Electromyographical study of two styles of full pushups

Carolyn Ruos

The University of Montana

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ELECTROMYOGRAPHICAL STUDY OF TWO STYLES OF FULL PUSHUPS

By

Carolyn Ruos

B.S., University of Maryland, 1981

Presented in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

UNIVERSITY OF MONTANA

1983

Approved by:

[Signatures]

Chairman, Board of Examiners

Dean, Graduate School

3-15-83
The purpose of this study was to evaluate, with electromyography, the difference between two styles of full pushups. Pushups are often used to measure strength and endurance of the upper body in fitness evaluations although the pushup has not been standardized. Observations of students at the University of Montana revealed that pushup style is variable between individuals. Pushups may be performed with either flexion and hyperextension or horizontal flexion and extension at the shoulder joint. Twelve men and six women performed five pushups of both styles with surface electrodes attached to the (medial head) triceps brachii, anterior deltoid, and (clavicular) pectoralis major. Repeated measures ANOVA yielded significant differences between pushup styles for the (medial head) triceps brachii. EMG activities of the anterior deltoid and (clavicular) pectoralis major were not significantly different between styles. The results of this study suggest that pushup style is learned. Unless maximal activity of the (medial head) triceps brachii is desired pushup style should be a matter of personal choice.
I would like to express my appreciation to the members of my committee: Dr. Kathleen Miller, Dr. Mark Clark, and Mr. Richard Gajdosik. A special thanks to Dr. Sally Phillips and Steven Stanhope of the University of Maryland for their assistance.

I would like to thank Jennifer Ruos and Greg Appler and all the other subjects who made this study possible. I am grateful to my family and friends for their love and patience.
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Chapter 1

INTRODUCTION

The pushup is frequently used as a measure of strength and endurance of the arms and shoulder girdle. Despite wide use in training programs and fitness evaluations the pushup has been neither validated nor standardized. Historically the validity of the pushup has been accepted at face value which may account for a general lack of scientific analysis of the pushup with regard to standardization. This study, which approached the question of standardizing the pushup, developed from observations of students enrolled in physical education classes at the University of Montana. Students were observed to execute full pushups in two basic styles and the style of pushup varied between men and women.

The discussion of pushup style concerns the major movements which occur at the shoulder joint. Movement at the shoulder joint may be flexion and hyperextension or horizontal flexion and horizontal extension. For the purpose of this study the combined movements of horizontal flexion and horizontal extension are called "winging." Observations of students at the University of Montana were that men tended to demonstrate flexion and hyperextension and women almost exclusively winged. There is no documentation in the literature supporting or contradicting these observations.

Women are generally assumed to have less upper body strength
than men and perhaps winging provides some real or imagined advantage while performing pushups. An early study of pushup energy cost by Hamlin and Waterman (14) found that oxygen uptake during pushup performance was greater for women than for men. If the hypothesis that women in the study demonstrated winging can be accepted then winging may recruit more muscle fibers and therefore require a greater expenditure of energy. Doody et al. (11) discussed anatomical differences in the shoulder joint and thoracic wall between men and women. The smaller bony structure of women permits a greater range of movement at the glenohumeral joint which may allow women to wing more easily than men. Conversely, men have larger muscle masses which may restrict shoulder joint movement.

Another consideration is that pushup style may be a learned activity. If women have only performed modified pushups and then are required to execute full pushups for the first time in college physical education classes they may intuitively wing. Men may be taught at a younger age to perform full pushups with flexion and hyperextension at the shoulder joint.

The purpose of this study was to determine if a significant difference in muscle activity existed between two styles of full pushups. Within the established limitations and delimitations the study was designed with a practical approach. If pushups are to be used in fitness evaluations then standardization of pushup style may be a consideration. Therefore, the results of the study will be of use to physical educators and others interested in testing or developing strength and endurance of the upper body.
Statement of the Problem

The purpose of this study was to compare the electromyographic activity of the medial head triceps brachii (MHTB), anterior deltoid (AD), and clavicular pectoralis major (CPM) between two styles of full pushups.

The subproblem was to determine if electromyographic muscle activity was affected by the sex of the subject.

Hypotheses

Ho: The EMG activity of the MHTB is not significantly different between pushup style IN and pushup style OUT.

H1: The EMG activity of the MHTB is significantly different between pushup style IN and pushup style OUT.

Ho: The EMG activity of the AD is not significantly different between pushup style IN and pushup style OUT.

H1: The EMG activity of the AD is significantly different between pushup style IN and pushup style OUT.

Ho: The EMG activity of the CPM is not significantly different between pushup style IN and pushup style OUT.

H1: The EMG activity of the CPM is significantly different between pushup style IN and pushup style OUT.

