>
<td>Undergrip Giant Swing</td>
<td>53</td>
</tr>
<tr>
<td>Inlocated Undergrip Giant Swing</td>
<td>68</td>
</tr>
<tr>
<td>Overgrip Giant Swing</td>
<td>84</td>
</tr>
<tr>
<td>Inlocated Overgrip Giant Swing</td>
<td>99</td>
</tr>
<tr>
<td>V. SUMMARY, FINDINGS, DISCUSSION OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS</td>
<td>115</td>
</tr>
<tr>
<td>Summary</td>
<td>115</td>
</tr>
<tr>
<td>Findings</td>
<td>118</td>
</tr>
<tr>
<td>Discussion of Findings</td>
<td>130</td>
</tr>
<tr>
<td>Conclusions</td>
<td>131</td>
</tr>
<tr>
<td>Recommendations</td>
<td>132</td>
</tr>
<tr>
<td>SELECTED BIBLIOGRAPHY</td>
<td>133</td>
</tr>
<tr>
<td>VITA</td>
<td>138</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Subjects and Order of Analysis</td>
<td>42</td>
</tr>
<tr>
<td>II. Total Body Weight of Each Subject</td>
<td>44</td>
</tr>
<tr>
<td>III. Mathematical Computations for the Center of Gravity of Subject A Performing the Undergrip Giant Swing</td>
<td>64</td>
</tr>
<tr>
<td>IV. Mathematical Computations for the Center of Gravity of Subject B Performing the Undergrip Giant Swing</td>
<td>65</td>
</tr>
<tr>
<td>V. Mathematical Computations for the Center of Gravity of Subject C Performing the Undergrip Giant Swing</td>
<td>66</td>
</tr>
<tr>
<td>VI. Mathematical Computations for the Center of Gravity of Subject D Performing the Undergrip Giant Swing</td>
<td>67</td>
</tr>
<tr>
<td>VII. Mathematical Computations for the Center of Gravity of Subject A Performing the Inlocated Undergrip Giant Swing</td>
<td>79</td>
</tr>
<tr>
<td>VIII. Mathematical Computation for the Center of Gravity of Subject B Performing the Inlocated Undergrip Giant Swing</td>
<td>80</td>
</tr>
<tr>
<td>IX. Mathematical Computations for the Center of Gravity of Subject C Performing the Inlocated Undergrip Giant Swing</td>
<td>81</td>
</tr>
<tr>
<td>X. Mathematical Computations for the Center of Gravity of Subject D Performing the Inlocated Undergrip Giant Swing</td>
<td>82</td>
</tr>
<tr>
<td>XI. Mathematical Computations for the Center of Gravity of Subject A Performing the Overgrip Giant Swing</td>
<td>94</td>
</tr>
<tr>
<td>XII. Mathematical Computations for the Center of Gravity of Subject B Performing the Overgrip Giant Swing</td>
<td>95</td>
</tr>
<tr>
<td>TABLE</td>
<td>Mathematical Computations for the Center of Gravity of Subject C Performing the Overgrip Giant Swing</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>XIII.</td>
<td></td>
</tr>
<tr>
<td>XIV.</td>
<td></td>
</tr>
<tr>
<td>XV.</td>
<td></td>
</tr>
<tr>
<td>XVI.</td>
<td></td>
</tr>
<tr>
<td>XVII.</td>
<td></td>
</tr>
<tr>
<td>XVIII.</td>
<td></td>
</tr>
<tr>
<td>XIX.</td>
<td>Summary of Mathematical Findings of Four Expert Gymnasts Performing Four Giant Swing Skills on the Horizontal Bar</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>COMPOSITE GRAPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing</td>
</tr>
<tr>
<td>2. Shoulder Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing</td>
</tr>
<tr>
<td>3. Hip Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing</td>
</tr>
<tr>
<td>4. Ankle Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing</td>
</tr>
<tr>
<td>5. Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Undergrip Giant Swing</td>
</tr>
<tr>
<td>6. Shoulder Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Undergrip Giant Swing</td>
</tr>
<tr>
<td>7. Hip Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Undergrip Giant Swing</td>
</tr>
<tr>
<td>8. Ankle Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Undergrip Giant Swing</td>
</tr>
<tr>
<td>9. Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing</td>
</tr>
<tr>
<td>10. Shoulder Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing</td>
</tr>
</tbody>
</table>

PAGE

57
59
60
62
72
74
76
77
87
89
<table>
<thead>
<tr>
<th>COMPOSITE GRAPH</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Hip Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing</td>
<td>90</td>
</tr>
<tr>
<td>12. Ankle Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing</td>
<td>92</td>
</tr>
<tr>
<td>13. Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Overgrip Giant Swing</td>
<td>103</td>
</tr>
<tr>
<td>14. Shoulder Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Overgrip Giant Swing</td>
<td>104</td>
</tr>
<tr>
<td>15. Hip Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Overgrip Giant Swing</td>
<td>106</td>
</tr>
<tr>
<td>16. Ankle Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Overgrip Giant Swing</td>
<td>107</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pictorial Illustration of the Undergrip Giant Swing</td>
<td>8</td>
</tr>
<tr>
<td>2. Pictorial Illustration of the Inlocated Undergrip Giant Swing</td>
<td>9</td>
</tr>
<tr>
<td>3. Pictorial Illustration of the Overgrip Giant Swing</td>
<td>10</td>
</tr>
<tr>
<td>4. Pictorial Illustration of the Inlocated Overgrip Giant Swing</td>
<td>11</td>
</tr>
<tr>
<td>5. Cinematographic Presentation of the Undergrip Giant Swing as Performed by an Expert Gymnast (Subject A)</td>
<td>54</td>
</tr>
<tr>
<td>6. Cinematographic Presentation of the Inlocated Undergrip Giant Swing as Performed by an Expert Gymnast (Subject A)</td>
<td>70</td>
</tr>
<tr>
<td>7. Cinematographic Presentation of the Overgrip Giant Swing as Performed by an Expert Gymnast (Subject A)</td>
<td>85</td>
</tr>
<tr>
<td>8. Cinematographic Presentation of the Inlocated Overgrip Giant Swing as Performed by an Expert Gymnast (Subject A)</td>
<td>100</td>
</tr>
</tbody>
</table>
ABSTRACT

The main purpose of this investigation was to analyze and compare four mechanically different giant swing skills, each of which was performed on the horizontal bar by four selected national class gymnasts. The sub-purposes attempted to mathematically describe the activity of each subject's center of gravity relative to its radius of rotation, centripetal force, angular velocity, and angular acceleration in order to extract those qualities indicative of highly skilled execution.

The four mechanically different giant swing skills that provided the test data were the: (1) Undergrip Giant Swing; (2) Inlocated Undergrip Giant Swing; (3) Overgrip Giant Swing; and the (4) Inlocated Overgrip Giant Swing. The cinematographic method was employed to obtain the necessary data for the analyses and comparisons.

The center of gravity, shoulder, hip, and ankle trajectory paths for each subject in each of the four selected giant swing skills were plotted on separate polar-coordinate graphs. Upon compilation of these graphs, composite graphs for each skill were constructed
so that specific points of reference common to each subject were compared in terms of their trajectory paths.

The cinematographic analysis consisted of descriptive explanations based upon the composite graphs. Sequence-overlay presentations of those positions pertinent to an understanding of each skill was provided in order to allow both for visual observation of the relevant changes in the shoulder and hip angles and for further clarification of the verbal description of the analysis.

By superimposing the center of gravity paths of each subject on composite graphs, the techniques employed in each skill were compared in terms of general trajectory pattern. The trajectory paths for the shoulder, hip, and ankle reference points were also superimposed upon their respective composite graphs. These graphs were utilized to further compare and explain the cumulative effect of segmental body variations upon their respective centers of gravity.

An additional procedure utilized in the comparative analysis consisted of the construction of tables depicting the following pertinent computations: (1) the degrees of circular rotation realized by the center of gravity every ten frames; (2) the distance of the center of gravity to the horizontal bar every tenth frame; (3) the distance traveled by the center
of gravity every tenth frame; (4) the angular velocity of the center of gravity every tenth frame; (5) the incremental angular acceleration of the center of gravity every tenth frame; and (6) the centripetal force realized by the center of gravity every tenth frame. These computations served not only to fulfill the sub-purposes of the study, but also to reveal, in mathematical terms, the total activity for each subject's center of gravity throughout each of the four giant swing skills.

Based upon the findings, the limitations and the basic assumptions of the study, these conclusions were derived:

1. Highly skilled performers utilized similar, and often times identical, motor movement patterns in the execution of the four selected giant swing skills.

2. The shortening of the radius of rotation in order to increase the angular velocity in performing the selected giant swing skills was accomplished, in every instance, by changes in two basic angles: (1) the shoulder articulation; and (2) the hip articulation.

3. Since the timing factor relative to when the actual shortening of the radius of rotation occurred was not consistent among subjects in any of the selected giant swing skills, a specific point within the respective circular swings could not be determined.
4. Since the amount the radius of rotation was shortened in order to successfully complete the given skill was not consistent among subjects, a specific, ideal amount within the respective circular swings could not be determined.
INTRODUCTION

Ever since the beginning of time man has sought to identify and explain observable movement. The human eye, characterized by perspective error, lends interesting, and often times controversial, findings to movement in the applied form. Even in the light of current scientific techniques, explanations and mechanical analyses for any given motor skill appear to vary significantly from text to text. This has typically been the case in the area of gymnastic skill analysis.

One needs only to review current gymnastic texts and manuals to realize this fact. Kunzle's book on horizontal bar provides a notable example. This text contains stop-action photographs of gymnastic champions performing many of the giant swing skill variations. These photographs, together with explanations based upon observation and experimentation, have proven to be quite popular in the gymnastic world. In all of the giant swing skills, Kunzle stressed maintaining as straight a

body line as is appropriate with the skill-in-question, keeping the body fully extended throughout the bottom of the swing, and decreasing primarily the hip angle on the upswing.

Somewhat controversial viewpoints have been found in books written by Takemoto\(^2,3\) of Japan. Progressive stop-action photographs of top performers from Japan, Russia, Finland, and the United States provide the readers with an in-depth coverage of the mechanical techniques involved in performing a large majority of the standard gymnastic skills in all events. These photographs are depicted from both the front and the side view. This approach, in addition to tracing the trajectory of the center of gravity in various selected horizontal bar skills, has proved to be very informative from the mechanical analysis point of view. Takemoto agreed with Kunzle regarding the maintenance of a straight body line where appropriate. However, he felt that the body does not remain extended throughout the bottom of the swing and that a decreasing shoulder angle


is a more important factor for upward momentum than hip angle decrement on both the overgrip and undergrip giant swings.

In a text written by Bunn, several horizontal bar illustrations were employed as examples of applied mechanical principles. The analysis of the forward giant swing depicted the body in an arched position initially and in a decreased shoulder angle position on the upswing.

Johnson's text on beginning gymnastic skills dealt, in part, with general mechanical descriptions of basic horizontal bar skills. Although progressive illustrations were utilized to clarify these descriptions, the extremely arched body line indicated another technique in the execution of giant swing skills.

A comprehensive book dealing with most of the major aspects in physical education gymnastics was recently written by Loken and Willoughby. In addition to covering most of the popular skills in all events for both men's and women's gymnastics, the authors elaborated upon such areas as values of gymnastics, organization,


area, equipment, teaching methods, safety, and programs of instruction. Pictorial progressive illustrations of giant swing skills were presented to clarify mechanical procedures. Further controversy can be found regarding mechanics of giant swing skills in the statement:

Remember not to kip or pull with the arms too soon, but instead wait for the moment when the body has almost reached the peak of the backward swing, then pull it toward the bar and allow the shoulders and head to shift over the bar to swing upward in the handstand position.

Exacting application of mechanical principles to these skills seems to be further removed in that both Takemoto and Kunzle take separate and different views on the very same skills.

Such discrepancies relative to the technical and mechanical explanations of human motor skills inevitably lend themselves to scientific investigation. A control and study of those factors specifically relevant to giant swing skills on the horizontal bar will increase both the scope and breadth of applied human mechanics and hopefully will shed light upon the stated controversies regarding the "what" and the "how" of basic giant swings.

I. STATEMENT OF THE PROBLEM

The problem of this investigation centered about an analysis and comparison of four mechanically different
giant swing skills, each of which was performed on the horizontal bar by four selected national class gymnasts. The cinematographic method was employed to obtain the necessary raw data for the analyses and comparisons.

