

AN ELECTROMYOGRAPHIC ANALYSIS OF SOME OF
THE MUSCLE GROUPS INVOLVED IN THE
PERFORMANCE OF THE BENCH PRESS EXERCISE

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William J. Mickschl

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ABSTRACT

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This study investigated the effects of a wide, medium, and narrow grip width on the muscle activity produced by the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii during the performance of the bench press exercise. The 28 Ss involved in the study were trained and experienced in the performance of the bench press exercise. Bipolar surface electrodes were used to detect maximal and 85% of maximal myoelectrical activity from the muscle bellies of the 4 muscles studied, during eccentric and concentric contractions. A Two-way ANOVA with repeated measures revealed significant differences ($p < .05$) between the ratios of EMG activity produced by the 4 muscles when using a wide, medium, and narrow grip width position. A Friedman ANOVA by ranks revealed significant differences between the sums of the recruitment order ranks ($p < .001$), and between the absolute EMG activity ranks ($p < .01$) and ($p < .001$) for the wide, medium, and narrow grip widths. The results of this study provides evidence that the grip width position used during the performance of the bench press effects the amplitude and frequency of the EMG muscle activity, the pattern of muscle recruitment, and the degree of involvement for each muscle analyzed. The EMG activity produced by the muscles involved in the bench press exercise indicate that one grip width position might be more advantageous for developing muscle activity in the muscles studied. The results of this study may be applied to help improve the performance and understanding of the function of the muscles involved in the bench press exercise.

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UNIVERSITY OF WISCONSIN-LA CROSSE
College of Health, Physical Education and Recreation
La Crosse, Wisconsin 54601

Candidate: William J. Mickschl

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Human Performance

The candidate has completed his oral report.

E. Keith French 6/20/84
Thesis Committee Chairperson Date

Sandra Aker 6/20/84
Thesis Committee Member Date

S. T. ... 6/21/84
Thesis Committee Member Date

This thesis is approved for the College of Health, Physical Education and Recreation.

John C. Mitchem 7/29/84
Dean, College of Health, Physical Education and Recreation Date

Howard E. Rose 7/28/84
Dean of Graduate Studies Date

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CHAPTER I

INTRODUCTION

The use of free weights for increasing muscle strength, conditioning, and improving muscle performance during specific sports movements has been recognized as an acceptable method of training. Many sports such as football, basketball, baseball, and track and field have begun to incorporate weight training as a part of the training program. Both athletes and non-athletes are using free weights to improve muscle performance, strength, body composition, speed, and personal appearance. Free weight exercises are universally used to increase the strength of specific muscles primarily involved in a sports movement.

The bench press may be considered the finest free weight exercise for developing strength and improving performance in the muscles of the upper body. The bench press exercise can be performed using many different types of equipment. However, the free bar is the most widely used apparatus in strength training programs across the country and also is the most challenging and complex in technique (Algra, 1982).

It was stated above that the bench press exercise involves muscle groups of the upper body. Among the primary muscle groups involved in the performance of the bench press exercise are the pectoralis major, the deltoids, and the triceps brachii. However, the extent of the muscle involvement has not been determined by electromyography (EMG).

The mechanical performance of the bench press involves extension and flexion of the shoulder and elbow joints. Research has demonstrated that the primary muscles involved in flexion of the shoulder joint includes the pectoralis major and anterior deltoid (Thompson, 1977; Gardner and Osburn, 1973; Kent, 1971; Lehmann and Lucci, 1969; Okamoto, Takagi and Kumamoto, 1967; Clarke, 1966; Scheving and Pauly, 1959). Where as the primary muscle involved in extension of the arm is the triceps brachii (Travill, 1962). The involvement of the pectoralis major, anterior deltoid, and the triceps brachii during flexion and extension of the shoulder and elbow joints has been determined by EMG. Since the bench press may be one of the most beneficial and most widely used exercise by athletes for increasing muscular strength in the upper body, more extensive research should be performed to determine the function of the muscles involved in the bench press exercise.

When investigating the muscular activity of the muscles involved in a athletic movement the EMG is a valuable piece of equipment. The EMG is used to obtain the electrical signals associated with the contraction of a specific muscle (Guyton, 1981; Winter, 1979). Therefore, when a muscle contracts the degree in which the muscle is involved in a movement may be associated with the amount of electrical activity the muscle produces.

There is a lack of kinesiological EMG studies involving the analysis of gross muscular function during isotonicly performed free weight contractions. The lack of EMG research analyzing the isotonic contraction was thought to be due to the uncontrolled velocity of the

muscle contraction (Bigland and Lippold, 1954a). The uncontrolled contraction made it difficult to interpret the EMG data. The use of the EMG to analyze the function of the muscle groups involved in free weight lifting exercises may provide researchers with the following information: voluntary muscle activity; the muscles involved in a free weight exercise; the chronological recruitment pattern of the muscles involved in a movement; the tension developed in each muscle; the degree and duration of the muscle involvement; and possibly the most advantageous way to perform the movement. The information obtained from the EMG analysis of the muscular function during isotonic, free weight lifting exercises would be beneficial to strength coaches, trainers, coaches, physical therapists and athletes.

The lack of kinesiological EMG studies analyzing eccentric and concentric contractions during free weight lifting exercises, such as the bench press, has limited the understanding of the muscular function during the performance of free weight exercises. More research is needed studying the muscular function during these type of free weight contractions. This research will provide new information on the performance of the specific muscles involved in the free weight bench press exercise.

Statement of the Problem

The primary problem of the study was to electromyographically analyze the muscle activity and function of the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii during the performance of the bench press

exercise.

The second problem of the study was to determine the effects of a wide, medium, and narrow grip width position, and the development of muscle activity for the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii during the performance of the bench press exercise.

The third problem of the study was to determine the order of recruitment for the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii during the eccentric (lowering phase) and concentric (pressing phase) contractions of the bench press exercise.

The fourth problem of the study was to determine the effects of the shoulder joint angle on the muscle recruitment order, and the degree to which the muscles are involved in the bench press exercise.

Purpose of the Study

It was the purpose of this research to provide kinesiological EMG data which will contribute to the understanding of the muscular function of the muscles involved in the performance of the bench press exercise. The electromyographic testing of the response of the sternal and clavicular heads of the pectoralis major, anterior deltoid, and the medial head of the triceps brachii to different grip width positions, will provide descriptive information which may be used to determine the role of each muscle during the performance of the bench press exercise. The specific levels of muscle activity attained from each muscle group may provide some justification for the use of different grip width positions during

the performance of the bench press exercise.

Need for the Study

Kinesiological electromyographic research has been used to reveal information about the interplay between specific muscles and their function during motion. However, many of the kinesiological EMG studies have analyzed the muscular function during athletic movements (Schapekahn, 1977; Olgesby, 1969; Finanger, 1969; Garrison, 1965; Flint and Gudgell, 1964; Hermann, 1960). With the increasing use of free weight training to increase strength and improve muscle conditioning and performance, there is a need to determine the function of specific muscles involved during the performance of these free weight exercises.

The bench press is one of the most often used free weight exercises for improving muscle conditioning in the upper body. The bench press exercise involves specific muscles of the shoulder joint and elbow joint. Therefore, determining the activity of the specific muscle groups would be very beneficial for improving the performance of the bench press exercise.

There is insufficient research investigating the muscle mechanics and function for the bench press exercise. Since the bench press exercise is frequently used for training purposes, an EMG analysis would be helpful for understanding the actual function of the muscle groups involved. In addition, it was of significant importance that a distinction be made between the effects of a wide, medium, and narrow grip width position on the muscle activity produced by the different muscle groups. The lack of information on the muscle activity for the

bench press and other free weight exercises is enough reason to warrant further research. This research will hopefully present information necessary for increasing the understanding of the bench press exercise and optimize it's performance.

Hypotheses

The following hypotheses were formulated and tested at the $P < .05$ level of significance.

1. There were no significant differences in the ratios of EMG muscle activity (.85RM/1RM) between the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii, during the performance of the eccentric and concentric contractions of the bench press exercise.
2. There were no significant differences in the ratios of EMG muscle activity (.85RM/1RM) between the wide, medium, and narrow grip width positions, during the eccentric and concentric contractions of the bench press exercise.
3. There were no significant differences between the sums of the recruitment order ranks for the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii, during the performance of the bench press using a wide, medium, narrow, and normal grip width position.
4. There were no significant differences between the shoulder joint angle and the EMG activity for the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii during the concentric contraction of the bench press.

Assumptions

The following assumptions were formulated regarding the research.

1. The subjects gave a true representation of a 100% maximal voluntary contraction during the performance of the bench press exercise.
2. The subjects were all healthy, presently trained and performing the free weight bench press exercise at least twice a week.
3. All subjects used and maintained correct lifting form during the performance of the bench press exercise.
4. All subjects understood the procedures that were followed throughout the testing.
5. The EMG data was randomly and independently sampled, and the sample was analyzed with respect to the wide, medium, and narrow grip width positions.

Delimitations

The research involved the following delimitations.

1. The sample size for the experimental group was delimited to individuals who were experienced and presently trained in the performance of the bench press exercise.
2. The subjects must have trained with the bench press exercise at least twice weekly for a period of at least one year prior to testing.
3. The subjects were delimited to individuals who could maximally press the equivalent of the subject's own body weight.
4. The subjects were required to perform the bench press exercise

using standardized powerlifting form during all training and testing sessions.

5. All subjects performed the bench press without verbal or other external motivation.

Limitations

The following limitations were involved in the research.

1. The researcher was unable to control for the subject's individual physical characteristics such as muscle size, arm length, shoulder width, and chest size.

2. The researcher was unable to control for individual motivational techniques used in preparation for performing the bench press exercise.

3. The researcher was unable to control for the thickness of the subcutaneous tissue and percentage of body fat between the surface electrodes and the muscle being analyzed.

4. The researcher was unable to control for the velocity of the eccentric and concentric contractions during the performance of the bench press exercise.

5. The researcher was unable to control for individual shoulder joint angles.

6. The researcher was unable to control for the subject's individual training grip width position.

7. The researcher was unable to control for changes in the maximal contraction.

Definition of Terms

Bench Press: The bench press is a free weight upper body exercise which involves flexion and extension in the muscles of the shoulder and elbow joints. The bench press involves two types of contractions, an eccentric contraction (lowering phase) and a concentric contraction (pressing phase). The bench press is performed by lying supine on a bench and supporting the bar over the chest with the arms. The bar is lowered to the chest and then pressed back up to a supported position.

Action Potential: The action potential is the electrical signal associated with the movement of ions during the muscle membrane depolarization (Basmajian, 1979).

Concentric Contraction: The concentric contraction is a contraction in which the muscles involved shorten as the joint segments move closer together. The concentric contraction is involved in the pressing phase of the bench press exercise.

Eccentric Contraction: An eccentric contraction is a contraction in which the muscles involved lengthen as the joint segments move further apart. The eccentric contraction is involved in the lowering phase of the bench press exercise.

Efficiency of Electrical Activity (EEA): The efficiency of electrical activity was a term used to describe the effects of increased muscular strength on the level of muscle fiber activation or recruitment.

Electromyograph: The electromyograph is a high gain amplifier with a preference or selectivity for frequencies in the range from about 10 cycles per second to several thousand. It is used for recording

action potentials produced by the motor units and the muscle fibers.

Electromyography: Electromyography is the study of the electrical signal or action potential associated with the contraction of a muscle.

Elbow Joint Angle: The elbow joint angle formed between the upper and lower arm segments. In this study the angle was determined by measuring the angle formed between the head of the humerus and the midpoint between the radial and ulnar styloid processes. The lateral epicondyle was used as the axis point. The elbow joint angle was used for determining the subject's wide, medium, and narrow grip width positions.

Grip Width: The grip width position is the spacing between the hands when grasping the bar. The three grip width positions were based on the elbow joint angles. The wide grip width is represented by a 80° elbow joint angle, the medium grip is represented by a 60° elbow joint angle, and the narrow grip width is represented by a 40° elbow joint angle.

Isometric Contraction: An isometric contraction is a contraction in which the muscle fibers shorten while developing maximal tension, however, there is no change in the joint angle involved.

Isotonic Contraction: An isotonic contraction is a contraction in which the muscle produces the same amount of tension while shortening against a resistance.

Kinesiological EMG: Kinesiological EMG is a study in which the researcher is mainly concerned with the activity of the whole muscle rather than individual motor units. Its purpose is to reveal specific muscles or muscle groups, and their function during motion (Winter, 1979).

Maximal Voluntary Contraction (MVC): For this study, the maximal voluntary contraction was attained for the bench press exercise in order to obtain maximal EMG muscle activity. The MVC is the maximal amount of effort or force that a muscle is able to produce during a contraction against a maximal weightload.

85% Maximal Voluntary Contraction: The 85% MVC is defined as lifting 85% of the MVC, given that the width and position are similar. The 85% was used to obtain 85% muscle activity for the muscles analyzed.

Ratio of EMG Activity: The ratio of EMG activity was determined by $85\% \text{ EMG activity} / 1\text{RM}_N \text{ EMG activity}$. The ratio of EMG activity represents the amplitude of EMG activity produced by the wide, medium, and narrow grip width positions compared to the maximal EMG activity.

Recruitment Order: The recruitment order refers to the order in which the muscles are stimulated to contract.

Repetition Maximum (1RM): The 1RM is a term used to indicate the maximal amount of weight that can be lifted for a single repetition.

Repetition Maximum Using a Normal Grip Width (RM_N): For this study, the RM_N represents the maximal repetition using the subject's normal training grip width position.

Quantitative EMG: The quantitative EMG is the study of the amount of electrical muscle activity that is present in a given muscle under varying conditions.

CHAPTER II
REVIEW OF RELATED LITERATURE

Introduction

In the past, the knowledge of muscular function and contraction was investigated and determined largely through palpation. Since the introduction of the electromyograph, researchers have more precisely determined the muscle involvement and activity during given movements. Electromyography, when properly applied to the subject, provides an excellent method for studying human muscle activity. The electromyograph has been recognized as one means of sampling the activity of the motor neurons that control motor units and muscle fibers. Electromyography is the study of the amount of electrical activity produced by motor units in a muscle under varying conditions. The EMG recording reflects the muscle activation at a level of sensitivity at which palpation fails to produce evidence (DeVries, 1980).