Definitions

Movements of the Shoulder Joint

Horizontal flexion— a forward movement of the abducted humerus
in a horizontal plane.

Horizontal extension—a backward movement of the flexed humerus in a horizontal plane.

Flexion—a forward upward movement in a plane at right angles to the plane of the scapula.

Extension—return movement from flexion.

Hyperextension—a backward movement in a plane at right angles to the plane of the scapula.

Movements of the Elbow Joint

Flexion—from the anatomic position a forward—upward movement of the forearm in the sagittal plane.

Extension—return movement from flexion.

Types of Muscle Contraction

Concentric—a muscle shortening contraction.

Eccentric—a gradual releasing of a contraction such that the muscle returns from a shortened condition to normal resting length.

Isotonic—contraction with constant tension as the muscle shortens.

Isometric—contraction without appreciable change in muscle length (42).

Pushup Style

Pushup OUT— from a starting position with the hands positioned beneath the shoulders, elbows fully extended, the weight of the body supported by the hands and toes (see Figure 1).

Let down phase— eccentric contraction
Figure 1
Pushup Style OUT

Figure 2
Pushup Style IN
shoulder joint—hyperextension
elbow joint—flexion

Extension phase—concentric contraction
shoulder joint—flexion
elbow joint—extension

Pushup IN— from a starting position with the hands positioned beneath the shoulders, elbows fully extended, the weight of the body supported by the hands and toes (see Figure 2).

Let down phase—eccentric contraction
shoulder joint—hyperextension
elbow joint—flexion

Extension phase—concentric contraction
shoulder joint—hyperextension
elbow joint—flexion

Abbreviations

MHTB—medial head triceps brachii
AD—anterior deltoid
CPM—clavicular pectoralis major
IEMG—integrated electromyography
EMG—electromyography
Chapter 2

REVIEW OF LITERATURE

There are no studies in the literature which address pushup style as defined by this study and few studies pertaining to pushups in general. This chapter reviews a study done by Hinson (16) which examined muscle activity during performance of pushups by college women. Subsequent discussion focuses on descriptions of the muscles tested in this study and on some aspects of electromyographic testing, methods, and interpretation of data.

Hinson (16) examined, with surface electrodes, the activity of the triceps brachii, deltoid, pectoralis major, trapezius, serratus anterior, rectus abdominus, and external oblique when college women performed ten full pushups. The pushups were performed at the rate of five seconds/exercise and the angle of the humerus was standardized within subjects. No further mention of the humeral angle was made.

The data were descriptively analyzed for each muscle. The range of scores and the mean were presented. Hinson found that all the muscles were more active in the extension phase than in the let down phase. She concluded the muscles most active in pushup performance were (in decreasing order): the anterior deltoid, triceps brachii, trapezius, and clavicular portion of the pectoralis major.

The Shoulder Joint and Associated Muscles

The shoulder joint is a broad term which includes four
individual joints: sternoclavicular, acromioclavicular, scapulothoracic, and glenohumeral (19). The glenohumeral joint is most commonly referred to as the shoulder joint (3). An enarthrodial, or ball and socket joint, it allows many movements: flexion, extension, abduction, adduction, circumduction, rotation, horizontal extension and flexion (12,32,42).

The primary movers of the glenohumeral joint are: the deltoid, pectoralis major, latissimus dorsi, teres major, and rotator cuff muscles (3,12,32). The triceps brachii is included as a muscle acting on the shoulder joint because the long head originates from the scapula (3,19). Table 1 presents an analysis of the movements at the shoulder joint and the muscles associated with each movement.

With reference to Hinson's study, the AD, CPM, and MHTB were selected for analysis in this study. Although Hinson reported that the trapezius was the third most active muscle in pushup performance, it is not directly responsible for movement at the shoulder joint. The trapezius operates exclusively on the shoulder girdle (12,32).

**Anterior Deltoid**

The deltoid is a large multipenniform muscle which originates on the clavicle, scapula, and acromion process and extends to the humerus. By virtue of the muscle fiber arrangement and anatomical position, the deltoid acts exclusively at the shoulder joint. This muscle is considered the abductor of the humerus (12,19,32,42). Inman et al. (19) showed that the activity of the deltoid increased progressively to 90 degrees abduction with maximal activity between 90 and 180 degrees. Studies by Yashon and Bierman (44) and
## Table 1