The four mechanically different giant swing skills that served as the test data were: (1) The Undergrip Giant Swing; (2) The Inlocated Undergrip Giant Swing; (3) The Overgrip Giant Swing; and (4) The Inlocated Overgrip Giant Swing. A pictorial illustration and corresponding explanation for each of these gymnastic skills were included in the 'Definition of Terms' section of this chapter.

II. PURPOSE OF THE STUDY

The purpose of the study was to analyze and compare by means of cinematography four mechanically different giant swing skills and in each instance to apply the following five sub-purposes in order to extract those qualities indicative of highly skilled execution.

1. To determine the change in the radius of rotation of each subject in each of the four giant swing skills.

2. To determine the change in centripetal force realized by each subject in each of the four giant swing skills.
3. To determine the change in angular velocity realized by each subject in each of the four giant swing skills.

4. To determine the change in incremental angular acceleration realized by each subject in each of the four giant swing skills.

5. To determine the change in the elbow angle realized by each subject in each of the four giant swing skills.

III. DEFINITION OF TERMS

In order to facilitate a better understanding of the study, the following definition of terms have been provided.

**Cinematography.** Cinematography is motion picture photography in which a set of controls have been employed in order to reduce many of its inherent variables. A reduction in the number of such photographic variables serves to increase the reliability of the analysis.

**Giant swing.** A giant swing is a common gymnastic term used to identify those anatomical movements that enable a suspended body to circle a full 360 degrees about a horizontal bar.

**Undergrip giant swing.** The undergrip giant swing is a gymnastic skill performed on the horizontal bar with the subject in an undergrip handstand position.
Refer to Figure 1 on page 8.

**Inlocated undergrip giant swing.** The inlocated undergrip giant swing is a gymnastic skill performed on the horizontal bar in which the subject assumes an undergrip handstand position with his shoulder articulations in full anatomical hyperextension. Refer to Figure 2 on page 9.

**Overgrip giant swing.** The overgrip giant swing is a gymnastic skill performed on the horizontal bar with the subject in an overgrip handstand position. Refer to Figure 3 on page 10.

**Inlocated overgrip giant swing.** The inlocated overgrip giant swing is a gymnastic skill performed on the horizontal bar in which the subject assumes an overgrip handstand position with his shoulder articulations in full anatomical hyperextension. Refer to Figure 4 on page 11.

**Vertical axis.** A vertical axis is a point of reference in the field of view which is representative of the vertical plane.

**Horizontal axis.** A horizontal axis is a point of reference in the field of view which is representative of the horizontal plane.
Enlarged View of the Undergrip Handgrasp

Figure 1. Pictorial Illustration of the Undergrip Giant Swing.
Enlarged View of the Undergrip Handgasp

Figure 2. Pictorial Illustration of the Inlocated Undergrip Giant Swing.
Enlarged View of the Overgrip Handgrasp

Figure 3. Pictorial Illustration of the Overgrip Giant Swing.
Figure 4. Pictorial Illustration of the Inlocated Over-grip Giant Swing.
Radius of rotation.\(^7\) The radius of rotation is the distance from the axis of rotation to the point at which the entire mass of the rotating body can be considered concentrated to give the same inertial reaction.

Centripetal force.\(^8\) Centripetal force is that force which is directed toward the center of rotation.

Angular velocity.\(^9\) Angular velocity refers to the rate of change of position of a body about some point as a center of rotation.

Acceleration.\(^10\) Acceleration is the rate of change in velocity. It may or may not be uniform and it may be positive or negative.

Gravitational acceleration.\(^11\) Gravitational acceleration refers to a fixed value of acceleration for any air-borne body. Careful experiments have fixed the value of acceleration of gravity at 32.16 feet per second at sea level in the latitude of New York City.


\(^8\)Bunn, op. cit., p. 54.

\(^9\)Ibid., p. 22.

\(^10\)Ibid., p. 23.

The formula for the law of falling bodies states that the distance traveled is equal to one-half of the standard value of acceleration of gravity (32.16 feet per second per second) multiplied by the time in seconds squared.

Center of gravity. The center of gravity of a body is that point at which the effective weight of the body is centered. It is that point which the whole mass may be considered as concentrated for purposes of computing the moment of the gravitational forces about any axis.

IV. LIMITATIONS OF THE STUDY

This investigation was characterized by the following limitations:

1. Only the analyses and comparisons of the four giant swing skills themselves were considered in the study. Hence the mechanical techniques for any of the transitional skills were not considered.

2. Motivational factors affecting the quality of performance were not considered. The investigator, however, made every attempt to equally motivate each

\[ \text{Bunn, op. cit., p. 5.} \]
of the four subjects to give a quality performance for each of the four selected skills.

3. The coefficient of friction relative to the handgrasp of each subject was not considered.

V. DELIMITATIONS OF THE STUDY

This investigation was characterized by the following delimitations:

1. The subjects selected for this study were delimited to four current United States national class gymnasts.

2. The study was delimited to four cinemographic film sequences of the four selected skills performed by each of the four subjects.

3. The four skills utilized in the cinemographic and comparative analyses were: (1) The Undergrip Giant Swing; (2) The Inlocated Undergrip Giant Swing; (3) The Overgrip Giant Swing; and (4) The Inlocated Overgrip Giant Swing.

4. Only the best performance for each of the four subjects in each of the four skills was considered as the raw data. Selection of the best performance in each instance was based upon a panel of gymnastic experts using the standard 1970 Federation of International Gymnastics (F.I.G.) Rating Scale as the norm.
VI. ASSUMPTIONS OF THE STUDY

For purposes of the study, it was assumed that:

1. Cinematography was a reasonably valid and reliable method for obtaining the necessary kinesiological data.

2. The motion pictures were taken under good environmental conditions.

3. The four subjects were sufficiently motivated to produce their best performance in each of the four skills.

4. Each of the four skills were representative of a performance typical to each of the four subjects.

VII. SIGNIFICANCE OF THE STUDY

This investigation provided a logical analysis and comparison of the mechanics and techniques used in performing the four selected skills on the horizontal bar. It was believed that studies of this nature not only broaden the existing concepts in kinesiology, but also that they encourage a desire for deeper investigation in those spheres of physical education that lend themselves to science.

The investigator believed that cinematographic techniques help to establish more concrete relationships between the laws of physics and human movement. It
was further felt that such studies serve as an invaluable aid to performers, coaches, and educators in understanding both "how" these skills are executed and "why" they are executed in a specific way.

Through science a more meaningful appreciation and realization of the discipline of gymnastics and the field of physical education can be engendered. It was hoped that this investigation could serve as a source and/or reference for students utilizing cinematography as a tool in the analysis of human movement.
CHAPTER II

REVIEW OF THE LITERATURE

For the purpose of clarity and organization, the review of literature presented in this chapter was divided into the following three categories: (1) literature related to the historical development of cinematography as an aid to physical education research; (2) books and articles relating mechanical principles to gymnastic activities; and (3) studies related to cinematographic research in the area of gymnastics.

I. LITERATURE RELATED TO THE HISTORICAL DEVELOPMENT OF CINEMATOGRAPHY AS AN AID TO PHYSICAL EDUCATION RESEARCH

It was not until 1873 that the first experimental attempt was made to study animal movement. Eadweard Muybridge1 successfully conducted a study of the movement of a trotting horse to determine whether or not the horse had all four hooves off of the ground at the same time.

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A series of still cameras were appropriately placed so as to view the progressive leg movements of the horse. Since that time, innumerable studies have been conducted in the field of kinesiology.

Although human movement was cinematographically studied in the early 1900's, not until 1930 when Fenn made two studies of sprint running did many of the current photographic methods come to be realized. Of particular interest to Fenn were the energy factors and the center of gravity of the moving body. The subject, marked at the neck and waist for points of reference, ran behind a white lattice-work frame. This frame served as a reference point to measure distances accurately. Wooden balls were progressively dropped in front of a vertical scale for use as a time reference. Fenn reported that investigators using his methods could determine, almost without exception, angles on film within two degrees of the actual angle.

In 1939 Cureton published a review of elementary principles and techniques of cinematography. He stressed


4Cureton, op. cit., pp. 3-24.
the need for understanding physical principles in sports skills. Basic premises centered about the fact that dissection of movement, dimensions, time relations, and indirect values of force and velocity all could be studied by the projected film. McCloy \(^5\) also directed various research problems in motion picture analysis. He believed that further study was needed in the mechanics of movement, in the coordination of complex skill activities, in arm control, balance, and timing.

In the early forties Glassow \(^6\) discussed the use of motion pictures in research as a practical method for analysis. Included were suggestions for the use of:

1. clock measurement of time;
2. a known dimensional object in the field of vision;
3. angles;
4. identifying marks on the subject; and
5. a stationary check mark in the background as a guide to drawing successive movements.

Regna \(^7\) and White \(^8\) used motion picture analysis to study elements of horseback riding. Regna concentrated...
upon the relative body position and joint movements occurring as a result of adjustments to variations in gait. He traced selected body positions to measure pelvic displacement, rise from the saddle, and shoulder and leg movements. Various body marks were suggested as aids in measurement. When White conducted his experiment the following year, jointed bars were strapped to the rider to aid in determining knee and hip joint actions. White recommended that spots be marked so as to be consistent in the two sets of pictures.

Francis\(^9\) made a mechanical analysis study of the shot put in 1948. Six body spots were noted on each of the eight subjects. By use of the data secured from the motion pictures, Francis measured the distances between the respective dots every sixth frame in order to compute velocities and accelerations.

In recent years, the cinematographic method has been applied to many sports skills, with the principles of movement becoming more clearly defined as a result. In a study which presented improved techniques for a more critical analysis of motion pictures, Hanson\(^{10}\)

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developed a device which would make possible the computation of body movements in any given plane of motion as seen by the camera. Utilized in the study were techniques involving descriptive geometry, plane trigonometry, and spherical trigonometry.

Certain techniques which have proven to be quite effective in analysis are: (1) microfilm viewing; (2) tracings from projected films of various sports; (3) overlays; and (4) line and dot approximations of body segments. Lanoue\textsuperscript{11} used the tracing technique effectively in his analysis of selected fancy diving skills. In 1957 Verwey\textsuperscript{12} used a similar method to analyze several types of softball pitches. Bartkowiak\textsuperscript{13} presented a major portion of his study of selected wrestling positions in the form of tracings. Schaefer\textsuperscript{14} utilized

\begin{itemize}
\item Fred Lanoue, "Analysis of the Basic Factors Involved in Fancy Diving," \textit{Research Quarterly}, XI (March, 1940), pp. 102-09.
\end{itemize}
polar graphs to analyze the body movements of a giant circle on the horizontal bar. In addition, Schaefer presented various methods of analyzing body movements which will readily apply to the majority of gymnastic skills.

Whitmore's technique for collecting data was interesting in that an overhead camera and a side view camera were employed simultaneously for obtaining out-of-door pictures of discus throwers. The relationship of the top and side views served to reveal a further innovation in cinematographical analysis.

More recent techniques for securing kinesiological data included techniques of electromyography, electrogoniometry, and stroboscopic photography. Plagenhoef discussed the advantages and disadvantages of each technique and concluded:

The use of motion pictures is probably the best single technique for obtaining kinetic and kinematic data related to whole body motion. In addition, the use of computers has put detailed mechanical analysis within the realm of practicality.

In addition to the utilization of computer analysis for quick, intricate human movement, there have


been some recent innovations dealing with the measurement of time lapse per unit of film. Blievernicht's research dealt with various methods for securing more accurate time measures for camera calibration and film analysis. He devised the Conical Timer as a multi-dimensional timing device for cinematography.

The most recent research in the area of cinematography has been conducted by Purdy. Many of the important techniques used in still and motion picture photography were summarized as follows:

1. To arrest motion, one must reduce the image blur on film to a point where it cannot be seen upon enlargement.

2. Shutter speeds of 1/1000th of a second should be used to arrest a body and limb movement with a 35 millimeter still picture camera.

3. Single flash exposures of extremely short duration (1/40,000) are necessary to stop clubs or balls traveling at velocities in excess of 100 feet per second.

4. Multiple flash strobographic photography is the proper technique to use for multiple images on a single negative.

5. Latent grid printing is an effective way to link space to time without the use of active background grids.

6. Copy work should be done by an auxiliary device attached to the camera.

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7. Photographs should be printed on Kodabromide Type A enlarging paper for inclusion in studies which present photographs in the body of the work.

