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AN ELECTROMYOGRAPHIC INVESTIGATION OF MUSCLE ACTION POTENTIALS OF SELECTED MUSCLES CONTRACTING ISOMETRICALLY AT VARIOUS JOINT ANGLES

by

Charles Bennett Williamson

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Approved by

Dissertation Advisor

APPROVAL SHEET

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WILLIAMSON, CHARLES BENNETT. An Electromyographic Investigation of Muscle Action Potentials of Selected Muscles Contracting Isometrically at Various Joint Angles. (1972) Directed by: Dr. Frank Pleasants. pp. 94

The purpose of this study was to investigate the muscle action potentials present in the biceps brachii, the triceps brachii, the biceps femoris, and the rectus femoris as these muscles were contracted isometrically at 90°, 105°, 120°, 135°, 150°, and 165° of elbow and knee flexion and extension. In addition to these angles the triceps brachii were also investigated at angles of 45°, 60°, and 75°. Lengths of the upper arms and legs were correlated with the angles of maximum amounts of muscle action potentials in each muscle. Muscle action potentials were recorded for both the dominant and nondominant sides of the body.

Electromyograms from twenty-five male subjects were recorded for each muscle at each angle. Angles of maximum muscle action potentials were determined by the amplitude of pen deflection.

Based on the data collected and within the limitations of this study, the following conclusions are warranted:

1. The angles of maximum muscle action potentials vary with the individual, therefore, no common angle exists which provides maximum strength training benefits.

2. There are no distinct similarities in regard to angles at which maximum muscle action potentials occur between dominant and nondominant muscles.

3. Limb length is not a factor in determining the location of angles at which maximum muscle action potentials would occur.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Approximately fifty years ago the use of weights for strength training for athletes was hardly in existence. There were many ideas about detrimental effects of weight training upon athletes and their performance with little, if any, evidence to indicate that weight training could be beneficial. Delorme and Watkins (4) were the first to publish significant material in this area and make known some of the benefits of strength training programs. Since this initial work, progressive resistance exercise programs have undergone a considerable amount of critical examination and experimentation by many researchers in attempts to find the most efficient methods of strength training. Hettinger and Muller (3) caused quite a bit of controversy in the strength training field when they published their findings in the area of isometric strength training. They claimed almost unbelievable results with their new technique of training. As a result there were more concentrated efforts among researchers attempting to verify and improve upon the initial findings. Serious errors were found in Hettinger's and Muller's original work, but isometric strength training was shown to have benefits which could be used advantageously in strength training programs.

Isometric weight training involves contraction of skeletal muscle at a fixed position in regard to joint angle. Individual muscles cannot act with constant force throughout an entire movement due to changes in joint angles and positions of the muscle (1), but there appears to be a position at which a muscle can function best in its application of strength (2). Research also indicates that strength gains as a result of isometric training vary with the angles used in training (18, 27, 53, 54).

The relatively new technique of electromyography could help determine the existence or non-existence of optimal joint angles for isometric strength training. This could be done by measuring the muscle action potentials developed in isometrically contracting muscle. Research indicates that muscle action potentials developed during isometric contractions have a direct linear relationship with the degree of tension in the muscle (6, 31, 36, 42). The degree of tension is determined by the number of motor units involved in the contraction. Therefore, the point at which the greatest muscle action potentials are recorded in a muscle would be the point at which the greatest number of motor units are being used. This same point, or position, would be the position at which the maximum number of motor units could be employed in a single isometric contraction. The significance of such information would greatly enhance strength training programs for athletes and laymen and programs designed for hypertrophy and rehabilitation of underdeveloped or injured muscle.

Statement of Purpose

The purpose of this study was to investigate the muscle action potentials present in the biceps brachii, the triceps brachii, the biceps femoris, and the rectus femoris muscles when the joints which these muscles actuate were placed under maximum isometric flexion or extension at selected angles.

The following related factors were investigated:

1. The relationships between the lengths of both segments of the arms and legs and the angle of maximum muscle action potentials.

2. The dominant and nondominant limbs in regard to joint angles of maximum muscle action potentials.

Limitations of the Study

The study was limited to twenty-five college males ranging from age eighteen years to twenty-four years. The subjects had no history of severe muscle or bone injuries, malfunctions, or limited use of the muscles, bones and joints involved in the study.

Definition of Terms

<u>Isometric Contraction</u>

The contraction of muscle with no change in length of the muscle.

<u>Maximum Contraction</u>

An effort by each subject to generate maximum tension in the muscle by contracting against resistance with a maximum effort. (The instructions given to the subjects were "...to pull as hard as you can until you feel that you have given a maximum effort.")

<u>Maximum Isometric Flexion</u>

Subjection of a joint to tension as applied by a maximum effort of muscles flexing that joint with no movement of the joint.

<u>Maximum Isometric Extension</u>

Subjection of a joint to tension as applied by a maximum effort of muscles extending that joint with no movement of the joint.

<u>Electromyography</u>

The recording of muscle action potentials.

<u>Muscle Action Potentials (MAPS)</u>

Electrical changes which accompany contraction of muscle tissue.

Electromyogram (EMG)

Record of muscle action potentials.

Motor Point

Surface area of the skin especially sensitive to electrical stimulation due to entrance of nerves into muscle or regions of great density of terminal elements (8).

CHAPTER II

REVIEW OF THE LITERATURE

Electromyography

Near the end of the eighteenth century Galvani (1) discovered what he called "animal electricity." There were many initial skepticisms regarding this phenomena of electrical properties of nerve and muscle, but investigations were soon underway to find the structures and mechanisms responsible for this electrical activity.

Early kinesiological evaluations of muscle were made by inspection, palpation, or by electrical stimulation of the muscle and observation of the action which took place. As electrical technology advanced, so did the technique and equipment used in electromyography, Adrian and Bronk (9) invented the coaxial needle and made possible the study of the activity of motor units. With refinements such as this, single motor units have been isolated and their action observed and recorded (1). The intramuscular or needle electrodes have been used quite extensively by physicians seeking causes of certain pathological conditions as well as enabling them to understand the precise actions of particular muscles. Data gathered by electromyographic techniques have answered many kinesiological questions as well as correcting many earlier false concepts related to muscle involvement.

Surface electrodes have been developed and are more suitable to needs of physical educators and others who are interested in kinesiological functions of muscle (3). This type of study, quantitative electromyography, is concerned with the total activity of the whole muscle.

Integrated Electromyography

The electrical action which takes place during muscle contraction can be recorded by loud speaker, oscilliscope, or on paper in graph form. The graph of muscle action potentials (EMG) is recorded with an ink writing pen which deflects and records a spike of each voltage wave released by contracting motor units. The height of the spike, or amplitude, depends upon the amount of electrical energy released by the muscle. Through the use of an integrator unit, the simultaneous release of electrical energy by many contracting motor units of a muscle is picked up and recorded as the summation of the action potentials of the total muscle action (60). By proper placement of the surface electrodes it is possible to determine the degree of involvement of a particular muscle in specific movements.

Related Studies

McCloy (38) was one of the first physical educators to study the action of different muscles with the use of electromyography while Slater-Hammel (46, 47) was one of the first to study the actions of various muscles in a complex movement. One of Slater-Hammel's early studies was an investigation of muscle involvement in the golf stroke and was soon followed by a similar study of the complex movements in the tennis strokes.

Other studies (44, 48, 51, 52, 56, 59, 61, 64, 65, 66) have been conducted to determine the specific kinesological functions of various muscles or groups of muscles acting upon a particular joint. Most of the large muscles in the body have been investigated in this manner with the use of electromyography. Other studies have been conducted to determine the action of specific muscles involved in the execution of certain sports skills. Herman (57) investigated major muscle involvement in the execution of the shotput, and Kitzman (58) conducted a similar study of the baseball batting swing. Each study determined which muscles play the major roles in the execution of the skills, and concluded that for better performance, these same muscles should be strengthened through a weight training program. Heintz (56) compared action potentials of the three digitations of the trapezius during physical education activities such as pull-ups, grip strength, push-ups, and the tennis and badminton forehand and backhand strokes. Hinson (29) investigated the push-up as performed by women, and Randall investigated two methods of chinning (60).

In other studies, Sills and Olson (45) recorded slight action potentials in an unexercised limb while the contralateral limb was being exercised, and Schramm (63) verified the presence of action potentials in muscles involved in a skill which was mentally performed. Bos and Blosser (13) studied selected isometric exercises of the thigh muscles to determine which was most effective, and Flint and Gudgell (26) conducted a similar study to determine the effectiveness of various exercises designed to strengthen the rectus abdominus and external oblique muscles. Joseph (32, 33, 34) has studied the roles of leg and thigh muscles used in posture and the patterns of muscle activity in walking as influenced by high heels on women's shoes. De Vries (20, 21, 22, 23) has conducted some interesting studies regarding the presence of action potentials in injured or distressed muscle. He found that static stretching of distressed muscle caused a reduction of action potentials which was associated by a corresponding relief from discomfort in some of the subjects.

Substantial evidence has been found to verify the existence of a linear relationship between the amount of muscle action potentials and the degree of tension in muscle subjected to isometric contraction (1, 10, 24, 31, 35, 36, 42). As force of the contraction increases, the amplitude of the observed action potentials increases in height when measurements are taken by electromyographic techniques.

This indicates a corresponding increase in the number of motor units being employed in the contraction. Inman and others (31) and Ralston (42) have stated that the integrated EMG may be used as an index of the degree of tension in muscles undergoing isometric contraction.

Isometric Exercises

Isometric exercises caused quite a bit of controversy in the early stages of the development of this type of strength training program. Probably the reason for this controversy was that the initial research produced almost unbelievable conclusions (39). These claims contradicted popular strength training methods and everyday practice and experience. The original research was not altogether correct, but it did prompt many researchers to investigate the possibilities of isometric training programs. This research proved fruitful, and now it is common knowledge that isometric exercises or isometric weight training will produce favorable gains in strength (1, 11, 12, 15, 19, 28, 43, 50, 55).

Liberson, Dondey, and Asa (35) investigated brief repeated isometric exercises using electromyographic techniques. They found that muscle action potentials were greater in the biceps and triceps during isometric exercises than during isotonic exercises. Their findings indicated that at no moment during the classical resistive exercises did the amount of muscle action potentials approach the value which was obtained during isometric exercises. They concluded that the greater activation of the muscles during isometric exercises seem to contribute to the efficiency of the exercises.