The EMG signal occurs only and always in response to motor unit impulses. When the EMG activity is isolated in a recording, the activity of a single motor unit during a movement can be determined. Electromyography has become a useful tool for the investigation of muscle function. By means of a multiple channel electromyogram, it is possible to determine the participation of a specific muscle during a contraction, and the extent of participation during the performance of a certain movement.

In the past twenty years, the number of kinesiological EMG studies investigating the muscular function of specific muscle groups involved in particular athletic movements has increased (Eloranta and Tomi, 1981; Schapekahn, 1977; Finanger, 1969; Flint et al., 1964; Oglesby, 1964; Garrison, 1963; Hermann, 1960). These kinesiological EMG investigations are mainly concerned with the function of the whole muscle rather than isolated motor units (DeVries, 1980). The review of literature revealed limited research involving the kinesiological EMG analysis of isotonicallly performed free weight contractions. Therefore, the purpose of this research was to obtain kinesiological EMG data on the muscles involved in the bench press exercise.

The review of related literature was divided into the following areas:

1. Muscle Physiology
2. Kinesiological Electromyographic Studies
3. Electromyographic Responses to Muscle Tension
4. Bench Press
5. Summary

Muscle Physiology

Motor Units

The main factor involved in the study of electromyography is the motor unit. It is known that each individual motor unit contracts rhythmically and repetitively in response to an impulse reaching the motor unit. However, not all motor units in a muscle contract at the same moment. Throughout an individual muscle there is a complete

asynchrony of the motor unit contraction (Basmajian, 1979). As the motor units are contracting and relaxing asynchronously with twitch like action, the result is a smooth contraction of the muscle (Basmajian, 1979). It has been demonstrated that when an impulse reaches a motor unit, the motor units of the muscles involved follow the all or none principle (Astrand and Rodahl, 1971; DeVries, 1980). A minimal stimulus causes the individual muscle fiber to contract to the same extent as a stronger stimulus does. The all or none principle holds true for individual muscle fibers and motor units, but does not apply to the muscle as a whole (Mathews and Fox, 1976).

In 1973 Bouisset stated that the smallest natural contraction is a twitch, which is produced by the fibers of one motor unit. The largest contraction is the synchronous tetanic contraction of all the motor units in a muscle.

The number of muscle fibers that are controlled by one motor unit varies greatly. Generally, muscles that control fine movements have fewer muscle fibers per motor unit. The larger contracting muscles responsible for gross movements control a greater number of muscle fibers per motor unit. The number of human muscle fibers innervated by one motor unit (innervation ratio) may range from 1 or 2 to almost 2000 muscle fibers.

It is known that the diameter of a muscle fiber varies from one muscle to another, and the number and size of a motor unit plays an important role in grading voluntary muscle activity (Fischer, 1961). Therefore, the size of a motor unit and the number of muscle fibers innervated by the same nerve fiber could be different for various

muscles.

Motor Unit Recruitment

The tension developed by a muscle during a contraction depends on the number and size of the motor units stimulated, the length of the muscle fibers, the oxygen supply to the muscle, the frequency of the stimulus, and the proportion of different metabolic motor units. The recruitment of motor units usually occurs according to the size principle so that the smaller or slow motor units become active first, followed by the larger or fast motor units (Henneman and Olson, 1965). The smaller, slow twitch motor units are called tonic units. They have been classified as smaller units (Type I) and metabolically have fibers rich in mitochondria, and have a high capacity for aerobic metabolism (Winter, 1979). The larger, fast twitch motor units are called phasic (Type II) units. These motor units have little mitochondria and rely on anaerobic metabolism (Winter, 1979).

The smaller or slow motor units have been shown to be recruited first at lower stimulation thresholds and increase their firing rate at lower muscle activation levels. The small motor units produce twitches with a low peak tension with a long time to peak (60 to 130 m/sec). The larger or fast motor units are recruited at higher stimulation thresholds and increase their firing rate up to maximal activation levels. The twitches have large peak tensions in a shorter time (10 to 15 m/sec).

In 1981 Belanger and McComas analyzed the extent of motor unit activation during effort. It was found that muscles capable of producing larger torques and slower twitch speeds reflected greater muscle bulk

and a higher percentage of slow twitch fibers. Also, during extreme effort full activation of motor units were not achieved as easily.

In isometric work, the threshold for the slow motor units has been shown to range from 0 to 50% of the maximal contraction. The range for the fast motor units were 30 to 80% (Gydikov and Kosarov, 1973). It was determined that the slow motor units attained their maximum discharge frequency fairly early in submaximal contractions, where as the fast motor units continued to increase their firing frequency up to maximal tension.

The development of tension in a muscle is due to motor unit recruitment, and further tension is produced by the increase in motor unit firing rates. In 1965 Woodbury, Gordon and Conrad stated that the recruitment of motor units was due to the increase in the discharge frequency of the active motor units (temporal recruitment) and the increase in the number of active motor units (spatial recruitment), and the synchronization between the contracting motor units. It was known that each motor unit has a maximal firing rate and it is possible that the maximal rate is reached just as a new motor unit is recruited (Winter, 1979). When the tension is reduced, each motor unit decreases its firing rate until a minimal rate is attained and then it drops out. Each motor unit usually drops out in the reverse order in which it was recruited (Winter, 1979).

Motor Unit Action Potentials

The action potential is the signal produced by the motor unit and is recorded by the EMG. Action potentials are produced by biochemical

changes which occur in the motor nerve cell, axon, end plate and all the muscle fibers it innervates (Denny-Brown, 1949). The patterns of the action potentials reveal the activity of the muscle in response to various movement patterns and postures. It is the sum of the individual action potentials which is usually demonstrated by the kinesiological EMG. The interpretation of the EMG recording is based on the analysis of the action potential parameters (Magora and Gonen, 1975). The analysis of the action potential parameters include the amplitude, duration and shape, and frequency.

In 1967 Basmajian explained the motor unit action potential as occurring when an impulse reaches the myoneural junction. The wave of contraction spreads over the fiber resulting in a brief twitch, followed by a rapid and complete relaxation. The duration of the twitch varies from 1 to 2 milliseconds, to as much as 2 seconds, depending on the type of fiber involved (fast or slow). Since all the muscle fibers of a single motor unit do not contract at exactly the same time, the electrical potential developed by a single twitch of all the fibers in a motor unit is prolonged to about 5 to 12 milliseconds. The result of the motor unit twitch is an electrical discharge with an amplitude measured in millivolts. The analysis of the EMG recording involves the examination of the amplitude, duration, shape, and frequency of the motor unit action potential.

Amplitude

The amplitude of the action potential spike is the sum of the action potentials of the individual muscle fibers which are related to spatial and temporal summations (Basmajian, 1979). The amplitude

of the action potentials are dependent on the diameter of the muscle fiber, the distance between the active muscle fiber and the recording site, and the filtering properties of the recording device as well (Basmajian, 1979). Therefore, the size of the action potential must be related to the action potentials from the same recordings. This means that the absolute value of the action potentials cannot be compared to the spikes from EMGs of different muscle samples. The relative amplitude of the action potential spike directly indicates the degree of muscle activity. In 1973 Komi related the amplitude of the EMG activity to the tension developed by a muscle. Komi stated that the EMG amplitude indicates the state of tension of the contractile elements.

In 1965 Henneman et al. determined that initially, during a slight contraction smaller motor unit action potentials were found to appear first. As the force is increased, larger and larger motor unit action potentials were produced, along with increases in motor unit firing rates. This indicated that the action potentials from smaller or slow twitch motor units are less in amplitude than the action potentials from the larger or fast twitch motor units.

Duration and Shape

The duration and shape of the action potentials revealed certain characteristics about the motor unit. The conduction velocity of the muscle fiber is represented by the duration of the action potentials (Basmajian, 1979). The relative time of initiation of each action potential is directly proportional to the differences in the length

of the nerve branches, and the distance the wave of depolarization must propagate along the muscle fiber before it approaches the detectable range of the electrodes. The shape of the spike is variable with the geometric organization of the motor unit (Basmajian, 1979). The action potential spike features of duration and wave pattern distinguish one motor unit from another motor unit. The shapes of the action potentials are somewhat affected by the tissue between the muscle fibers and the recording site. With the surface electrode, the distance causes slightly prolonged durations of action potentials (Basmajian, 1979).

Frequency

The frequency of the motor unit firing is strongly related to the demand for muscle activity. The repetition of firing of the motor unit potentials is reliably detected by surface electrodes in contractions which are less than 50% of maximal voluntary contractions (Basmajian, 1979). The recruitment of motor units during an isometric contraction showed the action potential signals to increase in frequency with the development of force or tension. In addition, in contractions of constant velocity the EMG activity is proportional to the tension developed. Smaller motor units have lower stimulation thresholds and increase their firing rate at lower muscle activation levels than do larger motor units. It is the asynchronous firing rates of different sized motor units which produce a smooth contraction (Basmajian, 1979).

Kinesiological Electromyographic Studies

Within the past twenty years a new area of research has begun to develop. This research involves the use of the electromyograph to analyze the function of a muscle during a particular movement. This area of research has been referred to as "EMG Kinesiology" (Jonsson, 1973). The Kinesiological EMG investigates how the movement of specific body segments occur, and analyzes the function of the muscles during specific movements.

There have been a large quantity of EMG studies completed investigating selected muscle groups during the performance of a variety of movements. The EMG has been shown to be useful for determining the muscular function of specific muscles involved in a movement. This section reviewed completed research analyzing different muscles and their function as they relate to the bench press.

In 1959 Scheving and Pauly, using EMG extensively researched several muscles involved in the movement of the upper extremities. The muscle groups examined in the study included the sternal and clavicular heads of the pectoralis major, the anterior, medial and posterior deltoids, the latissimus dorsi, and the serratus-anterior. The muscle activity recorded from the muscle belly of each muscle was picked-up by bipolar surface electrodes. EMG recordings were measured from the shoulder joint complex during the movement of flexion, extension, abduction, adduction, and medial and lateral rotation. The EMG recordings indicated that the sternal and clavicular heads of the pectoralis major, and the anterior deltoid were predominantly

active during flexion of the shoulder joint. It was also evident from the data that the clavicular head of the pectoralis major was more active than the sternal head during shoulder flexion. When the shoulder was flexed against a resistance the amplitude and frequency of the action potentials, from the pectoralis major and the anterior deltoid, were increased (Scheving et al., 1959).

During extension of the shoulder joint, the sternal and clavicular heads of the pectoralis major, and the anterior deltoid were not significantly active. Scheving et al., (1959) showed that during extension of the shoulder joint, the latissimus dorsi was the most active of the muscles studied. The posterior deltoid was also active but less than the latissimus dorsi.

Experts in the area of weight training, and the bench press exercise have stated that the sternal and clavicular heads of the pectoralis major and the anterior deltoid are the primary muscles of the shoulder joint involved in the performance of the bench press exercise (Algra, 1982; Hatfield, 1981; Gillett, 1980; Rosentswieg, Hinson and Ridgway, 1975). It was determined by Algra (1982) and Gillett (1980), with an indepth biomechanical analysis of the bench press, that the primary movement of the shoulder joint during the performance of the bench press is horizontal shoulder flexion. Algra (1982) also found that along with the pectoralis major and the anterior deltoid, the triceps brachii was the third major muscle group involved in the bench press exercise.

In 1962 Travill investigated the function of the three heads of the triceps brachii, the long head, the lateral head, and the medial head during extension of the forearm. Travill used bipolar concentric needle electrodes that were placed into the muscle bellies of the three heads of the triceps brachii. The recordings were obtained with and without applying resistance during extension of the forearm. The observations made from the research showed that the medial head of the triceps brachii was most significantly active during free movement of the arm and during extension against a resistance.

With changes in the shoulder joint position during extension, no significant changes in muscle activity were found in the medial head. The lateral head of the triceps brachii was shown to have slightly less muscle activity than the medial head during free extension. However, during extension against a resistance the lateral and long heads produce greater EMG activity than during free movement. The EMG activity produced by the lateral head was greater than the EMG activity produced by the long head. Travill's research showed the medial head of the triceps brachii as the primary extensor of the elbow joint. In addition, it was stated that the primary function of the elbow joint during the performance of the bench press exercise was extension (Gillett, 1980). These two factors could lead researchers to assume that the most significant arm extensor muscle involved in the bench press exercise is the medial head of the triceps brachii, although this has not been determined by EMG.

During the performance of the bench press exercise, the brachium is placed in horizontal abduction. The degree of abduction remains

relatively constant throughout the eccentric and concentric contractions of the exercise. The degree of abduction is usually determined by individual physical characteristics and preference. However, no research has been completed to determine the optimal degree of abduction for the performance of the bench press exercise. Abduction of the shoulder joint has shown to produce muscle activity in the deltoid muscles. The muscle activity in the deltoids increased progressively during abduction, and became the greatest between 90° and 180° of shoulder abduction (Inman, Saunders and Abbott, 1944). The muscle activity in the medial deltoid was greater during abduction. The posterior deltoid, anterior deltoid, and the serratus anterior were also involved, and produced less muscle activity (Inman et al., 1944). When the shoulder joint was adducted, the muscle activity showed the pectoralis major as the primary muscle involved, and limited activity produced from the latissimus dorsi (Scheving et al., 1959; Inman et al., 1944).

In 1969 Hinson investigated the EMG activity of the primary muscle groups (triceps brachii, anterior deltoid, and pectoralis major) involved in the performance of the push-up exercise. The mechanics of the push-up are very similar to the mechanics of the bench press exercise. Both involve the triceps brachii, anterior deltoid, and the pectoralis major; both involve flexion and extension of the shoulder and elbow joints, and abduction of the shoulder joint. The muscle activity of 156 adult female subjects was detected by bipolar surface electrodes. The subjects were placed into four groups: (1) let-down, least difficult;

(2) knee push-up; (3) bench push-up; and (4) full push-up, most difficult. The research indicated that the anterior fibers of the deltoid were predominantly active during the push-up portion of the push-up exercise. The degree of muscle involvement decreased in order with the anterior deltoid being the most active, the triceps brachii, the clavicular head of the pectoralis major and then the sternal head of the pectoralis major.

Hinson included both trained and untrained subjects in the study of the push-up exercise. Hinson discovered that the EMG analysis revealed a greater level of muscular involvement and activity for the untrained subjects, than for the trained subjects while performing the push-up exercise.