8. If positive prints are not needed, 8 millimeter film may be used in analytical studies.

9. Chronocyclography is a useful technique in securing light tracings of certain points on the body of the subject.

10. The 16 millimeter camera becomes a good analytical tool if the framing rate of the camera is established.

11. In order to get negatives for producing selected positive prints, the shutter speed of the motion picture camera must freeze the motion of the subject.

12. A variable shutter should be used if faster shutter speeds than the normal open shutter are needed.

13. To study activities which involve striking actions, it is helpful to use a cine' camera with a framing rate of 200 frames per second.

II. BOOKS AND ARTICLES RELATING MECHANICAL PRINCIPLES TO GYMNASIC ACTIVITIES

An overview of the review indicated that authors of books and articles relating mechanical principles to gymnastic activities emphasized various, and often times controversial, concepts in their presentations. While the basic scientific principles of human motor movement were commonly agreed upon, it appeared that their specific application to many of the sports' activities has been, and still is, in the process of critical review. The
general trend, however, seemed to indicate that these scientific principles are now being "scientifically applied" with an ever-increasing exactness to all motor movement activities. This horizontal expansion of the scientific method is the very essence of new-found knowledge.

Most of the earlier gymnastic texts emphasized elements of fitness moreso than attainment of skill levels. A notable example can be found in a book written by Zwarg\textsuperscript{19} in 1928. He listed, illustrated and explained, in layman's terms, basic hold and swing moves on the side horse and horizontal bar. Various tumbling exercises were noted and explained from a fitness point of view.

In a more recent text, Dyson\textsuperscript{20} employed a number of gymnastic examples in his discussion on the mechanics of athletics. A relevant example was found in the application of selected principles of angular velocity to the basic overgrip giant swing as performed on the horizontal bar. Dyson related two basic principles of angular velocity in the following statements:

I. To turn an object, force must be exerted at a distance to its axis, and the greater the distance, the greater


will be the rotational or spinning effect. But it is important to note that the distance from the line of action of the force to the axis - the lever arm, as it is called - must be measured along the perpendicular, i.e., at right angles to the direction of force.

II. A larger force will produce a greater turning effect.

Dyson believed that, in horizontal bar exercises, the turning effect of the force of gravity is greater when the body is exactly horizontal and diminishes progressively as the body assumes a more vertical position. He also felt that a change in body position during the swing serves to increase or decrease, as the case may be, the lever arm and thereby influence the rate of speed of the swing.

A stop-action sequence of a gymnast performing a backward somersault in tumbling can be found in a text written by Rasch and Burke.21 Although this single photographic series was presented in order to demonstrate certain applied principles of angular and curvilinear motion, many of the involved lever actions in the body were similar to those of the basic overgrip and undergrip giant swings.

A section on mechanical principles as applied to tumbling activities has been included in a text written by Balev. He related that tumbling is the foundation of all gymnastic activities and demonstrated, through the use of mechanical principles applied to illustrated drawings, that tumbling encompasses all of the core body movements characteristic of gymnastic skills en toto. Although the majority of the mechanical principles were employed in some form or another, their application was rather general in that specific skills were not separately considered.

Musker presented a teacher's text for gymnastics in the broad sense. His section on the mechanics of gymnastics dealt primarily with explaining "how" the basic skills in all events can be taught. Mechanical principles applied to specific skills were not emphasized.

Mechanical techniques of giant swing skills have been discussed in a text written by Cooper and Glassow. In analyzing arm supported swinging movements on the horizontal bar, the authors stated:

On the downswing, the skilled performer will move the body's center of gravity as far as possible from the center of rotation;


this is done by full hip extension and shoulder girdle elevation. On the upswing, he will move the center of gravity toward the center of rotation by hip flexion and shoulder girdle depression.

Hip flexion and shoulder girdle depression were considered to be the prime factors in maintaining upward momentum. Discussion relative to which of the above actions occurs first, if not simultaneously, was not considered. In addition, no mention was made concerning the degree and relative importance of specific body angle variations.

In the early 1960's, Tonry initiated a continuing series of articles dealing with pictorial illustrations of selected parallel bar skills. Since that time, the series has expanded to encompass selected skills on the side horse and still rings events. In each of the skill sequences, those mechanical techniques essential to successful performance were emphasized.

Another series of articles dealing with mechanical analysis of basic gymnastic skills has been presented by Bosco. The majority of these articles were based upon actual scientific studies. Several procedures in


cinematography and film analysis were presented in the light of their contribution to obtaining valid and reliable data. In addition, selected skills in most of the gymnastic events were mechanically analyzed from the scientific point of view.

George published a continuing series of articles dealing with cinematographic illustrations of selected horizontal bar skills. In those articles dealing with the four major giant swing skills, the progressive cinematographic illustrations were presented from a strictly mechanical analysis point of view. The following list was found to be characteristic of all giant swing skills:

1. At the onset of the skill, the center of gravity of the body is kept as far away from the point of support as is anatomically possible.


2. During the initial phase of the descent, the distance of the body's center of gravity from the bar should be steadfastly maintained.

3. In the final phase of the descent, there is a light, yet observable, hip angle decrement.

4. The feet trail the hips during the lowest vertical point in the swing.

5. The hips extend immediately after transcending the lowest vertical point in the swing.

6. In the initial phase of the ascent, a slight, yet observable, hip angle decrement again occurs.

7. During the final phase of the ascent, the hip and shoulder angles begin to assume positions characteristic to the nature of the giant swing in-question.

In summarizing those books and articles that relate mechanical principles to gymnastic activities, the investigator found the following to be true: (1) there was common agreement regarding the specific mechanical principles that related to gymnastic skills; (2) widely differing opinions were held concerning the "application" of these accepted mechanical principles to gymnastic activities; and (3) many of the current gymnastic books and articles tended to generalize principles of body mechanics to a point where specific application became quite difficult.
There have been a number of studies related to cinematographic research in the area of gymnastics. As early as 1939, Cureton demonstrated the techniques of cinematography in the analysis of a giant swing forward on the horizontal bar. A single subject weighing 160 pounds and measuring 5 feet 9 inches tall was used in the analysis. The distance from handgrasp on the bar to the toes measured 79 inches. A tracing was made of the body position at various points during the giant swing, using a slow motion film of the execution. A data sheet was compiled depicting the number of positions, the relative time, velocity, and force of these positions. Both the camera and the projection were calibrated to facilitate accurate analysis.

Seven young men in a physical education major's curriculum were used as subjects for a study conducted by Harris. Various formulae, charts, diagrams and graphs were used to determine which subject most proficiently performed an upstart on the high horizontal bar.

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Again the principles and techniques of cinematography were utilized as the method of collecting and analyzing the data.

Five national horizontal bar competitors were used as subjects in a study conducted by Runkle. A 35 millimeter camera, exposing film at the rate of 48 frames per second, recorded each gymnast performing the overgrip flyaway. Strict cinematographic controls were followed in order to insure more reliable findings. The downswing, the upswing, the release, the turn, the arm action, and the landing were treated separately in the analysis.

Lundien used two male and two female tumblers in his analysis of the backward somersault. Critical frames from selected sequences were enlarged and printed in an ordered progression so that a representative performance of each subject could be presented. Measurements of the relevant angles, heights, and distances were made by projecting the 35 millimeter film directly onto paper mounted on a screen, tracing the pictures, and then measuring directly from the tracings. The


investigator was primarily concerned with analyzing the actual take-off, the movement of the knees, arms, and head and the trajectory of the respective centers of gravity.

A full twisting backward somersault on the trampoline served as the cinematographic data in a study conducted by Moorse. Separate 35 millimeter cameras were placed in the three fields of view, i.e., front, side and top. The subject performed the skill under various conditions. The first full twist sequence was done without any part of the body immobilized. In the second and third sequences, the neck region and the trunk region respectively were immobilized in an effort to determine which body part, if any, contributed most to the performance of the skill. Tracing paper was placed directly on the screen and pencil tracings were made of each seventh frame. Eleven key positions for each twist were illustrated.

Gustafson undertook a study in an effort to analyze, according to principles of mechanics, thirty-six competitive gymnastic skills that were performed on the


\[\text{\footnotesize \textsuperscript{36} William Frank Gustafson, "A Mechanical Analysis of Selected Gymnastics on the Horizontal Bar, the Parallel Bars, the Side Horse, the Still Rings, and the Swinging Rings," (unpublished Doctoral dissertation), The State University of Iowa, Ames, Iowa, 1955.}\]

horizontal bar, twenty-three on the parallel bars, eighteen on the side horse, twelve on the swinging rings, and nine on the still rings. The overgrip and undergrip giant swings were included in his analysis. Pictorial descriptions and accompanying mechanical principles were provided.

In 1959, several cinematographic studies were conducted at the University of Illinois. Austin demonstrated the use of cinematography in his analysis of the double backward somersault executed on the tumbling mat. Photographic records of four national champion tumblers were used as the data for the study. The positive filmstrips were projected from a microfilm reader onto a graph. The successive body positions of each performer were recorded with particular emphasis on their angular and linear measurements. The location of their respective centers of gravity throughout their flight was determined. A composite was made of the best performance to illustrate body action. Tables of data were compared to determine key factors.

Bare utilized cinematography in an analysis of the stutzkehre on the parallel bars. Five gymnasts

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with varied ability on the parallel bars were selected as subjects for the analysis. Thirty-five millimeter films were taken of each subject and projected through a microfilm reader. Measurements were taken of the projected images with reference to differences in time, in arm-trunk angles, in leg-trunk angle, and in height attained by the center of gravity. Outline drawings were made for comparison of selected positions throughout the skill.

Grossfeld\textsuperscript{39} cinematographically analyzed six subjects of varied ability executing the underbar somersault on the parallel bars. Angular and linear measurements as well as time differences were recorded. Selected images were outlined on graph paper. To illustrate body action, a composite was prepared from consecutively arranged prints of the most skilled performance. Tables summarizing significant data were computed to determine key factors.

A follow-up study on the mechanics of the double backward somersault in tumbling was conducted by Hatano\textsuperscript{40}. A cinematographic field of view was staged in order to


compare the two subjects' time of flight, time of take-off, distance of flight, body angle at take-off, height attained by the center of gravity, initial velocity of body flight, force at the kick, flight angle of the center of gravity, angle of force at the kick, maximum angular velocity of body rotation, and maximum angle of hip and knee flexion. The more successful performance was explained in terms of the aforementioned measurements.

Studies conducted by Sarver\textsuperscript{41} and Blievernicht\textsuperscript{42} were quite similar in that both investigators studied the mechanics of side horse double leg circles using the cinematographic method. Front, side, and top cameras were employed because of the intricate turning nature of the skill. Factors such as circular amplitude, circular velocity, time of regrasp, pattern of the swing, angle of arm lean, and position of the hips were considered in the light of correct mechanical technique.

George\textsuperscript{43} conducted a cinematographic and mechanical analysis of the arched kip on the horizontal bar. The respective velocities, accelerations, and


centrifugal forces were computed in order to compare the performances of the three subjects. The segmental method was utilized in plotting each subject's center of gravity trajectory throughout the entire execution of the skill. In addition, graphs depicting the shoulder, hip, and ankle trajectories were designed to compare the relative body actions of the subjects. A mechanical analysis of the arched kip was provided with variations in technique relative to any of the three subjects noted.

Plagenhoef recently conducted the first kinetic analysis of a whole body motion in gymnastics in his analysis of a peachbasket on the parallel bars. Through the use of computer programming of the necessary anatomical data, Plagenhoef demonstrated how to obtain instantaneous velocities and accelerations, vertical and horizontal forces, joint moments of force, total body centers of gravity, and the contribution of each body segment to the whole motion.

In summarizing studies related to cinematographic research in the area of gymnastics, the investigator found the following trends: (1) cinematographic procedures were becoming more exacting; (2) advanced cinematographic

techniques were providing a greater amount of information about relative body movement; (3) cinematography was fast becoming the most popular method in the analysis of human motor movement; and (4) cinematographic data was currently being processed by computer analysis.
CHAPTER III

PROCEDURE FOR THE STUDY

I. INTRODUCTION

The purpose of this investigation was to analyze and compare four mechanically different giant swing skills, each of which was performed on the horizontal bar by four selected national class gymnasts. The sub-purposes attempted to describe, in mathematical terms, the activity of each subject's center of gravity relative to its radius of rotation, centripetal force, angular velocity, and angular acceleration in order to extract those qualities indicative to highly skilled execution.