Joint-Angle Studies

Some of the early criticism lodged at isometric strength training was that the training would be beneficial only at the specific joint angle where the training occurred. Studies have since shown that strength gains may be greater at some angles than others, but they also show that the benefits can be measured in terms of strength gains at other angles (12, 18, 27, 53, 54). Evidence indicates that certain muscles can exert more force when the muscle is near its "natural length" indicating that contraction at larger joint angles during flexion and smaller angles during extension would result in better performances. In his work with cable tension techniques and joint angle testing, Clarke (2) found the most effective angle for elbow extension in terms of force exerted to be 40°, elbow flexion 120°, knee extension 120°, and knee flexion 160°. Clarke's measurements were the results of a group of muscles acting upon a certain joint which indicates mechanical output of the muscles. With the possible exception of the knee flexors, this information indicates maximum performance when the muscles are in an elongated state rather than shortened to a considerable degree. Liberson, Dondey, and Asa (35) point out that during isometric strength training, angles at which the muscle loses its mechanical output and shortens to a significant degree should be avoided.

Anthropometric Studies

One of the initial areas of extensive research in physical education was in the area of anthropometric measurement. Many studies were conducted to determine relationships of anthropometric measures and certain factors in physical performance. Measurements were taken of the first five place winners of the Michigan Intercollegiate Track Meet in 1900 and compared with measurements of non-athletes (62). The most significant difference found was in the length of the lower legs. The lower legs of the athletes were longer in proportion to their upper legs than were the legs of the non-athletes.

Buskirk and others (14) concluded that changes in anthropometric measures of limbs would occur due to vigorous activity of that body part. Seven nationally ranked tennis players were compared to eleven soldiers, and it was clearly indicated that the dominant arm of the tennis players had increased in length, strength, muscle diameter, hand area, and wrist width as a result of the vigorous activity of the limb.

In correlating anthropometric measures with strength, the factor which usually has the highest correlation is the girth of the muscle involved. Tornvall (49) correlated isometric muscle strength with several anthropometric measurements and found body weight to be the highest correlation at 0.56. Tibial length only correlated 0.08 with the isometric strength of the leg muscles measured. Clarke (17) found a correlation of 0.34 between total length of the leg and strength of the leg lift. The same leg length had a 0.39 correlation with the back lift. In a similar study involving the arm, Clarke (16) found the length of the upper arm to correlate 0.47 with strength as measured by pull-ups and 0.42 as measured by push-ups. McCloy's Arm Strength Index was employed in the determination of arm strength scores.

Dominant-Nondominant Strength Studies

The review of literature reveals very little research regarding the differences, if any, in strength of the opposites sides of the body. Apparently, in contradiction to popular belief, only slight differences exist between strength of the two sides of the body (30). Martin (37) confirmed that there is less difference from the right to left side of the body than is commonly supposed. He studied 240 subjects and concluded that the percentage difference between the left and right sides of the body is neither great enough or constant enough to involve serious error if the two sides of the body are assumed to be equally strong.

In a study of twenty right dominant preschool age children, right grip strength was significantly stronger than left grip strength (41). The dominant hand was also less vulnerable to fatigue than was the nondominant hand. Elbel (25) compared right and left leg strength of 540 pilots and potential pilots. The potential pilots showed the mean strength of the left leg to be significantly greater than the mean strength of the right leg. The pilots showed the same difference in means, but it was not significant. No explanation for the differences was given.

As stated earlier the difference in strength of the two sides of the body vary only slightly rather than distinctly, however, vigorous use of a particular limb may definitely increase its strength over its contralateral segment (14).

No studies have been found in the literature comparing electromyographic differences in the dominant and nondominant sides of the body. It may not be possible to determine strength differences through electromyographic techniques. Ralston (42) has warned that this is a limitation of electromyography in the quantitative study of skeletal muscle function.

CHAPTER III

PROCEDURE

The purpose of this study was to investigate the muscle action potentials present in the biceps brachii, the triceps brachii, the biceps femoris, and the rectus femoris muscles when the joints which these muscles actuate were placed under maximum isometric flexion or extension at selected angles.

A pilot study, included in the Appendix, was conducted to solve problems and answer questions related to the study. The results of the pilot study, a description of the apparatus and electromyographic techniques used, and methods of selection and preparation of the subjects are explained below.

Pilot Study

Approximately six weeks were spent conducting the pilot study which is presented in detail in the Appendix.

Purpose of the Pilot Study

The purpose of the pilot study was twofold; one was to familiarize the writer with the use of the equipment and electromyographic procedures necessary to obtain the desired data, and the other purpose was to answer the following problems related to the study:

1. The range of angles to be investigated.

2. If an investigation of both the dominant and nondominant limbs in regard to joint angles of maximum muscle action potentials would be worthy of further study.

<u>Results of the Pilot Study</u>

The range of angles that were investigated as determined by the pilot study is presented later in this chapter. It was concluded that an investigation of the dominant and nondominant sides of the body in regard to joint angles of maximum muscle action potentials should be conducted.

Subjects

Twenty-five healthy college males were chosen for the study. Ages ranged from eighteen to twenty-four years. The subjects were questioned about their past history of athletic participation and injuries sustained in the past. Anyone who had sustained severe injury to or had limited use of a muscle, joint, or limb involved in the study was not accepted as a subject. The subjects were determined as being left or right dominant according to their preference of use of limbs in athletics and sports skills. Five of the subjects were left dominant, and the other twenty were right dominant.

Muscles Investigated

The right and left biceps brachii, triceps brachii, biceps femoris, and rectus femoris were chosen for this study. The muscles were selected because of their major role in the flexion and extension of the knee and elbow joints and their major role in the performance of physical skills.

Angles Investigated

The angles investigated were determined by the pilot study (see Appendix A). The angles for the triceps brachii were 45, 60, 75, 90, 105, 120, 135, 150, and 165 degrees. For the biceps brachii, biceps femoris, and rectus femoris, the angles were 90, 105, 120, 135, 150, and 165 degrees. The fifteen degree interval was chosen arbitrarily for the pilot study, which was in close accord with the muscle testing done by Clarke (2).

Selection of Electromyographic Procedure

Surface electromyography was selected for the following reasons:

1. There would be no discomfort to the subjects in application of the surface electrodes, therefore, eliminating possible inhibitions of the subjects.

2. Gross muscular activity is better indicated by surface electromyography.

3. No tissue injury would occur as caused by intramuscular electrodes. This would decrease the possibility of artifacts being present in the electromyogram.

Equipment Used

The electromyographic equipment used in this study were products of Narco-Biosystems, Inc. of Houston, Texas (Figure 1).

Recording Instrument

The Physiograph Four was used to record MAPS (Muscle Action Potentials) in this study. One channel was used to record direct action potentials, and another channel was used to record the integrated action potentials.

Input Device

The input device used was a Hi-Gain Preamplifier. This piece of equipment had controls which determined the amplitude setting of the pen on the direct recording channel. The Physiograph Four was calibrated so one microvolt of current would equal one centimeter of pen deflection.

Integrator Unit

The integrator unit Model EEG EKG MK II was used to monitor the direct channel and relay the integrated action potentials to another channel for recording on paper. The integrator unit contained a control which calibrated

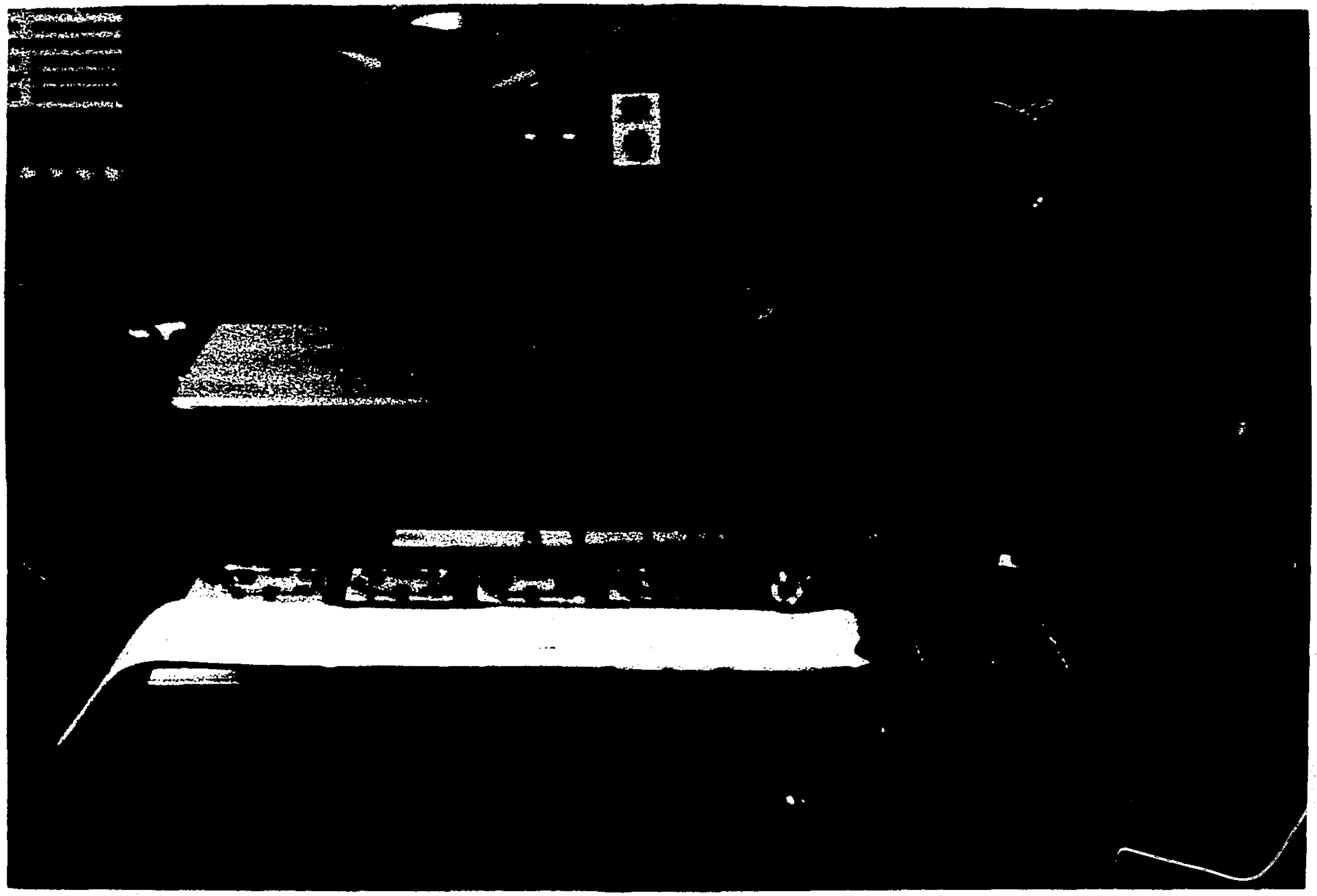

FIGURE 1

PHYSIOGRAPH FOUR, INTEGRATOR UNIT (top center) AND
HI-GAIN PREAMPLIFIER

the recording pen and was calibrated so one microvolt of current equaled one half centimeter of pen deflection.