It was concluded that the greater a muscle was trained, or the greater strength a muscle possessed, the less activation and recruitment of additional muscle fibers was needed to contract against a given muscle load (DeVries, 1980). The term "Efficiency of Electrical Activity" (EEA) was developed to describe the effect of increased muscular strength, or training on the degree of muscle fiber activation and recruitment (DeVries, 1980; Fischer and Merhautova, 1961). It is common knowledge that a muscle contracts greater against a resistance. Therefore, the stronger a muscle becomes through training, the greater efficiency it has when contracting against a resistance. The effect that strength training has on EMG activity produced by a muscle has been demonstrated by Thorstensson, Karlsson, Viitasalo, Luhtanen and Komi, 1976; Komi and Buskirk, 1972. The research showed that the EMG activity produced by a muscle decreased after training, indicating a

reduction in the EMG activity as a result of training and increasing the strength of the muscle.

Electromyographic Responses to Muscle Tension

Since the development of electromyography, the study of muscle tension has been one of the most important functions investigated by electromyography. Another significant function researched in kinesiological EMG studies has been the function of the muscles during specific movements. When researching the function of a muscle during a specific movement, it becomes important to know the tension developed by that muscle. The EMG activity is most often used as a quantitative measure of the amount of neural energy required to produce a certain level of muscle tension (Komi and Viitasalo, 1976).

The first useful information produced by the investigation of EMG action potentials resulted from the work of Bigland and Lippold (1954). The research showed that the tension developed, the velocity (nerve conduction velocity) and the electromyogram are interdependent. The electromyogram was useful for providing a complete and composite picture of the number and frequency of active muscle fibers.

Many of the EMG studies investigating muscle tension development in specific muscle groups have dealt with isometric muscle tension (Komi et al., 1976; Milner-Brown and Stein, 1975; Vrendenbregt and Rau, 1973; Inman, Ralston, Saunders, Feinstein and Wright, 1952). The predominant reason for studying muscle tension under isometric conditions was due to the controlled rate of muscle contraction.

On the other hand, previous studies researching muscle tension under isotonic conditions were shown to be difficult. Bigland et al. (1954) felt the difficulty was due to the velocity and the uncontrolled nature of the muscle contraction. Since then there has been an increase in the number of studies analyzing the EMG activity of isotonicly performed movements.

Other investigations examined the reliability of the data from the use of surface electrodes positioned over human muscles during active muscle contractions at different intensities of muscle contraction, or tension development (Viitasalo and Komi, 1975; Vredenburg et al., 1973; Inman et al., 1952). The results indicated that surface electrodes provided reliable and valid information concerning the frequency and amplitude of action potential spikes during active muscle contractions. The amplitude of the action potential spikes and how they relate to the development of tension was in agreement with the description provided by Henneman et al. (1965). The action potential activity was found to be directly related to the tension developed during isometric contractions, and contractions of controlled velocities.

Isometric Contraction

The isometric contraction was researched quite extensively using a majority of muscle groups, and under varying conditions using electromyography. Research by Lippold (1952) has contributed significantly to the study of muscle tension development during isometric contractions. Lippold (1952) had shown that the EMG activity produced by a muscle was proportional to the tension produced by an isometric contraction. DeVries (1980) stated that the main physiological factor

behind tension development is that when tension is developed in a muscle, there exists a recruitment of a greater number of motor units. The greater the tension produced in a muscle during a contraction, the greater the action potential amplitude.

In 1976 Komi and Viitasalo studied the effects of different levels of muscle tension on the EMG signal. Komi et al. (1976) investigated the EMG activity produced by the rectus femoris muscle of 12 male and female subjects. Bipolar surface electrodes were used to detect EMG muscle activity from the rectus femoris. The EMG activity obtained from maximal and submaximal isometric tensions (20%, 40%, 60% and 80%) of the rectus femoris were analyzed. A specially designed dynamometer chair was used for the testing. The results of the research showed that greater tension and greater muscle activity was produced from the upper portion of the rectus femoris, than from the lower portion. It was also found that as the muscle activity and tension increased, the percentage of force of the contraction increased. The increase in tension during a muscle contraction is considered to be due to both the recruitment of new motor units and the increase in the firing rate of active motor units (Adrian and Bronk, 1929; Ruch, 1963).

Pollak (1980); Milner-Brown (1975); Vredenbregt et al. (1973) obtained similar results as Komi et al. (1976) while studying the development of muscle tension during isometric contractions. The research showed that both the muscle tension and muscle activity increased as the force of the contraction increased. Therefore, as the muscle exerts greater force against a resistance, or a weighted bar as with the bench press, both the muscle activity and muscle

tension increased.

In 1968 DeVries investigated the effect of muscle training on muscle efficiency as measured by electrical output. The mean force of pre-training isometric muscle contractile strength and pre-training efficiency of electrical activity, which is the percentage of the muscular contractile force to the amplitude of recorded action potentials, was determined. The training groups were involved in a strength training program for 4 months. This included training the flexors and extensors of the right elbow and the right dorsi flexor of the ankle. The results of the study indicated that when maximal strength increased significantly due to training, the efficiency of the electrical activity level increased significantly. The unexercised muscle did not change in either strength or efficiency of the electrical activity level.

It was determined by DeVries (1968) that changes in the efficiency of a muscle contraction following strength training may be demonstrated by the fall in electrical output of the activated muscle. The research showed that as a muscle increases its strength from training, the involved fibers become more effective when producing tension. Therefore, either fewer motor units are recruited, or the same motor units fire at a slower stimulation rate, to produce a given level of isometric tension.

DeVries (1968) also discovered that one subject increased strength in the unexercised arm along with the exercised arm. However, the muscle efficiency which was measured by electrical output was not lower in the unexercised arm. DeVries felt that the unexercised arm improved

only on a neurophysiological basis. This involves learning to innervate motor units which would not change the level of electrical activation. It is also believed that cross excitation may play a role in the transfer of activity to the unexercised side. In 1975 Gregg, Mastellone and Gersten found that the overflow to the unexercised, contralateral muscle was greater after training against a resistance, than when training against no resistance. The overflow of activity was found to be between 10% and 20% of the maximal intensity of activity in the exercised muscle (Moore, 1975). This phenomenon may explain the role of motor learning in cross-education and early gains in strength, before muscle hypertrophy occurs.

In 1979 Moritani and DeVries investigated the effect of muscle activation levels (motor learning) versus true muscle hypertrophy (morphological changes) on strength increases. The results from the study demonstrated that the neural factors (increased innervation of muscle) played a major role in strength development at early stages of strength gains. The hypertrophic factors gradually dominated over neural factors in the contribution to strength gains. The significant gains in strength observed at the early stages of training was not accompanied by a significant increase in the cross-sectional area of the muscle. This factor may explain the major role of the neural factors in the early course of strength development.

In 1952 Inman et al. noted that the tension a muscle develops varies with the length the muscle was stretched under isometric conditions. Inman and associates found that the EMG amplitude would decrease when the muscle was stretched prior to recording. The findings

indicated that when the muscle was fully stretched or lengthened prior to contraction, greater maximal tension was developed. However, the EMG activity produced was reduced.

In contrast, when a muscle was in a shortened position prior to contraction, less maximal tension was developed. However, the EMG activity remained maximal. These results also indicated that the EMG activity was directly related to the tension exerted in an isometric contraction (Viitasalo and Komi, 1978; Vrendenbregt et al., 1973; Inman et al., 1952).

Isotonic Contraction

Normal everyday human movements are performed mainly by eccentric and concentric contracting muscles (Komi and Rusko, 1974; Komi, 1973). The eccentric and concentric contracting muscles allow the various body parts movement through a complete range of motion. As discussed above, the isometric contraction was used more often to study the relationship between the EMG activity and the development of muscle tension in contracting muscles. As a result, there is limited research analyzing the response of the EMG activity and muscle tension during eccentrically and concentrically contracting muscles.

In 1956 Asmussen discovered that the integrated EMG activity of a muscle, which was shortened against a resistance (concentric contraction) was greater than when the same muscle was lengthened against a resistance (eccentric contraction) while lifting the same weightload.

In 1953 Bigland and Lippold tested 5 young adult males and females. A special dynamometer was constructed to permit isotonic contractions.

of the gastrocnemius muscle during plantar flexion. This dynamometer was used so the subject could control the velocity of the contraction. Action potentials were recorded by surface suction electrodes. It was determined that at a constant velocity, during either shortening or lengthening of a muscle, the EMG activity was directly proportional to the tension produced. The amplitude of EMG activity was greater in a muscle during shortening than during lengthening. The research showed that at a constant tension the electrical activity increased in a linear manner with the velocity of shortening. Although, the tension seemed almost independent of the speed during lengthening of the muscle.

In 1973 Komi researched the relationship between maximal muscle EMG activity and maximal tension development of the elbow flexors. The measurements of the elbow flexors were made at different velocities for both concentric and eccentric contractions. A special dynamometer which was powered by an electrical motor to control the velocity of the contraction was used. The range of movement at the elbow joint was 120° (50° to 170°) which corresponds to a 7 centimeter change in the length of the biceps muscle of an adult man. The muscle activity was picked-up by inserted wire electrodes. The results of the research indicated that during a concentric contraction, the muscle activity of a muscle was dependent on the velocity of the contraction.

These findings were consistent with the research by Wilke (1949) who investigated the development of muscle tension during the isotonic contraction of the arm. Wilke found that during a isotonic contraction the faster a muscle shortened, the greater the EMG activity produced.

The amount of EMG activity was associated with the amount of tension developed by a muscle. Therefore, as the tension increases in a muscle the EMG amplitude and frequency (activity) also increases.

In 1950 Sullivan electromyographically investigated the medial biceps brachii of 8 subjects during voluntary movement. Recordings were obtained during flexion and extension of the elbow joint against a resistance of 10 to 20 kilograms. The forearm was placed in both a supine and pronated position. Elbow positions at 135, 90 and 45 degrees of flexion were recorded. Sullivan reported that repeated recordings from one subject, taken during the same testing session, were similar. In addition, repeated EMG recordings from one subject within an interval of several weeks were also similar.

Sullivan (1950) concluded that each muscle is made up of many motor units and that all the motor units are not active during the same movement. All movement is initiated by a slow response of a few motor units. As the tension increases during a contraction, the motor units increase the frequency of firing and other motor units are activated. However, when the increase of tension is stopped and the effort maintained, all the responding motor units continue to fire in an asynchronous rhythmic discharge. If the tension was developed gradually, there was a consistent increase in the discharge frequency up to the maximal rate attained. This was followed by a gradual decrease in the frequency of firing as the tension was slowly decreased.

A second study was completed by Bigland and Lippold (1954b) in which they measured the motor unit activity during the voluntary contraction of a muscle. Bigland et al. (1954b) investigated the

function of the abductor digiti minimi brevis and the abductor pollicis through the artificial stimulation of the ulnar nerve. It was the purpose of the research to determine the relationship between the frequency and the tension produced. In addition, recordings of action potentials associated with the motor unit activity and tension development in the muscles were measured. The results of the study indicated that a rise in stimulation frequency produced a proportional rise in the muscle tension until a certain frequency was reached. Further stimulation above that point caused no additional increase in muscle tension. This information was interpreted as an indication that full tetanic frequency in a muscle was reached. Bigland et al. (1954b) concluded that the increase in the contraction of a muscle was brought about mainly by motor unit recruitment, with the exception of the muscles at very low or high contractile strengths in which the frequency of firing was increased.

It was also stated by Bigland et al. (1954b) that the measurement of the electrical activity could be obtained by determining the area under the action potential curve. It was determined that the height of the integrated action potential curve was a direct function of the number and frequency of the discharging motor units. During a voluntary contraction, the tension was found to be proportional to the measurable EMG activity under both isometric and isotonic conditions.

In conclusion, the research completed analyzing muscle tension development using electromyography, determined that the increase in tension during a muscle contraction was due to both recruitment of new motor units and the increased firing rate of active motor units.

(Basmajian, 1979; Komi et al., 1976; Komi, 1973; DeVries, 1968; Woodbury et al., 1965; Bigland et al., 1954; Adrian et al., 1929). Where as Person and Kudina (1972) felt that the increase in tension was caused only by the recruitment of additional motor units.

As discussed above, motor units were shown to be recruited according to the size principle (Henneman et al., 1965). This indicated that the smaller or slow motor units became active first, and then the larger or fast motor units were recruited as the muscle tension increased (Henneman et al., 1965; Gydikov et al., 1973). During isometric contractions, the threshold for the slow motor units to initiate firing was shown to range from 0 to 50% of the maximal contraction. The faster motor units initiated firing at 30 to 80% of a maximal contraction (Gydikov et al., 1973).

In the research presented by Gydikov et al. (1973) it was concluded that the slow motor units attained maximal discharge frequency fairly early during submaximal contractions. A steady firing rate was maintained by the slow units during a maximal contraction level. On the other hand, the fast motor units continued to increase the firing rate up to maximal tension. The muscle activity was related to the discharge frequency of active motor units. Therefore, as the tension in a muscle increased, the number of motor units that were previously active proportionally increased.

Bench Press

The bench press exercise is a free weight isotonicly performed exercise, and the primary exercise used to strengthen and improve the

the efficiency of the muscles of the upper body. The performance of the bench press exercise is divided into 2 phases, the lowering phase and the pressing phase. The lowering phase or the eccentric contraction involves the lowering of the bar to the chest, and the pressing phase or concentric contraction involves the pressing of the bar upward until the arms are fully extended. During the eccentric contraction the muscles involved lengthen, while during the concentric contraction the muscles involved shorten. The bench press exercise was designed to develop specific muscles of the chest, shoulder and arm. The primary muscle groups determined to be involved in the execution of the bench press included the pectoralis major, the anterior deltoid, and the triceps brachii (Algra, 1982; Gillett, 1980; Rosentswieg, Hinson and Ridgway, 1975).

In 1954a Bigland et al. found that greater EMG activity was produced by a muscle during shortening (concentric contraction) of the muscle fibers. During lengthening (eccentric contraction) of the muscle fibers less EMG activity was recorded. These findings could possibly be related to the muscle contraction during the performance of the bench press exercise. Since the research states that the EMG activity is greater during the concentric contraction of a muscle, it may be assumed that the pressing phase, in which the muscle fibers shorten, produces the greatest muscle activity. On the other hand, less EMG activity was recorded during the eccentric contraction of a muscle. This indicates that during the lowering phase of the bench press, in which the muscle fibers lengthen, less EMG muscle activity is produced.