**Movements of the Shoulder Joint and Associated Muscles**

<table>
<thead>
<tr>
<th>Movement</th>
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<tr>
<td>Flexion</td>
<td>anterior deltoid</td>
<td>12,19,25,35,36,37,44</td>
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<tr>
<td></td>
<td>pectoralis major—clavicular</td>
<td>12,19,32,35</td>
</tr>
<tr>
<td></td>
<td>coracobrachialis</td>
<td>12,32</td>
</tr>
<tr>
<td></td>
<td>biceps brachii</td>
<td>12,29,32,37,38</td>
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<tr>
<td>Extension</td>
<td>posterior deltoid</td>
<td>12,32,35,37,44</td>
</tr>
<tr>
<td></td>
<td>teres major</td>
<td>12,32</td>
</tr>
<tr>
<td></td>
<td>latissimus dorsi</td>
<td>12,32,35,37</td>
</tr>
<tr>
<td></td>
<td>pectoralis major—sternocostal</td>
<td>32,35</td>
</tr>
<tr>
<td></td>
<td>triceps brachii</td>
<td>12,29,32,37,39</td>
</tr>
<tr>
<td>Abduction</td>
<td>middle deltoid</td>
<td>12,25,32,35,37,44</td>
</tr>
<tr>
<td></td>
<td>supraspinatus</td>
<td>12,19,32</td>
</tr>
<tr>
<td></td>
<td>biceps brachii</td>
<td>32,37</td>
</tr>
<tr>
<td>Adduction</td>
<td>pectoralis major</td>
<td>12,32,35,37</td>
</tr>
<tr>
<td></td>
<td>latissimus dorsi</td>
<td>21,32,35</td>
</tr>
<tr>
<td></td>
<td>teres major</td>
<td>12,32,37</td>
</tr>
<tr>
<td></td>
<td>triceps brachii—long head</td>
<td>12,32,37</td>
</tr>
<tr>
<td></td>
<td>coracobrachialis</td>
<td>12</td>
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<tr>
<td>Lateral Rotation</td>
<td>posterior deltoid</td>
<td>12,32,35</td>
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<td></td>
<td>infraspinatus</td>
<td>12,32</td>
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<tr>
<td></td>
<td>teres minor</td>
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<td>Medial Rotation</td>
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<td></td>
<td>latissimus dorsi</td>
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<td></td>
<td>anterior deltoid</td>
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<tr>
<td></td>
<td>subscapularis</td>
<td>12,32</td>
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<tr>
<td>Horizontal Flexion</td>
<td>anterior deltoid</td>
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<td></td>
<td>pectoralis major—clavicular</td>
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<td>subscapularis</td>
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<td></td>
<td>infraspinatus</td>
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others (25,35,37,38) demonstrated that the entire deltoid participates in all movements of the shoulder joint. The principle action of the anterior deltoid is flexion of the humerus, the secondary action is medial rotation of the humerus. Shevlin et al. (36) reported the anterior deltoid increased in activity from horizontal flexion to horizontal extension.

**Pectoralis Major**

The pectoralis major acts on the shoulder girdle but its primary action is on the shoulder joint (12,32). Originating from the clavicle, sternum, and costal cartilage, it inserts on the humerus. This muscle is a powerful adductor of the humerus (35) and the two portions—clavicular and sternocostal—function together in pushing, punching, and throwing movements (12,32,42). The clavicular portion is active in flexion at the shoulder joint, aiding the anterior deltoid (12,19,32,42), and initiates horizontal flexion (32,36).

**Triceps Brachii**

The triceps brachii functions in movements of the shoulder joint and the elbow joint. The muscle, composed of lateral, medial, and long heads, covers the posterior surface of the upper arm and inserts on the olecranon process of the ulna. The medial and lateral heads originate from the humerus and the long head originates from the scapula (12,32,42). All heads of the triceps brachii act to extend the elbow. According to Travill (39) the medial head is the primary elbow extensor. The lateral and long heads become increasingly active when extension of the elbow joint is resisted (30,32,37,39). The long head
is more active than either the medial or lateral head in adduction of the humerus (12,29,32,35).

**Electromyography**

Electromyography is a method of determining the electrical activity of a muscle. The electromyographic (EMG) signal is a manifestation of the motor unit action potential (MUAP) which is a summation of individual muscle action potentials (MAP) in a given motor unit. The MAP is the result of the depolarization and repolarization of the sarcolemma which occurs when the action potential transmitted by the motoneuron arrives at the motor end plate (3,13,40). When two electrodes are placed about a muscle site the EMG signal registers a difference in potential between the two electrodes. The greater the surface area between the two electrodes the longer the duration of the MUAP (40). Surface electrodes therefore register longer levels of excitation than invasive electrodes although Bouisset and Maton (6) demonstrated that the relationship between IEMG values of surface electrodes and intramuscular electrodes was linear. The smaller the interelectrode distance, the more localized the pickup (3). The electrical activity measured from superficial muscle fibers with surface electrodes is considered indicative of the activity of all fibers involved in a contraction (5).