Electrical Impulse Stimulator and Electrodes

The impulse stimulator used was model SI-10, a retractable unit inserted in the chassis of the Physiograph Four. The stimulator had controls which varied the frequency, duration, and amount of voltage used for the stimulus applied to the muscle.

Electrodes used with the stimulator were constructed in the laboratory (Figure 2). A dispersive type electrode was made by covering one side of a three inch by five inch piece of one fourth inch plywood with several thicknesses of cotton felt, and then covering the felt side of the piece of wood with copper screen wire. The copper screen wire was folded around the piece of wood and soldered together at the corners. A twelve foot piece of insulated automotive wire was soldered to the back of the electrode.

A probe electrode was constructed by inserting the naked end of another twelve foot piece of insulated wire into a piece of one half inch ceramic tube eight inches long. The wire was secured in the tube by packing a fine grade of steel wool around the wire and forming a tip for the probe with lead solder. The naked end of the wire was embedded in the tip on the electrode.

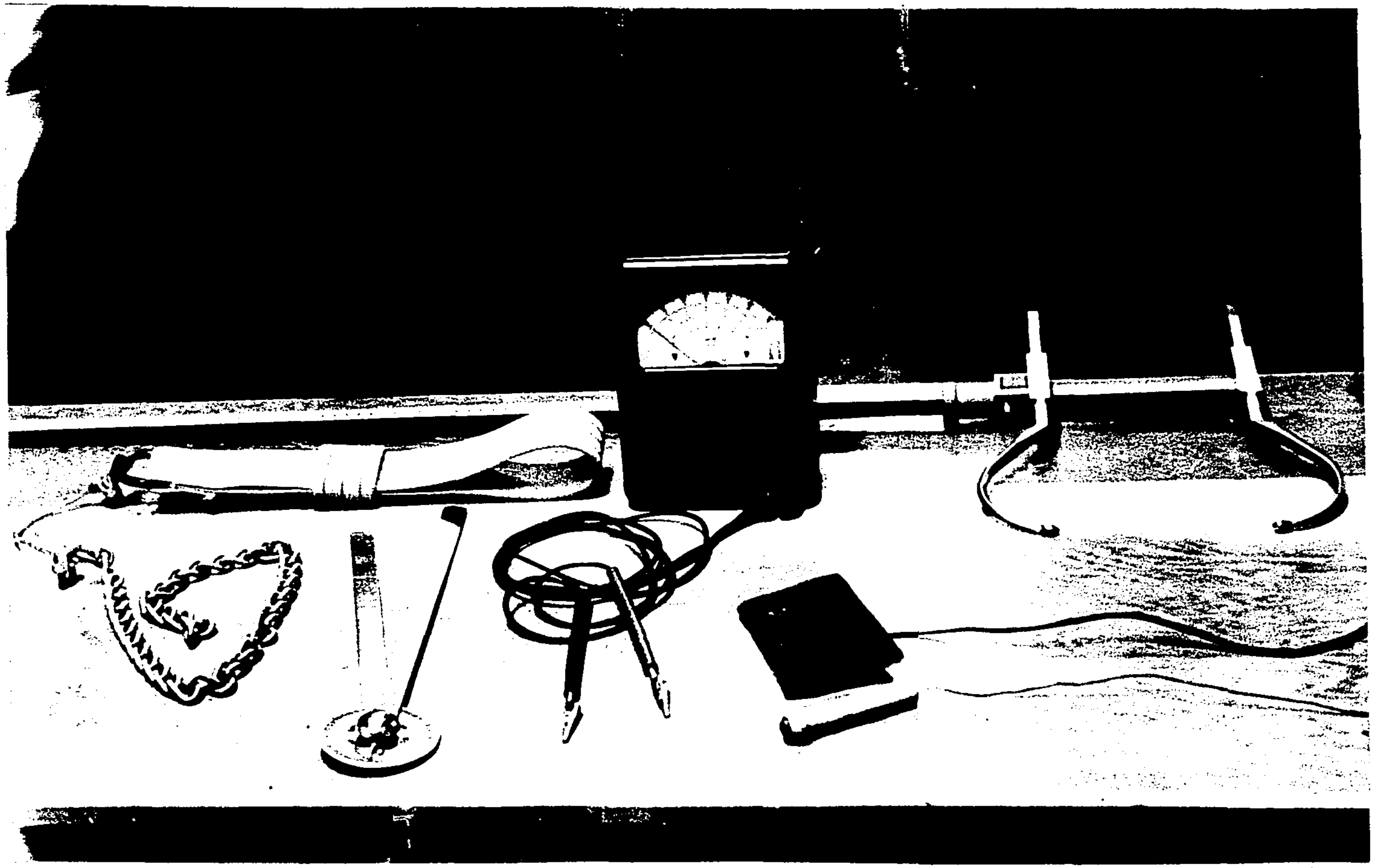

FIGURE 2

LEFT TO RIGHT: TESTING STRAP AND CHAIN, GONIOMETER, VOLT-OHM METER, DISPERSIVE AND PROBE ELECTRODES, ANTHROPOMETER

Surface Electrodes

The surface electrodes used were concave silver discs with a diameter of twelve millimeters and forty-two inch wire leads.

Goniometer

The goniometer used for measuring angles was a Zimmer Model 137, a manual type goniometer.

Anthropometer

The anthropometer used was Model 101 made by Siber Hegner and Co. of Zurich. Model 102 curved crossbars, simulating large calipers, were used to facilitate measurement of limbs.

Examination Table

The table used in this study was similar to the one used by Clarke (2) in his muscle strength testing techniques. The table was equipped with numerous three-eighths of an inch steel hooks strategically located underneath and to the side for hooking the testing strap at various angles while examining subjects. Various hooks were placed in a wall above the table to accomplish testing at angles not afforded by the hooks in or beneath the table.

Testing Strap

The strap used for securing the limb while testing the muscles was constructed of a strong piece of two inch webbing material which formed a loop and was attached via a plastic coated one eighth of an inch steel cable to a two foot length of small link chain. The links in the chain were used to make adjustments of the angles of pull by hooking the chain in different hooks on the testing table and in different links.

Preparation for Applying Surface Electrodes

Location of Motor Points

A motor point chart (5) was studied for the approximate location of motor points of the muscles selected for the study. The exact location of each motor point was determined with the use of the electrical impulse stimulator (Figure 3).

Each subject was dressed in gym shorts and was positioned on the examining table after a brief explanation of what was to take place. The pad of the dispersive electrode was soaked with saline solution and placed on the side of the limb opposite the muscle being examined. For the stimulus a frequency setting of two frequencies per second and a duration of one millisecond were used. With the voltage setting on zero, the probe electrode was dipped into the saline solution and placed on the muscle in the

FIGURE 3

TECHNIQUE USED IN DETERMINING MOTOR
POINT OF RECTUS FEMORIS

approximate location of the motor point. The subject was told to expect a slight pulsation of the muscle as the voltage was slowly increased. The subject indicated when he first felt a slight contraction although no visible contraction was evident. The probe electrode was then slowly moved around the motor point area, and the subject would indicate if he felt a stronger contraction. Using the point of strongest contraction, as indicated by the subject, the voltage was increased until a visible contraction was evident. Again the probe was moved over the motor point area in search of a stronger contraction caused by the same amount of voltage. The most sensitive area found, the area where the least amount of current would produce a contraction, was marked with a grease pencil and designated as the motor point.

The motor point used for the biceps brachii was located on the inner border of the muscle bulge. This motor point was one of three located on the biceps brachii and proved to be the most sensitive. A weak current bulged the belly of the muscle, while a strong current flexed the elbow and supinated the forearm.

The motor point used for the triceps brachii was located on the medial head of the muscle. Stimulation caused extension of the elbow.

The rectus femoris had a motor point located about one third of the length of the upper leg above the patella.

A strong stimulation to this point caused a visible tug on the patella and patellar tendon.

The motor point for the biceps femoris was located in the approximate center of the thigh one third of the distance below the gluteal fold. The muscle bulged when stimulated at this point.

Skin Preparation

The motor point area was shaved and roughened with a safety razor and then scrubbed with a clean rough towel which had been saturated with alcohol until the skin appeared red and irritated. The subject indicated when a stinging sensation was experienced and was asked to make mental note of the amount of discomfort for comparison in preparation of the remaining motor point areas. When the first preparation was successful in reducing skin resistance to the required level, the subject was able to indicate when the approximate same level of discomfort was reached in preparation of the other motor points, therefore eliminating the unpleasant task of scrubbing the area again in case of too much skin resistance. After the brisk scrubbing of the motor point area, the area was given a final cleansing with alcohol. The area was then allowed to dry while electrodes were prepared for attachment.

Application of Surface Electrodes

Twelve millimeter diameter silver disc electrodes with forty-two inch wire leads were used in the study. The electrodes were filled with electrode paste and placed two centimeters apart, spanning the motor point and parallel to the muscle. One inch wide BLENDERM surgical tape, a product of 3M Company, was used to attach the electrodes to the skin (Figure 4). A four inch strip of this tape, which had slight elastic qualities, was sufficient to hold the electrodes in place.

A ground was employed by the subject holding the tip of a wire lead in his fingers.

Skin Resistance

After the attachment of the electrodes, a volt-ohm meter was used to check the skin resistance of each hook-up. In all cases the resistance was below 10,000 ohms and in most cases was less than 5,000 ohms.

Collection of Data

Electromyographic Data

MAPS were measured for the muscles selected and at the angles selected for each subject, totaling fifty-four measurements per subject. The information was recorded on continuous one millimeter grid physiograph paper (Figure 5).

