# THE DYNAMIC STRENGTH OF THE FOREARM FLEXORS MEASURED WITH THE HILL INERTIA WHEEL AND ITS RELATION TO UPPER ARM DIMENSIONS DETERMINED VIA ANTHROPOMETRIC MEASUREMENTS

A THESIS

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We hereby recommend that the thesis prepared under our supervision by Sylvia J. Robertson, B.A. entitled The Dynamic Strength of the Forearm Flexors Measured with the Hill Inertia Wheel and Its Relation to Upper Arm Dimensions Determined Via Anthropometric Measurements

be accepted as fulfilling this part of the requirements for the Degree of

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TABLE OF CONTENTS

LIST OF TABLES

## LIST OF ILLUSTRATIONS

# CHAPTER I

# ORIENTATION TO THE STUDY

## Introduction

Muscle strength is the source of all human labor.[1] Thus, muscle strength tests have occupied a prominent position in the evaluation of man's physical fitness and working capacity. Man's existence and effectiveness in completing everyday activities depend upon the strength and endurance of his muscles.[2]

As a physio-mechanical parameter, accurate and objective measurement of strength is a problem of major proportions.[3] Measures of static strength are routinely collected in laboratories throughout the world, while measures of dynamic strength are extremely rare or nonexistent. Consequently, the efficiency of muscle groups during activity is inferred rather than measured objectively.

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[1] Michio Ikai, Daquo Asahina, and Sakae Yokobori, Sports Medicine in Japan (Tokyo, Japan: Meiji Life Foundation of Health and Welfare, 1964), pp. 118-119.

[2] H. Harrison Clarke, Muscular Strength and Endurance in Man (New Jersey: Prentice-Hall, Inc., 1966), p. 1.

[3] Herbert A. deVries, Physiology of Exercise for Physical Education and Athletics (Dubuque, Iowa: Wm. C. Brown Company Publishers, 1966), p. 310.

Most strength measuring devices available today utilize a stiff spring or tension device which registers force on a dial when the subject squeezes, pushes, or pulls the device.[1] The subject being tested bends or stretches a spring or strain gauge a fraction of an inch and the resultant tension is magnified many times to record the force developed. These devices do not permit a noticeable change in muscle length or joint angle and are thus, by definition, measurements of static (isometric) strength.[2]

In this study, the principle of the Hill Inertia Wheel was utilized which permits the subject to apply a torque to a heavy steel wheel consisting of eight pulleys of varying radii mounted on ball bearings.[3] The wheel is free to rotate; therefore, the subject's arm can be flexed or extended through its full range of motion. Dynamic strength can then be measured by calculating the maximum force developed or total work produced. The measurement of dynamic strength in this study is a unique technique never heretofore experimented with in the North American Continent and used previously only in

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[1]Leonard A. Larson and Rachael Dunaven Yocom, Measurement and Evaluation in Physical, Health, and Recreation Education (St. Louis: The C. V. Mosby Company, 1951), p. 80.

[2]Ibid., p. 87.

[3]A. V. Hill, Living Machinery (New York: Harcourt, Brace and Company, 1927), pp. 196-197.

England[1] and Japan.[2]

Although there are innumerable factors that may conceivably affect muscle strength, one of the criteria for evaluating the force producing capabilities of the muscle during isometric contractions is the girth of the muscle.[3] DeVries[4] observed that a group of well-conditioned, non-obese young men showed a high positive correlation between the force produced and the girth of the muscle. The relationship between dynamic strength and muscle girth has not heretofore been established and warrants investigation. The purpose of this study was to explore the relationship between the girth of the upper arm, specifically the forearm flexor muscle group, and the dynamic strength of the forearm flexors in university women utilizing the Hill Inertia Wheel as modified by Ikai[5] and constructed especially for this investigation.

## Statement of the Problem

The dynamic strength of the forearm flexor muscles

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[1] A. V. Hill, "The Maximum Work and Mechanical Efficiency of Human Muscles, and Their Most Economical Speed," Journal of Physiology, Vol. 56, (1922), pp. 19-41.

[2] Michio Ikai, "Work Capacity of the Japanese Related to Age and Sex," The Journal of Sports Medicine and Physical Fitness, Vol. 6, No. 2, (June, 1966), pp. 100-105.

[3] Laurence E. Morehouse and Augustus T. Miller, Physiology of Exercise (Saint Louis: The C. V. Mosby Company, 1963), p. 59.

[4] deVries, Physiology of Exercise, p. 303.

[5] Ikai, "Work Capacity of the Japanese," pp. 100-105.

measured with an especially constructed inertia wheel was correlated with the girth of the forearm flexors obtained via conventional anthropometric techniques. One hundred women enrolled in the Texas Woman's University during the academic year of 1968-1969 participated in the study.

## Definitions and Explanations of Terms

For the purpose of clarification, the following definitions and/or explanations of terms are accepted for use as they relate to this study.

Dynamic Strength: Asmussen states that "dynamic strength is the maximum tension that a muscle can produce during movement."[1] In this study, the terms "dynamic strength" and "muscle force" will be used interchangeably.

Forearm Flexors: Sobotta states that "the principal flexors of the forearm are the biceps brachii, brachialis, and brachioradialis; and the assistant movers are the pronator teres and possibly the flexors of the hand and fingers."[2]

Mass: Arons defines mass "as the product of density and volume."[3] Christiansen and Garrett state that "a body's

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[1]Erling Asmussen, "The Neuromuscular System and Exercise," Exercise Physiology, ed. by Harold B. Falls, (New York: Academic Press, Inc., 1968), p. 34.

[2]Johannes Sobotta, Atlas of Descriptive Human Anatomy, ed. and trans. by Eduard Uhlenhuth, Vol. I, (New York: Hafner Publishing Company, Inc., 1957), pp. 259-264.

[3]A. B. Arons, Development of Concepts of Physics (Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1965), p. 420.

inertia, measured by a standard unit, is called its mass."[1]

Moment of Inertia: Christiansen and Garrett state that "the fundamental property of all matter--resistance to change of motion--is called inertia."[2] Arons defines moment of inertia as "the instantaneous angular velocity of each particle in the rigid group making up the wheel."[3] Benumof further states that "the unit of moment of inertia is the product of the unit of mass and the square of a length unit."[4]

Equivalent Mass: Arons describes equivalent mass as:

> When equal forces, but unequal torques, are applied to identical wheels, it is observed that a larger angular acceleration is imparted to the wheel experiencing the larger torque; that is, the same force does not necessarily impart the same rotational acceleration to identical bodies. If equal torques are applied to wheels of identical mass but with different distributions of this mass around the axis of rotation, it is observed that a larger angular acceleration is imparted to that wheel whose mass is, on the average, closer to the axis; that is, the effective rotational inertias [equivalent mass] of the two wheels are very different even though their inertial masses are identical.[5]

Force: Christiansen and Garrett state that "force

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[1]G. S. Christiansen and Paul H. Garrett, Structure and Change: An Introduction to the Science of Matter (San Francisco: W. H. Freeman & Company, 1960), p. 43.

[2]Ibid.

[3]Arons, Concepts of Physics, p. 442.

[4]Reuben Benumof, Concepts in Physics (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1965), p. 155.

[5]Arons, Concepts of Physics, pp. 439-440.

is that which accelerates a body."[1] Benumof describes force as:

> The second law [Newton's laws of motion] may be expressed mathematically as follows: $F = ma$ where F is the resultant force acting on the mass m and a is the acceleration measured relative to an inertial system. To use the above equation properly, a consistent system of units must be used. If mass is measured in kilograms, and acceleration in meters per second$^2$, the unit of force is the newton. If mass is measured in slugs, and acceleration in feet per second$^2$, the unit of force is the pound.[2]

Newton: Arons states that "one Newton is that force which imparts acceleration of one meter/second$^2$ to the one kilogram standard. A Newton is 0.225 pound."[3]

Inertia Wheel: Hill, who designed the original inertia wheel, describes the inertia wheel as:

> A machine consisting of a heavy flywheel mounted in ball-bearings on a stand. It is supplied with a number of pulleys of different size. A flexible wire can be wound round any one of these pulleys, and a subject can start up the flywheel by pulling on a handle attached to the end of the wire. Each pulley has a short peg standing out from it, round which goes a loop at the other end of the wire, so that it does not slip. When the wire is completely unwound the loop comes off the peg, and the wheel is free to rotate. The work done by the muscles . . . is communicated to the wheel and can be measured by measuring the angular velocity of the wheel with a tachometer (speedometer). The whole of the work done by the muscles of the arm in shortening appears as the energy of motion (kinetic energy) of the wheel, and this is ascertained by multiplying a constant

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[1]Christiansen and Garrett, Structure and Change, p. 43.