EMG recordings reflect which muscles are active and the intensity of the activity. When more than one muscle is involved in a movement the EMG recordings indicate the order of muscle recruitment and the degree and duration of contraction of the individual muscles (2).
When a muscle is contracted isotonically the EMG signal cannot be correlated with the force, tension or strength of the contraction within or between muscles. When a muscle is allowed to change in length the number of muscle fibers recruited to produce a contraction is affected in part by the degree of actin-myosin crossbridging. The force of contraction is greatest when the muscle is shortened and decreases with muscle lengthening. The amplitude of the EMG signal decreases as the muscle is stretched (18). When a muscle is shortened the electrical activity is maximal although the tension level is low.

**Effect of Fatigue on the EMG Signal**

Localized muscle fatigue occurs when metabolic demands of the contractile fibers cannot be met due to ischemia or depletion of energy substrates (43). As the tension of individual fibers decreases additional motor units must be recruited (3,10,43). The amplitude of the EMG recording increases progressively and the integrated voltage level rises (3,15). In addition the duration of the MAP increases as the velocity of the MAP is reduced causing shifts in the EMG signal of the MUAP. Mortimer et al. (28) suggested that this may be due to recruitment of slower twitch fibers, which have a longer MAP, as fast twitch fibers drop out.

**Technique and Data Interpretation**

A "clean" EMG signal can be affected by a variety of noises within the body or the environment (3,43). Proper electrode placement is essential in order to reduce electrical interference from other muscles which may also be active in a given movement. For this reason
surface electrodes are acceptable only when the muscles to be studied are superficial. Movement artifacts can result when the surface electrodes are moved or when the cables leading from the electrodes to the amplifiers are moved. Strong adhesive collars and flexible cables are the most effective way of reducing movement artifacts. Under ideal conditions all EMG testing is conducted in a shielded room (3) where copper or bronze screening prevent attraction of radio and electromagnetic signals to the subject, cables, and equipment. When shielded rooms are not available a ground metal attached to the subject is considered adequate.

Surface electrodes have certain advantages and limitations. They are considered appropriate when: the muscle to be studied is superficial, interest is in the activity of the whole muscle, and the movement is neither violent nor fast, making it unlikely that the electrodes will become detached. In addition, there is minimal discomfort to the subject during electrode placement and testing (3,28).

A major consideration when using surface electrodes is the electrode/skin interface which causes electrical impedance at the skin and distorts EMG signals. Electrical impedance results from a variety of factors: skin thickness, skin preparation, temperature of the electrode paste, and the electrode site (40,42). Effective reduction of electrical impedance requires that the electrode site be carefully selected and cleansed of skin oils and dead cells. Distortion of the EMG signal by electrical properties of the skin itself and the electrodes can be reduced by proper amplitude and signal frequency ranges (40).
Once the EMG signal has been amplified it may be processed online. Selection of the average mode on the Beckman R611 Dynograph passes the raw EMG signal through a linear envelope detector which is a full wave rectifier followed by a low pass filter. This reverses the sign of all negative voltages (40) and records an average level which fluctuates with the strength of the electrical activity (43). Integration of the EMG signal (IEMG) refers only to the mathematical term of the area under a curve. The linear envelope is not in itself integrated. Integration permits quantitative discussion of the data and reflects the number and frequency of active muscle fibers (3,6).
Chapter 3

METHODOLOGY

Subject Selection and Test Location

The subjects were 12 men and 10 women volunteers between the ages of 18 and 25 years who were enrolled at the University of Maryland-College Park, during the fall semester 1982. Prior to testing all subjects were required to read and sign an informed consent form (Appendix A). Volunteers with chronic or acute injuries to the elbow or shoulder joints were restricted from participation. None of the volunteers performed pushups on a regular basis.

All testing was conducted in the Exercise Physiology Lab in the North Gym at the University of Maryland-College Park. The room was not shielded from extraneous electromagnetic and electrostatic interference.

Equipment

Data for this study were collected on a Beckman R6111 Dynograph which can accept up to four separate input signals. Each pen has an independent preamplifier and amplifier. EMG signals were accepted by type 9852 Direct Average EMG couplers in the average mode. All couplers were linked with type 96110 preamplifiers. Type 411 amplifiers provided power to the recording pens.

The preamplifier gain controls the sensitivity of the preamplifier and was set within the range of .2-1.0 millivolts/millimeter.
The preamp multiplier multiplies the sensitivity of the preamplifier and was set within the range of .01-1.0. The High frequency response was set at 0.3 Hertz (Hz). Data were recorded on Beckman curvilinear paper and the paper speed was set at 50 millimeters/second.