The bench press exercise involves both extension and flexion of the shoulder and elbow joints. Research by Scheving et al. (1959) indicated that during extension of the shoulder joint (the movement involved in the eccentric contraction or lowering phase) the pectoralis major and the anterior deltoid were not significantly involved. However, during flexion of the shoulder joint (the movement involved during the concentric contraction or pressing phase) the pectoralis major and the anterior deltoid muscles produced significantly greater muscle activity.

The triceps brachii was determined as another primary muscle involved in the performance of the bench press exercise. During the execution of the bench press, the elbow joint moves through flexion and extension. Research conducted by Travill (1962) stated that the greatest EMG activity was produced during extension (shortening of the muscle) of the elbow. Extension of the elbow joint occurs during the pressing phase of the bench press exercise.

In 1980 Gillett stated that during the eccentric contraction or lowering phase of the bench press, the shoulder joint moves through horizontal extension, while the range of motion at the elbow joint was from complete extension to about 120° of flexion. Gillett's analysis showed that the controlled lowering of the weight was achieved primarily by the eccentric contraction of the pectoralis major and the anterior deltoid. However, this was not in agreement with the results that Scheving et al. (1959) presented. The same muscles serve as the primary movers during the concentric contraction or pressing phase of

the bench press exercise.

Another area of the bench press exercise that researchers have ignored is the determination of an appropriate grip width position. No research was found involving different grip widths and their effect on the performance of the bench press. Authorities involved with the bench press and authors of weight training books suggested that a standard grip width is slightly wider than shoulder width (Algra, 1982; Todd, 1978; Schwarzenegger and Hall, 1977; Columbu and Fels, 1977; Starr, 1976). However, due to individual physical characteristics a standard grip width might not be appropriate for all individuals.

Investigators involved in studying the bench press have stated that individuals should grip the bar at a width that feels most comfortable (Algra, 1982). Although individuals with longer arms usually prefer a somewhat wider grip, while those with shorter arms often find that a narrow grip width works better. Algra (1982) theorized that a wider grip width placed greater pressure on the outer part of the pectoralis major and deltoid muscles. As the hand position moved closer together, so did the point of pressure. It was also theorized that when using a narrow grip width, the pressure was placed on the inside of the pectoralis muscle and the triceps muscle (Algra, 1982). Gillett (1980) theorized that a wide grip width involved the clavicular portion of the pectoralis major, while a narrow grip width involved the sternal head of the pectoralis major and the triceps brachii.

In 1975 Rosentswieg, Hinson and Ridgway performed an EMG analysis on the bench press exercise. The analysis was performed on an isokinetic bench press apparatus. Eleven college females performed 3 trials at 3 different speeds (1.5 sec., 2.0 sec., and 3.5 sec./3 ft.). Bipolar surface electrodes were used to detect the muscle activity from the anterior deltoid, pectoralis major and triceps brachii. The bench press was performed with the hands in a pronated position with the elbows flexed at a 30° angle. The measurement of the flexed elbow joint angle was made using a goniometer, while the hands were positioned at chest level. Rosentswieg et al. (1975) used the elbow joint angle as an indication of the subject's grip width. All elbow joint angles were measured at a 30° angle. This was done to maintain a consistent grip width position for all subjects. However, grip width data was not presented in the study.

The findings showed that the muscle action potentials for the slowest speed setting (3.5 sec./3 ft.) elicited a much greater output of muscle activity than the faster speeds (1.5 sec. and 2.0 sec./3 ft.) for each muscle. Rosentswieg et al. (1975) theorized that a greater amount of work being done over a longer period of time might be the reason that the slower speeds appear to develop strength quicker than isokinetic contractions using faster speeds. This may be explained by the fact that when training at slower speeds, a higher demand is placed on the muscle, thus a greater number of fast (large) twitch motor units respond for that activity. The fast twitch motor units are recruited at higher stimulation thresholds and fire up to maximal activation levels. The muscles involved in this analysis worked for a longer

period of time at a slower contraction speed. This indicated that the fast motor units were firing at near maximal levels for a longer time period, than the motor units firing at faster contraction speeds. Therefore, when training a muscle with greater demands on fast twitch motor units, and firing rates near or at maximal levels for a longer period of time may facilitate greater strength and hypertrophy in a muscle, than when training at faster contraction speeds. When training at faster contraction speeds fewer fast twitch motor units are recruited less often, so increases in strength and hypertrophy fail to occur.

In 1971 Santomier performed an EMG analysis of specific muscle groups during the performance of several isotonic free weight exercises. Santomier analyzed the pectoralis major and various other muscle groups during the performance of the bench press. Santomier found that the pectoralis major elicited the greatest integrated EMG muscle activity.

During the performance of any athletic movement, it becomes important to determine the involvement of the contributing muscles. The muscles involved in a movement are often analyzed individually to distinguish its specific function. It is common knowledge that when a group of muscles are involved in a movement or contraction not all muscles contract at the same time. The participation or involvement of a muscle during a movement is dependent upon the impulse sent, and when the muscle receives the neural stimulation from the brain. The brain learns the pattern of the bench press movement as it does with any other movement. When the brain performs a learned movement, it responds by increasing the neuromuscular activity to the muscles involved in

the movement (Basmajian, 1979). During the performance of the bench press, the muscles involved are recruited at certain points. The specific moment of recruitment can be determined when the brain increases the neuromuscular activity in the muscles as they become involved in the contraction of the lift.

Studies by Forrest and Basmajian (1965) and Basmajian and Latif (1957) have indicated that the interplay of motor units and their function are dedicated to specific postures and movements. This clearly indicates that the positioning of a limb during a movement is predetermined by a certain set of motor units which control the joints and muscles to produce that movement (Basmajian et al., 1957). The learned patterns are referred to as "specificity" (Forrest et al., 1965). Forrest et al. (1965) felt that specificity occurred when the image of a movement was learned by the brain, and the spinal motor neurons were dedicated to that learned response of a body part's specific movement through space. However, the ultimate performance of a skilled movement depends on the reproducibility of the movement pattern (Basmajian, 1977; Payton, Su and Meydrich, 1976).

The research discussed above may be related to the individual level of training. A well trained experienced lifter in the bench press develops a learned image in the brain of how to perform the movement pattern. The image of the bench press movement is stored in the brain and regardless of the amount of weight being lifted, the movement pattern of the muscles and joints should be consistent lift after lift. This learned image proves to be important for the success

of the bench press. If during the execution of the lift the shoulder joint deviates from its learned movement pattern, it may alter the involvement of specific muscle groups causing the contraction to be less effective.

Summary

In order to understand the mechanisms behind the movement and the function of muscle control, it has been essential to analyze the function of the basic structures. Electromyography was developed as a scientific method of investigating muscular function and coordination during movement. EMG studies have investigated the response of muscle involvement by analyzing the electrical activity of neuromuscular movement. The phenomenon of muscle behavior patterns during various contractions have been explained to be the result of various neuromuscular mechanisms. Research investigating the neuromuscular involvement during the contraction of isotonic free weight training exercises is very limited. Although, this type of research will provide a basis for the development of neurophysiological principles that can be applied to free weight exercises.

The research demonstrated characteristic patterns of muscle activity and how the activity responds to the tension developed during a contraction. The EMG response to an isometric contraction is proportional to the tension developed by the muscle. Both the muscle activity and the muscle tension increases as the force of the contraction increases. During contractions in which increases or

decreases in joint angles occurred, at constant velocities, the EMG activity was found to be directly proportional to the tension developed by the muscle. The EMG activity produced by a muscle was greater during the concentric contraction of a muscle than during the eccentric contraction. During a concentric contraction the EMG activity was dependent on the velocity of the contraction and the tension produced by the muscle. The increased stimulation frequency of a muscle is responsible for a proportional increase in muscle tension. During voluntary contractions the muscle activity was found to be proportional to the muscle tension for both isometric and isotonic contractions.

Kinesiological EMG research has been useful for determining and analyzing the function of a muscle during a specific movement. Researchers in this area are more concerned with the function of the whole muscle rather than the function of individual motor units. It was determined that the sternal and clavicular heads of the pectoralis major and the anterior deltoid produced the greatest EMG activity during flexion of the shoulder joint. The latissimus dorsi produced the greatest EMG activity during extension of the shoulder joint. The 3 heads of the triceps brachii were also investigated during extension of the elbow joint. The medial triceps produced the greatest EMG activity during extension, and was recognized as the primary extensor.

When reviewing the research on trained and untrained muscle groups, the trained muscle group always produced less EMG muscle activity than the untrained muscle. This demonstrated that when a muscle was trained, it contracted with greater efficiency. As a muscle obtained greater strength, the muscle required less activation and recruitment of

additional muscle fibers to contract against a weightload.

The free weight bench press exercise is considered one of the primary exercises used to strengthen and improve the performance of the muscles of the upper body. There are 3 main muscle groups primarily involved in the bench press exercise, the pectoralis major, the deltoid muscles, and the triceps brachii. The bench press exercise has been divided into 2 phases, the lowering phase, and the pressing phase in which the muscles lengthen and shorten, respectively. The mechanical functions of the shoulder and elbow joints during the bench press exercise includes extension and flexion. It was determined that the primary muscles involved in flexion of the shoulder joint were the pectoralis major and anterior deltoid, where as the triceps brachii was dominantly involved in the extension of the arm.

The results of the EMG analysis of human muscle during a variety of active and passive movements have demonstrated the principles developed by neurophysiological research. Necessary to the understanding of the EMG is the concept that the action potential signals are produced by motor units. The size of the motor nerve determines the motor unit structure and function. The recruitment of motor units occurred according to the size of the motor units. The smaller motor units are recruited first followed by the larger motor units. The increase of tension in a muscle is due to motor unit recruitment and the increase in their firing rates. The review of literature demonstrated a need for further study concerning the function of the muscle during isotonicly performed free weight training exercises.

CHAPTER III

METHODS

Introduction

It was the intent of this investigation to analyze the electromyographic (EMG) activity and function of the muscles during the eccentric and concentric contractions of the bench press exercise. The study includes the analysis of the muscle activity produced by the sternal and clavicular heads of the pectoralis major, the anterior deltoid and the medial head of the triceps brachii. The muscle activity produced by these muscle groups were analyzed while performing the bench press exercise using a wide, medium, and narrow grip width position. The EMG activity was used to determine the recruitment order for the muscle groups during the concentric contraction (pressing phase) of the bench press, and the degree of involvement of the muscle groups for each grip width position.

Subject Selection

The sample size selected for the research consisted of twenty-eight (N=28) trained volunteer male subjects from the University of Wisconsin-La Crosse. The subjects were restricted to individuals experienced and currently trained with the free weight bench press exercise. Trained subjects were determined by the following criteria; 1) the subjects were required to be experienced and knowledgeable in the performance of the bench press exercise; 2) subjects who participated in weight training

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It was the intent of this investigation to analyze the electromyographic (EMG) activity and function of the muscles during the eccentric and concentric contractions of the bench press exercise. The study includes the analysis of the muscle activity produced by the sternal and clavicular heads of the pectoralis major, the anterior deltoid and the medial head of the triceps brachii. The muscle activity produced by these muscle groups were analyzed while performing the bench press exercise using a wide, medium, and narrow grip width position. The EMG activity was used to determine the recruitment order for the muscle groups during the concentric contraction (pressing phase) of the bench press, and the degree of involvement of the muscle groups for each grip width position.

Subject Selection

The sample size selected for the research consisted of twenty-eight (N=28) trained volunteer male subjects from the University of Wisconsin-La Crosse. The subjects were restricted to individuals experienced and currently trained with the free weight bench press exercise. Trained subjects were determined by the following criteria; 1) the subjects were required to be experienced and knowledgeable in the performance of the bench press exercise; 2) subjects who participated in weight training

at least 3 times a week and performed the bench press exercise at least 2 times per week; 3) the subjects were required to use correct lifting form and technique throughout the lift, according to the powerlifting rules for the bench press (Appendix A); 4) the subjects were required to bench press at least the equivalent of their own body weight; and 5) the subjects were required to have at least one year's experience performing the bench press exercise.

The subjects met twice with the investigator, first to determine the elbow joint angles and to determine a single repetition maximum (1RM) for the bench press. The second time for the actual EMG recording of the 1RM and 85% of the 1RM for the wide, medium, and narrow grip width positions. Prior to any testing, all subjects were required to read and sign the informed consent form explaining the purpose and procedure of the study (Appendix B).

Instrumentation

Electromyograph

A 4 channel TECA Electromyograph recording unit, Model TE-4, was used to retrieve, amplify and record myoelectrical action potentials from the muscle groups being analyzed (sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii) during the performance of the bench press exercise (Figure 1). In 1973 McLeod stated that the electromyograph was capable of signal handling, which includes amplification and recording of myoelectrical signals. The TECA TE-4 fiber optic paper recorder, recorded the EMG activity from the oscilloscope record. The same paper

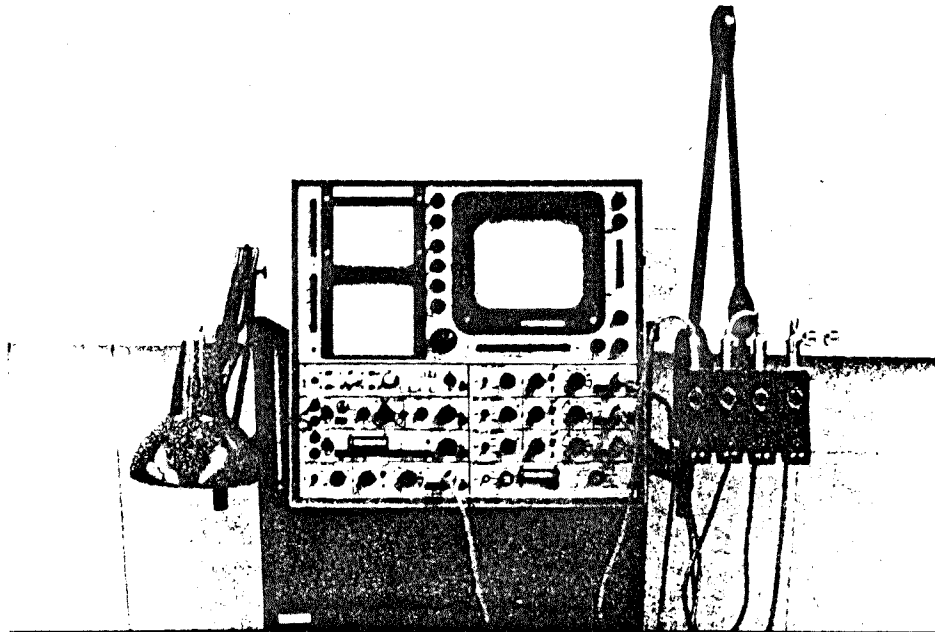


Figure 1. The four channel TECA TE-4 electromyograph used to retrieve myoelectrical activity. The TECA TE-4 electromyograph includes the TECA PA 62A preamplifier, the TECA AA6 Mk II amplifier, oscilloscope, chart recorder, and NS6 stimulator.

recording speed, 2 cm/sec., was used to record the EMG action potentials produced during the eccentric and concentric contractions.