[2]Benumof, Concepts in Physics, p. 120.

[3]Arons, Concepts of Physics, p. 134.

depending upon the weight and dimensions of the wheel (the moment of inertia) by half the square of its angular velocity.[1]

The inertia wheel used for this study consists of eight pulleys with the following radii: .59 inches, .79 inches, 1.38 inches, 1.97 inches, 2.56 inches, 3.15 inches, 3.74 inches, 4.33 inches, and 4.92 inches. The total weight of the inertia wheel is 120 pounds. The purpose of the varying sizes of pulleys can best be understood with Hill's explanation:

> It is possible to vary the speed at which the muscles shorten. If the wire is wound round a very small pulley the arrangement will be like that of a very high gear on a bicycle and the movement will occur only slowly. It may take several seconds to complete it. If, however, the wire is wound round a large pulley, it will be like a low gear, and the movements of the arm will occur very rapidly. Now the same muscular effort has been made in both cases. The subject has pulled as hard as he possibly can, and only when his full force has been developed is the wheel released. If we were to make the same experiment with a steel spring instead of with a man's arm, stretching it always to the same extent by winding the wire up on one of the pulleys, we should always get the same work done on the wheel and the same final velocity, whatever the time occupied in shortening. With the human arm, however, the work done is very different in the two cases. When the shortening of the muscles is very slow a large amount of work is done; when the shortening is rapid, very little work. It is not exactly a case of "more haste less speed," but of "more speed less work."[2]

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[1]Hill, Living Machinery, pp. 196-197.

[2]Ibid., pp. 197-198.

## Purpose of the Study

The general purpose of this study was to determine if there existed a relationship between the dynamic strength of the forearm flexors and the girth of the upper arm determined by using anthropometric techniques of college women. This study was unique in that, heretofore, the dynamic strength of muscles had never been measured in this manner in the United States because appropriate equipment was non-existent and could not be purchased.

Many investigators have, allegedly, measured dynamic strength objectively; however, all of the techniques employed involve the measurement of a skilled performance of varying difficulty to throw or lift the body or an object. Thus, the estimate of dynamic strength has been by implication rather than experimentation.[1,2,3,4]

By utilizing the inertia wheel especially developed for this study the dynamic strength of the forearm flexors can

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[1]Harold M. Barrow and Rosemary McGee, A Practical Approach to Measurement in Physical Education (Philadelphia: Lea & Febiger, 1964), pp. 143-267.

[2]National Research Council of the Research Section, Measurement and Evaluation Materials in Health, Physical Education, and Recreation (Washington, D. C.: American Association for Health, Physical Education, and Recreation, 1950), pp. 35-45.

[3]John F. Bovard, Frederick W. Cozens, and E. Patricia Hagman, Tests & Measurements in Physical Education (Philadelphia: W. B. Saunders Company, 1949), pp. 127-142.

[4]Larson and Yocom, Measurement and Evaluation, pp. 84-100.

be measured through their full range of motion and quantitatively related to the dimensional measurements of the upper arm without the necessity of the subject undergoing a special skill training or an endurance training program.

## Delimitations of the Study

The present study was subject to the following delimitations:

1. Volunteer students numbering 100 enrolled in the Texas Woman's University in Denton, Texas, during the academic year of 1968-1969.

2. The objectivity, reliability, and validity of the measurement of dynamic strength through the use of the Hill Inertia Wheel and the measurement of the girth of the upper arm of the subjects.

## Survey of Previous Studies

The present study is similar to the related studies only in one of the following ways: (1) the use of the inertia wheel to measure dynamic strength, (2) the use of anthropometric measurements to determine girth of the forearm flexors, or (3) the use of college women as subjects.

The present study is unique in the following ways: (1) the only study ever completed utilizing an inertia wheel on the North American Continent and (2) the investigation of the relationship between muscle girth of the upper arm and the dynamic strength performance of the forearm flexors of college women utilizing the unique measuring device.

The following reviews are presented as illustrative of studies which have provided guidelines and background information in the development of the present investigation.

Early investigations involving measures of strength were anthropomorphic in nature indicating a belief that bulk of muscle was more important than functional performance.[1] The movement trend away from simple tape measurements to more sophisticated appraisals of fitness was pioneered by Dudley A. Sargent in 1880 when he employed a spring dynamometer to determine the static strength of the legs and back of incoming Harvard freshmen.[2] Students were tested standing on a small platform where they pulled on the handles of a dynamometer which was securely fastened to a platform. The dial on the dynamometer indicated back strength by showing the pull in kilograms. Leg strength was measured in a similar fashion except that the individual was seated and placed the handles of the dynamometer on his thighs. The dial movement indicated the subject's ability to push upward with his legs. Dynamic strength of the upper arms and chest was estimated by counting the number of dips one could execute on the parallel bars. Chinning was used as a measure of dynamic strength of the upper

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[1]Bovard, Cozens, and Hagman, Tests & Measurements, p. 124.

[2]C. W. Hackensmith, History of Physical Education (New York: Harper & Row, Publishers, 1966), p. 365.

arms and back. Sargent supplemented the strength measures with measurements of the chest circumference.[1]

Since the 1880's the trend has been to measure the strength of large muscle groups during the execution of some relatively simple motor task. Activities such as chins, dips, and the Sargent jump (Larson's Dynamic Strength Test);[2] back and leg dynamometers, standing broad jumps, et cetera (Anderson Strength Index for High School Girls);[3] hand grips, back and leg dynamometers, and chins (McCloy Athletic Strength Index);[4] and hand grips, pull-ups, and vital capacity (Rogers Strength Index)[5] are illustrative of items included in strength tests which require execution of a motor task to determine the dynamic strength of a muscle group. Thus, instead of focusing attention upon the basic strength and work producing capabilities of a limited number of muscles, a variety of more or less complex skill elements were introduced into the evaluation of strength.

At present, every device used to measure muscle strength in laboratories the world over, with two exceptions, measures

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[1]Bovard, Cozens, and Hagman, Tests & Measurements, pp. 124-125.

[2]Ibid., pp. 131-132.

[3]National Research Council of the Research Section, Measurement and Evaluation, pp. 35-45.

[4]Ibid., p. 124.

[5]Bovard, Cozens, and Hagman, Tests & Measurements, p. 129.

only isometric strength. These devices, dynamometers and strain gauges,[1] measure the torque exerted about a joint when the joint is held in a fixed position.[2] With these devices the joint angle does not change during the application of the force as is natural during sports activities.[3] Thus, it is possible to compute only the maximum force developed by the biceps with the elbow joint held at a given angle; it is impossible to determine the total work capacity of the muscle throughout its full range of motion.

In an attempt to remedy these problems, A. V. Hill explored the measurement of muscle force with a large wheel or iron around which a cable was wrapped. As the subject pulled the cable, the wheel rotated freely in such a way that the total force for a period of time or total work could be calculated.[4] The wheel came to be known as the "Hill Inertia Wheel", an appellation it has retained. In 1965, a second inertia wheel was constructed in Japan, where one study of the arm and leg strength of boys and girls aged six to twenty

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[1]H. D. Darcus, "A Strain-Gauge Dynamometer for the Measurement of the Strength of Isometric Contraction," Proceedings of the Physiological Society (London), _Journal of Physiology_, Vol. 127, (January, 1955), pp. 48-49.

[2]H. Harrison Clarke, "Recent Advances in Measurement and Understanding of Volitional Muscular Strength," _Research Quarterly_, Vol. 27, No. 3, (1956), pp. 263-275.

[3]deVries, _Physiology of Exercise_, pp. 311-318.

[4]Hill, _Living Machinery_, pp. 196-199.

has been completed.[1]

Hill[2] experimented with the inertia wheel to determine the maximum work performed by human muscles in a single voluntary contraction, the various factors affecting the work done, and the mechanical efficiency of muscular movement in man. Hill concluded:

> . . . the maximum work of human muscles (biceps and brachialis anticus) can be determined. This instrument employs the inertia reaction of a fly-wheel to take up the pull of the muscle, the work done being calculated from the speed of revolution of the fly-wheel, as measured by a hand tachometer of standard pattern.
>
> . mechanical efficiency of a submaximal effort is always less than that of a maximal effort occupying the same time, and in general the stronger effort is the more efficient. Moreover the stronger effort has the greater optimum speed.[3]

Lupton[4] investigated the work of Hill[5] by developing a "quick release" mechanism for the inertia wheel to correct possible error in testing techniques. The findings showed agreement with Hill's work. The differences in calculations were explained by the fact that in Hill's paper the velocities

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[1]Ikai, "Work Capacity of the Japanese," pp. 100-105.