Other equipment used in the collection of data included a Franz-Electric metronome which emitted audio and visual signals at a rate of 60 per minute. Subjects performed pushups on a padded bench seven feet long and three feet wide.

EMG curves were integrated using an Apple II and accessory Graphics Tablet and Software at the University of Montana. Selection of the AREA function measured the area under a curve with automatic closure at the baseline. DELTA and calibration settings were one and ten screen units/centimeter, respectively.

Experimental Preparation

Dynograph Calibration

Prior to testing each subject the dynograph was calibrated. The pens were manually aligned in the center of their respective tracing areas with the preamplifiers and amplifiers turned off. The preamp multipliers were set at CAL 1/2 SCALE, a factory installed calibration signal. At this setting, the pen deflected 2.5 centimeters. Gain adjustments were made to align the pens with the calibration deflection.

Subject Preparation

Male subjects were asked to remove their shirts and female subjects were asked to put on a loose fitting tank top. Electrode attachment sites were identified according to diagrams by Delagi (9),
Figures 3, 4, and 5 indicate the electrode placement sites. In order to reduce impedance between the skin and the electrodes, the skin over the muscles was dry shaved and firmly sanded with fine grade sandpaper. The skin was then firmly rubbed with an ethyl-alcohol gauze pad.

Beckman standard recessed electrodes (effective diameter one centimeter) were attached to double sided adhesive collars and filled with Beckman Electrode Electrolyte paste. The electrodes were attached to the subject's dominant side three centimeters apart in the direction of the muscle fibers. The electrodes were connected to the dynograph by flexible shielded cables. The subject was grounded by means of a rectangular metal plate covered with Beckman Electrode Electrolyte paste taped to the distal end of the ulna.

In order to ensure proper electrode placement the subject performed specific movements for each muscle while dynograph recordings were monitored. The test maneuvers were those outlined by Delagi and were performed against resistance. For the AD the subject performed forward elevation of the arm. The movement for the MHTB was elbow extension and for the CPM was horizontal adduction.

Test Procedure

Testing was conducted in two phases: dynamic and static. The dynamic phase was pushup performance. The static phase was designed to elicit maximal isometric contraction. The static phase was included so that data from pushup performance could be expressed as a percentage of maximal activity and thus permit comparison between subjects (29).
Figure 3
Electrode Placement—MHTB
Figure 4

Electrode Placement--AD
Figure 5

Electrode Placement—CPM
Dynamic
All subjects performed two sets of five consecutive pushups: style IN and style OUT. The order of style assignment was randomly determined. Between pushup sets the subjects rested for five minutes. Pushups were performed at the rate of four seconds/exercise. The subject lowered his/her body to an eight inch marker which was positioned between the hands and aligned with the manubrium. Each phase of the pushup, let down and extension, took two seconds.

Static
The subject laid supine on the bench and held a 36 inch long metal pole over his/her chest. A nylon rope was passed under the bench and tied to both ends of the pole. The rope was adjusted so that the pole would be eight inches above the subject's manubrium during maximal exertion.

The subject positioned his/her palms flat against the metal pole shoulder width apart. The subject was instructed not to let the fingers roll around the pole. The subject was instructed to position his/her elbows to simulate pushup IN or pushup OUT (Figure 6,7). Upon signal, the subject was instructed to push up against the pole as hard as possible and hold the contraction for five seconds. For each pushup style the procedure was conducted three times with a one minute rest between trials. After three trials the subject rested five minutes and then repeated the procedure for the alternate pushup style.

Data Reduction
For each subject there were 30 EMG curves, representing the
Figure 6
Pushup Style IN—Static Position

Figure 7
Pushup Style OUT—Static Position
the activity of three muscles during performance of five pushups for pushup style IN and pushup style OUT. Each curve was integrated by tracing the curve from baseline to baseline with an Apple II Graphics Tablet pen. Each curve was measured three times and the mean value was recorded.

The mean IEMG value was determined for each curve by dividing the mean area under the curve by the length of the baseline. In order to express muscle activity in millivolts the mean IEMG values (in square centimeters) were converted to square millimeters and multiplied by the preamplification and amplification settings.

Maximal isometric IEMG recordings were determined in the same manner. The trial which showed the greatest activity was selected for analysis. The area under the EMG curve was measured for the three seconds of highest activity.

Statistical Analysis

Repeated measures ANOVA (41) was used to determine if the electrical activity of the AD, CPM, and MHTB differed significantly between two styles of pushups. The repeated measure design removes the dependence imposed by repeated measurements on the same subject allowing each subject to act as his/her own control. Overall variability is reduced and subject differences are removed from the error term (17).