In light of the purposes of the study and the nature of the activity involved, the investigator utilized cinematography as the method for securing the raw data. According to Cureton,¹ the cinematographic method is characterized by the following potentialities:

1. To estimate the major factors governing performance and their relative importance.

2. To derive the scientific principles of coaching, including an understanding of the physical mechanics of the skill.

3. To lay the basis for a philosophical interpretation of athletic performance based upon relatively accurate theoretical considerations subject to some degree of verification.

A selection of the most representative performance for each of the four giant swing skills served as the data for the cinematographic analysis. By plotting selected shoulder, hip, and ankle reference points, the investigator was able to provide a sequence-overlay presentation of those positions pertinent to an understanding of the given skill. This procedure allowed for visual observation of the relevant changes in the shoulder and hip angles. In addition, it served to clarify the verbal description of the analysis.

Several procedures were employed for the comparative analysis. Initially, the center of gravity of each subject relative to the given skill was separately plotted on polar-coordinate graph paper. They were then superimposed on a single polar-coordinate graph for comparison. This procedure allowed for visual observation both of the point at which the effective shortening of the radius of rotation had occurred and of the total path of trajectory for each subject's center of gravity. This graphic presentation revealed the subjects' general trajectory pattern.
Identical procedures were then followed to record the paths of trajectory for the shoulder, hip, and ankle points of reference. These composite graphs were utilized to further analyze and explain the cumulative effect of segmental body variations upon the trajectory paths of the respective centers of gravity.

An additional procedure utilized in the comparative analysis consisted in the construction of tables depicting the following pertinent computations: (1) the degrees of circular rotation realized by the center of gravity every ten frames; (2) the distance of the center of gravity to the horizontal crossbar every tenth frame; (3) the distance traveled by the center of gravity in radians every tenth frame; (4) the angular velocity of the center of gravity in radians per second every tenth frame; (5) the incremental angular acceleration of the center of gravity in radians per second squared every tenth frame; and (6) the centripetal force realized by the center of gravity in foot pounds every tenth frame. These computations served not only to fulfill the sub-purposes of the study, but also to reveal, in mathematical terms, the total activity for each subjects' center of gravity throughout the given skill.
II. SELECTION OF SUBJECTS

In order to help insure quality performance, the investigator used 'current national participation' as the criterion for selection of the subjects. An attempt was made to select those national class gymnasts who had trained in different geographic locations of the United States. The actual selection and filming of these subjects took place at the Western Summer Gymnastic Clinic, Las Vegas, New Mexico, August 23-30, 1969. Refer to Table I for the subjects and order of analysis.

Table I
 Subjects and Order of Analysis

<table>
<thead>
<tr>
<th>Name of Subject</th>
<th>Order of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Manna</td>
<td>Subject A</td>
</tr>
<tr>
<td>Ronald Baretta</td>
<td>Subject B</td>
</tr>
<tr>
<td>Dusty Ritter</td>
<td>Subject C</td>
</tr>
<tr>
<td>Bruce Keeshin</td>
<td>Subject D</td>
</tr>
</tbody>
</table>

III. MATERIALS

The following supplies and equipment were utilized in gathering the cinematographic data.
Horizontal bar. A System Nissen horizontal bar (No. 615) was utilized as the apparatus upon which the giant swing skills were performed.

Strobotac. A standard portable 110 volt strobotac with a pre-set rate of 6 flashes per second was placed in the camera field of view during the entire filming. The strobe served as a calibration standard for establishing the framing rate of the camera.

Motion picture camera. The Bolex H-16 Rex motion picture camera was used to collect the raw data. This 16 millimeter camera employed a variable focal length lens pre-set at 30 millimeters. The camera was pre-set to record the film at 64 frames per second and the variable shutter was pre-set at one-half opening to insure an exposure time of 1/304th of a second per frame.

Film. Black and white 16 millimeter Kodak Tri-X 7278 Reversal film recorded the raw data. Negative prints were then obtained from a Versamat Kodak processing machine for the analysis.

Projection device. The Eastman Kodak Recordak film reader, Model MPE-1, served as the projection device for analyzing the negative prints. This model projected an eight-by-ten inch image of each frame, allowing for ease in tracing, recording, and measuring raw data on standard size paper.
Graph paper and pen. The data was recorded on standard polar-coordinate graph paper using a Rapidograph pen.

IV. REFERENCE POINTS

The following reference points were utilized in the study in order to help reduce the number of errors inherent in motion picture photography.

Subject reference points. The securing of elastic cross-tape (black on white) on the following body parts of each subject served as the segmental points of reference for the analysis: (1) lateral aspect of the shoulder-humerus articulation; (2) lateral aspect of the ilio-femoral articulation; and (3) lateral aspect of the malleolus articulation. In addition, the total body weight of each subject was recorded in order to compute the relevant velocities, accelerations, and forces. Refer to Table II for the total body weight of each subject.

Table II

Total Body Weight of Each Subject

<table>
<thead>
<tr>
<th>Name of Subject</th>
<th>Weight of Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject A - Robert Manna</td>
<td>150 pounds</td>
</tr>
<tr>
<td>Subject B - Ronald Baretta</td>
<td>140 pounds</td>
</tr>
<tr>
<td>Subject C - Dusty Ritter</td>
<td>128 pounds</td>
</tr>
<tr>
<td>Subject D - Bruce Keeshin</td>
<td>120 pounds</td>
</tr>
</tbody>
</table>
Field of view reference points. The more proximal horizontal bar upright was leveled so as to provide a reliable initial reference. A standard T-square was employed to establish vertical and horizontal points of reference on the projected field of view.

In addition, a twelve-inch wooden block was placed in full view of the camera's field. This procedure served to facilitate the measurement of linear distances. Since the images projected on the Recordak were not actual life size, it was necessary to utilize a reduction factor as a means of insuring reliable corrections. Bunn stated, "The size of the image varies directly as the distance from the lens to the screen. The further the projection lens away, the larger is the image, and vice versa." This reduction factor was expressed by the following formula:

\[
\text{True Measurement in Feet} = \frac{\text{Projected Measurement in Centimeters}}{\text{Multiplier in Feet}}
\]

The measurement of the wooden block when projected by the Recordak was found to be seven-tenths of a centimeter. By dividing this figure into the block's actual life

size, twelve inches, the multiplier was found to be 1.43 feet. All centimeter measurements taken from the projected images were multiplied by 1.43 feet in order to bring such measurements up to their actual size.

V. CINEMATOGRAPHIC PROCEDURES

The following cinematographic procedures were employed to insure accurate recording.

Filming specifications. The camera was mounted on a stationary, level tripod. Both the camera lens and the horizontal crossbar had a vertical distance of 8 feet 1 inch from the ground. The horizontal distance from the camera lens to the median aspect of the horizontal crossbar was 60 feet. Using this distance, the pre-set focal lens length of 30 millimeters allowed the camera to photograph the entire field of activity without having to make adjustments. The camera was positioned at 90 degrees to the frontal plane of the horizontal bar. Both the horizontal bar and the camera lens were checked by means of a level to insure that their respective horizontal-vertical positionings were identical.

The camera was re-wound to its maximum tension immediately prior to filming each separate skill. Proper lighting was insured by means of a light meter reading prior to each filming.
Camera calibration. The camera was calibrated throughout the entire filming process by means of the Strobotac. The strobe unit was placed in the field of view at a pre-set rate of 6 flashes per second. By counting the number of exposed frames between each flash interval, the investigator was able to establish the average calibration standard of the camera at 60 frames per second.

VI. RECORDING PROCEDURES

The location of the center of gravity throughout each of the four skills was a necessary aspect of the analysis. Although several methods for locating the center of gravity in the moving body have been used in the past century, the segmental method appeared to be the most appropriate.

Segmental method. Cooper and Glassow\(^3\) have indicated that the segmental method has been proven to be the most acceptable and the most accurate. The following information must be known in using this approach:

1. the percentage of total body weight for each segment;
2. the location of the center of gravity of each segment;

(3) the horizontal distance of each center of gravity from the vertical line; and (4) the vertical distance of each center of gravity from the horizontal line. With this information, the center of gravity was approximated in the light of the recorded body segments.

By placing a horizontal and vertical scale so that its axis arbritarily passed through some aspect of the projected pelvic region, the location of the center of gravity of the total body, for each chosen motion picture frame, was mathematically calculated and plotted on the appropriate graph.

Cooper and Glassow\textsuperscript{4} stated:

\begin{quote}
The distance of each center of gravity from the vertical line can be measured, and the effect of the gravitational force on each segment will be equal to the distance times the percentage of weight. The difference between the sum of these products which are to the left of the vertical line and those to the right will show whether the line marks the true plane of the body's center of mass and, if not, the direction and amount which it should be moved. The same procedure with reference to the horizontal line will determine the transverse plane of the center of gravity of the body.
\end{quote}

Plotting the trajectories. The following trajectories were plotted on standard polar-coordinate graph paper for all four giant swing skills as performed by

\textsuperscript{4}Ibid., p. 160.
each subject: (1) the center of gravity of the moving body relative to the horizontal crossbar was plotted every tenth motion picture frame; (2) the shoulder articulation reference point relative to the horizontal crossbar was plotted every fifteenth motion picture frame; (3) the hip articulation reference point relative to the horizontal crossbar was plotted every tenth motion picture frame; and (4) the ankle articulation reference point relative to the horizontal crossbar was plotted every fifth motion picture frame.

These graphs served as the primary source from which both the composite graphs and the mathematical computations, necessary to the fulfillment of the purposes of the study, were derived.

Composite graphs. Upon compilation of the raw graph data, composite graphs specific to each of the four giant swing skills were constructed. All subjects' center of gravity trajectory paths relative to the given skill were superimposed upon a single composite graph. The same procedure was followed for the shoulder, hip, and ankle trajectory paths. Thus a total of four composite graphs were employed to describe each skill.

Mathematical computations. The following formulae were used in computing the pertinent data for the purposes of the study:
1. **Angular velocity** - Angular velocity is a function of the distance traveled in radians per unit of time. It is represented by the formula:

\[ V = \frac{D}{T} \]

where:
- \( V \) = Velocity in radians per second
- \( D \) = Distance traveled in radians
- \( T \) = Time in seconds

2. **Angular acceleration** - Angular acceleration of a body in rotation is defined as the rate of change of angular velocity. It is represented by the formula:

\[ A = \frac{V - V_0}{T} \]

where:
- \( A \) = Angular acceleration in radians per second squared
- \( V_0 \) = Initial angular velocity in radians per second
- \( V \) = Final angular velocity in radians per second
- \( T \) = Time in seconds

3. **Centripetal force** - Centripetal force is a function of the weight of the body in pounds times linear velocity in feet per second divided by gravity (32.16) times the radius of rotation in feet. It is represented by the formula:

\[ F = \frac{Wv^2}{gr} \]

where:
- \( F \) = Centripetal force in foot pounds
- \( W \) = Weight of body in pounds
- \( V \) = Linear velocity in feet per second
- \( g \) = Value of gravity or 32.16 feet per second squared
- \( r \) = Radius of rotation in feet

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5Bunn, op. cit., p. 35.


7Bunn, op. cit., pp. 54-55.
Construction of tables. The data relative to the center of gravity for each subject in each of the four giant swing skills were compiled in separate table form. Each of these sixteen tables, derived from the aforementioned mathematical formulae, revealed the total activity for each subject's center of gravity.

VII. CINEMATOGRAPHIC AND COMPARATIVE ANALYSIS

In the light of data gathering and recording, the following analyses were realized.

Cinematographic analysis. The plotting of the separate center of gravity, shoulder, hip, and ankle trajectories on the polar-coordinate graphs served as the data for the selection of the most representative performance for each of the four giant swing skills. In each skill analysis, a sequence-overlay presentation of those positions pertinent to an understanding of the skill was provided in order to allow both for visual observation of the relevant changes in the shoulder and hip angles and for further clarification of the verbal description of the analysis.

Comparative analysis. By superimposing the centers of gravity of each subject on a single composite graph, the techniques employed in the given skill were compared in terms of general trajectory pattern. In
addition, the effective shortening of the radius of rotation for each subject was realized.

The paths of trajectory for the shoulder, hip, and ankle reference points were also superimposed upon their respective composite graphs. These graphs were utilized to further compare and explain the cumulative effect of segmental body variations upon their respective centers of gravity.

The construction of the mathematical tables served to fulfill the following sub-purposes of the study:

1. To determine the change in the radius of rotation of each subject in each of the four giant swing skills.

2. To determine the change in centripetal force realized by each subject in each of the four giant swing skills.

3. To determine the change in angular velocity realized by each subject in each of the four giant swing skills.

4. To determine the change in incremental angular acceleration realized by each subject in each of the four giant swing skills.