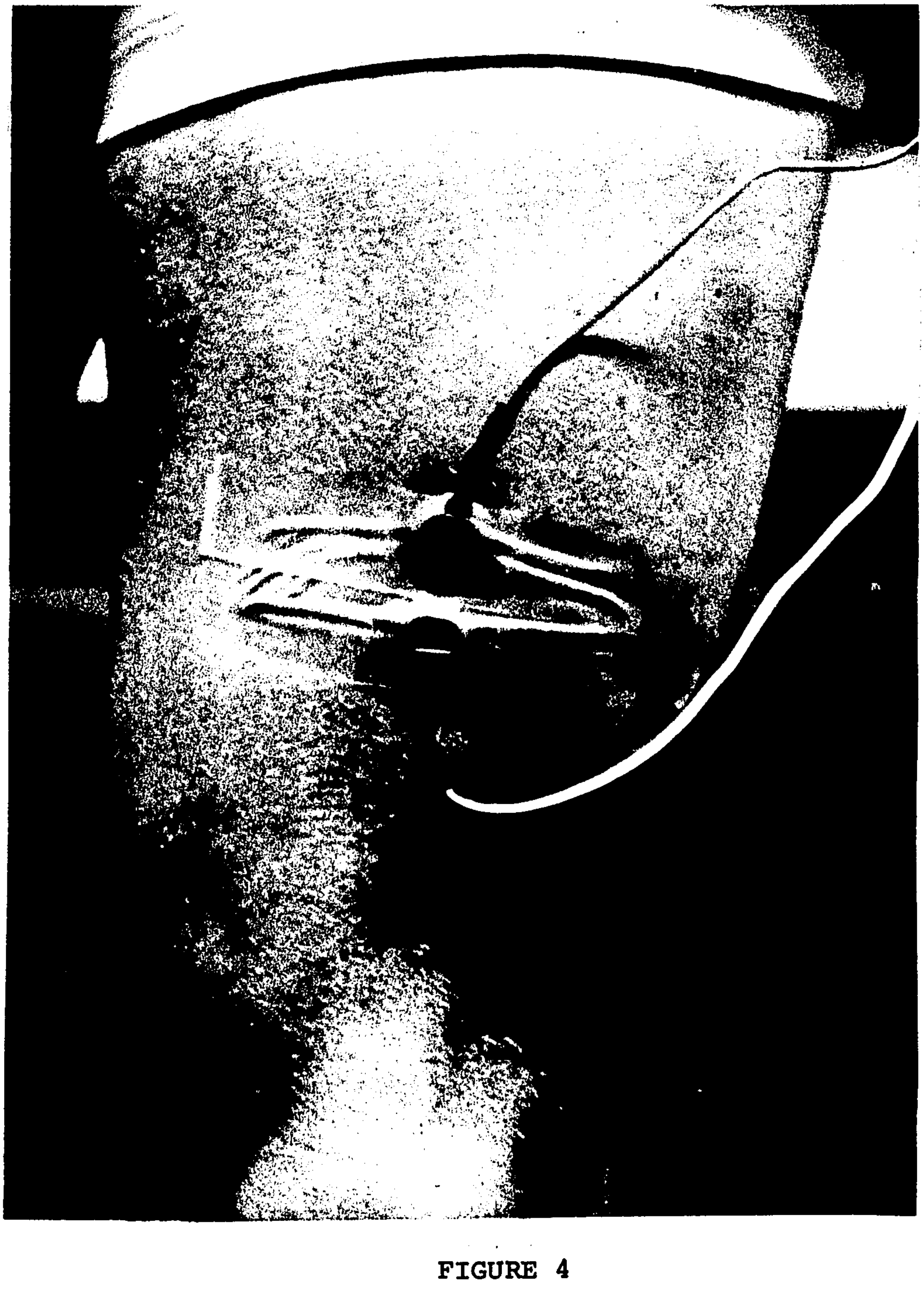

FIGURE 4

ATTACHMENT OF SURFACE ELECTRODES TO
MOTOR POINT OF RECTUS FEMORIS

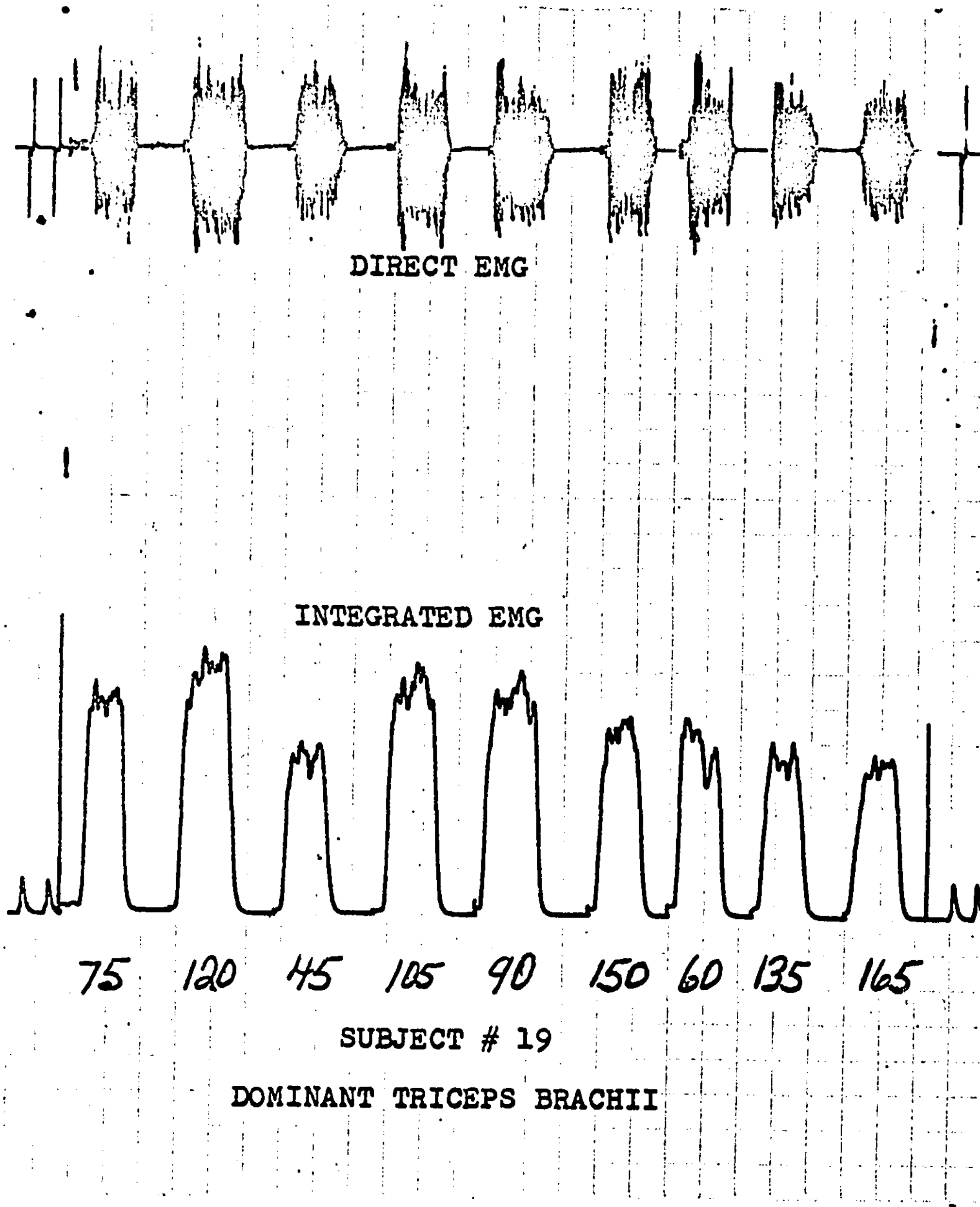

FIGURE 5

DIRECT AND INTEGRATED EMG OF MAPS RECORDED FOR THE DOMINANT TRICEPS BRACHII AT EACH ANGLE

Sequence of examination of muscles and angles. The names of each muscle were written on tiny pieces of cardboard and placed in a small box. After being mixed thoroughly, the cards were drawn from the box one at a time to determine the sequence of examination for the eight muscles. The same procedure was employed to determine the sequence of examination for the angles of each muscle. This procedure was used for each subject to diminish the possible effects of fatigue.

Position of subject for examination. After the subject was prepared for examination, he was positioned on the examining table in a manner that would facilitate the collection of the data for each muscle at the appropriate angles. The testing strap was adjusted so the angle of pull formed a ninety degree angle with the strap and limb segment being used.

For measuring the action potentials in the rectus femoris the subject was seated on the end of the table (Figure 6). His legs were hanging from the table and his body was leaning slightly backward with elbows extended and palms down on the table. The testing strap was placed around the lower leg just above the ankle and hooked underneath the table to position the knee at the proper angle. The angle was measured on the lateral side of the knee and leg with the goniometer.

FIGURE 6

POSITION FOR MEASURING MAPS IN
THE RECTUS FEMORIS

The position for measuring the action potentials in the biceps femoris required that the subject be in a prone position with the leg being examined placed over an opening in the table and arms hanging down grasping the sides of the table (Figure 7). The testing strap was placed around the lower leg just above the ankle and hooked through the opening in the table or on the wall for proper angle adjustment. The goniometer was placed against the lateral side of the knee and leg for determination of the proper angle.

The subject was in a supine position for measuring action potentials in the biceps brachii with the upper portion of the arm resting on the table (Figure 8). The forearm was supinated, and the testing strap was placed around the wrist and hooked to the side of the table or wall for proper angle adjustment. The goniometer was placed on the lateral side of the elbow and arm for angle measurement.

The same position used in measuring the biceps brachii was used for measuring the triceps brachii with slight variations (Figure 9). The testing strap was hooked on the wall above and behind the subject, and the forearm was pronated to simulate a throwing or pushing motion. Since the electrodes were placed on the medial head of the triceps brachii, a cloth covered block two inches thick was placed under the elbow to prevent the electrodes from