Methodological Assumptions

1. Subjects could be taught to perform two different styles of pushups.
2. Testing was conducted in such a manner that the order of pushup style assignment and the number of pushups performed reduced the influence of muscle fatigue on the data.

**Delimitations**

1. Subjects had no chronic or acute injuries to the shoulder or elbow joints.
2. All subjects could perform a minimum of five style OUT pushups and a minimum of five style IN pushups.
3. None of the subjects performed pushups on a regular basis.
4. Generalizations drawn from this study will apply only to the subjects tested under the conditions established by this study.

**Limitations**

It is recognized that the following limitations existed in this study:

1. Electrical interference from the environment and surrounding muscles could not be totally eliminated.
2. The researcher acknowledged that impedance levels between electrode pairs should be less than 10,000 Ohms (40) but no equipment was available to measure impedance levels.
3. Mechanical resistance varied between subjects and throughout the movements tested due to individual differences in arm length and both weight.
Chapter 4

RESULTS

The purpose of this study was to determine if the EMG activity of the MHTB, AD, and CPM differed between two styles of full pushups. If a difference did exist then pushup style would need to be a consideration when designing or administering fitness tests. For each muscle the null hypothesis was established that EMG activity between two styles of full pushups would not differ significantly.

Repeated measures ANOVA yielded:

1. A significant difference in the EMG activity of the MHTB between pushup style IN and pushup style OUT.

2. No significant difference in the EMG activity of the AD between pushup style IN and pushup style OUT.

3. No significant difference in the EMG activity of the CPM between pushup style IN and pushup style OUT.

The second focus of the study was based on the observation that men and women appear to perform pushups differently. The null hypothesis was that subject sex would have no significant affect on the EMG activities of the MHTB, AD, and CPM for either pushup style.

Repeated measures ANOVA yielded:

No significant interaction between the sex of a subject and the EMG activities of the MHTB, AD, and CPM for either pushup style. Differences were tested at the .05 level of significance. The results of the analyses are presented in Tables 2, 3, and 4.
### Table 2

ANOVA for Repeated Measures for Subject Sex and MHTB

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^a_p < .05
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**ANOVA for Repeated Measures for Subject Sex and AD**

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### Table 4

ANOVA for Repeated Measures for Subject Sex and CPM

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Discussion

The original test population consisted of 12 male and 10 female subjects. Statistical analyses were conducted on the data collected from 12 male and 6 female subjects. Data were not included in the analyses when penning occurred during any point in testing. Penning indicated that the sensitivity settings of the dynograph were too high, artificially limiting the amplitude of the EMG tracing. Four female subjects had penning occur during testing. The repeated measures ANOVA utilized the mean score from five pushups. Unless a mean score based on five pushups was available, a subject's data were not included.

Static Testing

The purpose of eliciting maximal isometric contractions was to allow comparison between subjects by expressing pushup muscle activity as a percentage of maximal activity. Subjective analysis of the data indicated that the static tests did not produce a true measure of maximal EMG activity. Conversion of dynamic test values to percentages of maximal activity produced some values in excess of 100 percent. Based on this study, the static procedure was considered ineffective for eliciting maximal isometric contractions. The following are some explanations for this phenomenon.

Using an isometric test to determine percentages of maximal activity produced by isotonic contraction may not be valid. According to Komi (21) there should be no difference in the degree of muscle unit recruitment produced by a maximal isometric contraction or a maximal isotonic contraction. Rosentsweig and Hinson (34) concurred that
maximal isometric and maximal isotonic contractions measured by electromyography did not differ significantly. They stated that neurologically there is little reason to expect a difference to exist between the two types of maximal contractions provided the joint angle and contraction times are held constant. Conversely, Rose and Willison (33) argued that maximal isometric contractions should not be used for comparative electromyography because the effort varies too much between individuals.

The static phase was designed to represent the pushup position where muscle activity was maximal. Subjective analysis of the data indicated that the EMG activities of the MHTB, AD, and CPM were maximal just after two seconds had elapsed. This corresponded to the beginning of the extension phase.

Anatomical positioning for the isometric test varied from the positioning used in the isotonic test. In the isometric position the body weight was supported by a bench, a much different position from the pushup where body weight is supported by the hands and feet. The literature suggests that maximal EMG activity of a given muscle is influenced in part by the anatomical positioning of the limb. Little and Lehmkuhl (24) measured elbow extension force in three test positions. They found that the force generated by an isometric contraction of the triceps brachii was determined by the position of the elbow. Additional studies by Larson (23) and Basmajian (3) found similar results for elbow flexors. Pitcher (31) reported that the patterns of EMG activity for the triceps brachii recorded when weights were pushed in the air from a supine position differed from the data collected during performance of a girl's modified pushup. The
literature therefore suggests that maximal EMG activity of a specific muscle is due in part to the anatomical positioning of the limb. Astrand (2) reiterated that if the aim is to perform in one position then it may be ineffective to test in another.