5. To determine the change in the elbow angle realized by each subject in each of the four giant swing skills.
CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

The filmstrip of each subject performing the undergrip giant swing, the inlocated undergrip giant swing, the overgrip giant swing, and the inlocated overgrip giant swing on the horizontal bar served as the source of data for the cinematographic and comparative analyses. Each of the individual skills and its composite factors were dealt with separately in order to provide a systematic examination.

I. UNDERGRIP GIANT SWING

A. Cinematographic analysis. Selected positions pertinent to an analysis of the undergrip giant swing were taken directly from the filmstrip and reproduced in progressive-sequence fashion so as to facilitate a more accurate understanding of the techniques employed in the successful execution of the skill. By comparing each of the four subjects' execution of the skill, Subject A's performance was found to be most representative.

1. Initial position. As shown in Figure 5 on page 54, examination of the initial position
Figure 5. Cinematographic Presentation of the Undergrip Giant Swing as Performed by an Expert Gymnast (Subject A).
revealed that the body assumed a near handstand position with an undergrip handgrasp. There was a very slight, yet observable, decrease in both the shoulder and hip angles. The center of gravity of the body was found to be located slightly within Quadrant I.

2. **Quadrant I.** As shown in Figure 5 on page 54, examination of the beginning of the descent phase revealed that both the shoulder and hip angles had been extended to a point such that the total body unit prescribed a near straight line. However, at the terminal point of this quadrant, a very slight, yet observable decrease in the shoulder and hip angles was again realized.

3. **Quadrant II.** As shown in Figure 5 on page 54, the slightly decreased shoulder and hip angles were maintained throughout the entire quadrant.

4. **Quadrant III.** As shown in Figure 5 on page 54, the slightly decreased shoulder angle extended to a point such that the arm-trunk segment prescribed a nearly straight line and the hip angle realized a slightly arched position. However, at the terminal point of this quadrant, both the shoulder and hip angles began to progressively decrease in order to insure the mechanics necessary to successfully complete the upward circular swing.
5. **Quadrant IV.** As shown in Figure 5 on page 54, the decrease in shoulder and hip angles was maintained until the body assumed a near handstand position. As the subject approached the completion of the skill, both the shoulder and hip angles began to increase to a point such that the body assumed a nearly straight line.

**B. Comparative analysis.** By comparing each of the four subjects' center of gravity, shoulder, hip and ankle paths of trajectory, similarities and dissimilarities relative to specific techniques were realized. Composite graphs served to illustrate the cumulative effect of segmental body variations upon the execution of the undergrip giant swing.

1. **Composite Graph 1.** In Composite Graph 1 on page 57, each of the four subjects' center of gravity paths of trajectory were compared. The general pattern relative to their centers of gravity revealed a progressively increasing radius of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Subjects A and D began to shorten the radius of rotation 29 degrees and 47 degrees respectively after transcending the lowest vertical point in the circular swing. Subjects B and C began to shorten the radius of
Composite Graph 1

Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing

Subject A (x x x x) Subject C (- - - -)
Subject B (--------) Subject D (• • • •)

Note: The center of gravity trajectories have been enlarged from their projected images by a factor of 3.
rotation 32 degrees and 60 degrees prior to transcending the lowest vertical point in the circular swing.

2. **Composite Graph 2.** In Composite Graph 2 on page 59, each of the four subjects' shoulder paths of trajectory were compared. Although direct observation of the filmstrip revealed no apparent change in the zero-degree extension of the elbow articulations for any of the four subjects, their respective paths of trajectory were not congruent. The investigator attributed this discrepancy to the following two factors: (1) the continuous shifting of the hand-grasp position about the horizontal crossbar; and (2) the characteristic elasticity of the horizontal crossbar subject to the continuous and varying degrees and directions of force during the execution of the skill.

3. **Composite Graph 3.** In Composite Graph 3 on page 60, each of the four subjects' hip paths of trajectory were compared. The general pattern relative to each subject's hip trajectory revealed that the distance from the hip to the horizontal crossbar progressively increased during the descent phase and progressively decreased during the ascent phase. The incongruous trajectories relative to the final 91 degrees of circular rotation were attributed to the following two factors: (1) slight differences among the subjects relative to the degree of angular change in
Composite Graph 2

Shoulder Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing

Subject A (x x x x) Subject C (- - - -)
Subject B (-----) Subject D (• • • •)

Note: The shoulder trajectories have been enlarged from their projected images by a factor of 3.
Composite Graph 3

Hip Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing

Subject A (x x x x)          Subject C (- - - -)
Subject B (----------)        Subject D (• • • •)

Note: The hip trajectories have been enlarged from their projected images by a factor of 2.
both the shoulder and hip articulations; and (2) the timing factor relative to these angular changes.

4. **Composite Graph 4.** In Composite Graph 4 on page 62, each of the four subjects' ankle paths of trajectory were compared. The general pattern relative to each subject's ankle path of trajectory revealed that the distance from the ankle to the horizontal crossbar progressively increased during the descent phase and progressively decreased during the ascent phase. The incongruous trajectories relative to the final 140 degrees of circular rotation were attributed to the following two factors: (1) slight differences among subjects relative to the degree of angular change in both the shoulder and hip articulations; and (2) the timing factor relative to these angular changes.

In light of the purposes of the study, the following factors of the undergrip giant swing relative to each subject's center of gravity were considered to be pertinent:

(1) the degrees of circular rotation every ten frames;
(2) the distance from the center of gravity to the horizontal crossbar in feet every tenth frame; (3) the distance traveled by the center of gravity in radians every tenth frame;
(4) the angular velocity of the center of gravity in radians per second every tenth frame; (5) the incremental angular acceleration of the center of gravity in radians per second squared every tenth frame; and (6) the centripetal force realized by the center of gravity in foot-pounds every tenth frame.
Composite Graph 4

Ankle Trajectory Paths of Four Expert Gymnasts Performing the Undergrip Giant Swing

Subject A (x x x x)  Subject C (_______)
Subject B (_________)  Subject D (• • •)

Note: The ankle trajectories are identical in scale to their projected images.
Tables III, IV, V, and VI, on pages 64, 65, 66, and 67 respectively, served to relate the mathematical changes relative to each subject's center of gravity in terms of: (1) radius of rotation; (2) centripetal force; (3) angular velocity; and (4) incremental angular acceleration. These tables also served to compare the subjects' centers of gravity relative to similarities and dissimilarities as follows:

1. The greatest amount of centripetal force was realized:
   (A) By Subject A at 229 degrees of circular rotation;
   (B) By Subject B at 220 degrees of circular rotation;
   (C) By Subject C at 210 degrees of circular rotation; and
   (D) By Subject D at 226 degrees of circular rotation.

2. The smallest amount of centripetal force was realized at 360 degrees of circular rotation by all four subjects.

3. The greatest amount of angular velocity was realized:
   (A) By Subject A at 229 degrees of circular rotation;
   (B) By Subject B at 220 degrees of circular rotation;
Table III
Mathematical Computations for the Center of Gravity of Subject A
Performing the Undergrip Giant Swing

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<th>Degrees of Rotation</th>
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<th>Distance traveled C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Angular Accelerations (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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Mathematical Computations for the Center of Gravity of Subject B
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<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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Table V
Mathematical Computations for the Center of Gravity of Subject C
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Table VI

Mathematical Computations for the Center of Gravity of Subject D
Performing the Undergrip Giant Swing

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<th>Distance traveled every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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</table>
(C) By Subject C at 210 degrees of circular rotation; and
(D) By Subject D at 226 degrees of circular rotation.

4. The smallest amount of angular velocity was realized at 360 degrees of circular rotation by Subjects A, C, and D. Subject B realized his smallest angular velocity at 334 degrees of circular rotation.

5. The sum of the values for positive incremental angular acceleration and negative incremental angular acceleration for each of the four subjects was found to be, in each instance, zero.

II. INLOCATED UNDERGRIP GIANT SWING

A. Cinematographic analysis. Selected positions pertinent to an analysis of the inlocated undergrip giant swing were taken directly from the filmstrip and reproduced in progressive-sequence fashion so as to facilitate a more accurate understanding of the techniques employed in the successful execution of the skill. By comparing each of the four subjects' execution of the skill, Subject A's performance was found to be most representative.
1. **Initial position.** As shown in Figure 6 on page 70, examination of the initial position revealed that the body assumed an inlocated handstand position with an undergrip handgrasp. Approximately 93 degrees of hip flexion was realized. The shoulder angle was hyperextended rearward to its fullest range without as yet incurring dislocation. The center of gravity of the body was found to be located slightly within Quadrant I.

2. **Quadrant I.** As shown in Figure 6 on page 70, examination of the beginning of the descent phase revealed a vigorous extension of the hip angle. Careful observation revealed that this extension, although quite vigorous, was such that the leg segment did not transcend a straight line relationship with the trunk segment. The shoulder angle remained in its fully hyperextended position.

3. **Quadrant II.** As shown in Figure 6 on page 70, the slightly decreased hip angle began to extend and continued this extension throughout the lowest vertical point in the circular swing. The shoulder angle remained in its fully hyperextended position. The progressively increasing centripetal force was made apparent in that the horizontal crossbar began to bow slightly in a direction tangent to the movement of the center of gravity of the body.
Figure 6. Cinematographic Presentation of the Inlocated Undergrip Giant Swing as Performed by an Expert Gymnast (Subject A).
4. **Quadrant III.** As shown in Figure 6 on page 70, the hip angle momentarily realized a position of slight hyperextension. As soon as this hyperextended hip position was realized, the hip angle began again to decrease. The shoulder angle remained in its fully hyperextended position.

5. **Quadrant IV.** As shown in Figure 6 on page 70, the progressive decrease of the hip angle continued in a direct relationship to the mechanics necessary to successfully complete the upward circular swing. This progressive decrease in hip angle continued until assuming a position of maximum anatomical flexion. The shoulder angle remained in its fully hyperextended position. As the body approached the completion of the upward circular swing, the initial position at the onset of the skill was again realized.

B. **Comparative analysis.** By comparing each of the four subjects' center of gravity, shoulder, hip, and ankle paths of trajectory, similarities and dissimilarities relative to specific techniques were realized. Composite graphs served to illustrate the cumulative effect of segmental body variations upon the execution of the inlocated undergrip giant swing.

1. **Composite Graph 5.** In Composite Graph 5 on page 72, each of the four subjects' center of gravity paths
Composite Graph 5

Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Undergrip Giant Swing

Subject A (x x x x)       Subject C (----)
Subject B (--------)       Subject D (• • • •)

Note: The center of gravity trajectories have been enlarged from their projected images by a factor of 3.
of trajectory were compared. The general pattern relative to their centers of gravity revealed a progressively increasing radius of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Subjects A and C began to shorten the radius of rotation 55 degrees and 13 degrees respectively after transcending the lowest vertical point in the circular swing. Subjects B and D began to shorten the radius of rotation 2 degrees and 21 degrees respectively prior to transcending the lowest vertical point in the circular swing.

2. Composite Graph 6. In Composite Graph 6 on page 74, each of the four subjects' shoulder paths of trajectory were compared. Although direct observation of the filmstrip revealed no apparent change in the zero-degree extension of the elbow articulations for any of the four subjects, their respective paths of trajectory were not congruent. The investigator attributed this discrepancy to the following two factors: (1) the continuous shifting of the handgrasp position about the horizontal crossbar; and (2) the characteristic elasticity of the horizontal crossbar subject to the continuous and varying degrees and directions of force during the execution of the skill.
Composite Graph 6

Shoulder Trajectory Paths of Four Expert Gymnasts
Performing the Inlocated Undergrip Giant Swing

Subject A (x x x x)  Subject C (- - - -)
Subject B (------)  Subject D (····)

Note: The shoulder trajectories have been enlarged from their projected images by a factor of 3.
3. Composite Graph 7. In Composite Graph 7 on page 76, each of the four subjects' hip paths of trajectory were compared. The general pattern relative to each subject's hip trajectory revealed that the distance from the hip to the horizontal crossbar progressively increased during the descent phase and progressively decreased during the ascent phase. The incongruous trajectory patterns were attributed to the following two factors: (1) slight differences among the subjects relative to degree of angular change in both the shoulder and hip articulations; and (2) the timing factor relative to these angular changes.