FIGURE 7

POSITION FOR MEASURING MAPS IN THE BICEPS FEMORIS

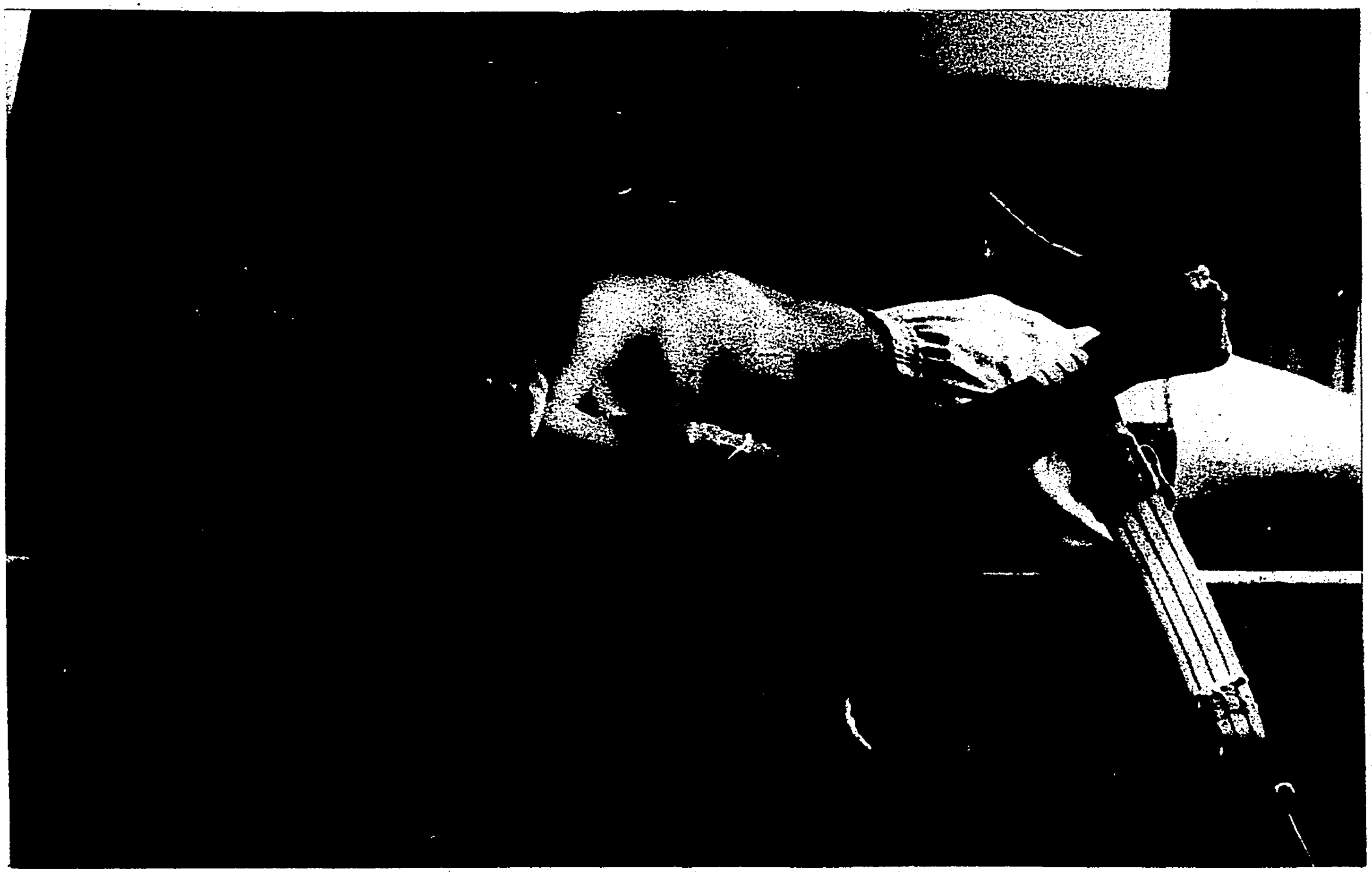

FIGURE 8

POSITION FOR MEASURING MAPS IN THE BICEPS BRACHII

FIGURE 9

POSITION FOR MEASURING MAPS IN THE TRICEPS BRACHII rubbing on the table. The goniometer was placed on the lateral side of the arm and elbow for proper angle measurement.

Method of obtaining data. While the subject was being prepared for examination, the Physiograph Four was turned on and allowed to warm-up so all circuits would function properly. Paper speed was set at two tenths of a centimeter per second, and the machine was calibrated so one microvolt of current would equal one centimeter of pen deflection on the direct channel and one half centimeter on the integrated channel. The calibration was checked at the beginning and end of measurement of each muscle. An assistant monitored the Physiograph Four and stopped the paper motor between each measurement. The directions given to the subject were: "When you are told to contract, pull (or push) against the strap as hard as you can until you have given a maximum effort." A minimum of thirty seconds was allowed to elapse between each contraction to offset the possible effects of fatigue.

Anthropometric Data

The lengths of the upper and lower arms and legs of each subject were measured with an anthropometer similar to methods employed by Reuter (62), (Figure 10). The reference points were marked with a grease pencil.

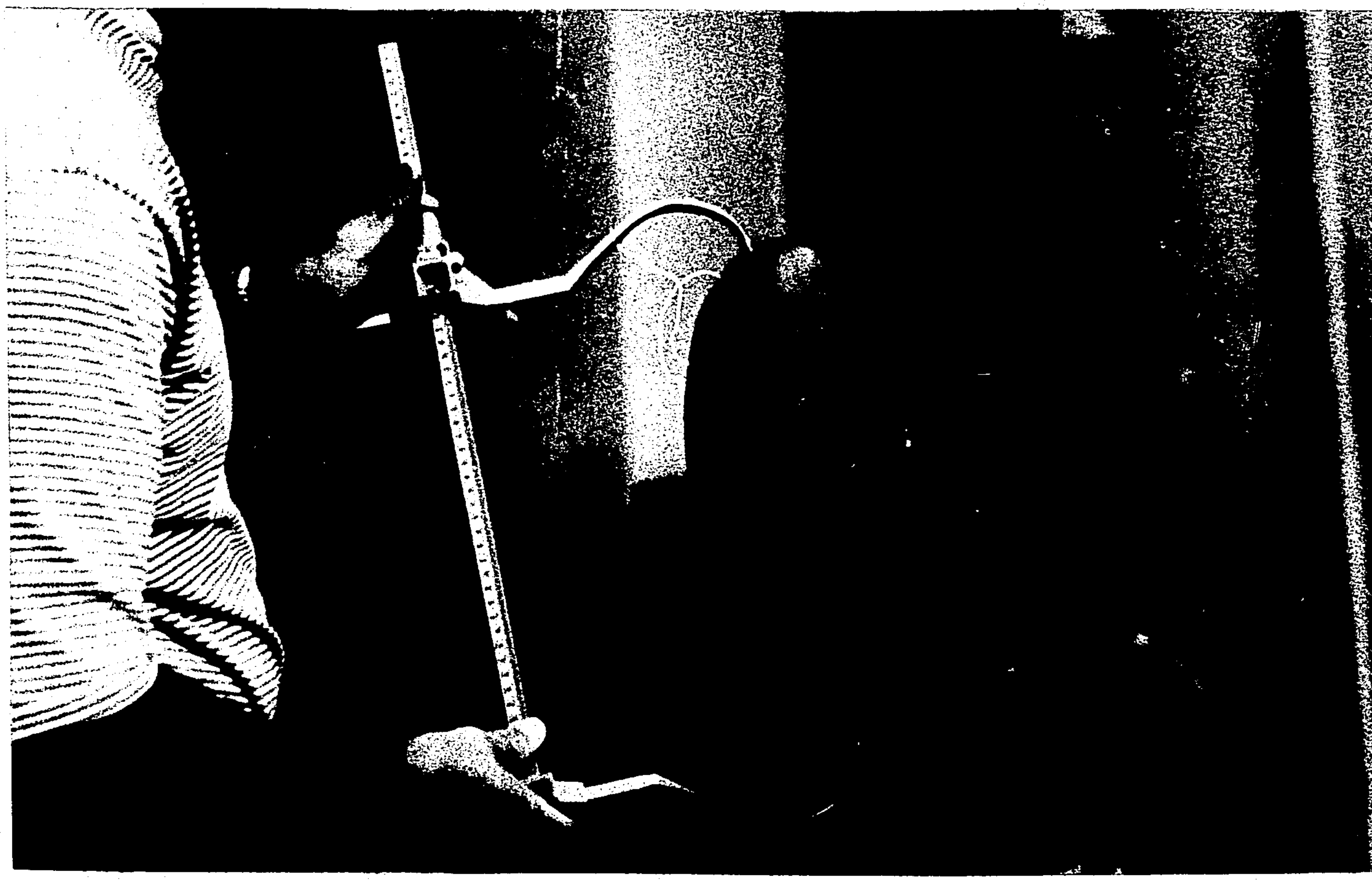

FIGURE 10

MEASUREMENT OF UPPER ARM LENGTH WITH ANTHROPOMETER

Upper arm. The length of the upper arms was measured between the upper border of the tip of the acromion process of the scapula and the upper border of the radius which could be felt articulating with the humerus as the elbow was flexed.

Lower arm. Measurement of the lower arms was taken from the styloid process of the ulna at the wrist to the tip of the olecranon at the elbow.

Upper leg. The length of the upper legs was taken by measuring from the top of the great trochanter of the femur to the top of the medial tuberosity of the tibia. The top of the great trochanter was felt by sinking the fingers into the soft tissue of the hip.

Lower leg. The measurement for the lower leg was taken by measuring the distance between the lower border of the medial malleolus of the ankle to the top of the medial tuberosity of the tibia.

Analysis of the Electromyogram

The analysis of the EMG for each muscle was in terms of millimeters of pen deflection at each angle. The highest point of pen deflection was the point at which the maximum amount of MAPS was recorded. In several cases the pen deflection had to be measured in tenths of a millimeter in order to determine the angle of maximum MAPS.

Treatment of Data

Maximum MAPS in the Dominant and Nondominant Limbs

Each EMG was analyzed, and the angle at which the maximum amount of MAPS occurred for each muscle was determined for each subject. The number of times maximum MAPS occurred at each angle for each muscle was recorded in Table I for both dominant and nondominant muscles.

Relationships of Length of Limbs and Angles of Maximum MAPS

The TSAR Program for Pearson Product Moment Correlation stored at Triangle Universities Computation Center was used to determine the relationships of the length of each limb segment and the angle of maximum MAPS of the muscles actuating that limb.

TABLE I

MAXIMUM MUSCLE ACTION POTENTIALS
RECORDED AT EACH ANGLE

Muscles	45°	60°	75°	90°	105°	120°	135°	150°	165°
Dominant Biceps Brachii				13	4	5	1	2	0
Nondominant Biceps Brachii				11	1	3	4	5	1
Dominant Triceps Brachii	3	5	2	3	5	2	2	2	1
Nondominant Triceps Brachii	4	4	2	4	2	3	2	4	0
Dominant Rectus Femoris				4	7	2	2	3	7
Nondominant Rectus Femoris				3	5	3	1	5	8
Dominant Biceps Femoris				5	7	5	6	1	1
Nondominant Biceps Femoris				5	2	4	4	6	4

CHAPTER IV

ANALYSIS OF DATA

Muscle Action Potentials

Dominant Biceps Brachii

In thirteen of the subjects, the angle of maximum MAPS was ninety degrees, and the other twelve occurred from 105° to 150°. No maximum MAPS were recorded at the angle of 165°. Only three maximum MAPS were recorded beyond the angle of 120°. Of the thirteen maximum MAPS which were recorded at ninety degrees some might have occurred at angles of less than ninety degrees had smaller angles been investigated in the study. The results of the pilot study did not indicate that investigation of angles less than ninety degrees was necessary.

Nondominant Biceps Brachii

The pattern of MAPS in the nondominant biceps brachii was somewhat similar to that of the dominant biceps brachii. At the ninety degree angle eleven maximum MAPS were recorded as compared to thirteen at the same angle for the dominant biceps brachii. The remaining maximum MAPS occurred at angles greater than ninety degrees, and thirteen of them, more than half, occurred at angles of 120° or greater. Had angles of less than ninety degrees been investigated, some of the eleven maximum MAPS recorded at the ninety degree angle might have been recorded at angles less than ninety degrees. As previously stated the pilot study did not indicate that it was necessary to investigate angles less than ninety degrees.

Dominant Triceps Brachii

The triceps brachii were the only muscles investigated at angles less than ninety degrees, and maximum MAPS were recorded at each angle investigated. The 165° angle had only one which was the least at any angle. The greatest number of maximum MAPS which was only five, was recorded at the sixty and 105° angles.

Nondominant Triceps Brachii

The nondominant triceps brachii was somewhat similar to the dominant triceps brachii in the distribution of maximum MAPS. No maximum MAPS occurred at the 165° angle, while two, three, or four were recorded at each of the other angles.