[2]Hill, "Maximum Work and Mechanical Efficiency of Human Muscles," pp. 19-41.

[3]*Ibid.*, p. 39.

[4]Hartley Lupton, "The Relation Between the External Work Produced and the Time Occupied in a Single Muscular Contraction in Man," *Journal of Physiology*, Vol. 57, (1923), pp. 68-75.

[5]Hill, "Maximum Work and Mechanical Efficiency of Human Muscles," pp. 19-41.

were averaged for the full extent of the pull, while in Lupton's paper the velocities were directly observed over a slightly smaller range of movement.

Hansen and Lindhard[1] also investigated the findings of Hill[2] concerning the maximum work of human muscles using an inertia wheel and reported the following results:

> The theoretical maximum work, $W_o$ cannot be attained in practice for (at least) two reasons:
>
> Because some potential energy is degenerated into heat when the muscle shortens (as shown by Hill) . . .
>
> Because some sort of fatigue is coming on very soon (most probably within about 1 second).

Hill, Long, and Lupton[3] utilized the inertia wheel to determine the effect of fatigue in diminishing the work done in prolonged maximal contraction of the flexor muscles of the elbow. The results of this investigation showed that after every previous one second of maximal contraction, the work diminishes by about six per cent, but the relationship between work and speed of shortening are not seriously influenced by fatigue.

The effects of six-week programs of isotonic and

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[1]T. E. Hansen and J. Lindhard, "On the Maximum Work of Human Muscles Especially the Flexors of the Elbow," Journal of Physiology, Vol. 57, (1923), pp. 287-300.

[2]Hill, "Maximum Work and Mechanical Efficiency of Human Muscles," pp. 19-41.

[3]A. V. Hill, C. N. H. Long, and H. Lupton, "The Effect of Fatigue on the Relation Between Work and Speed, in the Contraction of Human Arm Muscles," Journal of Physiology, Vol. 57, (1923), pp. 334-337.

isometric exercises were observed by Rasch and Morehouse[1] in forty-nine male subjects to determine which subjects showed the greatest gains in strength and greatest gains in girth of the elbow flexor muscles. Strain gauge dynamometer measurements of strength were obtained by means of a Baldwin SR-4 load cell, which was firmly attached to the floor. Changes in tension in a flexible airplane cable exerted against the sensing element in the cell were translated into proportional changes in output voltage, which were electronically amplified and recorded on an ink-writing dynograph. Comparison of the deflection of these recordings with those produced by known weights hung from the load cell made it possible to calibrate the amount of tension exerted. The mean strength for the isotonic group increased by 14.38 pounds, but there were no significant changes in strength in the isometric group. As a result of the exercises, the mean hypertrophy of the exercised arm increased 1.22 centimeters in the isotonic group and 0.[illegible] centimeters in the isometric group. The investigators suggested that isotonic exercises probably produce better results from the psychological as well as the physiological viewpoint.

An experiment to produce hypertrophy of the right triceps of normal subjects by progressive resistance exercises

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[1]Philip J. Rasch and Laurence E. Morehouse, "Effect of Static and Dynamic Exercises on Muscular Strength and Hypertrophy," Journal of Applied Physiology, Vol. 11, (1957) pp. [illegible]-31.

was undertaken by McMorris and Elkins.[1] Isometric strength measurements were taken with a wire strain gauge, while the weekly ten-resistance-maximum values were recorded as the isotonic strength measurements. After twelve weeks, the eleven subjects showed a mean gain in triceps circumference of 0.88 centimeters. The investigators concluded:

> There is no correlation between the percentage gain in right arm circumference and strength of elbow extension as recorded from the subjects in this study.[2]

Clarke[3] measured the speed of a lateral arm movement and the strength/mass ratio of forty-eight university male students. Strength was measured by applying a maximum upward pull against a 90-centimeter wooden arm support, at the end of which was attached a spring balance, which in turn was securely anchored to the floor at right angles to the direction of pull. The spring balance had a maximum scale deflection of 16.3 kilograms. Measurement of arm mass was determined by weighing the arm on a spring scale while the subject was lying in a supine position on a table. The negative correlation between movement time and strength/mass ratio was not significant

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[1]Rex O. McMorris and Earl C. Elkins, "A Study of Production and Evaluation of Muscular Hypertrophy," Archives of Physical Medicine and Rehabilitation, Vol. 35, (July, 1954), pp. 421-426.

[2]Ibid., p. 426.

[3]David H. Clarke, "Correlation Between the Strength/Mass Ratio and the Speed of an Arm Movement," Research Quarterly, Vol. 31, No. 4, (1960), pp. 570-574.

(r= -.277); strength alone correlated with movement time (r= -.369). Although this latter correlation was significant, when the two r's were compared statistically the difference between them was not significant since the t-ratio was only 0.67. The results of this study suggest that there is no appreciable correlation between strength/mass ratio and movement time.

Ikai and Steinhaus[1] investigated the maximum effort of the right forearm flexors under designated "psychologic" factors. The "psychologic" factors included a loud noise, the subject's own outcry, certain pharmacologic agents, and hypnosis. The investigators observed significant changes ranging from +26.5 per cent to -31 per cent in the maximum effort of the forearm flexors under "psychologic" factors. Analysis of these data prompted the investigators to conclude that all performances of supposed maximal effort are short of the true maximal limit of the muscle measured.

A study to measure the strength of the flexors and extensors of the forearms and of the lower legs of twenty-four subjects relative to the cross section of the muscles was undertaken by Morris.[2] Anthropometric measurements included

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[1]Michio Ikai and Arthur H. Steinhaus, "Some Factors Modifying the Expression of Human Strength," Journal of Applied Physiology, Vol. 16, (1961), pp. 157-163.

[2]Carrie Belle Morris, "The Measurement of the Strength of Muscle Relative to the Cross Section," Research Quarterly, Vol. 19, (1948), pp. 295-303.

girth at the largest part, depth, width, and four fat measurements of the muscles being studied. For each subject an x-ray of the knee and elbow joints was taken with each joint at a 90-degree angle to obtain estimates of muscle attachments on the bones in order to get the leverage of the pertinent muscles. Strength was measured from a right-angle position of the elbow joint with a strap from the wrist to a push-pull attachment of a dynamometer. Leg flexors were tested in a similar manner. The results of this study indicated that 10 kilograms of force per square centimeter of muscle is the average force exibited by the flexors and extensors of the forearms and of the lower legs.

Techniques and devices utilized in the measurement of strength have been reviewed by the investigator of this study. Clarke,[1] Hellebrandt and Houtz,[2] and Banister[3] provide valuable general information pertaining to methods of testing strength in addition to the studies mentioned. However, the present investigation does not duplicate any of the previously reported studies.

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[1]H. Harrison Clarke, "Recent Advances in Measurement," pp. 263-275.

[2]F. A. Hellebrandt and Sara Jane Houtz, "Mechanisms of Muscle Training in Man: Experimental Demonstration of the Overload Principle," The Physical Therapy Review, Vol. 36, No. 6, (June, 1956), pp. 371-383.

[3]E. W. Banister, "Physiological Principles Applied to a New Method of Strength Training," Paper from the Human Performance Laboratory, The University of British Columbia, (   ).

## Summary

Man's existence and effectiveness in completing everyday activities depend upon the strength and endurance of his muscles.[1] The study of dynamic strength of the forearm flexors utilizing the inertia wheel provides data concerning measurement of strength under dynamic conditions which more closely simulate everyday activities.

Numerous research studies related to the topic investigated were examined. The writer presented a brief review of studies related to the development of this research project. Also included in the first chapter were the Statement of the Problem, Definitions and Explanations of Terms, Purpose of the Study, and the Delimitations of the Study.

Chapter II includes a detailed description of the equipment and procedures employed in the development of this study.

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[1]H. Harrison Clarke, Muscular Strength and Endurance in Man, p. 1.