Preamplifier. The TECA PA 62A preamplifiers were used to conduct impulses from the electrodes to the amplifier without the influence of unwanted electrical effects which would distort the EMG signal (Figure 1). The preamplifier amplifies the action potentials to a sufficient voltage for recording (Johnson, 1980). The preamplifier also filters unwanted electrolytically generated DC potentials, without altering the EMG signal (TECA, 1976).

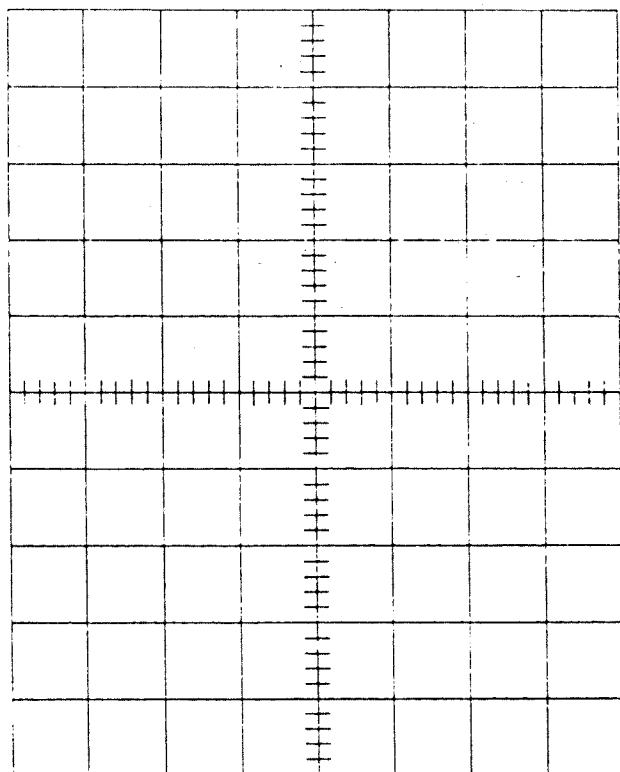
Amplifier. The TECA AA6 MK II amplifiers were used to magnify the signals from the electrodes. The 4 channels were used to record the muscle activity from the sternal and clavicular heads of the pectoralis major, anterior deltoid and the medial head of the triceps brachii. The amplifiers were equipped with a frequency filter and a voltage gain. The frequency filters were set at 16Hz (low frequency) and 16KHz (high frequency) to filter interference. The filter setting selectivity eliminated amplifier noise and movement artifact without significant loss of motor unit potentials (Basmajian, 1979). The voltage gain was calibrated to a setting of 5000 millivolts per major division or 5 kilovolt millivolts throughout the duration of the study. The voltage gain is responsible for fluctuating the amplitude (millivolts per division) of the action potentials.

Measurement of Muscle Activity

The myoelectrical activity obtained from the EMG recordings were measured using a TECA trace analyzer (Figure 2). The trace analyzer

TECA

TRACE ANALYZER



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TECA CORPORATION ■ WHITE PLAINS, NEW YORK 10603

Figure 2. TECA Trace Analyzer.

measured the amplitude of the muscle action potentials in kilo-millivolts per minor division, or 5 kilo-millivolts per major division. The major division line on the trace analyzer was lined up with the midpoint of the action potential recording. Using the minor deflection marks, the amplitude of the positive action potential deflections (upper portion) and the amplitude of the negative action potential deflections (lower portion) are added together to obtain the total action potential amplitude. The total action potential amplitude was used for the analysis. The TECA trace analyzer measured the action potential deflections, produced by the muscles, at the point on the recordings where the amplitude and the frequency of the spikes were the greatest. At those points, the amplitudes obtained in millivolts represented the maximum muscle activity produced by each muscle group for the 1RM and the 85% of the 1RM.

For the analysis of the EMG activity produced by each muscle, a ratio of EMG activity was determined. The ratio was obtained by dividing the 85% EMG activity from the wide, medium, and narrow grip widths into the maximal EMG activity obtained from the 1RM using a normal grip width.

(Ratio of EMG activity = $\frac{.85 \text{ EMG activity}}{1RM_N \text{ EMG activity}}$, $1RM_N$ = Repetition maximum using a normal training grip width. Eighty-five percent of the 1RM was arbitrarily selected for the wide, medium, and narrow grip width as the weightload used. The ratio of maximal EMG activity was used because differences exist between individual physical characteristics. The physical characteristics that may alter the EMG signal from one

individual to another includes muscle size, cross-sectional area of a muscle over which the electrode was placed, the distance of the electrode from the muscle, the subcutaneous fat and skin thickness.

Measurement of Shoulder Joint Angle

A Cannon 35 mm camera was used to photograph the subject's shoulder joint angle while the bar was held motionless on the chest. The camera was positioned at a height of 7 feet to the supine subject's dominant shoulder. The subject's shoulder joint angles were determined for the wide, medium, narrow, and normal training grip width positions (refer to Figures 6,7,8, and 9). The shoulder joint angles were determined by measuring the photographed angles using a Numonics Model 1224 Digitizer (Figure 3). The shoulder joint angle was measured between the segmental endpoint of the humerus at the midpoint between the medial and lateral epicondyles and a perpendicular line from the acromion process through the center of the shoulder joint, with the center of the shoulder joint being the axis.

Equipment Set-Up

The equipment set-up used during the analysis of the bench press exercise (Figure 4) included: 1) A TECA TE-4 electromyograph; 2) York olympic style weight lifting bar, which is 7 feet, 2 inches in length, and weighs 45 lbs; 3) York olympic style weights, ranging from 2.5 lbs. to 75 lbs. Each subject was required to assume a supine position on a regulation sized York bench which was 16 inches high and 11.75 inches wide, to ensure stabilization of the scapulae on the bench. The width

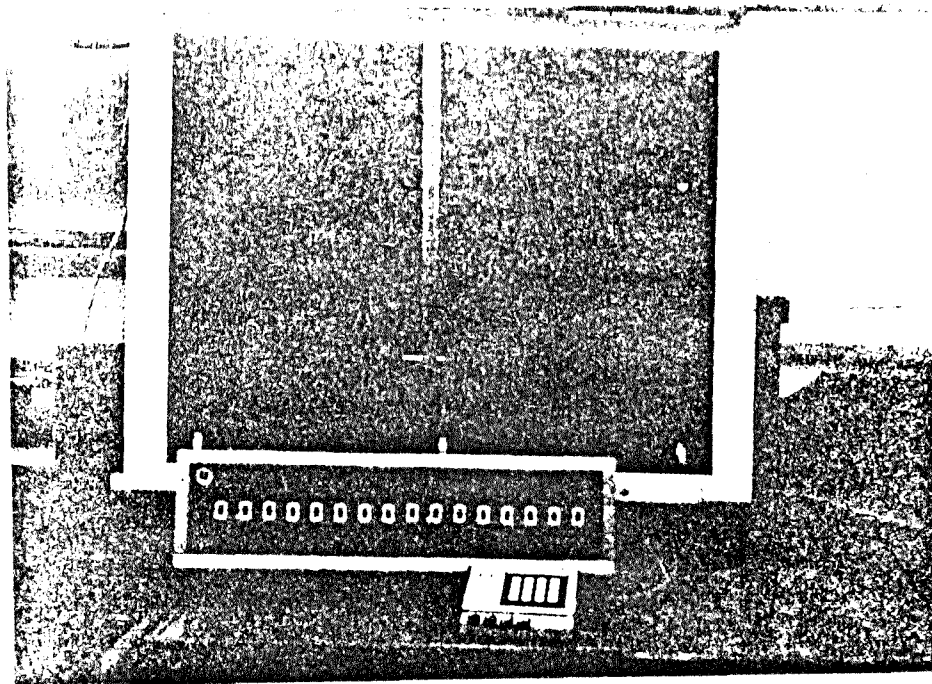


Figure 3. The Numonics Model 1224 Electronic Digitizer. The Numonics Digitizer consists of 4 major components, the display console, keyboard, reading head, and traverse arm. The digitizer was used to measure segmental end-points which formed the shoulder joint angle.

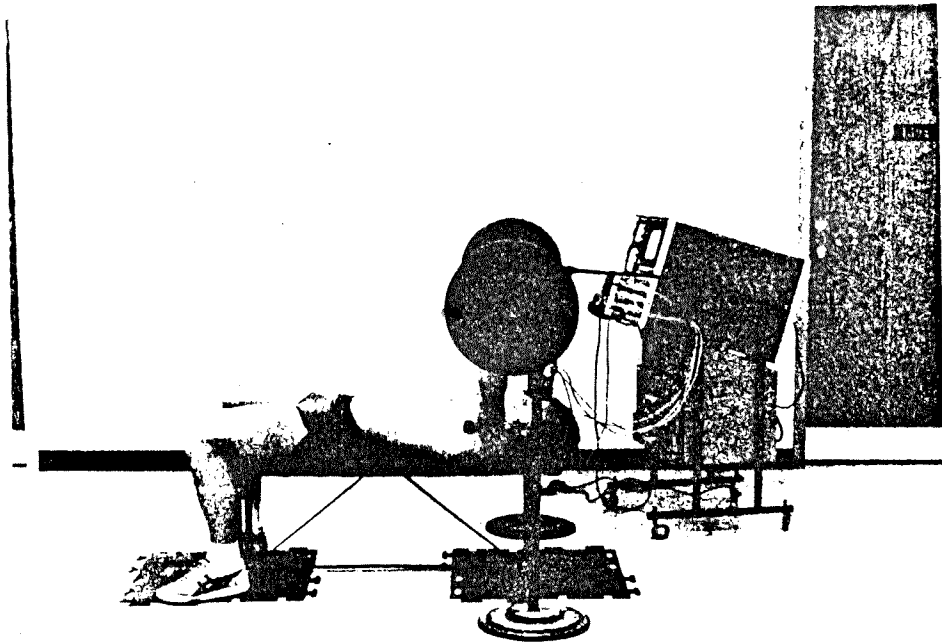
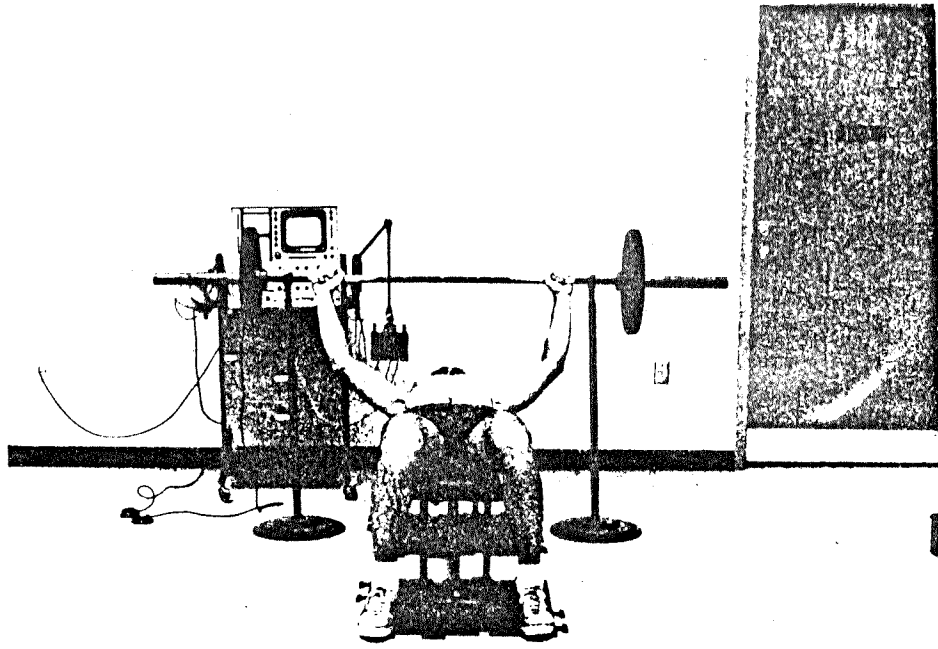


Figure 4. Equipment set-up and subject positioning.

and height of the bench is consistent with the requirements of the USA powerlifting rules (Appendix A). The weighted bar was supported overhead using 2 York weight standards.

Pilot Study

A pilot study was performed on 6 males from the University of Wisconsin-La Crosse, with at least 1 year of experience performing the bench press. The subjects were presently training with the bench press at least twice weekly. This pilot study was conducted to determine which head of the triceps brachii was more active during the performance of the bench press exercise. Bipolar surface electrodes were placed superficially over the muscle belly of the 3 heads of the triceps brachii, the medial head, the lateral head and the long head.

The electrode sites were determined by Delagi and Perotto (1980). The positive electrode for the medial head of the triceps was placed 3 fingerbreadths proximal to the medial epicondyle of the humerus, and the negative electrode was placed 2.5 cm proximal to the positive electrode over the muscle belly and parallel with the muscle fibers. The positive electrode for the lateral head of the triceps was placed immediately posterior to the insertion of the deltoid or deltoid tubercle, and the negative electrode was placed 2.5 cm distal to the positive electrode over the muscle belly and parallel to the muscle fibers. The positive electrode for the long head of the triceps was placed 4 fingerbreadths distal to the posterior axillary fold, and the negative electrode was placed 2.5 cm distal to the positive electrode over the muscle belly and parallel to the muscle fibers. The procedures

for skin preparation and instrumentation were the same as those described in the sections on instrumentation and electrode placement.