Dominant Rectus Femoris

Maximum MAPS were recorded at all angles for the dominant rectus femoris. Seven maximum MAPS were recorded at the 105° angle and at the 165° angle, while only two were recorded at the 120° and the 135° angle. A greater number of maximum MAPS occurred at the two extremes rather than in the middle of the range of angles investigated.

Nondominant Rectus Femoris

The greatest number of maximum MAPS for the nondominant rectus femoris, which was eight, occurred at the 165° angle. Only one occurred at the 135° angle, while the remaining maximum MAPS were distributed at the other angles. The nondominant rectus femoris responded somewhat similarly to the dominant rectus femoris with fewer maximum MAPS recorded at the 120° and 135° angles than were recorded at the two extremes of the range of angles investigated.

Dominant Biceps Femoris

The highest number of maximum MAPS for the dominant biceps femoris was recorded at the 105° angle. This value was only seven while six were recorded at the 135° angle and five were recorded at both the ninety and 120° angles. Only one maximum MAPS occurred at the 150° and 165° angles.

Nondominant Biceps Femoris

The nondominant biceps femoris had six maximum MAPS recorded at the 150° angle and five were recorded at the ninety degree angle. The nondominant biceps femoris responded quite differently than did the dominant biceps femoris. The dominant biceps femoris had its highest number of maximum MAPS at the 105° angle and one of its lowest at the 150° angle, while the dominant biceps femoris had its lowest number at the 105° angle and its highest number at the 150° angle.

Relationships Between Lengths of Limbs and Angles of Maximum Muscle Action Potentials

Table II presents Pearson Product Moment Correlation Co-efficients for the length of limbs and angles of maximum MAPS of the muscles investigated in the study. A correlation co-efficient was computed for each muscle and both the upper and lower segment of the limb which the muscle actuated. A co-efficient of .396 was needed for a significant relationship, and the highest correlation co-efficient obtained from the data was .28. This highest correlation co-efficient was found to exist between the nondominant upper leg and the nondominant rectus femoris.

TABLE II

PEARSON PRODUCT MOMENT CORRELATION COEFFICIENTS OF LENGTHS OF LIMBS AND THE ANGLES OF MAXIMUM MUSCLE ACTION POTENTIALS

Dominant side	biceps brachii	triceps brachii	rectus femoris	biceps femoris
upper arm	.07	.11		
lower arm	.14	.10		
upper leg			.20	.07
lower leg			.03	−.12
Non dominant side				
upper arm	−.07	.15		
lower arm	.12	.03		
upper leg			.28	.16
lower leg			.21	.23

Interpretation of Results

Maximum Muscle Action Potentials

The results of this study indicate that the distribution of angles which might possibly record a maximum amount of MAPS in the selected muscles varies from individual to individual. No real pattern in the distribution of the maximum MAPS is evident for any of the muscles, although the ninety degree angle recorded a greater number of maximum MAPS for the dominant and nondominant biceps brachii than any other angle. Even this might not have occurred if angles of less than ninety degrees had been investigated in the biceps brachii muscles. For the other muscles the maximum MAPS seem to be randomly scattered throughout the range of angles investigated. To determine through electromyography the most beneficial angle at which to strength train a particular muscle, the results of this study indicate that the angle would have to be determined for each individual muscle and for each individual since no common angle seems to exist.

Dominant and Nondominant Limbs

In comparing the dominant and nondominant sides of the body in regard to MAPS in the muscles investigated, there appear to be no distinct differences or similarities. The limbs of both sides seem to have a random distribution of maximum MAPS throughout the range of angles investigated.

Limb Length and Angles of Maximum MAPS

The data in Table II indicated no significant relationships between the length of a limb segment and the angle of maximum MAPS in either of the muscles which actuate the limb segment. The highest correlation coefficient obtained was .28 which is far short of a coefficient of .396 needed for significance.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to investigate by means of electromyography the muscle action potentials present in the biceps brachii, the triceps brachii, the biceps femoris, and the rectus femoris muscles when the joints which these muscles actuate were placed under conditions of maximum isometric flexion or extension at selected angles.

Two related problems were investigated:

1. The relationships between the lengths of both segments of the arms and legs and angles at which maximum muscle action potentials were recorded for each muscle.

2. The dominant and nondominant sides of the body were investigated in regard to joint angles of maximum muscle action potentials.

A pilot study involving three subjects was conducted to determine the range of angles to be investigated and if an investigation of the dominant and nondominant sides of the body in regard to muscle action potentials should be conducted. On the basis of this pilot study, dominant and nondominant sides of the body were investigated, and the angles examined were 90°, 105°, 120°, 135°, 150°, and 165°

for all muscles in addition to angles of 45°, 60°, and 75° for the triceps brachii muscles.

Muscle action potentials of twenty-five subjects were recorded for the muscles selected for the study and at the specified angles while the joints which the muscles actuated were placed under conditions of maximum isometric flexion or extension.

The lengths of each segment of the arms and legs were taken from each subject and correlated with the angles of maximum muscle action potentials for each muscle acting upon that particular limb segment. None of the correlation coefficients were significant at the five per cent level of confidence.

Conclusions

Based on the data collected and within the limitations of this study, the following conclusions are warranted:

1. The angles of maximum muscle action potentials vary with the individual, therefore, no common angle exists which provides maximum strength training benefits.

2. There are no distinct similarities in regard to angles at which maximum muscle action potentials occur between dominant and nondominant muscles.

3. Limb length is not a factor in determining the location of angles at which maximum muscle action potentials would occur.

Recommendations

On the basis of the results of this study the following recommendations should be considered:

1. A similar study should be conducted using a different range of angles and different interval between angles.

2. A study of the dominant and nondominant biceps brachii should be conducted adding angles less than ninety degrees.

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APPENDIX A

THE PILOT STUDY

THE PILOT STUDY

A pilot study was conducted to familiarize the writer with the procedures and electromyographic techniques necessary to obtain the desired data and to solve specific problems pertinent to the study.

Preliminary preparations. Approximately four weeks were spent mastering the following techniques and procedures:

1. The operation of the Physiograph Four.
2. Calibration of the Physiograph Four.
3. Determination of the correct paper speed.
4. Location of motor points.
5. Skin preparation and application of electrodes.
6. Selection of sensitivity and amplitude settings appropriate for the study.
7. Determining the appropriate positions of the subjects for the examination.
8. Determining the appropriate and most efficient method of administering the examination.

Specific problems. After the preliminary preparations were completed, problems specific to the study were investigated in the pilot study. The problems were:

1. The range of angles to be investigated.
2. If an investigation of both the dominant and nondominant limbs in regard to joint angles of maximum muscle action potentials would be worthy of further study.

I. PROCEDURE

The procedure for the pilot study was the same as explained in Chapter III of the text except for slight variations explained below.

Subjects. Three subjects were used in the pilot study.

Angles investigated. The range of angles investigated was chosen to be that range which would closely parallel the range of motion most frequently used in performing physical skills. The angles investigated were 60, 75, 90, 105, 120, 135, 150, and 165 degrees for all muscles. The triceps brachii were investigated at the 45 degree angle in addition to those listed above.

The fifteen degree interval was arbitrarily chosen but is in close accord with previous work in muscle testing by Clarke (2).

II. RESULTS AND DISCUSSION

Graphs of the muscle action potentials for each muscle at the specified angles were constructed (Figures 11 and 12). Various types of curves were indicated by the data and most muscles showed a greater amount of muscle action potentials present at larger angles rather than at smaller angles. It appeared that the greater action potentials