# CHAPTER II

## METHODS AND PROCEDURES FOR THE DEVELOPMENT OF THE STUDY

The development of this study will be discussed in this chapter under the following major headings: Sources of Data, Preliminary Procedures, Procedures for Obtaining Subjects, Description and Techniques for Obtaining Measurements of the Forearm Flexors and Scores of Dynamic Strength on the Inertia Wheel, Treatment of the Data, and Summary.

### Sources of Data

The data utilized in this study were gathered from both documentary and human sources. The documentary sources included books, periodicals, theses, dissertations, pamphlets, and reports of research related to all aspects of the study. The human sources included one hundred women volunteers enrolled in the Texas Woman's University, Denton, Texas, during the academic year of 1968-1969. Personal correspondence was conducted with Dr. Michio Ikai.[1] The guidance of Doctor Jesse T. Matthews, Chairman of the Department of Physics, Texas Woman's University, was of greatest significance

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[1]Letter from Michio Ikai, Professor of Education, University of Tokyo, Hongo, Bunkyo-Ku, Tokyo, Japan, December 12, 1968.

in the calibration and calculation of the forces for this "new" inertia wheel.[1] Each wheel being constructed of different materials by different machinists required an individual calibration and calculation of forces.

## Preliminary Procedures

After the available literature related to the various aspects of this study had been reviewed, permission was obtained from Doctor Anne Schley Duggan, Dean of the College of Health, Physical Education and Recreation at the Texas Woman's University, Denton, Texas, to conduct the study utilizing students, members of the staff, equipment and facilities of the College of Health, Physical Education and Recreation during the academic year of 1968-1969.

A Gulick anthropometric tape was used to measure the girth of the forearm flexors according to established anthropometric technique.[2] The investigator developed a plan for the construction of the inertia wheel which appears on page 49 of the Appendix using as a model a sketch of an inertia wheel which accompanied correspondence from Dr. Ikai.

The steel inertia wheel was constructed and mounted in ball-bearings on a stand by the Denton Metal Works, Denton, Texas. Upon completion of the construction of the inertia

[1]Jesse T. Matthews, Chairman, Department of Physics, Texas Woman's University, Denton, Texas, July, 1969.

[2]Aleš Hrdlička, Anthropometry (Philadelphia: Wistar Institute of Anatomy and Biology, 1920), p. 29.

wheel, the investigator attached a one-eighth inch metal convex cam to the outer edge of the largest pulley which upon each revolution contacted a microswitch that was mounted on the frame of the inertia wheel. The microswitch was wired to a brush recorder and the distance between the pips which appeared on the paper of the brush recorder could be measured to determine the velocity of the wheel.

A suitable form for recording the anthropometric measurement and the data yielded during the trials on the inertia wheel was developed. This recording form appears in the Appendix on page 46.

The investigator prepared and presented a tentative outline of the study in July, 1969, at a Graduate Seminar at the Texas Woman's University. Upon the basis of the suggestions and recommendations which accrued from the seminar, the tentative outline was revised and approved by the members of the thesis committee. A copy of the approved prospectus of the thesis was filed in the office of the Dean of Graduate Studies at the Texas Woman's University.

## Procedures for Obtaining Subjects

The investigator utilized volunteer students enrolled in the required and major programs of the College of Health, Physical Education and Recreation at the Texas Woman's University as subjects for this study. The investigator visited all required Physical Education classes, explained her study to the students, requested volunteers for the study, and scheduled those who volunteered to appear for testing at their convenience. Students enrolled in the major programs of the College of Health, Physical Education and Recreation who volunteered to participate in this study were scheduled to appear for testing at their convenience. The volunteers were measured and tested individually by the investigator in the Human Performance Laboratory during the months of July and August, 1969.

## Description and Techniques for Obtaining Measurements of the Forearm Flexors and Scores of Dynamic Strength on the Inertia Wheel

The measurement of the forearm flexors was taken around the greatest prominence of the upper arm when the upper arm was raised to shoulder height, the forearm flexors maximally contracted and the hand supinated. Each subject was measured three times in succession with a Gulick anthropometric tape, and the average of the readings was recorded to the nearest 0.1 centimeter.

The scores of dynamic strength were in Newtons which expressed the amount of force exerted in moving the inertia wheel. The force, which is the work performed by the subject, was determined by applying the formula, Force = (mass) (acceleration). The moment of inertia of the wheel had to be calculated before mass could be determined. Moment of inertia is expressed as $I = \frac{1}{2}\text{mass} \times \text{radius}^2$. Mass is determined by applying the formula $\text{Volume} = \pi \times \text{radius}^2 \times \text{length}$ of each of the sections of the wheel. A table appears on page 52 of the

Appendix showing the calculations required to determine the moment of inertia of the wheel. Since radius was expressed in centimeters and mass in grams, the moment of inertia for the wheel constructed for use in this study was $29.6 \times 10^5$ gm-$cm^2$ or $29.6 \times 10^{-2}$ $Kgm^2$. The equivalent mass of each section of the pulley was then determined by applying the formula I/$radius^2$. The equivalent masses of the pulleys on the inertia wheel used in this study were 740 Kgms., 241.63 Kgms., 118.40 Kgms., 70.059 Kgms., 46.25 Kgms., 32.797 Kgms., 24.46 Kgms., and 19.59 Kgms. The smallest pulley yielded the largest equivalent mass since the greatest mass of the wheel was at a much greater radius than that of the smallest pulley and the torque required to move the wheel was therefore greatest.

The acceleration of the wheel was calculated by mounting a microswitch on the frame of the wheel and attaching a one-eighth inch metal convex cam to the outer edge of the largest pulley of the wheel which closed the circuit leading to the brush recorder each time the wheel made a revolution. Each revolution of the wheel was thus readable by measuring the distance between the pips on the paper of the brush recorder. The speed of the paper in the brush recorder was set at 25 millimeters per second and the measurements between the pips, time-marker scratches, were recorded in millimeters. Thus by dividing the number of millimeters between pips by 25 millimeters, the time in hundredths of a second for each revolution could be determined. The faster the wheel revolved the shorter the distance between the marks on the paper, and it was this distance that was recorded to calculate the velocity in the formula. The velocity of the wheel being determined in this manner to the nearest one hundredth of a second the force developed could then be expressed; Force = (equivalent mass) x ($2\pi$ radians/seconds$^2$). Since mass was expressed in kilograms and acceleration in meters/seconds$^2$, the unit for force expression was Newtons.

TABLE 1

FIGURES OBTAINED BY COMBINING EQUIVALENT MASS x ACCELERATION

| Pulley | Radius | Equivalent Mass | r x $2\pi$ radians | $I/r^2$ x $2\pi$ radians |
|---|---|---|---|---|
| 1 | 2.0 cms. | 740.0 Kgms. | 12.56 | 92.94 |
| 2 | 3.5 cms. | 241.63 Kgms. | 21.98 | 53.11 |
| 3 | 5.0 cms. | 118.40 Kgms. | 31.40 | 37.18 |
| 4 | 6.5 cms. | 70.059 Kgms. | 40.82 | 28.60 |
| 5 | 8.0 cms. | 46.25 Kgms. | 50.24 | 23.24 |
| 6 | 9.5 cms. | 32.797 Kgms. | 59.66 | 19.57 |
| 7 | 11.0 cms. | 24.46 Kgms. | 69.08 | 16.90 |
| 8 | 12.5 cms. | 19.59 Kgms. | 78.50 | 14.87 |

Table 1 shows the constant figures that were developed for this study to simplify the calculations of force. Only the seconds$^2$ needed to be inserted into the formula to determine the force exerted upon the wheel. The constant figures were obtained by combining a portion of the formula; Force = mass ($I/r^2$) x acceleration ($2\pi$ radians). Therefore, only the figure in the last column of Table 1 divided by seconds$^2$ needed to be computed to arrive at the force exerted upon the wheel. For example, pulley number three yielded a constant figure of 37.18 and if the velocity of the wheel was .40 seconds, the force exerted upon the wheel was $37.18/.40^2$ or 232.38 Newtons.