4. Composite Graph 8. In Composite Graph 8 on page 77, each of the four subjects' ankle paths of trajectory were compared. The general pattern relative to each subject's ankle path of trajectory revealed that the distance from the ankle to the horizontal crossbar progressively increased during the descent phase and progressively decreased during the ascent phase. The incongruous trajectories relative to the final 100 degrees of circular rotation were attributed the following two factors: (1) slight differences among the subjects relative to the degree of angular change in both the shoulder and hip
Composite Graph 7

Hip Trajectory Paths of Four Expert Gymnasts
Performing the Inlocated Undergrip Giant Swing

Subject A (x x x x) Subject C (- - - -)
Subject B (- - - -) Subject D (• • • •)

Note: The hip trajectories have been enlarged from their projected images by a factor of 2.
Ankle Trajectory Paths of Four Expert Gymnasts
Performing the Inlocated Undergrip Giant Swing

Subject A (x x x x)
Subject B (———)
Subject C (———)
Subject D (• • •)

Note: The ankle trajectories are identical in scale to their projected images.
articulations; and (2) the timing factor relative to these angular changes.

In light of the purposes of the study, the following factors of the inlocated undergrip giant swing relative to each subject's center of gravity were considered to be pertinent: (1) the degree of circular rotation every ten frames; (2) the distance from the center of gravity to the horizontal crossbar in feet every tenth frame; (3) the distance traveled by the center of gravity in radians every tenth frame; (4) the angular velocity of the center of gravity in radians per second every tenth frame; (5) the incremental angular acceleration of the center of gravity in radians per second squared every tenth frame; and (6) the centripetal force realized by the center of gravity in foot-pounds every tenth frame.

Tables VII, VIII, IX, and X, on pages 79, 80, 81, and 82 respectively, served to relate the mathematical changes relative to each subject's center of gravity in terms of: (1) radius of rotation; (2) centripetal force; (3) angular velocity; and (4) incremental angular acceleration. These tables also served to compare the subjects' centers of gravity relative to similarities and dissimilarities as follows:

1. The greatest amount of centripetal force was realized:

   (A) By Subject A at 155 degrees of circular rotation;
<table>
<thead>
<tr>
<th>Frame Number</th>
<th>Degrees of Rotation</th>
<th>Distance C. of G. to Bar (Feet)</th>
<th>Distance C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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</thead>
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<td>1</td>
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<tr>
<td>10</td>
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<tr>
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<tr>
<td>40</td>
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<td>8.31</td>
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<tr>
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Table VIII
Mathematical Computation for the Center of Gravity of Subject B
Performing the Inlocated Undergrip Giant Swing

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<th>Frame Number</th>
<th>Degrees of Rotation</th>
<th>Distance C. of G. to Bar (Feet)</th>
<th>Distance C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
</tr>
</thead>
<tbody>
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<td>244.40</td>
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Table IX
Mathematical Computations for the Center of Gravity of Subject C
Performing the Inlocated Undergrip Giant Swing

<table>
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<th>Frame Number</th>
<th>Degrees of Rotation</th>
<th>Distance to Bar (Feet)</th>
<th>Distance of C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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<td>100.52</td>
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<tr>
<td>100</td>
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<td>-15.84</td>
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</table>
### Table X

Mathematical Computations for the Center of Gravity of Subject D
Performing the Inlocated Undergrip Giant Swing

<table>
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<tr>
<th>Frame Number of Rotation</th>
<th>Degrees of C. of G. to Bar (Radians)</th>
<th>Distance C. of G. every 10th Frame (Feet)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.00</td>
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<tr>
<td>10</td>
<td>35</td>
<td>2.15</td>
<td>0.61</td>
<td>3.68</td>
<td>22.17</td>
</tr>
<tr>
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<td>2.43</td>
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<td>-6.27</td>
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<td>30</td>
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<td>6.99</td>
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<td>5.66</td>
</tr>
<tr>
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<tr>
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<td>0.63</td>
<td>3.79</td>
<td>-5.60</td>
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<tr>
<td>100</td>
<td>343</td>
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<tr>
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<td>360</td>
<td>1.86</td>
<td>0.30</td>
<td>1.73</td>
<td>-3.92</td>
</tr>
</tbody>
</table>
(B) By Subject B at 169 degrees of circular rotation;
(C) By Subject C at 187 degrees of circular rotation;
(D) By Subject D at 203 degrees of circular rotation.

2. The smallest amount of centripetal force was realized at 360 degrees of circular rotation by all four subjects.

3. The greatest amount of angular velocity was realized:
   (A) By Subject A at 155 degrees of circular rotation;
   (B) By Subject B at 169 degrees of circular rotation;
   (C) By Subject C at 187 degrees of circular rotation; and
   (D) By Subject D at 203 degrees of circular rotation.

4. The smallest amount of angular velocity was realized at 360 degrees of circular rotation by all four subjects.

5. The sum of the value for the positive incremental angular acceleration and the negative incremental angular acceleration
for each of the four subjects was found to be, in each instance, zero.

III. OVERGRIP GIANT SWING

A. Cinematographic analysis. Selected positions pertinent to an analysis of the overgrip giant swing were taken directly from the filmstrip and reproduced in progressive-sequence fashion so as to facilitate a more accurate understanding of the techniques employed in the successful execution of the skill. By comparing each of the four subjects' execution of the skill, Subject A's performance was found to be most representative.

1. Initial position. As shown in Figure 7 on page 85, examination of the initial position revealed that the body assumed a near handstand position with an overgrip handgrasp. The center of gravity of the body was found to be located slightly within Quadrant I.

2. Quadrant I. As shown in Figure 7 on page 85, examination of the beginning of the descent phase revealed a slight, yet observable decrease, in both the shoulder and hip angles.

3. Quadrant II. As shown in Figure 7 on page 85, both the shoulder and hip angles began to increase. The shoulder angle continued to increase until
Figure 7. Cinematographic Presentation of the Overgrip Giant Swing as Performed by an Expert Gymnast (Subject A).
the arms formed a forward-opening angle with the trunk. The hip angle continued to increase to a position of slight hyperextension.

4. Quadrant III. As shown in Figure 7 on page 85, both the shoulder and the hip angles began again to decrease in order to insure the mechanics necessary to successfully complete the upward circular swing.

5. Quadrant IV. As shown in Figure 7 on page 85, the decrease in shoulder and hip angles was maintained until the body assumed a near handstand position. As the subject approached the completion of the skill, both the shoulder and hip angles began to increase to a point such that the body assumed a nearly straight line.

B. Comparative analysis. By comparing each of the four subjects' center of gravity, shoulder, hip, and ankle paths of trajectory, similarities and dissimilarities relative to specific technique were realized. Composite graphs served to illustrate the cumulative effect of segmental body variations upon the execution of the overgrip giant swing.

1. Composite Graph 9. In Composite Graph 9 on page 87, each of the four subjects' center of gravity paths of trajectory were compared. The general pattern relative to their centers of gravity revealed a progressively increasing radius of rotation during
Composite Graph 9

Center of Gravity Trajectory Paths of Four
Expert Gymnasts Performing the
Overgrip Giant Swing

Subject A (x x x x)  Subject C (- - - -)
Subject B (--------)  Subject D (· · · ·)

Note: The center of gravity trajectories have been
enlarged from their projected images by a
factor of 3.
the descent phase and a progressively decreasing radius of rotation during the ascent phase. Subjects A, B, and D began to shorten the radius of rotation 32 degrees, 21 degrees, and 42 degrees respectively after transcending the lowest vertical point in the circular swing. Subject C began to shorten the radius of rotation 10 degrees prior to transcending the lowest vertical point in the circular swing.

2. Composite Graph 10. In Composite Graph 10 on page 89, each of the four subjects' shoulder paths of trajectory were compared. Although direct observation of the filmstrip revealed no apparent change in the zero-degree extension of the elbow articulations for any of the four subjects, their respective paths of trajectory were not congruent. The investigator attributed this discrepancy to the following two factors: (1) the continuous shifting of the handgrasp position about the horizontal crossbar; and (2) the characteristic elasticity of the horizontal crossbar subject to the continuous and varying degrees and directions of force during the execution of the skill.

3. Composite Graph 11. In Composite Graph 11 on page 90, each of the four subjects' hip paths of trajectory were compared. The general pattern
Composite Graph 10

Shoulder Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing

Subject A (x x x x)  Subject C (———)
Subject B (————)  Subject D (• • • •)

Note: The shoulder trajectories have been enlarged from their projected images by a factor of 3.
Composite Graph 11

Hip Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing

Subject A (x x x x)  Subject C (- - - -)
Subject B (- - - -)  Subject D (• • •)

Note: The hip trajectories have been enlarged from their projected images by a factor of 2.
relative to each subject's hip trajectory
revealed that the distance from the hip to the
horizontal crossbar progressively increased
during the descent phase and progressively
decreased during the ascent phase. The slightly
incongruous trajectories realized in the ascent
phase were attributed to the following two
factors: (1) slight differences among the
subjects relative to the degree of angular
change in both the shoulder and hip articulations;
and (2) the timing factor relative to these
angular changes.

4. Composite Graph 12. In Composite Graph 12 on page
92, each of the four subjects' ankle paths of
trajectory were compared. The general pattern
relative to each subject's ankle path of
trajectory revealed that the distance from the
ankle to the horizontal crossbar progressively
increased during the descent phase and progressively
decreased during the ascent phase. The slightly
incongruous trajectories relative to the ascent
were attributed to the following two factors:
(1) slight differences among subjects relative
to the degree of angular change in both the
shoulder and hip articulations; and (2) the
timing factor relative to these angular changes.
Composite Graph 12

Ankle Trajectory Paths of Four Expert Gymnasts Performing the Overgrip Giant Swing

Subject A (x x x x)  Subject C (--- -)
Subject B (-------)  Subject D (· · · ·)

Note: The ankle trajectories are identical in scale to their projected images.
In light of the purposes of the study, the following factors of the overgrip giant swing relative to each subject's center of gravity were considered to be pertinent: (1) the degrees of circular rotation every ten frames; (2) the distance from the center of gravity to the horizontal crossbar in feet every tenth frame; (3) the distance traveled by the center of gravity in radians every tenth frame; (4) the angular velocity of the center of gravity in radians per second every tenth frame; (5) the incremental angular acceleration of the center of gravity in radians per second squared every tenth frame; and (6) the centripetal force realized by the center of gravity in foot-pounds every tenth frame.

Tables XI, XII, XIII, and XIV, on pages 94, 95, 96, and 97 respectively, served to relate the mathematical changes relative to each subject's center of gravity in terms of: (1) radius of rotation; (2) centripetal force; (3) angular velocity; and (4) incremental angular acceleration. These tables also served to compare the subjects' center of gravity relative to similarities and dissimilarities as follows:

1. The greatest amount of centripetal force was realized:
   
   (A) By Subject A at 150 degrees of circular rotation;

   (B) By Subject B at 165 degrees of circular rotation;
Table XI
Mathematical Computations for the Center of Gravity of Subject A
Performing the Overgrip Giant Swing

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<th>Frame Number</th>
<th>Degrees of Rotation</th>
<th>Distance C. of G. to Bar (Feet)</th>
<th>C. of G. every 10th Frame (Radians)</th>
<th>Distance traveled C. of G. (Feet)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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### Table XII

Mathematical Computations for the Center of Gravity of Subject B Performing the Overgrip Giant Swing

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<th>Degrees of Rotation</th>
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<th>Angular Velocity (Rad/Sec)</th>
<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
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Performing the Overgrip Giant Swing

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<th>Distance C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
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Table XIV
Mathematical Computations for the Center of Gravity of Subject D
Performing the Overgrip Giant Swing

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<th>Distance C. of G. 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
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<th>Centripetal Force (Ft/Lbs)</th>
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(C) By Subject C at 149 degrees of circular rotation; and
(D) By Subject D at 177 degrees of circular rotation.

2. The smallest amount of centripetal force was realized at 360 degrees of circular rotation by all four subjects.

3. The greatest amount of angular velocity was realized:
   (A) By Subject A at 150 degrees of circular rotation;
   (B) By Subject B at 165 degrees of circular rotation;
   (C) By Subject C at 194 degrees of circular rotation; and
   (D) By Subject D at 177 degrees of circular rotation.

4. The smallest amount of angular velocity was realized at 360 degrees of circular rotation by all four subjects.

5. The sum of the values for the positive incremental angular acceleration and the negative incremental angular acceleration for each of the four subjects was found to be, in each instance, zero.
IV. INLOCATED OVERGRIP GIANT SWING

A. **Cinematographic analysis.** Selected positions pertinent to an analysis of the inlocated overgrip giant swing were taken directly from the filmstrip and reproduced in progressive-sequence fashion so as to facilitate a more accurate understanding of the techniques employed in the successful execution of the skill. By comparing each of the four subjects' execution of the skill, Subject A's performance was found to be most representative.