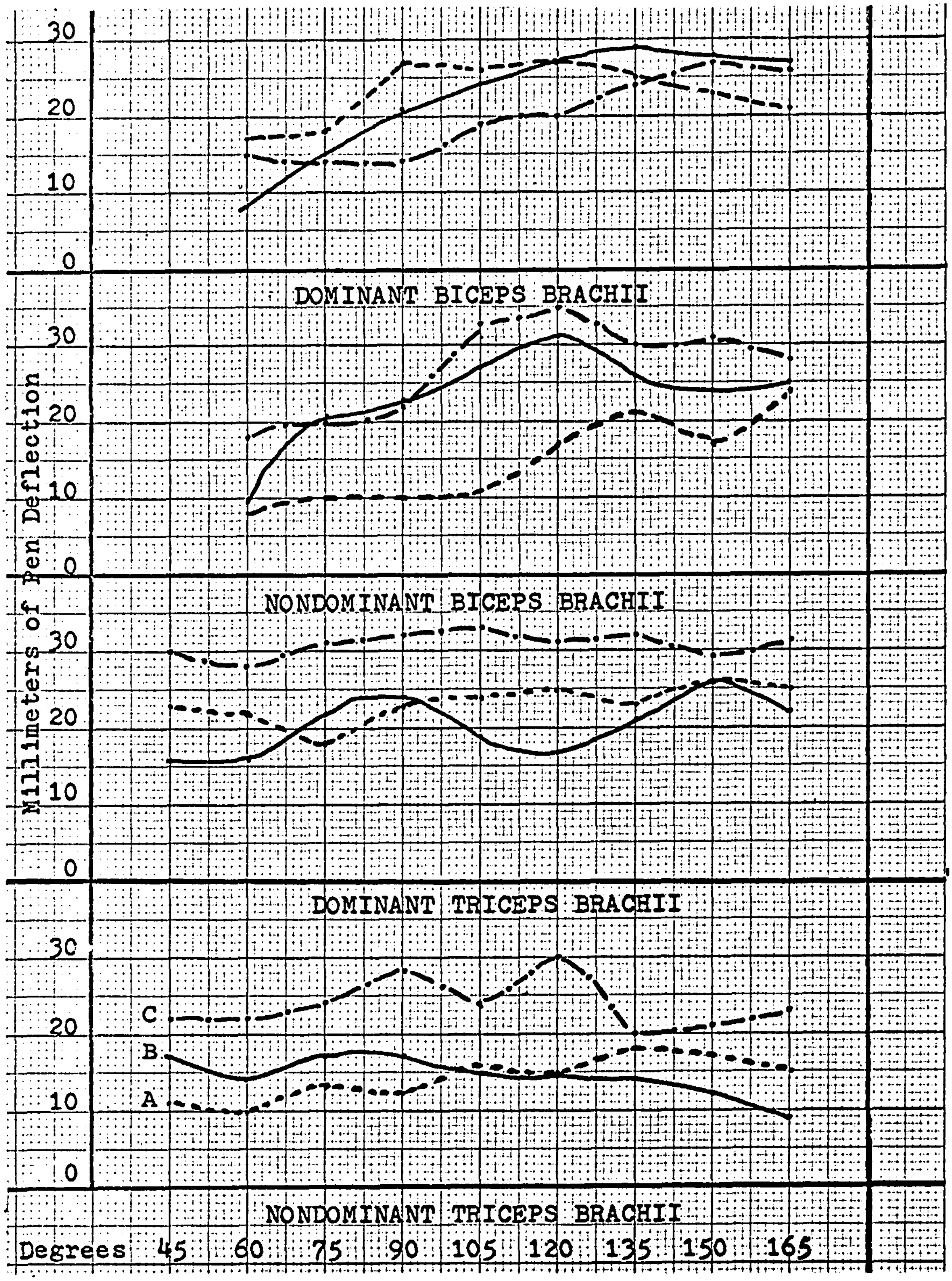

FIGURE 11

MAPS IN THE BICEPS BRACHII AND TRICEPS BRACHII OF THE THREE SUBJECTS OF THE PILOT STUDY

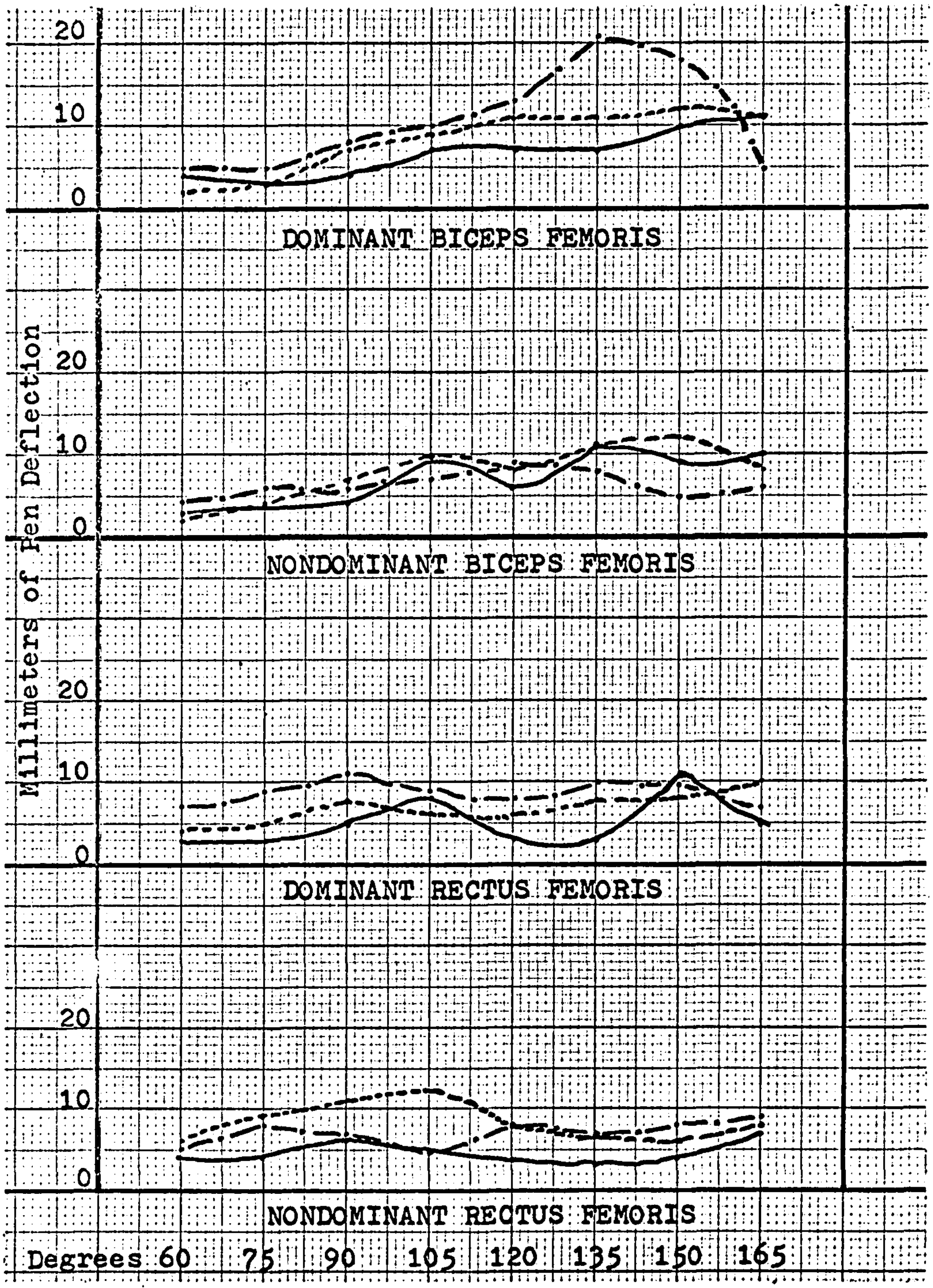

FIGURE 12

MAPS IN THE BICEPS FEMORIS AND RECTUS FEMORIS OF THE THREE SUBJECTS OF THE PILOT STUDY occurred at angles where the muscles were in an elongated state rather than in a shortened state and at angles included in the range of motion most frequently used by the muscles in performance of physical skills. The amount of action potentials decreased as the range of motion of each joint approached its limits. This was especially true in all cases of angles less than ninety degrees; however, for the triceps brachii the forty-five degree angle recorded a greater amount of action potentials than was recorded at the sixty degree angle.

The difference, if any, between the amount of muscle action potentials in the dominant and nondominant sides of the body could not be determined from data collected from three subjects. It was obvious that more data were necessary before definite conclusions could be made.

III. CONCLUSIONS

1. In all cases there was a decline in amount of muscle action potentials recorded at angles less than ninety degrees.
2. Data were not sufficient to make definite conclusions regarding types of curves of muscle action potentials for specific muscles.
3. Maximum amounts of muscle action potentials occurred at angles of ninety degrees or greater.
4. Differences, if any, in muscle action potentials between the dominant and nondominant sides of the body could not be determined from data collected from three subjects.

IV. RECOMMENDATIONS FOR FURTHER STUDY

The results of the pilot study warrant the following recommendations for further study:

1. The range of angles to be studied for the biceps brachii, biceps femoris, and rectus femoris muscles should be from 90 degrees to 165 degrees inclusive with a fifteen degree interval.

2. The range of angles to be studied for the triceps brachii should be 45 degrees to 165 degrees inclusive with a fifteen degree interval.

3. Muscle action potentials in both the dominant and nondominant sides of the body should be investigated using data from more than three subjects.

RAW DATA FOR SUBJECT A OF PILOT STUDY

MAPS RECORDED IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			23	11				
60	17	8	22	10	4	6	2	2
75	18	10	13	13	6	9	3	4
90	27	10	23	12	8	11	7	7
105	26	11	24	17	7	12	9	10
120	28	17	25	16	6	8	11	8
135	25	21	23	18	8	7	11	11
150	23	17	26	17	9	6	12	12
165	21	24	25	15	10	8	11	8

KEY

DBB= DOMINANT BICEPS BRACHII

NDBB= NONDOMINANT BICEPS BRACHII

DTB= DOMINANT TRICEPS BRACHII

NDTB= NONDOMINANT TRICEPS BRACHII

DRF= DOMINANT RECTUS FEMORIS

NDRF= NONDOMINANT RECTUS FEMORIS

DBF= DOMINANT BICEPS FEMORIS

NDBF= NONDOMINANT BICEPS FEMORIS

RAW DATA FOR SUBJECT B OF PILOT STUDY

MAPS RECORDED IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			16	17				
60	8	10	16	14	3	4	4	3
75	15	21	22	16	3	4	3	4
90	21	23	24	17	5	6	4	5
105	24	27	19	15	8	5	7	10
120	27	31	17	16	3	4	7	6
135	29	26	21	14	3	3	7	11
150	28	24	26	12	11	4	10	9
165	27	26	22	9	5	7	11	10

RAW DATA FOR SUBJECT C OF PILOT STUDY

MAPS RECORDED IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			30	22				
60	15	18	28	22	7	5	5	4
75	14	20	31	24	9	8	5	6
90	14	22	32	27	11	7	8	6
105	19	33	33	24	9	5	10	7
120	20	35	31	30	8	8	13	9
135	24	30	32	20	10	7	21	8
150	27	31	29	21	10	8	18	5
165	26	28	31	23	7	9	5	6

APPENDIX B

RAW DATA

APPENDIX B

RAW DATA FOR EACH SUBJECT

The complete raw data are presented in tabular form for all twenty five subjects. The lengths of the limbs measured are presented in tenths of centimeters, and the muscle action potentials at each angle for each muscle and for each subject are presented in millimeters of pen deflection. Several measurements were recorded in tenths of millimeters in order to determine at which angle the maximum amount of muscle action potentials was recorded.

The following abbreviations are applicable for the interpretation of the next twenty-five tables of raw data.

UA= UPPER ARM

LA= LOWER ARM

UL= UPPER LEG

LL= LOWER LEG

DBB= DOMINANT BICEPS BRACHII

NDBB= NONDOMINANT BICEPS BRACHII

DTB= DOMINANT TRICEPS BRACHII

NDTB= NONDOMINANT TRICEPS BRACHII

DRF= DOMINANT RECTUS FEMORIS

NDRF= NONDOMINANT RECTUS FEMORIS

DBF= DOMINANT BICEPS FEMORIS

NDBF= NONDOMINANT BICEPS FEMORIS

RAW DATA FOR SUBJECT NUMBER ONE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	35.4	29.0	46.8	39.3
Nondominant side	35.8	29.0	47.0	39.5

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			18	27				
60			21	24				
75			21	25				
90	37	14	27	32	12	21	16	13
105	32	16	24	25	9	22.5	30	8
120	32	23	29	25	11	21	32	4
135	23	22	35	30	8	22	33	6
150	18	19	29	29	8	20	32	10
165	27	19	24	31	15	14	17	9

RAW DATA FOR SUBJECT NUMBER TWO

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	34.2	29.1	47.2	47.0
Nondominant side	34.4	29.0	41.2	41.0

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			9	17				
60			14	12				
75			12	14				
90	17	11.4	11	14	4	3	3	2
105	17	10	9	12	4	3	5	6
120	17.8	11	9	12	4.8	3	3	8
135	16	9	10	11	4	2	5	12
150	17.6	10	10	12	3	4	6	7
165	17	8	10	12	4	3	2	7

RAW DATA FOR SUBJECT NUMBER THREE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	34.9	28.3	43.2	37.0
Nondominant side	34.8	28.1	43.4	37.3

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			14	13				
60			12	13				
75			14	17.8				
90	22	28	12	17	8	10	13	12
105	20	24	13	17	7.5	9	8	14
120	14	34	11	17	4	12	12	13
135	16	38	10	14	4	7	15	18
150	18	33	10	15	3	9	11	20
165	15	32	8	12	6	8	12	14

RAW DATA FOR SUBJECT NUMBER FOUR

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	37.5	30.0	50.2	43.2
Nondominant side	37.4	30.3	50.0	43.0