The scores of dynamic strength were repeated twice on each of three selected pulleys. The pulleys selected had equivalent masses of 118.40 Kgms., 46.25 Kgms., and 24.46 Kgms. These three pulleys of varying equivalent masses were selected to enable the investigator to establish the reliability of the machine by varying the difficulty of the force required of the subject to accelerate the wheel. The subject was seated and instructed to extend the preferred arm and hold the handle of the fine aircraft control cable which was wound around the pulley selected. On the command "pull" the subject pulled the handle directly toward the shoulder by flexing the forearm without turning the body or leaning away from the wheel. The pull was continued until the wire fell off of the pulley. Simultaneously with the command "pull", the investigator turned on the brush recorder. Any effort of the subject which was deemed incorrect by the investigator was repeated. If the subject was unable to execute the test after several trials she was excluded from the study.

## Treatment of the Data

A recording form was developed in order to record information about the subjects, the anthropometric measurements of the forearm flexors, and scores on the dynamic strength test. The information included on this form was: social security number, age in years to nearest birthday, classification in college, major sequence, height, and weight. Obvious visual ancestral differentiations were coded as follows: the circle signified Caucasian; triangle, Negroid; square, Latin American; and the hexagon, Oriental.

The following statistical and/or arithmetical computations were calculated from these data:

1. Number of subjects, mean, range, standard error of the mean, and standard deviation of the scores of dynamic strength and measurements of the forearm flexors.
2. Pearson's Product-Moment Correlation between the scores of dynamic strength and measurements of the forearm flexors.
3. Test of significance of the correlation coefficient.
4. Reliability of scores of dynamic strength and measurements of the forearm flexors utilizing the

Test-Retest method.

The details of the statistical program are included in the Appendix on page 53.

## Summary

In Chapter II the investigator presented a detailed discussion of the procedures followed in the development of this study under the following major headings: Sources of Data, Preliminary Procedures, Procedures for Obtaining Subjects, Description and Techniques for Obtaining Measurements of the Forearm Flexors and Scores of Dynamic Strength on the Inertia Wheel, Treatment of the Data, and Summary.

Chapter III contains the results of the data collected during the present study.

# CHAPTER III

# ANALYSIS OF THE DATA

## Introduction

In this chapter, the results of the investigation utilizing 100 subjects are shown in tabular form and interpreted in a brief discussion. The arm measurements were recorded in centimeters and will be reported in this unit of measurement. The scores resulting from the trials on the Inertia Wheel were recorded in Newtons and will be reported in this unit of measurement.

## Analysis of Data

Table 2 on the next page presents the subjects utilized in this study classified according to academic year. Ages of the subjects ranged from eighteen years to twenty-four years.

Measurements of the upper arm are presented in Table 3, page 30, of the study. The range of the upper arm dimensions was found to be from 20.3 centimeters to 29.9 centimeters with a mean upper arm circumference of 25.5 centimeters. The standard deviation of 4.10 indicated that all of the upper arm measurements were two standard deviations from the mean and the curve for the group was platykurtic.

TABLE 2

IDENTIFICATION OF SUBJECTS BY ACADEMIC YEAR

| Classification | N |
|---|---|
| Graduates | 17 |
| Seniors | 23 |
| Juniors | 16 |
| Sophomores | 22 |
| Freshmen | 22 |
| Total Subjects | 100 |

TABLE 3

MEASUREMENTS OF THE UPPER ARM

| Mean | Range | SD | SE | Reliability* |
|---|---|---|---|---|
| 25.5 cms. | 20.3 - 29.9 cms. | 4.10 | .44 | .99 |

*Reliability was computed through the Test-Retest method utilizing thirty subjects.

The reliability coefficient reported in Table 3 was based upon the test-retest method utilizing thirty of the one hundred subjects who participated in the study. The Pearson Product Moment technique for correlation was employed. The investigator remeasured the upper arm of thirty of the one hundred subjects two days after the first measurement was taken and the resulting reliability coefficient reported, .99, is "excellent" according to Barrow and McGee.[1]

The reliability coefficients of the inertia wheel as an instrument for measuring dynamic strength of the forearm flexors is reported in Table 4, page 32. The initial trial and second trial on the inertia wheel were performed by all the subjects in this study on the same day within a time period which did not exceed thirty minutes. The reliability coefficients were computed through the test-retest method. According to Barrow and McGee, the reliability coefficients reported of .80 and .87 are both "acceptable", and the reliability coefficient of .90 is "very good".[2] A study of Table 4 reveals that the reliability coefficients increase as the equivalent mass of the pulleys increase.

Also reported in Table 4 are the mean, range, standard deviation, and standard error of the mean computed from the data yielded through the initial trial and the second trial on the inertia wheel. A study of Table 4 reveals that the subjects did not exhibit significant change in their scores from the initial trial to the second trial on the inertia wheel. Pulley #3 yielded scores which ranged from 137.50 to 474.23 Newtons with a mean of 278.84 Newtons on the initial trial and 110.52 to 474.23 Newtons with a mean of 279.48 Newtons on the second trial. The standard deviation of 72.16 on the

[1]Barrow and McGee, *Measurement in Physical Education*, p. 42.

[2]*Ibid*.

TABLE 4

SCORES OBTAINED ON THE INERTIA WHEEL ON THE INITIAL AND SECOND TRIAL*

| Pulley | Equivalent Mass | Mean | | Range | | SD | | $SD_1-SD_2$ | SE | | $SE_1-SE_2$ | Reliability** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1st | 2nd | 1st | 2nd | 1st | 2nd | | 1st | 2nd | | |
| #3 | 118.40 Kgms. | 278.84 | 279.48 | 137.50-474.23 | 110.52-474.23 | 72.16 | 75.35 | 3.19 | 7.22 | 7.54 | .32 | .90 |
| #5 | 46.25 Kgms. | 136.27 | 136.27 | 56.74-226.95 | 64.56-226.95 | 36.80 | 37.20 | .40 | 3.68 | 3.72 | .04 | .87 |
| #7 | 24.46 Kgms. | 84.32 | 83.40 | 38.80-155.19 | 38.80 130.40 | 22.70 | 21.80 | .90 | 2.27 | 2.18 | .09 | .80 |

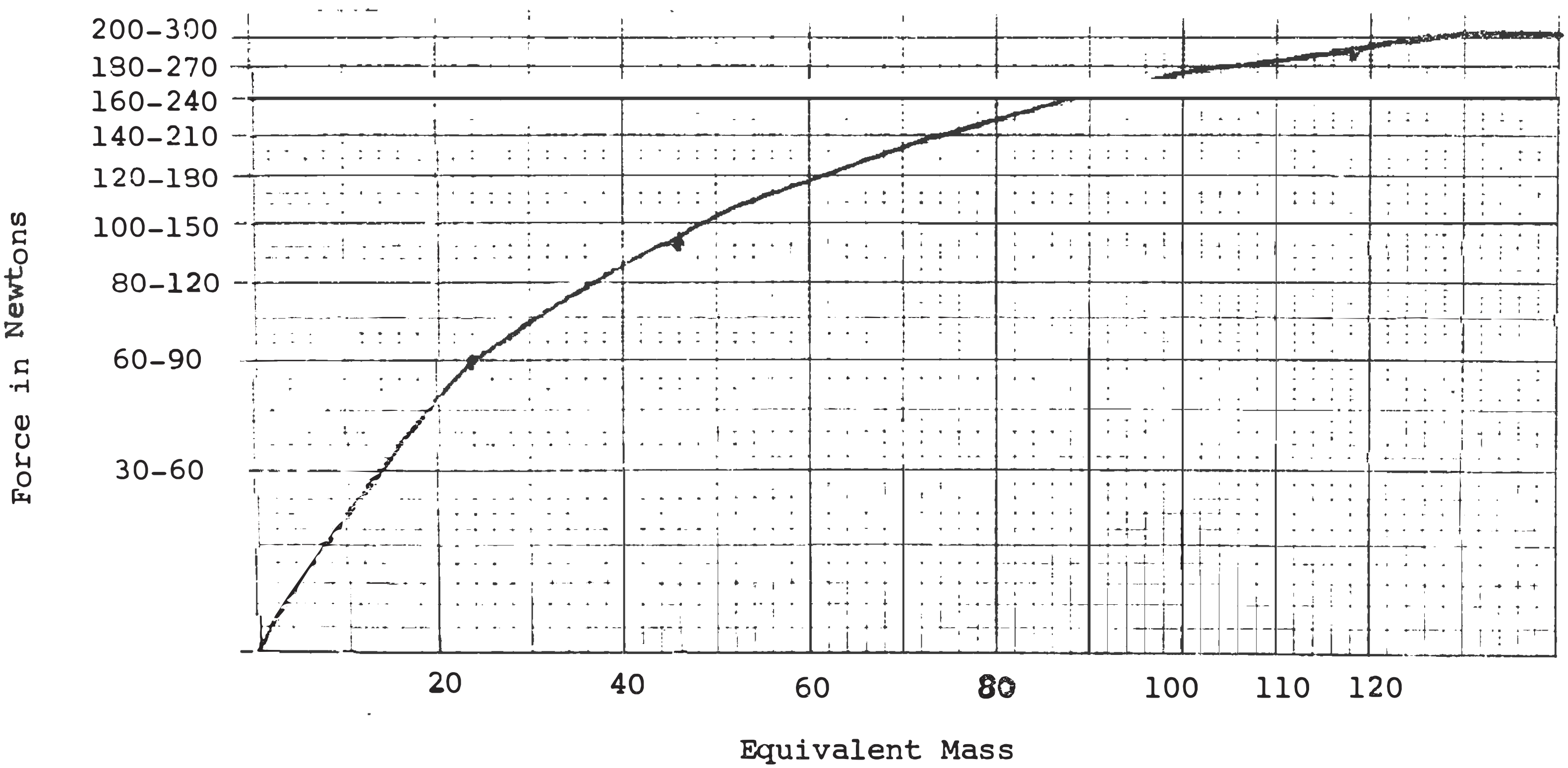
*Scores are reported in Newtons.
**Reliability was computed through the Test-Retest method utilizing 100 subjects.