1. **Initial position.** As shown in Figure 8 on page 100, examination of the initial position revealed that the body assumed a near inlocated handstand position with an overgrip handgrasp. Approximately 80 degrees of hip flexion was realized. The shoulder angle was hyperextended rearward approximately 95 degrees. The center of gravity of the body was found to be located slightly within Quadrant I.

2. **Quadrant I.** As shown in Figure 8 on page 100, examination of the beginning of the descent phase revealed progressively increasing shoulder and hip angles. The shoulder angle attained maximum anatomical hyperextension within this first quadrant. Careful observation revealed
Figure 8. Cinematographic Presentation of the Inlocated Overgrip Giant Swing as Performed by an Expert Gymnast (Subject A).
that the hip extension, although quite vigorous, did not as yet attain a position of hyperextension.

3. **Quadrant II.** As shown in Figure 8 on page 100, the hip angle momentarily realized a position of slight hyperextension. As soon as this hyperextended hip position was realized, the hip angle began again to decrease. The shoulder angle remained in its fully hyperextended position.

4. **Quadrant III.** As shown in Figure 8 on page 100, the progressive decrease of the hip angle continued in a direct relationship to the force necessary to successfully complete the upward circular swing. The shoulder angle remained in its fully hyperextended position.

5. **Quadrant IV.** As shown in Figure 8 on page 100, the progressive decrease in the hip angle continued until 95 degrees of hip flexion was realized. As the subject approached the completion of the skill, the shoulder angle began to decrease vigorously so as to allow the body to disengage from the inlocated position.

**B. Comparative analysis.** By comparing each of the four subjects' center of gravity, shoulder, hip, and ankle paths of trajectory, similarities and dissimilarities relative to specific techniques were realized. Composite
graphs served to illustrate the cumulative effect of segmental body variations upon the execution of the inlocated overgrip giant swing.

1. **Composite Graph 13.** In Composite Graph 13 on page 103, each of the four subjects' center of gravity paths of trajectory were compared. The general pattern relative to their centers of gravity revealed a progressively increasing radius of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Subjects A, B, and D began to shorten the radius of rotation 20 degrees, 14 degrees, and 6 degrees respectively prior to transcending the lowest vertical point in the circular swing. Subject C began to shorten the radius of rotation 20 degrees after transcending the lowest vertical point in the circular swing.

2. **Composite Graph 14.** In Composite Graph 14 on page 103, each of the four subjects' shoulder paths of trajectory were compared. Although direct observation of the filmstrip revealed no apparent change in the zero-degree extension of the elbow articulations for any of the four subjects, their respective paths of trajectory were not congruent. The investigator attributed
Composite Graph 13

Center of Gravity Trajectory Paths of Four Expert Gymnasts Performing the Inlocated Overgrip Giant Swing

Subject A (x x x x) Subject C (---)
Subject B (---------) Subject D (• • • •)

Note: The center of gravity trajectories have been enlarged from their projected images by a factor of 3.
Composite Graph 14

Shoulder Trajectory Paths of Four Expert Gymnasts
Performing the Inlocated Overgrip Giant Swing

Subject A (x x x x)                      Subject C (- - - -)
Subject B (--------)                      Subject D (• • • •)

Note: The shoulder trajectories have been enlarged from their projected images by a factor of 3.
this discrepancy to the following two factors: (1) the continuous shifting of the handgrasp position about the horizontal crossbar; and (2) the characteristic elasticity of the horizontal crossbar subject to the continuous and varying degrees and directions of force during the execution of the skill.

3. Composite Graph 15. In Composite Graph 15 on page 106, each of the four subjects' hip paths of trajectory were compared. The general pattern relative to each subject's hip trajectory revealed that the distance from the hip to the horizontal crossbar progressively increased during the descent phase and progressively decreased during the ascent phase. The incongruous trajectory patterns were attributed to the following two factors: (1) slight differences among the subjects relative to the degree of angular change in both the shoulder and hip articulations; and (2) the timing factor relative to these angular changes.

4. Composite Graph 16. In Composite Graph 16 on page 107, each of the four subjects' ankle paths of trajectory were compared. The general pattern relative to each subject's ankle path of trajectory revealed that the distance from the ankle to the
Composite Graph 15

Hip Trajectory Paths of Four Expert Gymnasts
Performing the Inlocated
Overgrip Giant Swing

Subject A (x x x x) Subject C (---)
Subject B (-----) Subject D (• • •)

Note: The hip trajectories have been enlarged from
their projected images by a factor of 2.
Composite Graph 16

Ankle Trajectory Paths of Four Expert Gymnasts
Performing the Inlocated Overgrip Giant Swing

Subject A (x x x x)                           Subject C (- - - -)
Subject B (________)                           Subject D (· · · ·)

Note: The ankle trajectories are identical in scale to their projected images.
horizontal crossbar progressively increased
during the descent phase and progressively de-
creased during the ascent phase. The incongruous
trajectories realized at 175 degrees and at 295
degrees of circular rotation were attributed to
the following two factors: (1) slight differences
among the subjects relative to the degree of
angular change in both the shoulder and hip
articulations; and (2) the timing factor relative
to these angular changes.

In light of the purposes of the study, the follow-
ing factors of the inlocated overgrip giant swing relative
to each subject's center of gravity were considered to be
pertinent: (1) the degree of circular rotation every ten
frames; (2) the distance from the center of gravity to the
horizontal crossbar in feet every tenth frame; (3) the
distance traveled by the center of gravity in radians every
tenth frame; (4) the angular velocity of the center of
gravity in radians per second every tenth frame; (5) the
incremental angular acceleration of the center of gravity
in radians per second squared every tenth frame; and
(6) the centripetal force realized by the center of gravity
in foot-pounds every tenth frame.

Tables XV, XVI, XVII, and XVIII, on pages 109,
110, 111, and 112 respectively, served to relate the
mathematical changes relative to each subject's center
Table XV

Mathematical Computations for the Center of Gravity of Subject A
Performing the Inlocated Overgrip Giant Swing

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<th>Frame Number</th>
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<th>Distance traveled C. of G. every 10th Frame (Radians)</th>
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<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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### Table XVI
Mathematical Computations for the Center of Gravity of Subject B Performing the Inlocated Overgrip Giant Swing

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<th>Distance C. of G. every 10th Frame (Radians)</th>
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<th>Incremental Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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Table XVII
Mathematical Computations for the Center of Gravity of Subject C
Performing the Inlocated Overgrip Giant Swing

<table>
<thead>
<tr>
<th>Frame Number</th>
<th>Degrees of Rotation</th>
<th>Distance C. of G. to Bar (Feet)</th>
<th>Distance C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Angular Accelerations (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>19.86</td>
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Table XVIII

Mathematical Computations for the Center of Gravity of Subject D
Performing the Inlocated Overgrip Giant Swing

<table>
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<tr>
<th>Frame Number</th>
<th>Degrees of Rotation</th>
<th>Distance C. of G. to Bar (Feet)</th>
<th>Distance C. of G. every 10th Frame (Radians)</th>
<th>Angular Velocity (Rad/Sec)</th>
<th>Angular Acceleration (Rad/Sec/Sec)</th>
<th>Centripetal Force (Ft/Lbs)</th>
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of gravity in terms of: (1) radius of rotation; (2) centripetal force; (3) angular velocity; and (4) incremental angular acceleration. These tables also served to compare the subjects' centers of gravity relative to similarities and dissimilarities as follows:

1. The greatest amount of centripetal force was realized:
   (A) By Subject A at 225 degrees of circular rotation;
   (B) By Subject B at 165 degrees of circular rotation;
   (C) By Subject C at 196 degrees of circular rotation; and
   (D) By Subject D at 213 degrees of circular rotation.

2. The smallest amount of centripetal force was realized at 360 degrees of circular rotation by Subjects A, B, and D. Subject C realized the smallest amount of centripetal force at 341 degrees of circular rotation.

3. The greatest amount of angular velocity was realized:
   (A) By Subject A at 225 degrees of circular rotation;
   (B) By Subject B at 165 degrees of circular rotation;
(C) By Subject C at 196 degrees of circular rotation; and

(D) By Subject D at 213 degrees of circular rotation.

4. The smallest amount of angular velocity was realized at 360 degrees of circular rotation by Subjects A, B, and D. Subject C realized the smallest amount of angular velocity at 341 degrees of circular rotation.

5. The sum of the values for the positive incremental angular acceleration and the negative incremental angular acceleration for each of the four subjects was found to be, in each instance, zero.
CHAPTER V
SUMMARY, FINDINGS, DISCUSSION OF FINDINGS,
CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

This investigation served to analyze and compare four mechanically different giant swing skills, each of which was performed on the horizontal bar by four selected national class gymnasts. In addition, the following subpurposes attempted to describe, in mathematical terms, the activity of each subject's center of gravity in order to extract those qualities indicative of highly skilled execution:

1. To determine the change in the radius of rotation of each subject in each of the four giant swing skills.

2. To determine the change in centripetal force realized by each subject in each of the four giant swing skills.

3. To determine the change in angular velocity realized by each subject in each of the four giant swing skills.

4. To determine the change in incremental angular acceleration realized by each subject in each of the four giant swing skills.
5. To determine the change in the elbow angle realized by each subject in each of the four giant swing skills.

The cinematographic method was employed to obtain the necessary raw data for the analyses and comparisons. The four mechanically different giant swing skills that served as the test data were: (1) The Undergrip Giant Swing; (2) The Inlocated Undergrip Giant Swing; (3) The Overgrip Giant Swing; and (4) The Inlocated Overgrip Giant Swing.

The following trajectories were plotted on standard polar-coordinate graph paper for all four giant swing skills as performed by each subject: (1) every tenth motion picture frame, the center of gravity of the moving body relative to the horizontal bar was plotted; (2) every fifteenth motion picture frame, the shoulder articulation reference point relative to the horizontal bar was plotted; (3) every tenth motion picture frame, the hip articulation reference point relative to the horizontal bar was plotted; and (4) every fifth motion picture frame, the ankle articulation reference point relative to the horizontal bar was plotted.

Upon completion of these sixty-four separate raw graphs, composite graphs for each of the four giant swing skills were constructed such that the specific points of reference common to each subject and to each
skill were compared in terms of their paths of trajectory.

The cinematographic analysis for each of the four giant swing skills consisted of descriptive explanations relative to: (1) The Initial Position; (2) Quadrant I; (3) Quadrant II; (4) Quadrant III; and (5) Quadrant IV. The plotting of the shoulder, hip, and ankle trajectory of the most representative performance for each skill served as the source of data for the analysis. Sequenceoverlay presentations of those positions pertinent to an understanding of each skill was provided in order to allow both for visual observation of the relevant changes in the shoulder and hip angles and for further clarification of the verbal description of the analysis.

By superimposing the centers of gravity of each subject on a composite graph, the techniques employed in the given skill were compared in terms of general trajectory pattern. In addition, the effective shortening of the radius of rotation for each subject was realized.

The paths of trajectory for the shoulder, hip, and ankle reference points were also superimposed upon their respective composite graphs. These graphs were utilized to further compare and explain the cumulative effect of segmental body variations upon their respective centers of gravity.
An additional procedure utilized in the comparative analysis consisted of the construction of mathematical tables depicting the following pertinent computations: (1) the degrees of circular rotation realized by the center of gravity every ten frames; (2) the distance of the center of gravity to the horizontal crossbar in feet every tenth frame; (3) the distance traveled by the center of gravity in radians every tenth frame; (4) the angular velocity of the center of gravity in radians per second every tenth frame; (5) the incremental angular acceleration of the center of gravity in radians per second squared every tenth frame; and (6) the centripetal force realized by the center of gravity in foot-pounds every tenth frame. These computations served not only to fulfill the sub-purposes of the study, but also to reveal, in mathematical terms, the total activity for each subject's center of gravity throughout each of the four giant swing skills.