Each subject performed 4 trials. One trial was performed at each of the 4 grip widths; wide, medium, narrow, and normal training grip width. Each trial was performed using a weight of 225 lbs. The muscle activity was recorded from all 3 heads of the triceps during the eccentric and concentric contractions of the bench press exercise.

The EMG recordings of the 3 heads of the triceps brachii showed that the medial head of the triceps produced the greatest muscle activity, followed closely by the muscle activity from the long head. The lateral head showed the least amount of muscle activity (Figure 5). However, the EMG activity from the lateral head remained relatively constant throughout the duration of the lift. The medial head of the triceps was determined as the primary triceps extensor during the performance of the bench press exercise. The medial head of the triceps produced the greatest amplitude of muscle activity and was selected for the study of the bench press exercise.

Experimental Treatment and Procedure

Required Techniques for the Bench Press

The purpose of the bench press is to exercise and develop specific muscles of the shoulder and brachium. The subjects involved in the study were required to be experienced and knowledgeable of the correct lifting techniques for the bench press exercise. During the testing of the bench press exercise, the subjects were required to lie supine on a bench which was 11.75 inches in width. The weighted bar was supported overhead by York standards. Each subject grasped the

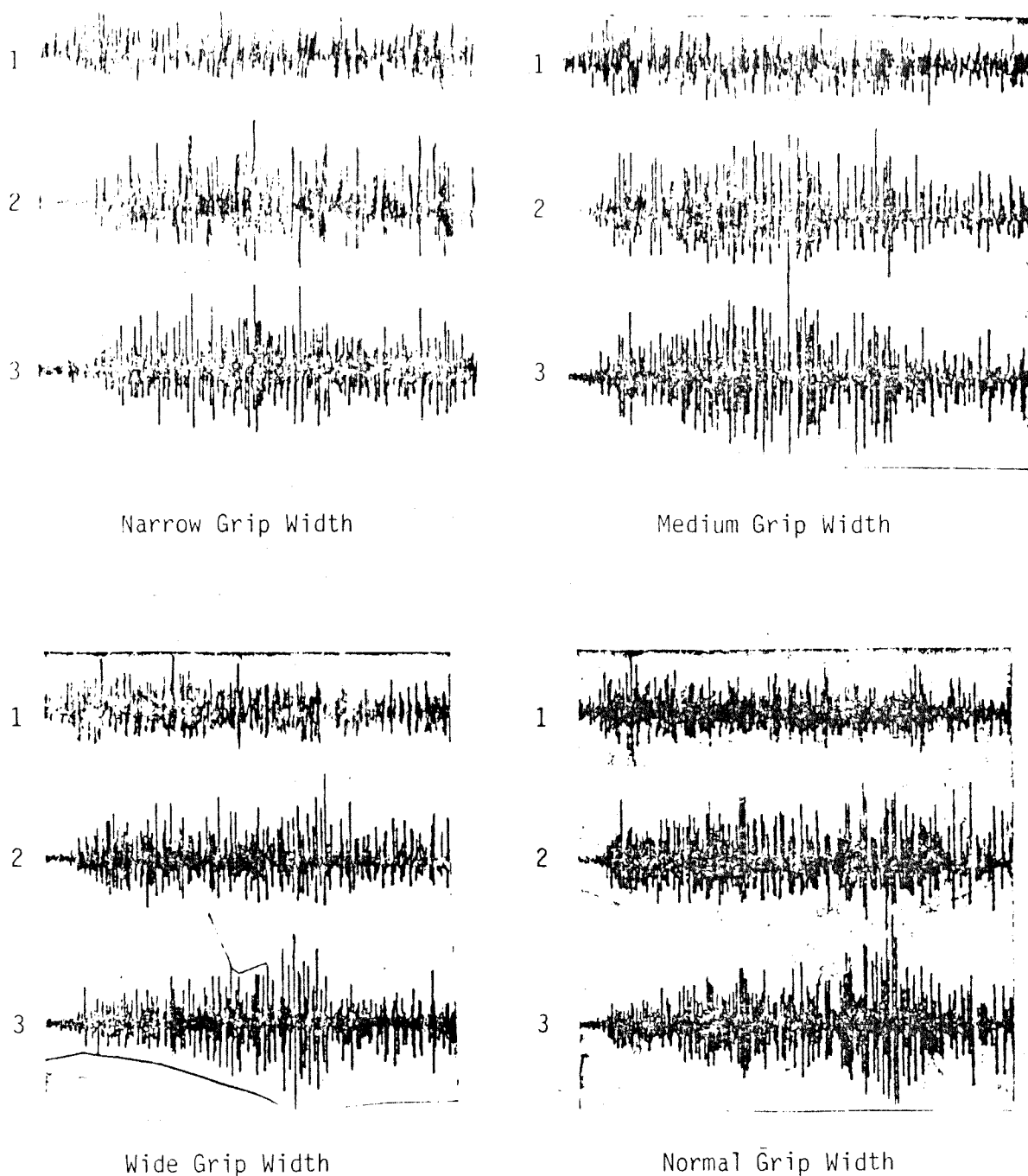


Figure 5. Illustrates the EMG activity obtained from the pilot study analyzing the three heads of the triceps brachii during the performance of the bench press exercise. The narrow, medium, wide, and normal grip widths were analyzed. The three heads of the triceps includes; (1) Lateral Head, (2) Long Head, and (3) Medial Head. The absolute EMG activity illustrates differences in the muscle activity produced by each grip width position.

bar, first using a normal training grip width and then using each of the 3 randomly assigned grip width positions. The bench press exercise was performed with the hands grasping the bar in a pronated position, and with the thumbs in an over-the-bar position. The subject lifted the bar off the standards and supported the bar with the arms. Assistance was given by the spotter to help the subject lift the bar off the standards. Once the weight was supported by the subject's arms the lift began.

The bar was lowered in a slow controlled eccentric contraction to a point between the distal end of the sternum and 1 inch above the nipple line. If the bar was to strike lower than the end of the sternum, the weight may damage the xiphoid process. In Algra's (1982) opinion, if the bar struck the chest higher than 1 inch above the nipple line, the muscles involved would be put in a disadvantageous position in which to press the weight upward. The lift was not considered if the bar touched outside the designated area. The bar was lowered until it touched or rested lightly on the chest. The bar was held motionless at that position for a period of approximately 1 second. The bar was then pressed upward in a controlled concentric contraction until the elbows reached full extension. During the performance of the lowering and pressing phase, the head, shoulders, buttocks and feet were required to remain in a fixed position. Any lifting or side to side movement of these fixed body parts would result in a disqualification of the lift (Appendix A).

The following were reasons for the invalidation of the lift:

- 1) if the bar was lowered in a fast and uncontrolled manner;
- 2) if the bar was bounced off the chest;
- 3) arching the back by lifting the buttocks off the bench;
- 4) any movement of the head or shoulders off the bench;
- 5) any lateral sliding movement on the bench;
- 6) any movement of the feet;
- 7) if one arm reaches full extension prior to the other arm;
- 8) any downward movement of the bar after the pressing phase began; and
- 9) if the subject was unable to press the weighted bar upward.

Grip Width Determination

Elbow joint angles were measured prior to testing and used to determine the 3 different grip widths for each individual. The elbow joint angles measured were chosen to represent wide, medium, and narrow grip width positions on the bar. The measurements taken of the elbow joint angles were measured using a goniometer while the bar was positioned on the subject's chest. The subject was informed to replicate the individual techniques used during the actual performance of the bench press exercise. The purpose for using the elbow joint angle as a method of determining grip width position was to take into consideration the subject's individual arm lengths. This procedure of measuring elbow joint angles was followed to make the subject's grip width proportional to the subject's arm length. Therefore, a subject with longer arms would grip the bar with a wider grip than a subject with shorter arms.

Elbow joint angles of 40° , 60° , and 80° were determined and associated with the narrow, medium, and wide grip widths, respectively. The narrow grip width was represented by a 40° elbow joint angle, the medium grip width was represented by a 60° elbow joint angle, and the wide grip width was represented by a 80° elbow joint angle (Figures 6, 7, and 8). The elbow joint angles were measured on the subject's dominant side. To determine the elbow joint angles used in the study, measurements were made on a random sample of 6 experienced male weight lifters. The angles selected were most representative of what experienced lifters, in the bench press, considered a wide, medium and narrow grip width represented.

The following procedure was utilized for determining the elbow joint angle for the subject's involved in the testing. The hands were positioned on the bar and the bar was lowered to the chest. The bar was held at the chest level replicating the subject's actual lifting style. With the elbow joint in a flexed position, a goniometer was placed on the axis. One arm of the goniometer was held along the humerus, and the other arm of the goniometer was set at the desired angle. The dominant hand on the bar was slid inward or outward until the hand lined up with the goniometer. This procedure was used to determine the wide, medium, and narrow elbow joint angles. The elbow joint angle for the subject's normal training grip width was also measured using a goniometer (Figure 9).

The segmental endpoints used as landmarks for measuring the elbow joint angle included the lateral epicondyle of the dominant elbow joint as the axis point, the midpoint of the head of the humerus, and the

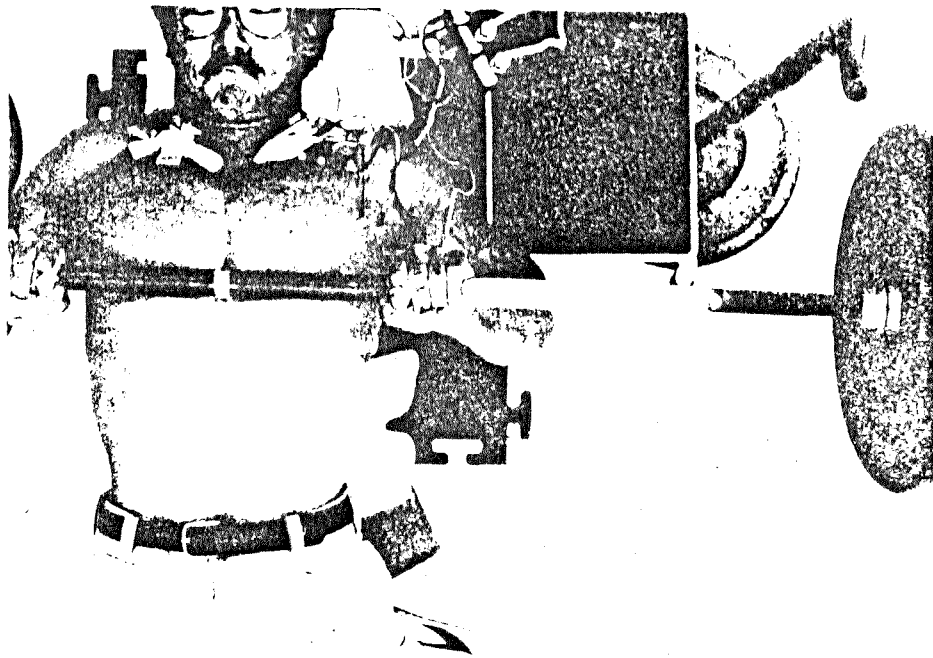


Figure 6. Actual testing photograph of the narrow grip width. The narrow grip width is equal to a 40° elbow joint angle. The bar was paused on the chest while the photograph of a 45° shoulder joint angle was recorded.

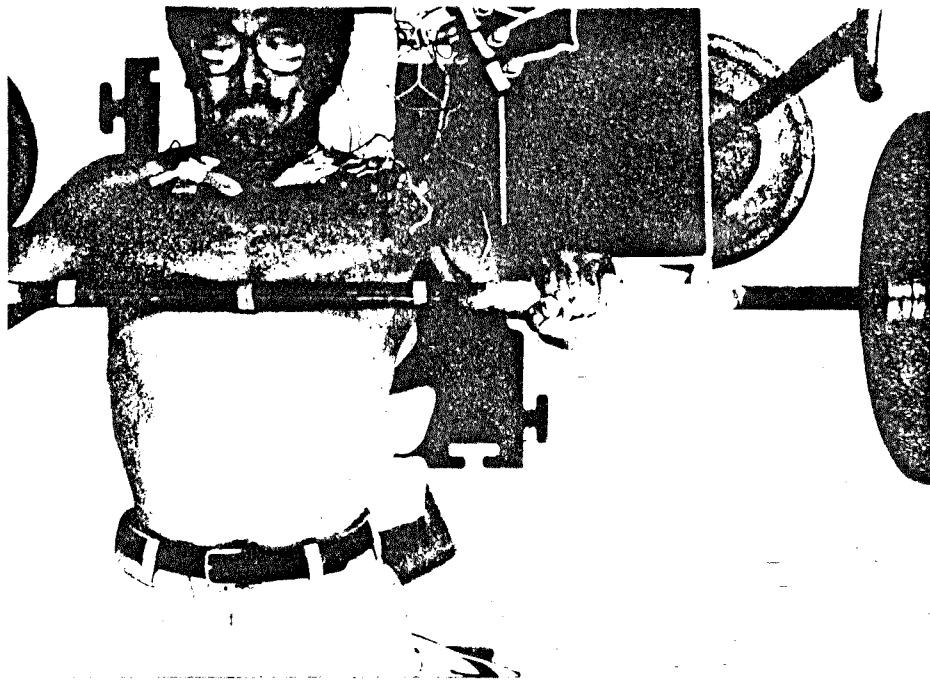


Figure 7. Actual testing photograph of the medium grip width. The medium grip width is equal to a 60° elbow joint angle. The bar was paused on the chest while the photograph of a 53° shoulder joint angle was recorded.