initial trial and 75.35 on the second trial reveals that the group variance was low throughout the two trials, but that individual variability on the second trial was greater than on the initial trial. Pulley #5 yielded scores which ranged from 56.74 to 226.95 Newtons with a mean of 136.27 Newtons on the initial trial and 64.56 to 226.95 Newtons with a mean of 136.27 Newtons on the second trial. The difference in the standard deviations of .40 (36.80 vs 37.20) between trials was very slight; however, more individual variability was evident on the second trial than on the initial trial. Pulley #7 yielded scores which ranged from 38.80 to 155.19 Newtons with a mean of 84.32 Newtons on the initial trial and 38.80 to 130.40 Newtons with a mean of 83.40 Newtons on the second trial. The standard deviation of 22.70 on the initial trial and 21.80 on the second trial reveals that the group variance was low throughout the two trials but that individual variability was greater on the initial trial than on the second trial.

In addition to Table 4, a graphic representation of the force produced on each of the pulleys relevant to the equivalent mass is presented in Plate I, page 34. A study of Plate I reveals that as the equivalent mass of the pulley increases the force produced also increases. However, as Table 4 reveals, as the equivalent mass of the pulley increases the force produced shows a wider range of scores.

The relation between the girth of the upper arm and the dynamic strength of the forearm flexors measured by the inertia wheel is presented in Table 5, page 35 of the study. A coefficient of correlation was obtained for each of the three pulleys plus a coefficient of correlation for the total

PLATE I




RELATION BETWEEN FORCE DEVELOPMENT AND EQUIVALENT MASS FOR 100 FEMALE SUBJECTS

TABLE 5

RELATION OF GIRTH OF UPPER ARM AND DYNAMIC STRENGTH OF THE FOREARM FLEXORS MEASURED BY THE INERTIA WHEEL

| | Mean | Range | SD | SE |
|---|---|---|---|---|
| Arm Dimensions | 25.5 cms. | 20.3 - 29.9 | 4.10 | .41 |
| Pulley #3 | 279.48 Newtons | 110.52 - 474.23 | 2.88 | .28 |
| Pulley #5 | 136.27 Newtons | 56.74 - 226.95 | 3.71 | .37 |
| Pulley #7 | 84.32 Newtons | 38.80 - 155.19 | 2.33 | .23 |
| Total of Best Scores on Wheel | 522.24 Newtons | 279.63 - 828.84 | 5.15 | .52 |

| | r | df | t | .05 | .01 |
|---|---|---|---|---|---|
| Pulley #3 | .43 | 99 | 5.22 | 1.98 | 2.63 |
| Pulley #5 | .37 | 99 | 4.23 | 1.98 | 2.63 |
| Pulley #7 | .34 | 99 | 3.81 | 1.98 | 2.63 |
| Total of Best Scores on Wheel | .41 | 99 | 4.45 | 1.98 | 2.63 |

of the best scores acquired by each individual subject on the three pulleys. The Pearson Product Moment Method of Correlation was applied to the data. The data yielded coefficients of correlation of .43 on Pulley #3, .37 on Pulley #5, and .34 on Pulley #7. Koenker interprets coefficients of correlation of .34 and .37 as showing "slight relationship" and .43 as a "fair degree of relationship."[1] The total of the best scores acquired by each individual subject on the three pulleys yielded a coefficient of correlation of .41; interpreted by Koenker as a "fair degree of relationship."[2] However, Barrow and McGee interpret a coefficient of correlation of .60 as "questionable (except for groups)" and give no interpretation for a coefficient of correlation of .41.[3] The investigator concluded that the coefficient of correlation of .41 indicates a slight relationship between the girth of the upper arm and the dynamic strength of the forearm flexors measured by the inertia wheel. A test of significance was applied to the coefficients of correlation and yielded values of 5.22 for Pulley #3, 4.23 for Pulley #5, 3.81 for Pulley #7, and 4.45 for the total of the best scores. Since all the values of t were greater than the .01 level of probability with 99 degrees of freedom (2.63) the correlations, although slight, show a significant relationship and should not be interpreted as due to chance.

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[1]Robert H. Koenker, Simplified Statistics (Bloomington Illinois: McKnight & McKnight Publishing Company, 1961), p. 52.

[2]Ibid.

[3]Barrow and McGee, Measurement in Physical Education, p. 42.

## Summary

In this chapter of the thesis, the investigator presented an analysis of the data collected for this study.

The coefficients of reliability for the dynamic strength test on the inertia wheel were .80, .87, and .90. The data collected from the scores of the dynamic strength test on the inertia wheel and the measurements of the upper arm were treated by means of the Pearson Product Moment Method of Correlation. This treatment of the data resulted in the following finding. The girth of the forearm flexors correlated moderately with the dynamic strength scores obtained on the inertia wheel. A test of significance was applied to the correlation coefficients and indicated that the relationship between the two variables was significant at the .01 level and could not have been due to chance.

Chapter IV presents a summary of the entire study, the conclusions of the investigation, implications of the study, and recommendations for future studies.

CHAPTER IV

# SUMMARY, CONCLUSION, IMPLICATIONS, AND RECOMMENDATIONS FOR FUTURE STUDIES

## Summary

Muscle strength is the ultimate source of all human labor. Measures of dynamic strength are extremely rare; consequently, the efficiency of muscle groups during activity is inferred rather than measured objectively. Utilizing the principle of the Hill Inertia Wheel, dynamic strength can be measured by calculating the maximum force produced by the forearm flexors in moving the wheel. Since muscle strength is essential for man's effectiveness in completing everyday activities, it is important to find reliable methods of evaluating dynamic strength.

One of the principal criteria for evaluating the force producing capabilities of the muscle is the girth of the muscle. Although many factors influence the work performed by any muscle, the girth of the muscle remains one important component for evaluating work performed.

## Statement of the Problem

The present investigation entailed a study of the relationship between the dynamic strength of the forearm flexors measured with an inertia wheel and the girth of the upper arm of 100 women enrolled in the Texas Woman's University during the academic year of 1968-1969.

## Procedures

The data relating to the dynamic strength of the forearm flexors were collected through the administration of the strength test on the inertia wheel. The strength test was repeated by each subject within a thirty minute time period in order to examine the reliability of the dynamic strength test. The data relating to the girth of the upper arm were collected by measuring the upper arm of each subject with a Gulick anthropometric tape. Measurements of the upper arm were taken around the greatest prominence of the upper arm when the upper arm was raised to shoulder height, the forearm flexors contracted and the hand supinated. The measurements of the upper arm were repeated on thirty of the one hundred subjects to examine the reliability of the measurements.