II. FINDINGS

In order to facilitate a better understanding of the findings of the study, each of the four giant swing skills were grouped under the following two categories: (1) Cinematographic findings; and (2) Comparative findings.
1. **Cinematographic findings.**

   a. **Undergrip giant swing.** The initial position revealed that the body assumed a near handstand position with an undergrip handgrasp. There was a very slight, yet observable, decrease in both the shoulder and hip angles. As the body began its descent, both the shoulder and hip angles extended to a point such that the total body unit prescribed a nearly straight line. However after approximately 90 degrees of circular rotation had occurred, the very slight, yet observable, decrease in the shoulder and hip angles was again realized and maintained until the body transcended the lowest vertical point in the circular swing. At this time the shoulder angle extended to a point such that the arm-trunk segment prescribed a nearly straight line and the hip angle realized a slightly arched position. As the body continued up the circular swing, both the shoulder and hip angles began to progressively decrease in order to insure the mechanics necessary to successfully complete the skill. This decrease in shoulder and hip angles was maintained until the body approached the completion of the skill. At this time, both the shoulder and hip angles began to increase to a point such that the body assumed a nearly straight line.
b. **Inlocated undergrip giant swing.** The initial position revealed that the body assumed an inlocated handstand position with an undergrip handgrasp. Approximately 93 degrees of hip flexion was realized. The shoulder angle was hyperextended rearward to its fullest range without as yet incurring dislocation. As the body began its descent, the hip angle realized a vigorous extension. This extension, although quite vigorous, was such that the leg segment did not transcend a straight line relationship with the trunk segment. The shoulder angle remained in its fully hyperextended position. It was not until the body had transcended the lowest vertical point in the circular swing that a momentarily hyperextended hip position was realized. As the body continued up the circular swing, the shoulder angle remained fully hyperextended and the hip angle began to progressively decrease in a direct relationship to the mechanics necessary to successfully complete the skill. This progressive decrease in hip angle continued until assuming a position of maximum anatomical flexion. As the body approached the completion of the upward circular swing, the initial position at the onset of the skill was again realized.
c. Overgrip giant swing. The initial position revealed that the body assumed a near handstand position with an overgrip handgrasp. Both the shoulder and hip angles assumed zero-degree extension. As the body began its descent, a slight, yet observable, decrease in both the shoulder and hip angles was realized. However, after approximately 130 degrees of circular rotation had occurred, a progressive increase in both the shoulder and hip angles was realized. As the body approached the lowest vertical point in the circular swing, the increasing shoulder angle continued to a point such that the arms formed a forward-opening angle with the trunk. The hip angle continued to increase to a position of slight hyperextension. As the body began to rise up the circular swing, the forward-opening angle of the shoulder articulation was maintained while the hip angle began to decrease. The progressively decreasing hip angle was immediately followed by a proportionate decrease in the shoulder angle. This decrease in both the shoulder and hip angles continued in a direct relationship to the mechanics necessary to successfully complete the skill. As the body approached the completion of the upward circular swing, both the shoulder and hip angles began again to increase until the body
realized its initial position at the onset of the skill.

d. Inlocated overgrip giant swing. The initial position revealed that the body assumed a near in-located handstand position with an overgrip hand-grasp. Approximately 80 degrees of hip flexion was realized. The shoulder angle was hyper-extended rearward approximately 95 degrees. As the body began its descent, the hip angle realized a vigorous extension. This extension, although quite vigorous, was such that the leg segment did not transcend a straight line relationship with the trunk segment. The shoulder angle increased to a position of full anatomical hyper-extension. It was not until 140 degrees of circular rotation had occurred that a momentarily hyperextended hip position was realized. As the body approached the lowest vertical point in the circular swing, the shoulder angle remained fully hyperextended and the hip angle began to progressively decrease in a direct relationship to the mechanics necessary to successfully complete the skill. This progressive decrease in the hip angle continued until 95 degrees of hip flexion was realized. As the body approached the completion of the skill, the shoulder angle began to
decrease vigorously so as to allow the body to disengage from the inlocated position.

2. Comparative findings.
   a. Undergrip giant swing. The general pattern relative to each subject's center of gravity revealed a progressively increasing radius of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Both the hip and ankle trajectories for each of the four subjects were almost identical, in terms of pattern, to their respective center of gravity trajectories. The elbow articulations of each subject remained at zero-degree extension throughout the entire skill. Although each subject utilized varying degrees of angular oscillation and timing, these factors were not of sufficient magnitude to indicate that atypical mechanical movements were being employed. The basic mechanics utilized by each of the four subjects were one and the same.

       Table XIX on page 127 related, in summary form, all pertinent mathematical findings relative to the sub-purposes of the study.

   b. Inlocated undergrip giant swing. The general pattern relative to each subject's center of gravity revealed a progressively increasing radius
of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Except for Subject A, the hip and ankle trajectories were almost identical, in terms of pattern, to their respective center of gravity trajectories. Subject A realized a significantly greater increment in the shoulder angle at the onset of the skill. With this greater initial magnitude of potential force, Subject A was able to shorten his radius of rotation strictly by means of hip flexion. This was not the case with the other three subjects. Because of not attaining total rearward hyperextension of the shoulder girdle initially, Subjects B, C, and D realized an insufficient magnitude of potential force. In order to insure successful completion of the skill, Subjects B, C, and D had to employ, in addition to maximum hip flexion, a relatively decreased shoulder angle during the ascent phase. All other varying degrees of angular oscillation and timing were not of sufficient magnitude to indicate that atypical mechanical movements were being employed.
The elbow articulations of each subject remained at zero-degree extension throughout the entire skill.

Table XIX on page 127 related, in summary form, all pertinent mathematical findings relative to the sub-purposes of the study.

c. Overgrip giant swing. The general pattern relative to each subject's center of gravity revealed a progressively increasing radius of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Both the hip and ankle trajectories for each of the four subjects were almost identical, in terms of pattern, to their respective center of gravity trajectories. The elbow articulations of each subject remained at zero-degree extension throughout the entire skill. Although each subject utilized varying degrees of angular oscillation and timing, these factors were not of sufficient magnitude to indicate that atypical mechanical movements were being employed. The basic mechanics utilized by each of the four subjects were one and the same.

Table XIX on page 127 related, in summary form, all pertinent mathematical findings relative to the sub-purposes of the study.
d. **Inlocated overgrip giant swing.** The general pattern relative to each subject's center of gravity revealed a progressively increasing radius of rotation during the descent phase and a progressively decreasing radius of rotation during the ascent phase. Both the hip and center of gravity paths of trajectory revealed that Subjects A and C obtained uniform increments in the shoulder angle. Subjects B and D realized slightly erratic initial shoulder angle increments as revealed by their hip and center of gravity paths of trajectory. Although these slightly atypical patterns did not affect the ascent phase, the investigator felt that they were worthy of note. All other varying degrees of angular vascillation and timing were not of sufficient magnitude to indicate that atypical mechanical movements were being employed.

The elbow articulations of each subject remained at zero-degree extension throughout the entire skill.

Table XIX on page 127 related, in summary form, all pertinent mathematical findings relative to the sub-purposes of the study.
### Table XIX

Summary of Mathematical Findings of Four Expert Gymnasts Performing Four Giant Swing Skills on the Horizontal Bar

<table>
<thead>
<tr>
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<th>Undergrip Giant Swing</th>
<th>Inlocated Undergrip Giant Swing</th>
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</thead>
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<td>A B C D</td>
<td>A B C D</td>
</tr>
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<td>Radius of rotation shortening was initiated at</td>
<td>209° 148° 120° 227°</td>
<td>235° 178° 198° 159°</td>
</tr>
<tr>
<td>Greatest amount of centripetal force was realized at</td>
<td>229° 220° 210° 226°</td>
<td>155° 169° 187° 203°</td>
</tr>
<tr>
<td>Smallest amount of centripetal force was realized at</td>
<td>360° 360° 350° 360°</td>
<td>360° 360° 360° 360°</td>
</tr>
<tr>
<td>Greatest amount of angular velocity was realized at</td>
<td>229° 220° 210° 226°</td>
<td>155° 169° 187° 203°</td>
</tr>
<tr>
<td>Smallest amount of angular velocity was realized at</td>
<td>360° 334° 360° 360°</td>
<td>360° 360° 360° 360°</td>
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<tr>
<td>Sum of values for positive and negative incremental angular acceleration</td>
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Table XIX (continued)

<table>
<thead>
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<th>Overgrip Giant Swing</th>
<th>Inlocated Overgrip Giant Swing</th>
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<td>A</td>
<td>B</td>
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<tr>
<td>Radius of rotation</td>
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<tr>
<td>shortening was</td>
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<td>initiated at</td>
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<td>was realized at</td>
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</table>
Based upon the mathematical findings relative to each subject and to each skill, the following patterns were found:

1. The shortening of the radius of rotation in order to successfully complete the given skill occurred within the range of the second half of Quadrant II and the first half of Quadrant III.

2. The greatest amount of centripetal force realized in the given skill occurred within the range of the second half of Quadrant II and the first half of Quadrant III.

3. The smallest amount of centripetal force realized in the given skill occurred during the final phase of Quadrant IV.

4. The greatest amount of angular velocity realized in the given skill occurred within the range of the second half of Quadrant II and the first half of Quadrant III.

5. The smallest amount of angular velocity realized in the given skill occurred during the final phase of Quadrant IV.

6. The change in incremental angular acceleration was not consistent for any of the subjects in any of the respective skills.

7. A zero-degree extension of the elbow articulations was realized by all of the subjects in all of the respective skills.
III. DISCUSSION OF FINDINGS

An overview of the findings indicated that several factors were found to be common to all subjects and to all skills. First of all, it was found that all radii of rotation trajectory patterns progressively increased during the descent phase and progressively decreased during the ascent phase. These relatively uniform changes in the radii of rotation suggested, in each instance, that the respective performances were of an expert nature.

In all but one of the sixteen investigated performances, it was found that the hip articulation reference points preceded the ankle articulation reference points as the subjects transcended the lower vertical axis. This appeared to be the more natural body position at that point in the given circular swing because the subjects were then realizing the greatest amount of angular velocity and centripetal force. The legs would naturally trail the center of gravity of the body under these conditions.

And finally, it was discovered that the mechanics involved in executing the four selected skills were quite similar. The only true difference found was the characteristic position of the body basic to the skill in question.
IV. CONCLUSIONS

Based upon the findings of the study, the limitations of the study, and the basic assumptions of the study, the following conclusions were derived:

1. Highly skilled performers utilized similar, and often times identical, motor movement patterns in the execution of the four selected giant swing skills.

2. The shortening of the radius of rotation in order to increase the angular velocity in performing the selected giant swing skills was accomplished, in every instance, by changes in two basic angles: (1) the shoulder articulation; and (2) the hip articulation.

3. Since the timing factor relative to "when" the actual shortening of the radius of rotation occurred was not consistent among subjects in any of the selected giant swing skills, a specific point with the respective circular swings could not be determined.

4. Since the "amount" the radius of rotation was shortened in order to successfully complete each of the selected giant swing skills was not consistent among subjects, a specific ideal amount within the respective giant swing skills could not be determined.
V. RECOMMENDATIONS

As a result of this investigation, the investigator made the following recommendations for further study:

1. Further studies should be conducted in an effort to determine an efficient, accurate method for locating the center of gravity of the body.

2. Similar gymnastic studies should be conducted utilizing subjects of various skill levels in an effort to determine the kind and amount of compensatory mechanics that come into play relative to each skill level.

3. The cinematographic method should be further studied and refined for use in those physical activities that lend themselves to three dimensional analysis.
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VITA

The author was born in New Orleans, Louisiana on April 30, 1942. He also received his elementary and secondary training in New Orleans, Louisiana.

Upon graduation from Jesuit High School in 1960, the author entered Michigan State University and completed three academic years. In 1964, he transferred to Louisiana State University and was graduated in May, 1966 with a Bachelor of Science degree in Physical Education and a minor in foreign language.

In 1966 the author entered Springfield College, Springfield, Massachusetts. He served for one academic year as assistant athletic coach in gymnastics while enrolled as a full-time graduate student. The author was graduated in May, 1967, with a Master of Science degree in Physical Education.

The author was employed as an instructor and athletic coach in gymnastics at Old Dominion University, Norfolk, Virginia in September, 1967.

The author was employed under a graduate administrative assistantship as athletic coach in gymnastics while enrolled as a full-time graduate student at Louisiana State University from September 1968 through August 1970.
He is married to the former Janet Ann Noyes of Brookfield, Massachusetts and they are parents of one child, Tasha Kirsten George.
EXAMINATION AND THESIS REPORT

Candidate: Gerald S. George

Major Field: Physical Education

Title of Thesis: A Cinematographic and Comparative Analysis of National Class Gymnasts Performing Selected Skills on the Horizontal Bar

Approved:

[Signatures and names of approval authorities]

EXAMINING COMMITTEE:

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