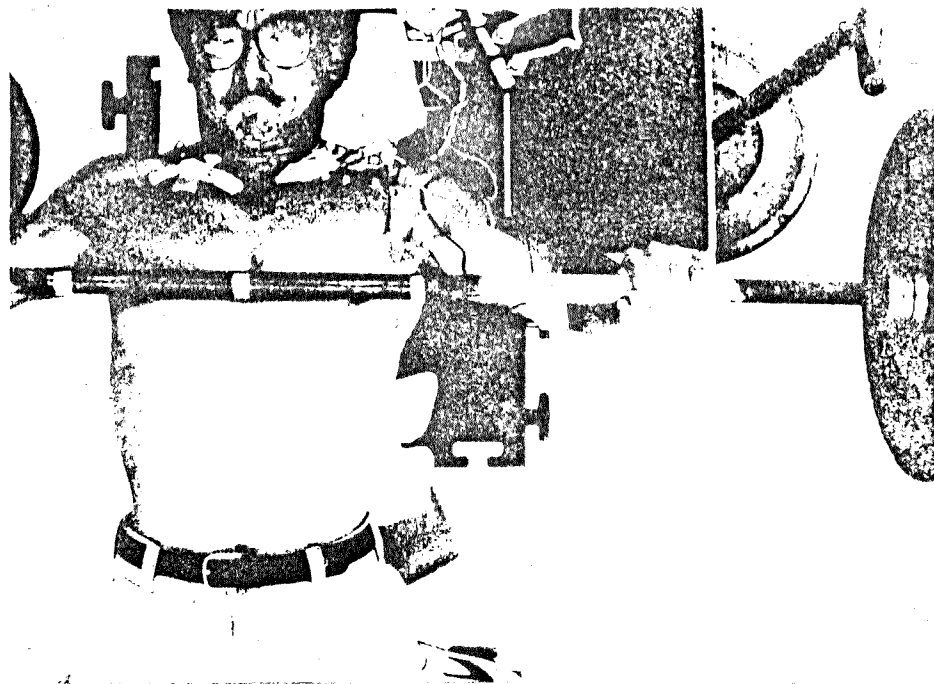


Figure 8. Actual testing photograph of the wide grip width. The wide grip width is equal to a 80° elbow joint angle. The bar was paused on the chest while the photograph of a 59° shoulder joint angle was recorded.

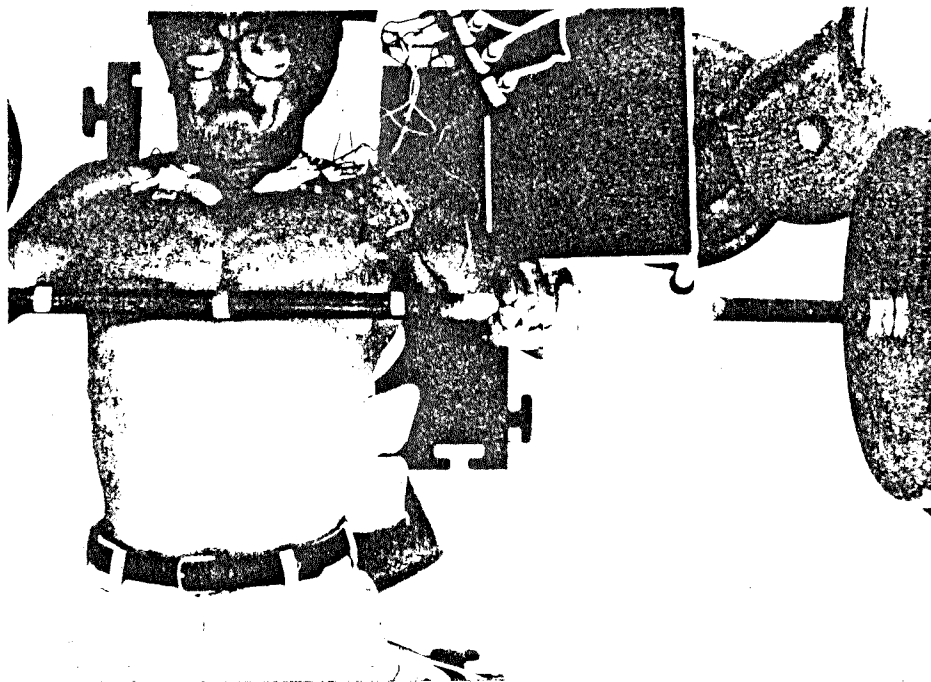


Figure 9. Actual testing photograph of the normal training grip width. The normal grip width was used to determine the MVC. The bar was paused on the chest while the photograph of a 54.5° shoulder joint angle was recorded.

midpoint between the ulnar and radial styloid process. Once the grip width was determined by the elbow joint angles, for the dominant arm, the distance between the center of the bar and the index finger of the dominant hand was measured in inches. This distance was then measured on the non-dominant side of the bar and marked. The distance between the index finger of the non-dominant hand and the index finger of the dominant hand equaled the total grip width distance. The total grip width distance was recorded in inches for each grip width position and used to determine the grip width during the actual testing. During the testing, the grip widths were marked on the bar and the index finger of each hand was placed on the corresponding marker.

Maximal Voluntary Contraction

The maximal voluntary contraction (MVC) was determined before the actual testing took place. The MVC was determined using the following procedure. Each subject performed one warm-up set of approximately 12 repetitions with a 135 lb. weightload. After the warm-up set, 4 additional single lifts were performed, gradually increasing the weightload with each lift. On the final lift, the subject attempted a maximal repetition (1RM). The 1RM is described as the maximal amount of weight that can be lifted for a single repetition (DeLorme, 1949). This predetermined maximum weight was used during the actual testing. The subject's were allowed 3 minutes rest between each trial repetition to reduce the effects of fatigue. Correct lifting form and position was required for the 1RM to be considered. The subject's normal training grip width was used to perform the maximal contraction. The maximal

repetition was performed during the actual testing with the electromyogram recording 100% maximal voluntary muscle activity for each muscle group being analyzed.

Electrode Placement

The muscle activity produced by the muscles being analyzed was detected by bipolar miniature Bechmann surface electrodes. The Bechmann surface electrodes were made of silver-silver chloride and the recording surface was approximately 3 mm in diameter. Surface electrodes deflect the average muscle activity from the superficial muscle and give a more reproducible result (Komi and Buskirk, 1972). The bipolar electrodes were positioned superficially over the muscle belly of the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii (Figure 10). The muscle belly of the muscles being analyzed were selected for electrode placement because the muscle belly represents the area of the muscle with the greatest cross-section of muscle fibers, and consequently produces the largest EMG signal (Zuniga, Truong, and Simons, 1970).

The following procedure was used to prepare the skin for electrode placement over the muscles being analyzed. The electrode sites were determined individually for each subject due to different physical characteristics, located and then marked. The electrode site was shaved of body hair, and then the skin was cleansed with an alcohol gauze pad to remove body oils in order to reduce the skin resistance. The skin was further abraded using fine sandpaper to roughen the skin. Electrode paste (Bechmann electrode paste) was applied to the electrode

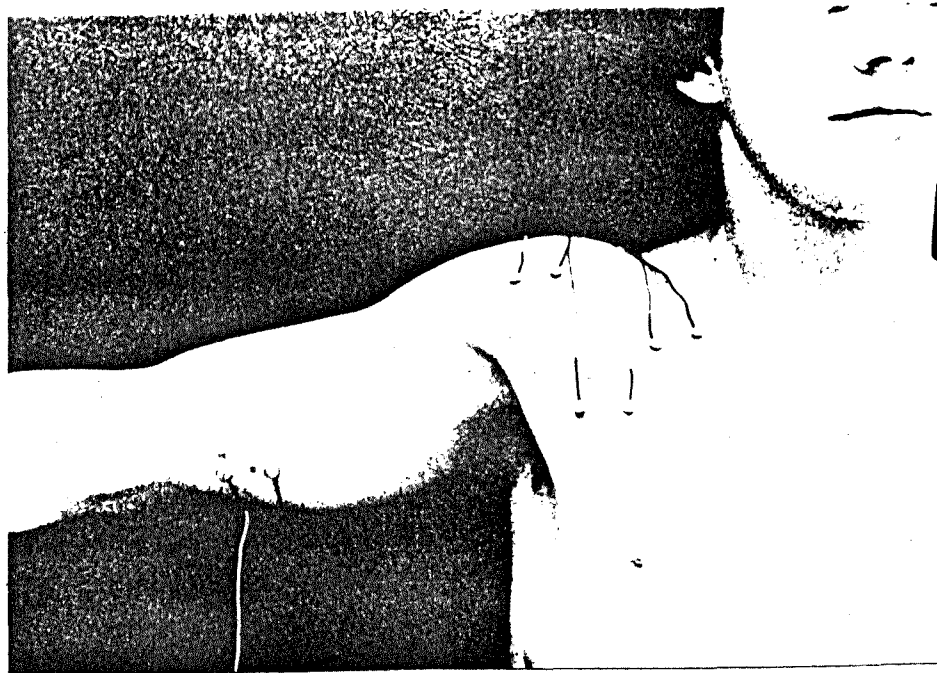


Figure 10. Illustration of the bipolar surface electrode sites for the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial triceps.

site and rubbed into the skin using a stiff fibered brush in order to increase conduction, and the excess jell was wiped off. The electrode paste was placed on the electrode and then the electrode was applied to the skin. The electrode was held in place with electrode adhesive tape. The skin preparation was performed to reduce the skin impedance to 5000 ohms or less.

The sternal bipolar surface electrode was used to detect myoelectrical activity from the muscle belly of the sternal head of the pectoralis major (Figure 11). The positive electrode was located 2 centimeters medially from the anterior axillary fold at the level of the third intercostal space of the ribs. The negative electrode was placed 2.5 centimeters medially from the positive electrode, over the muscle belly and parallel with the muscle fibers.

The clavicular bipolar surface electrode detected myoelectrical activity from the muscle belly of the clavicular head of the pectoralis major during the performance of the bench press exercise (Figure 12). The positive electrode was placed 1 centimeter inferior to the clavicle and parallel with the midclavicular line (Scheving et al., 1959). The negative electrode was placed 2.5 centimeters lateral to the positive electrode over the muscle belly and parallel with the muscle fibers.

The anterior deltoid bipolar surface electrode detected myoelectrical activity from the muscle belly of the anterior deltoid during the performance of the bench press exercise (Figure 13). The positive electrode was placed over the muscle belly 3 fingerbreadths, or the distance of the 3 fingers measured in centimeters, below the anterior margin of the acromion process and parallel with the anterior axillary

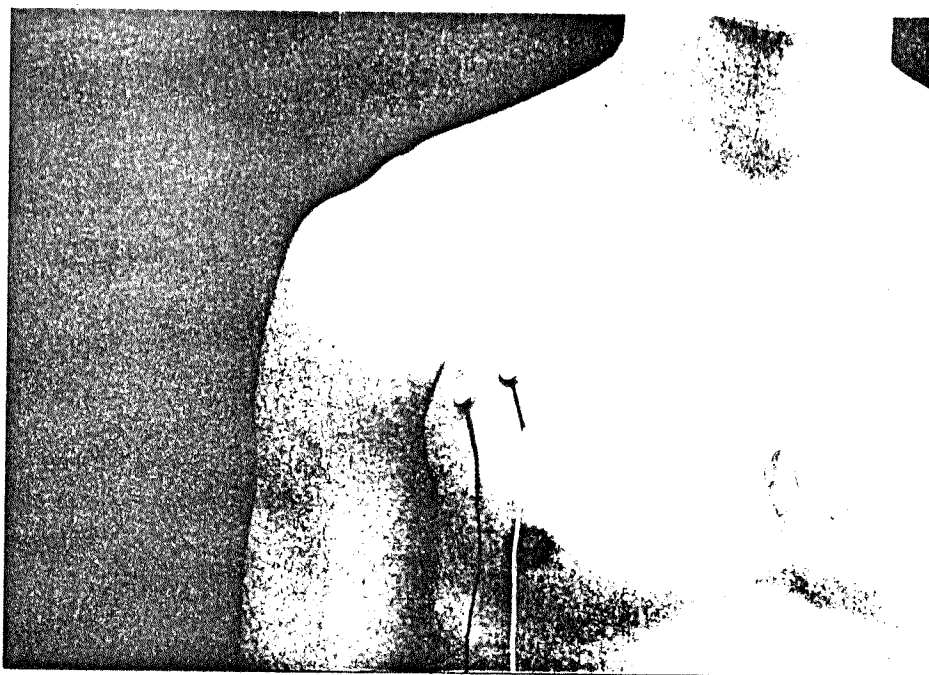


Figure 11. Sternal bipolar surface electrode. Detected muscle activity from the muscle belly of the sternal head of the pectoralis major.

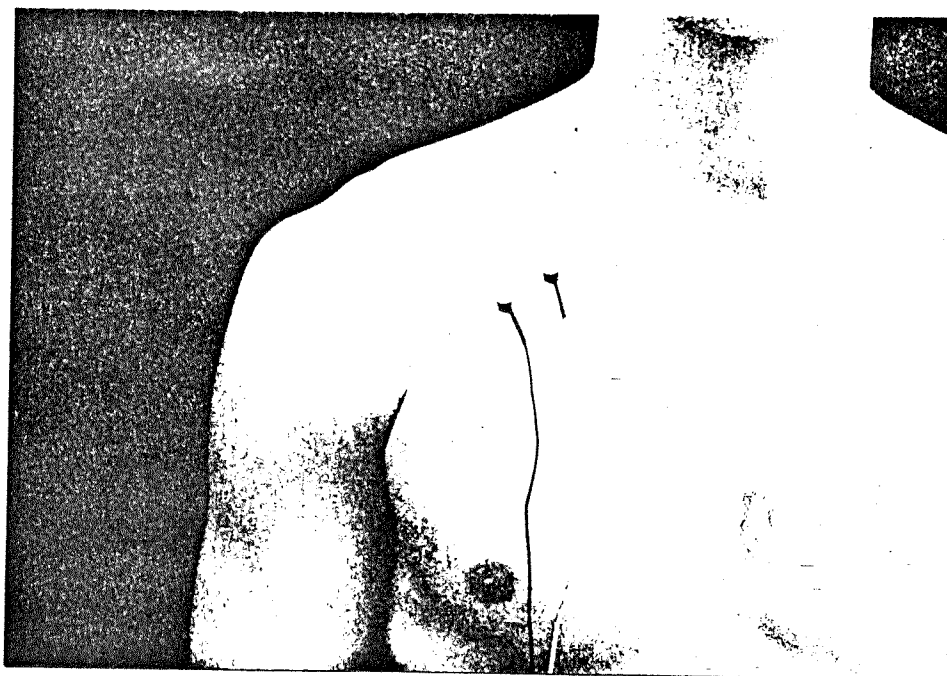


Figure 12. Clavicular bipolar surface electrode. Detected muscle activity from the muscle belly of the clavicular head of the pectoralis major.