## Discussion of Findings

The coefficient of correlation for reliability of the measurement of the upper arm was computed through the test-retest method utilizing thirty of the one hundred subjects participating in the study. The resulting coefficient of .99 was "excellent". The coefficients of correlation for the reliability of the scores obtained from the dynamic strength test on the inertia wheel were computed through the test-retest method utilizing all of the subjects participating in the study. The resulting coefficients of .80, .87, and .90

ranged from "acceptable" to "very good". The relationship between the dynamic strength of the forearm flexors measured by the inertia wheel and the girth of the upper arm was determined by means of the Pearson Product Moment Method of Correlation. The data yielded correlation coefficients of .43 on Pulley #3, .37 on Pulley #5, .34 on Pulley #7, and .41 when the total of the best scores acquired by each individual subject were treated. Such moderate scores are not considered adequate for predictive purposes. A test of significance was applied to the correlation coefficients and yielded values which were greater than the .01 level of probability with 99 degrees of freedom which indicated that the correlations showed a significant relationship and should not be considered due to chance.

This study shows that there is a definite trend for the performance of the subjects to improve their performance with the greatest equivalent mass. This factor was first noted by Hill[1] who studied the relation between the external work and contraction time of the forearm flexors with the inertia wheel. Lupton[2] in his work reaffirmed the original conclusions of Hill[3] that when the equivalent mass is low and the velocity of muscular shortening very rapid a large amount of the

[1]Hill, "Maximum Work and Mechanical Efficiency of Human Muscles," pp. 19-41.

[2]Lupton, "Relation Between External Work Produced and Time Occupied in Muscular Contraction," pp. 68-75.

[3]Hill, "Maximum Work and Mechanical Efficiency of Human Muscles," pp. 19-41.

muscular energy is dissipated as heat with a great loss in external work production. Theoretically, in order to obtain the maximum work from a contracting muscle it would be necessary to oppose its contraction at every stage by a force which it is only just able to overcome.[1]

Ikai[2] correlated the equivalent mass of the inertia wheel and the force developed by the knee extensors using four different pulleys. At the lowest equivalent mass the correlation was r = .708 but improved to r = .825 with the largest equivalent mass. This study also indicates clearly that for any given group of subjects there is an increased efficiency of muscular force production when the velocity of shortening is reduced to a minimum (e.g.) the largest equivalent mass.

Training obviously plays a significant role in performance capacity which may be independent of gross muscular dimensions. The difficulty in assessing the "true muscle volume" via the anthropometric tape manifests itself when one must consider the fact that the tape encompasses bone, muscle, fat, and in the upper arm perhaps one extensor (triceps) rather than only considering flexor muscle.

The performance pattern exhibited by the women subjects in this study is in agreement with the general observations of male subjects made by other investigators, none of

[1] Ibid., p. 21

[2] Ikai, "Work Capacity of the Japanese Related to Age and Sex," pp. 100-105.

whom actually measured the muscle girth, and tried to relate this factor to performance. Ikai was the only investigator to correlate force production with the equivalent mass of the wheel pulleys of his subjects. However, Hill, Lupton and others have provided graphic representations of the results of their experiments to illustrate the same general principles.

There is a definite need to pursue this line of investigation using a limited number of subjects who, after the initial test period, are given a specific arm flexor muscle training program. Another consideration of significance would be to supplement the circumferential measurements of the forearm flexors with x-rays of the upper arm to assess the contribution of fat and bone to the total volume of the muscle which the anthropometric tape does not adequately provide.

Innervation of muscle is enhanced by training even though the muscle girth may change relatively little. One could therefore expect an improvement in the correlation of force development with subjects on the inertia wheel with extensive training, perhaps in the absence of significant girth changes. It is imperative in all of these investigations that the investigator utilize a variety of equivalent masses so that each subject has the opportunity of working at his or her optimal rate of muscular contraction. Static strength testing may be misleading since all of the factors associated with heat dissipation and force production with a given muscle system cannot be brought into play and in actual practice in our daily activities all force production is of a dynamic nature.

## Conclusion

The findings of the study led the investigator to the conclusion: There is a significant degree of positive relationship between the dynamic strength of the forearm flexors measured by the inertia wheel and the girth of the upper arm of college women. Futhermore, the dynamic strength test utilizing the inertia wheel is a reliable test for measuring the dynamic strength of the forearm flexors of the 100 college women who participated in the study.

## Implications of the Study

The results of the investigation indicate that dynamic strength can be measured by utilizing the principle of the Hill Inertia Wheel. Although many methods of measuring dynamic strength have been developed, the measurement of dynamic strength without involving mastery of some skill has been a major concern. The inertia wheel is an instrument that may be utilized to study dynamic strength without involving the development of a skill. The significant degree of positive relationship between the girth of the upper arm and the dynamic strength of the forearm flexors indicates that dimensional measurements of muscle groups give some indication of the force producing capabilities of that muscle group but is not sufficient to consider for predictive purposes. Motivation factors may be the most important single criterion in strength testing, especially for women, and at present there is not an acceptable way to measure this factor.

Regardless of the technique used to study dynamic strength, it is of the utmost importance that muscle groups during movement be measured objectively. It is the responsibility of the physical education instructor to have knowledge of the best techniques available to study and develop dynamic strength in their students.

## Recommendations for Future Studies

The following suggestions have been recommended for future investigations:

1. A study of the relationship between the dynamic strength of the forearm flexors and the length of the lever performing the work.

2. A comparison of the dynamic strength of the forearm flexors and the static strength of the forearm flexors.

3. A study of the relationship between the dynamic strength of the forearm flexors and the volume of the upper arm girth measured via x-ray techniques.

4. A comparison of the dynamic strength and the static strength of the forearm flexors before and after participation in a training program utilizing the inertia wheel.

5. A comparative study of the dynamic strength of students rated as having high and low skill in the performance of some simple motor task such as chins or dips.

6. A correlational study of the strength of the various muscle groups in the extremities of the body.

# APPENDIX

DATA SHEET FOR INDIVIDUAL SUBJECTS

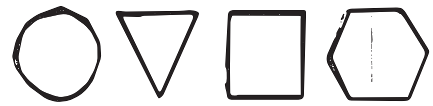
Name ______________________________

Social Security No. ________________

Age in Years ______________________

Classification _____________________

Major Sequence ____________________



Weight __________ Height __________

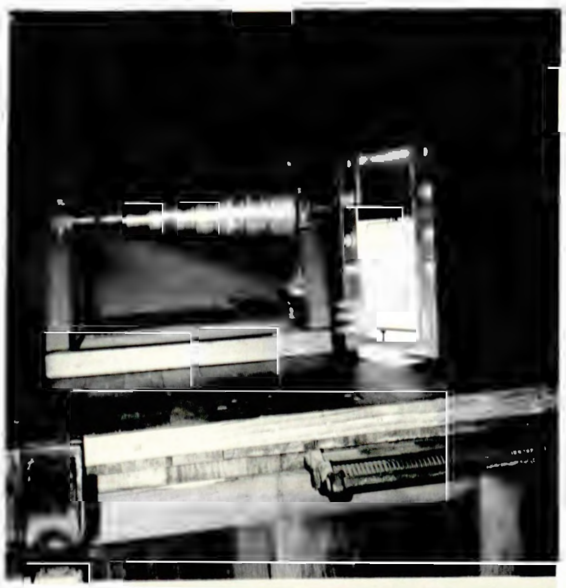
Biceps Circumference in Centimeters:

Measurement #1 _____ #2 _____ #3 ______ Mean _____

Scores on Inertia Wheel:

| | 1st | 2nd | Best |
|---|---|---|---|
| Pulley #3 | ________ | ________ | ________ |
| Pulley #5 | ________ | ________ | ________ |
| Pulley #7 | ________ | ________ | ________ |
| TOTAL | ________ | ________ | ________ |