The purpose of the isometric test was to cause maximal EMG activity in the MHTB, AD, and CPM. Joint angles for the elbows and shoulders were not controlled within or between subjects except by subjective positioning to mimic the two pushup styles. The assumption was made that these positions would represent the positions during the pushup where maximal activity would be expected. Because some subjects recorded higher muscle activity during actual pushup performance the assumption must be faulty. To elicit truly maximal activity in the MHTB, AD, and CPM each muscle should have been tested individually in the position where the literature suggests maximal activity occurs. Inman et al. (19) demonstrated that the AD exhibits maximal activity between 90 and 120 degrees of flexion and abduction. Currier (8) found that maximal activity of the MHTB occurred from 90 to 120 degrees from full elbow extension. Inman et al. (19) also demonstrated that the CPM showed peaks of maximal activity at 75 and 115 degrees of abduction and flexion.

The equipment used in this study may have been inadequate for eliciting maximal isometric contractions. According to Moritani and DeVries (26) any small movements during isometric contractions produced fallible results because shortening occurred. The lack of a bracing device to prevent inadvertent movement from possible stretching of the nylon rope or lateral movements may have permitted some muscle shortening to occur during what was supposedly an isometric contraction.
Hinson's Study

For the purposes of discussion the data from this study was compared to the results obtained by Hinson (16). The method used by Hinson to describe the data is of questionable validity. She combined the data from ten subjects and determined the range of EMG activity and the mean score for each muscle. From this information she concluded that the AD was the most active muscle in pushup performance followed in decreasing order by the triceps brachii, trapezius, and CPM. Treating the data from this study in the same way indicated that muscle activity was greatest for the MHTB and following in decreasing order by the AD and CPM. Basmajian (3), whose book *Muscles Alive* is considered a definitive text on the subject of electromyography and muscle function, cautions that comparing integrated output from different muscles is inappropriate.

Research Implications

Only the MHTB showed a significant difference in EMG activity between pushup style IN and pushup style OUT. A cautious subjective analysis of the data indicated that EMG activity of the MHTB appeared to be higher during performance of pushup style IN as compared to the activity during pushup style OUT. With regard to the MHTB the results of this study correspond with those reported by Pitcher (31). She found that the MHTB was more active when the girl's modified pushup was performed with the arms adducted. Although the medial head of the triceps is the primary elbow extensor, the lateral and long heads of the triceps brachii become increasingly active as resistance to elbow extension is increased (29,39). In the absence of photographic evidence, adduction
is interpreted to mean that flexion and hyperextension were the movements at the shoulder joint—corresponding to pushup style IN.

Increased EMG activity of the MHTB during pushup style IN suggests that the mechanical resistance to elbow extension is greater for pushup style IN than for pushup style OUT. The total resistance (body weight) is the same for both pushup styles but perhaps the differences in the shoulder joint angles redistributes the lines of force. Brunnstrom (6) states that the activity of the triceps is enhanced when elbow extension is performed with shoulder flexion as in pushup style IN.

The functions of the AD and CPM are closely related. According to Inman et al. (19) the two muscles work synchronously. Both muscles are active in forward flexion, abduction, and adduction (35, 44). A study by Yamshon and Bierman (44) showed that both muscles have higher electrical activity when working against resistance. This study found no significant difference in the EMG activities between pushup style IN and pushup style OUT for either the AD or CPM. Therefore, resistance acting on the shoulder joint must be the same for both pushup styles. This study suggests that there may be biomechanical variables which influence the EMG activity of the MHTB, AD, and CPM during pushup performance.

At the conclusion of testing each subject was asked to subjectively assess which pushup style was the least difficult. Twenty of the twenty-two subjects reported that pushup style OUT was easier to perform. If the hypothesis that pushup style IN increases the resistance acting on the elbow is correct, this may explain why subjects found
pushup style IN more difficult.

The results of this study were not affected by the subject's sex. Physiologically there appears to be no explanation for the observation that women and men perform pushups differently. Anatomical differences discussed in the introduction suggested that women would find pushup style OUT easier to perform than men due to greater range of movement and less muscle bulk at the shoulder joint. An additional anatomical consideration may be the variation in the carrying or cubital angle between men and women. This angle is more pronounced in women than in men (7) and may act in an advantageous position to reduce force on the elbow joint during pushup style OUT.