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			26	15				
60			27	14				
75			31	19				
90	34	24	26	19	5	11	12	10
105	25	19	24	24	3	8	13	11
120	24	18	24	22	5	10	8	10
135	25	15	21	17	5	11	20	11
150	28	19	19	25	8	16	18	11
165	24	13	23	21	10	14	11	13

RAW DATA FOR SUBJECT NUMBER FIVE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	32.0	27.2	45.1	38.8
Nondominant side	32.1	27.1	44.9	39.0

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			25	16				
60			26	17				
75			25	18				
90	22	28	26.7	23.1	6.4	5	9	14
105	19	29	24	22	4	6	10.4	13
120	20	30	22	23	5	3	8	11
135	17	29	17	19	3	5	9	9
150	14	33	23	17	3	4	7	8
165	11	31	16	19	6	4	10.1	8

RAW DATA FOR SUBJECT NUMBER SIX

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	38.2	29.4	45.0	40.2
Nondominant side	38.8	29.4	45.2	40.4

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			27	18				
60			28	18				
75			31	18				
90	35	30	34	17	4	8	10	13
105	37	29	33	17	3	10	11	14
120	38	17	28	23	3	5	9	15
135	31	24	25	19	4	8	10	12
150	41	21	22	29	5	7	10	10
165	30	23	23	19	7	7	10.5	9

RAW DATA FOR SUBJECT NUMBER SEVEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	38.5	28.9	50.4	40.9
Nondominant side	38.2	29.0	50.2	40.8

MAPS AT EACH ANGLE RECORDED IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			19	19				
60			22	19				
75			22	24				
90	37	11	25	28	7	4	8	3
105	36	12	27	24	6	4	9	8
120	32	17	20	23	4	8	12	12
135	29	21	22	21	4	3	10	13
150	28	24	14	22	6	4	9	28
165	26	20	15	17	9	9	7	13

RAW DATA FOR SUBJECT NUMBER EIGHT

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	39.4	32.0	47.9	44.7
Nondominant side	39.6	32.0	47.8	44.6

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			12	6				
60			12	10				
75			12	11				
90	23	12	12	11	4	3	10	6
105	16	10	15	14	3	5	12	8
120	23.7	8	16	12	2	4	8	10
135	23	7	11	11	6	2	8	14
150	22	6	11	11	2	2	7	12
165	23	8	13	12	5	2	7	13

RAW DATA FOR SUBJECT NUMBER NINE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	38.5	28.9	50.4	40.9
Nondominant side	38.2	29.0	50.2	40.8

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			17	27				
60			35	25				
75			31	30				
90	31	15	19	26	15	5	29	14
105	19	21	17	17	12	5	28	11
120	20	27	16	17	17	7	15	9
135	23	26	15	19	14	7	9	7
150	25	24	20	18	16	6	5	5
165	27	20	15	19	25	12	6	8

RAW DATA FOR SUBJECT NUMBER TEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	38.2	30.3	49.6	45.3
Nondominant side	38.4	30.4	49.8	45.3

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			11	10				
60			12	17				
75			14	15				
90	35	17	15	13	3	5	14	7
105	17	30	16	14	4	5.6	13	6
120	16	31	14	15	5	5	11	8
135	17	32	13	11	4	3	10	6
150	16	30	11	8	3	2	11	6
165	14	27	12	7	4	3	7	5

RAW DATA FOR SUBJECT NUMBER ELEVEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	36.6	30.2	48.0	43.6
Nondominant side	36.5	29.8	47.5	43.6

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			12	18				
60			12	24				
75			15	20				
90	31	20	16	22	11	9	7	4
105	27	16	17.3	17	10	9	5	5
120	30	11	15	23	9	10	8	7
135	28	10	13	21	8	6	7	6
150	28	13	17	16	7	5	7	7
165	19	10	12	19	5	6	7	7.3

RAW DATA FOR SUBJECT NUMBER TWELVE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	35.1	27.0	45.8	37.9
Nondominant side	35.0	26.7	45.6	37.6

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			33	26				
60			37	22				
75			32	22				
90	37	40	35	30	4	4	27	32
105	39	38	35	28	4	5	24	28
120	36	29	35	30.2	4	4	22	25
135	27	22	29	28	5	3	21	24
150	28	29	31	27	10	6	14	13
165	28	34	27	28	12	7	14	16

RAW DATA FOR SUBJECT NUMBER THIRTEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	39.7	30.9	48.3	41.7
Nondominant side	40.0	30.7	47.2	41.4

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			31	18				
60			32	22				
75			28	24				
90	13	22	28	27	12	7	9	6
105	19	33	25	24	9	5	11	7
120	20	35	17	30	9	8	12	8
135	22	30	17	20	11	7	22	8.7
150	27	31	11	21	10	8	19	5
165	26	28	10	23	7	9	4	6

RAW DATA FOR SUBJECT NUMBER FOURTEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	43.2	33.6	49.6	50.1
Nondominant side	42.9	32.9	46.4	46.3

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			14	18				
60			18	27				
75			14	19				
90	30	34	15	17	11	7	11	13
105	19	21	12	15	11	8	17	16
120	25	23	13	15	9	9	13	14
135	23	23	12	11	8	10	14	5
150	20	28	12	11	8	10	12	5
165	21	36	14	12	12	10.2	14	5

RAW DATA FOR SUBJECT NUMBER FIFTEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	33.9	28.7	44.7	39.2
Nondominant side	34.2	28.5	44.2	39.4

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			25	19				
60			22	14				
75			17	16				
90	41	33	15	16	14	8	12	13
105	39	23	19	18	17	8	16	12
120	18	23	14	12	12	16	17	15
135	17	20	17	12	12	12	12	15
150	17	8	19	11	10	10	16	17
165	19	9	11	11	14	11	12	10

RAW DATA FOR SUBJECT NUMBER SIXTEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	32.3	27.9	44.5	40.0
Nondominant side	32.9	27.4	44.1	40.3

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			21	17				
60			18	29				
75			19	31				
90	26	34	16	34	16	6	10	19
105	24	32	27	33	17	5	12	14
120	19	15	17	27	11	4	13	8
135	16	14	17	22	14	5	14	9
150	24	8	15	21	13	7	11	7
165	22	8	13	21	7	5	12	9

RAW DATA FOR SUBJECT NUMBER SEVENTEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	37.8	30.0	51.1	42.8
Nondominant side	37.8	29.9	51.2	42.8

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			12	20				
60			13	20				
75			13	16				
90	30	31	10	22	4	5	5	3
105	24	23	11	12	3	4	11	4
120	25	15	9	23	4	3	9	5
135	27	22	14	17	4	3	7	5
150	28	25	10	21	5	3	7	4
165	23	27	8	22	3	12	7	4

RAW DATA FOR SUBJECT NUMBER EIGHTEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	40.1	29.9	48.1	47.7
Nondominant side	40.0	29.9	43.2	43.8

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			12	13				
60			13	13				
75			16	14				
90	27	38	19	14	8	5	5	6
105	26	35	26	15	9	5	21	12
120	23	35	17	14	6	4	30	14
135	18	36	15	16	3	4	32	16
150	18	28	27	15	4	7	23	17
165	21	31	25	15	5	8	24	19

RAW DATA FOR SUBJECT NUMBER NINETEEN

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	35.2	29.0	44.8	44.9
Nondominant side	35.1	29.0	44.9	44.7

MAPS IN EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			25	14				
60			29	18				
75			34	19				
90	14	27	35	19	15	10	25	6
105	15	22	37	18	11	12	22	7
120	13	22	38	15	6	10	18	7
135	5	23	25	17	7	14	22	10
150	5	24	28	20	8	17	21	14
165	7	19	23	12	9	20	22	13

RAW DATA FOR SUBJECT NUMBER TWENTY

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	38.9	29.5	48.9	40.9
Nondominant side	38.6	29.3	48.4	40.5

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			11	27				
60			11	22				
75			12	24				
90	16	26	13	22	9	18	9	12
105	17	22	18	25	11	14	15	12
120	21	24	19	23	9	17	17	11
135	19	20	18	18	9	19	16	12
150	20	21	19	14	6	10	12	15
165	20	21	20	13	8	8	15	16

RAW DATA FOR SUBJECT NUMBER TWENTY-ONE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	36.5	30.4	49.1	40.9
Nondominant side	36.2	30.5	48.8	41.1

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			15	8				
60			16	8				
75			19	8				
90	17	21	18	10	3	5	2	4
105	20	18	17	10	5	3	3	8
120	23	22.8	18	11	4	3	5	8
135	12	23	15	11.6	4	3	6	9
150	8	22	18	10	4	3	7	10
165	11	22	16	9	3	2	8	8

RAW DATA FOR SUBJECT NUMBER TWENTY-TWO

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	34.4	28.7	46.3	40.1
Nondominant side	34.3	28.5	46.9	39.8

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			31	30				
60			27	13				
75			32	19				
90	38	26	30	24	11	9	15	22
105	34	31	34	15	16	8	15	19
120	34	28	32	20	15	9	25	18
135	35	34	24	20	20	9	19	22
150	37	36	28	32	23	13	23	23
165	35	28	19	24	17	12	24	16

RAW DATA FOR SUBJECT NUMBER TWENTY-THREE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	35.2	28.2	45.4	39.4
Nondominant side	35.1	28.3	45.4	39.5

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			3	12				
60			12	13				
75			11	9				
90	13	30	13	13	11	3.9	21	12
105	21	32	12	15	12	2	22	9
120	33	37	5	10	11	2	17	14
135	30	37.4	6	12	10	2	18	15
150	26	35	10	10	7	3	10	9
165	27	27	5	12	11	3	9	8

RAW DATA FOR SUBJECT NUMBER TWENTY-FOUR

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	33.2	29.5	41.6	42.0
Nondominant side	33.3	29.7	38.8	39.1

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			22	27				
60			21	34				
75			25	24				
90	15	13	26	19	14	12	5	29
105	9	15	24	20	11	12	8.9	35
120	10	12	24	25	16	9	8	28
135	16	16	23	20	16	12	5	25
150	7	18	27	18	20	15	5	10
165	8	13	23	16	14	14	6	13

RAW DATA FOR SUBJECT NUMBER TWENTY-FIVE

LENGTHS OF LIMBS IN CENTIMETERS

	UA	LA	UL	LL
Dominant side	33.5	28.5	44.0	38.2
Nondominant side	33.2	28.5	43.8	38.5

MAPS AT EACH ANGLE RECORDED
IN MILLIMETERS OF PEN DEFLECTION

Angle	DBB	NDBB	DTB	NDTB	DRF	NDRF	DBF	NDBF
45			55	54				
60			52	45				
75			54	54				
90	58	45	49	53	10	8	7	21
105	57	29	46	48	13	4	32	33
120	56	26	36	38	12	4	29	42
135	51	45	34	29	14	3	24	26
150	43	53	29	20	9	6	26	32
165	54	42	27	19	12	5	18	37