PLATE II



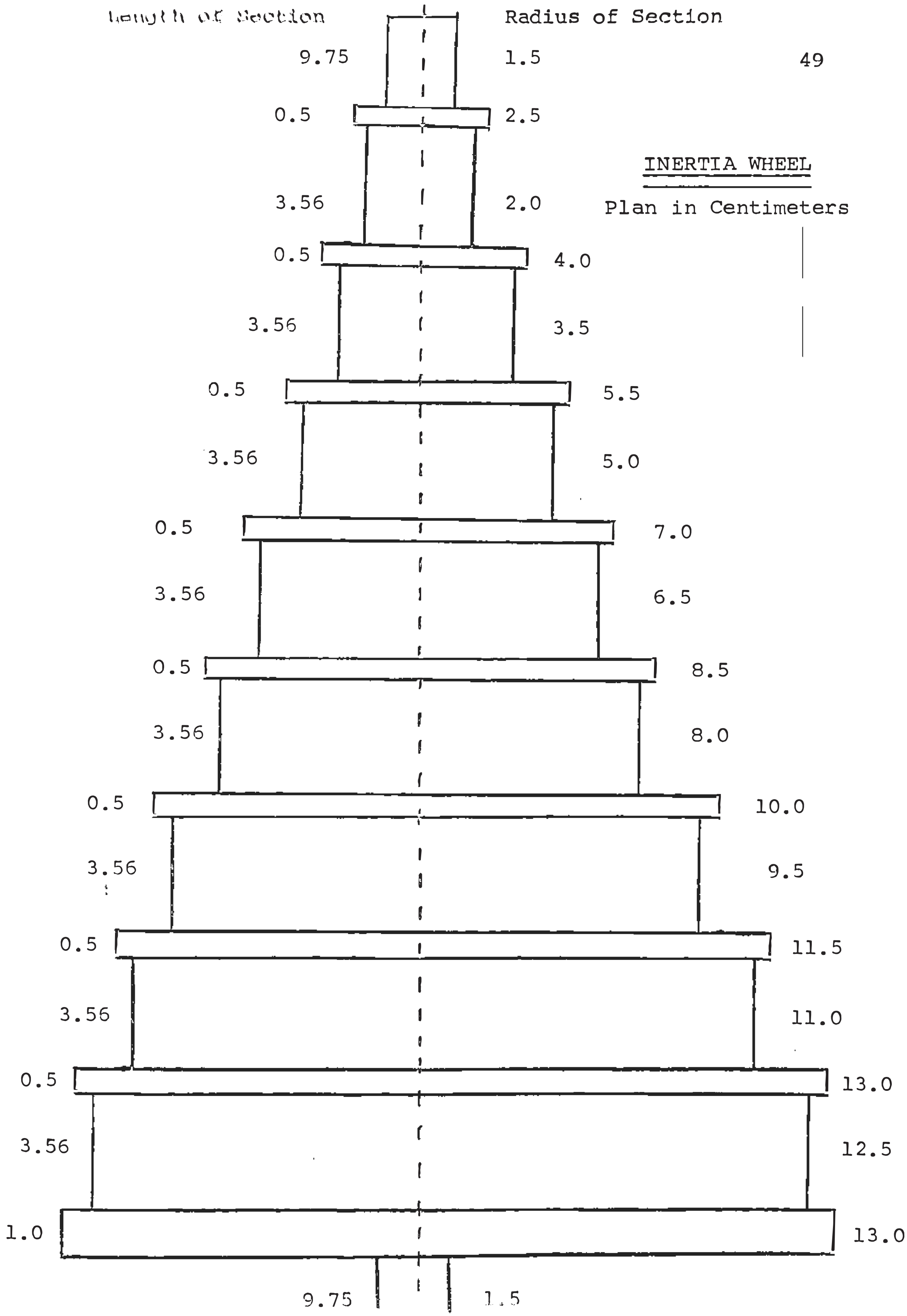
INERTIA WHEEL CO ST UCTED FOR THIS STUDY

PLATE III

POSITIO OF ARM FOR PULL ON WHEEL

## INERTIA WHEEL

Plan in Centimeters



MASS OF INERTIA WHEEL

| Section | radius in cms. | $radius^2$ | length | $r^2 l$ | $\pi r^2 l$ | Volume in $cm^3$ | Total Mass in gms. |
|---|---|---|---|---|---|---|---|
| 1 | 1.5 | 2.25 | 9.75 | 21.92 | 68.5 | 69 | 515 |
| 2 | 2.5 | 6.25 | 0.5 | 3.13 | 9.8 | 10 | 75 |
| 3 | 2.0 | 4.00 | 3.56 | 14.24 | 44.6 | 45 | 335 |
| 4 | 4.0 | 16.00 | 0.5 | 8.0 | 25.1 | 25 | 187 |
| 5 | 3.5 | 12.25 | 3.56 | 43.6 | 137.0 | 137 | 1020 |
| 6 | 5.5 | 30.25 | 0.5 | 15.1 | 47.4 | 47 | 350 |
| 7 | 5.0 | 25.00 | 3.56 | 89.0 | 279.0 | 279 | 2080 |
| 8 | 7.0 | 49.00 | 0.5 | 24.5 | 76.9 | 77 | 574 |
| 9 | 6.5 | 42.25 | 3.56 | 150.3 | 472.0 | 472 | 3520 |
| 10 | 8.5 | 72.25 | 0.5 | 36.1 | 114.0 | 114 | 850 |
| 11 | 8.0 | 64.00 | 3.56 | 227.5 | 715.0 | 715 | 5330 |
| 12 | 10.0 | 100.00 | 0.5 | 50.0 | 157.0 | 157 | 1170 |

MASS OF INERTIA WHEEL - continued

| Section | radius in cms. | $radius^2$ | length | $r^2l$ | $\pi r^2 l$ | Volume in $cm^3$ | Total Mass in gms. |
|---|---|---|---|---|---|---|---|
| 13 | 9.5 | 90.25 | 3.56 | 321.0 | 1010.0 | 1010 | 7550 |
| 14 | 11.5 | 132.25 | 0.5 | 66.1 | 207.0 | 207 | 1550 |
| 15 | 11.0 | 121.00 | 3.56 | 431.0 | 1350.0 | 1350 | 10080 |
| 16 | 13.0 | 169.00 | 0.5 | 84.5 | 265.0 | 265 | 1980 |
| 17 | 12.5 | 156.25 | 3.56 | 556.0 | 1740.0 | 1740 | 13000 |
| 18 | 13.0 | 169.00 | 1.0 | 169.0 | 531.0 | 531 | 3960 |
| 19 | 1.5 | 2.25 | 9.75 | 21.9 | 68.5 | 69 | 515 |
| | | | | | | 7319 - Volume | 54641 - Mass Density |

MOMENT OF INERTIA OF WHEEL*

| Section | Mass in grams | radius in cms. | $radius^2$ | $\frac{1}{2}mr^2$ in gm. cm. |
|---|---|---|---|---|
| 1 | 515 | 1.5 | 2.25 | 580 |
| 2 | 75 | 2.5 | 6.25 | 234 |
| 3 | 335 | 2.0 | 4.0 | 670 |
| 4 | 187 | 4.0 | 16.0 | 1496 |
| 5 | 1020 | 3.5 | 12.25 | 6250 |
| 6 | 350 | 5.5 | 30.25 | 5290 |
| 7 | 2080 | 5.0 | 25.0 | 26000 |
| 8 | 574 | 7.0 | 49.0 | 14050 |
| 9 | 3520 | 6.5 | 42.25 | 74400 |
| 10 | 850 | 8.5 | 72.25 | 30700 |
| 11 | 5330 | 8.0 | 64.0 | 170700 |
| 12 | 1170 | 10.0 | 100.0 | 58500 |
| 13 | 7550 | 9.5 | 90.25 | 340500 |
| 14 | 1550 | 11.5 | 132.25 | 102500 |
| 15 | 10080 | 11.0 | 121.0 | 610000 |
| 16 | 1980 | 13.0 | 169.0 | 167200 |
| 17 | 13000 | 12.5 | 156.25 | 1015000 |
| 18 | 3960 | 13.0 | 169.0 | 334000 |
| 19 | 515 | 1.5 | 2.25 | 580 |
| | | | | 2958600 |

*$I = \frac{1}{2}$ mass x $radius^2$

Moment of Inertia = 2,958,600 = $29.6 \times 10^5$ $gm\text{-}cm^2$ or $29.6 \times 10^{-2}$ $Kgm\text{-}m^2$

## STATISTICAL FORMULAE

Pearson Product-Moment Correlation to find the reliability of a test:[1]

$$r = \frac{N\ (\Sigma X'Y') - (\Sigma X')\ (\Sigma Y')}{\sqrt{\left[N(\Sigma X^2) - (\Sigma X)^2\right]\left[N(\Sigma Y^2) - (\Sigma Y)^2\right]}}$$

Pearson Product-Moment Coefficient of Correlation:[2]

$$r = \frac{\frac{\Sigma XY}{N} - (Cy\ Cx)}{(Sx)\ (Sy)}$$

t test for Significance of Correlation between two variables:[3]

$$t = \frac{r\sqrt{N - 2}}{\sqrt{1 - r^2}}$$

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[1]Koenker, _Simplified Statistics_, p. 57.

[2]Barrow and McGee, _Measurement in Physical Education_, p. 99.

[3]Koenker, _Simplified Statistics_, p. 60.

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