The influence of learning should not be overlooked when discussing the observation that men and women perform pushups differently. Perhaps men have been taught that pushup style IN is the correct way to perform pushups. If women have not been taught how to perform pushups, the preferred style may be simply a question of determining which style is easiest. Less muscle activity is required of the MHTB for pushup style OUT so effort and energy are conserved.
Chapter 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This study investigated the activity of the MHTB, AD, and CPM during performance of two styles of full pushups. The purpose of the study was to determine if the EMG activity of those muscles differed between pushup styles. The second focus of the study was to determine if the observation that men and women perform pushups differently was reflected in the comparison of EMG data between the sexes.

Twelve men and six women participated in this study. Each subject performed five style IN pushups and five style OUT pushups with surface electrodes attached to the MHTB, AD, and CPM. An analysis of variance for repeated measures was used to determine if the EMG activities associated with style IN were different than the EMG activities associated with style OUT. Significant F values for comparison between mean differences supported the alternate hypothesis that pushup style influenced the activity of the MHTB. No significant differences were found for either the AD or CPM between pushup styles. There was no interaction between the sex of a subject and the muscle activities for either pushup style.

A cautious analysis of the data suggests that higher EMG activity for the MHTB is recorded during performance of pushup style IN. The literature indicated that increased EMG activity during pushup style IN may be reflective of a difference in mechanical resistance at the elbow joint.
The method used in this study to elicit maximal isometric contractions in order to normalize IEMG values between subjects was determined to be invalid.

Conclusions

Within the limitations and delimitations of this study the following conclusions can be drawn:

A. EMG activity of the MHTB is significantly affected by pushup style.

B. EMG activity of the AD and CPM are not significantly affected by pushup style.

C. There was no measurable difference in the EMG activity of the MHTB, AD, and CPM between men and women. Therefore, this study does not explain the observable difference of pushup style variation between men and women.

D. Pushup style should be a matter of personal preference unless maximal activity of the MHTB is desired.

Recommendations

Based on the results of this study the following recommendations are proposed:

A. A thorough biomechanical analysis of the two pushup styles is necessary to test the hypothesis that mechanical resistance varies between the two pushup styles.

B. Further study needs to be done to establish a relationship between maximal isometric contractions and muscle activity recorded
during pushup performance.

C. Any replication study should control joint angles to ensure standardization of pushup style across subjects.


1. Explanation of electromyographic (EMG) testing:

You have been asked to participate in a master's thesis study sponsored by the Department of Health and Physical Education at the University of Montana.

Electromyography is a technique used to study the electrical activity of muscles. Surface electrodes will be attached to the anterior deltoid, pectoralis major (clavicular), and triceps brachii muscles in order to determine the recruitment of these muscles while performing two different styles of pushups.

You will be asked to perform two sets of five pushups at the rate of four seconds per exercise starting from a position of full elbow extension. You will lower your chest to a marker eight inches from the floor and return to the starting point. After completion of the first set of pushups you will have a five minute break before beginning the next set.

2. Risks and discomforts:

There exists the possibility of allergic reaction to the alcohol-ether solution used to prep the electrode sites and/or to the adhesive used to apply the electrodes. You may experience localized muscular fatigue during and/or after performance of the pushups. If at any time you feel unable to continue you may voluntarily terminate testing.

3. Benefits to be expected:

The results of this study will be used to determine the recruitment of the anterior deltoid, pectoralis major (clavicular), and the triceps brachii with respect to the movement at the shoulder joint during performance of two styles of pushups. The potential application of this study is to standardize the pushup for tests of upper body endurance and/or strength.

4. Inquiries:

Questions about the testing procedure are welcome. Please feel free to contact Carolyn Ruos at (301) 286-2027 for further explanation.
5. Freedom of Consent:

Permission for you to take part in this study is voluntary. You are free to deny consent if you so desire.

I have read this form and I understand the test procedures that I will perform and I consent to participate in this study.

"In the event physical injury results from biomedical or behavioral research the human subject should individually seek appropriate medical treatment and shall be entitled to reimbursement or compensation consistent with the self insurance program for Comprehensive General Liability established by the Department of Administration under authority of MCA Title 2, Chapter 9 or by satisfaction of the claim or judgement by the means provided by MCA, Section 2-9-315. In the event of a claim for such physical injury further information may be obtained from the University of Montana Legal Counsel."

Signature__________________________

Date _______________ Witness _________________________

Do you have any known allergies to alcohol-ether solutions? Yes/No
Do you have any known allergies to adhesive tapes? Yes/No
Do you have any chronic injuries to the shoulder and/or elbow joint? Yes/No
Do you have any acute injuries to the shoulder and/or elbow joint? Yes/No
## APPENDIX B

### Individual Data

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