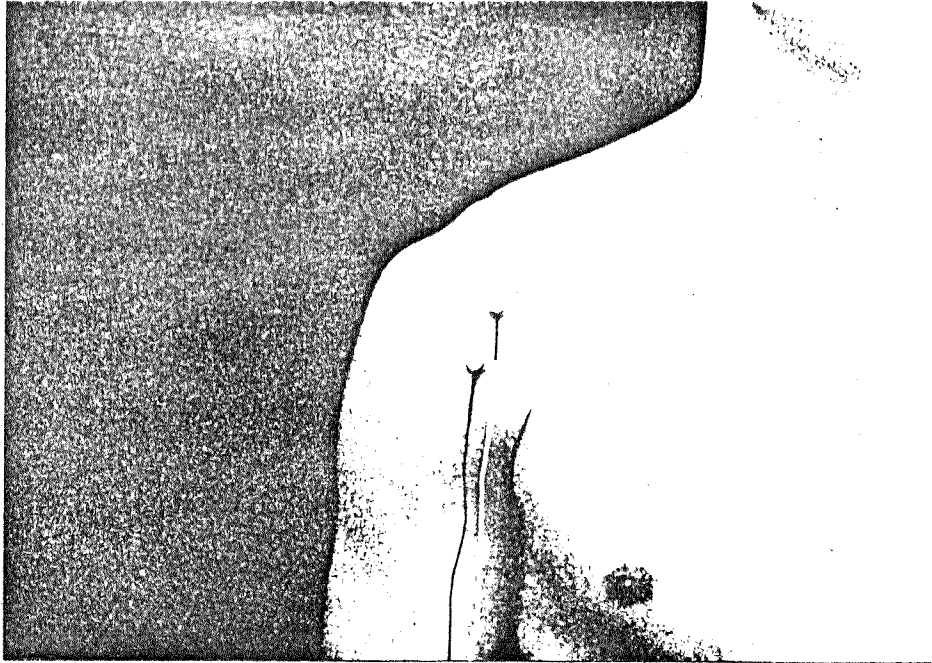


Figure 13. Anterior deltoid bipolar surface electrode. Detected muscle activity from the muscle belly of the anterior deltoid.

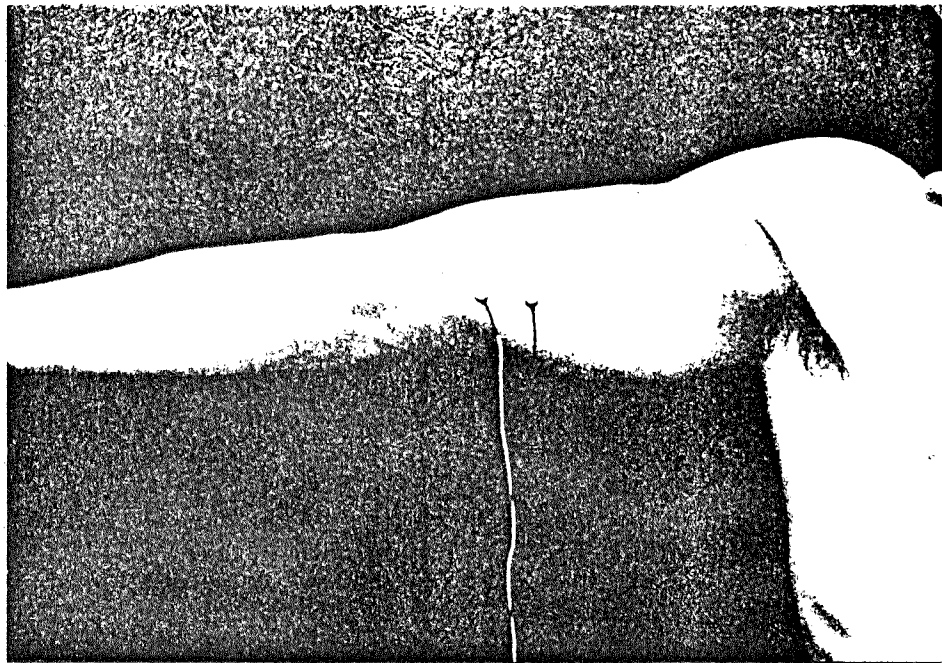


Figure 14. Medial triceps bipolar surface electrode. Detected muscle activity from the muscle belly of the medial triceps.

fold (Delagi et al., 1980). The negative electrode was placed 2.5 centimeters posteriolaterally from the positive electrode, over the muscle belly and parallel with the muscle fibers.

The medial triceps bipolar surface electrode detected myoelectrical activity from the muscle belly of the medial head of the triceps brachii during the performance of the bench press exercise (Figure 14). The positive electrode was placed 3 fingerbreadths, or the distance of the 3 fingers measured in centimeters, proximal to the medial epicondyle over the muscle belly and parallel with the muscle fibers (Delagi et al., 1980). The negative electrode was placed 2.5 centimeters proximal to the positive electrode over the muscle belly and parallel with the muscle fibers.

Delagi and Perotto (1980) used the distance of the 3 fingerbreadths as a method of locating the motor unit (electrode site) in the specific muscle belly. The fingerbreadths was related to the subject's individual physical size. For this study the fingers were measured in centimeters on the subject's dominant hand. The distance obtained from the 3 fingers were measured from a specific landmark determined by Delagi et al. (1980) to locate the site of the positive electrode. This procedure was followed for locating the positive electrode site for the anterior deltoid and the medial triceps.

Each of the 4 bipolar surface electrodes required a ground electrode. The ground electrodes were placed on the skin superficially to a nearby bony landmark. The bony landmarks included the medial epicondyle, the acromion process, and both sternoclavicular joints.

An additional bipolar surface electrode was used to administer an electrical stimulus to the subjects. The stimulating electrode was diagonally positioned between the muscles of the upper portion of the anterior deltoid and the clavicular head of the pectoralis major (Figure 15). The stimulating electrode site was prepared the same as previously discussed. The stimulating electrode administered an electrical stimulus to the subject, which was used as a command signal for the subject to initiate movement of the bar. The voltage administered by the stimulating electrode was calibrated to 150 volts for .1 to .2 seconds in duration. The first stimulus was administered to the subject to indicate initiation of the lowering phase (eccentric contraction) of the bench press. The second stimulus was administered to the subject to indicate initiation of the pressing phase (concentric contraction) of the bench press. The electrical stimulus was recorded by the electromyograph during the recording of the muscle activity on fiber optic recording paper. The stimulus registered as a distinguishable mark on the paper in the shape of a single spike (Figure 16). The spike was used as the method for determining the initiation of the muscle activity for each muscle being analyzed. The stimulus was administered from the TECA NS6 stimulator by applying pressure to a foot switch.

Test Description

Each subject was allowed sufficient time to warm-up before the testing procedure began. Once the skin preparation and electrode placement was completed, the subject was ready to begin the warm-up

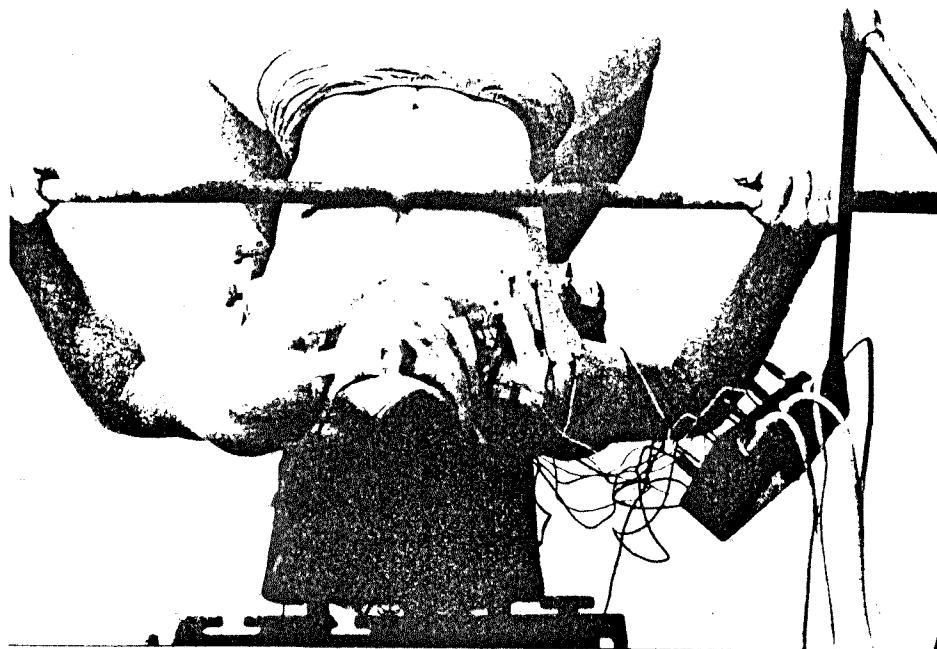
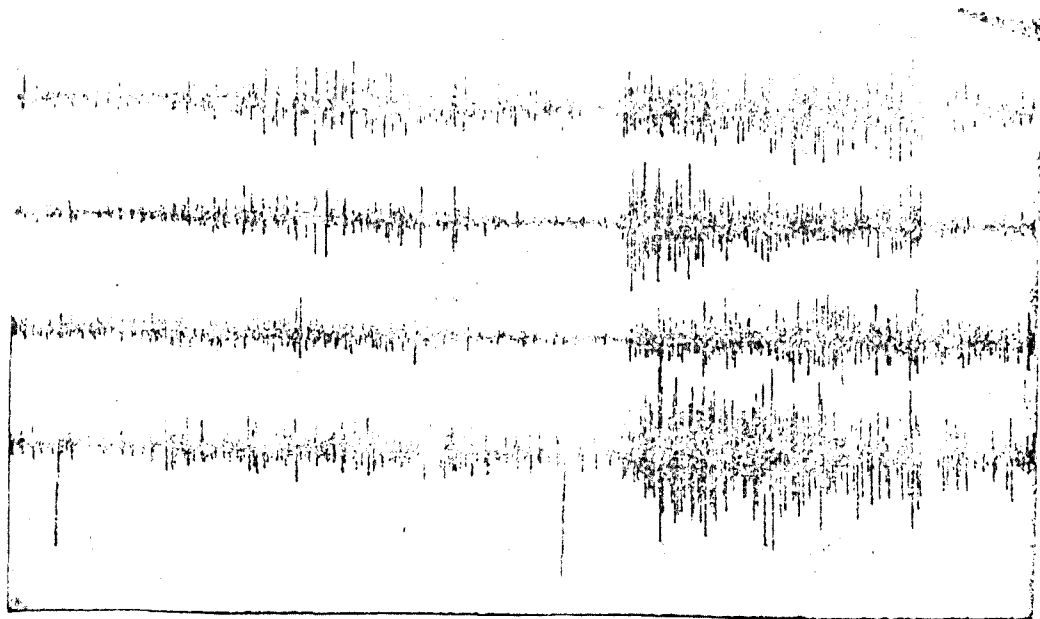


Figure 15. Illustrates the bipolar surface electrodes, the ground electrodes, the stimulating electrode, and the electrode connection to the preamplifier during the actual testing.

Maximal Contraction



85% of the Maximal Contraction

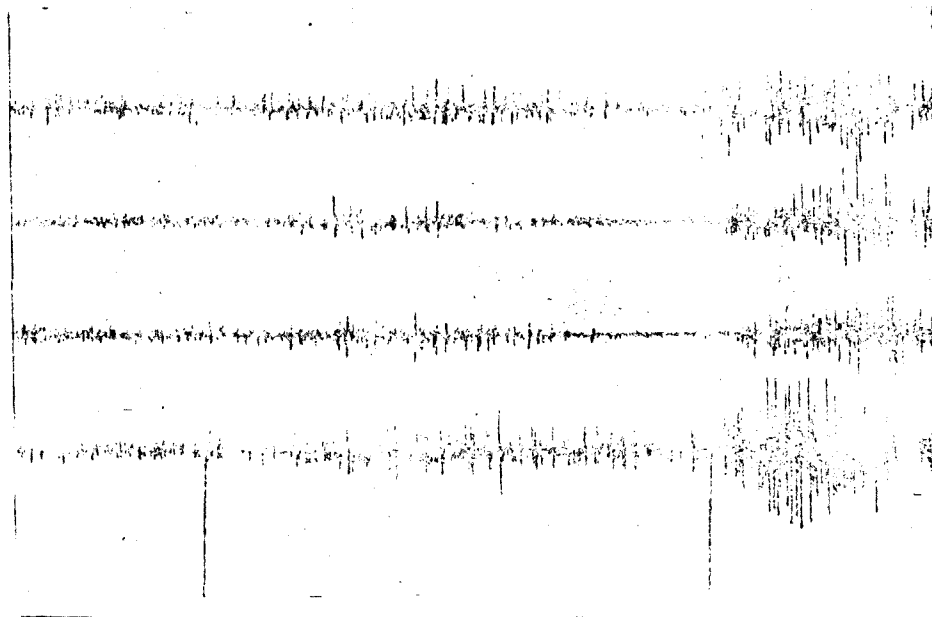


Figure 16. Illustrates the duration of the EMG activity during the maximal and 85% of the maximal muscle contraction for the 4 muscle groups analyzed. The recording clearly shows the first spike representing the beginning of the eccentric contraction, while the second spike represents the beginning of the concentric contraction.

lifts. The warm-up lifts were performed using the subject's normal training grip width. Each subject performed several single repetitions gradually adding weight up to the predetermined maximum weightload. The single repetitions were set at 70%, 80%, and 90% of the predetermined maximum weightload. The subjects were allowed 3 minutes rest between each warm-up repetition and each actual testing repetition.

During the actual testing procedure, each subject was required to perform a maximal repetition at the predetermined maximal weightload, using a normal training grip width (Figure 9). A 1RM was performed to determine 100% muscle activity for the 4 muscle groups analyzed. The subject then performed single repetitions at 85% of the maximal weightload for each of the 3 randomly assigned grip width positions, to determine 85% muscle activity for the 4 muscle groups analyzed (Figure 6, 7, and 8). The EMG activity for each muscle group was recorded at 100% and 85% muscular contraction during the performance of the bench press exercise.

The subjects were required to lie supine on the bench press and grasp the bar using a normal training grip width for the maximal repetition. The maximal repetition was performed first for all subjects. After the maximum repetition, the randomly assigned predetermined wide, medium, and narrow grip widths were used to perform 3 single repetitions at 85% of the maximal weightload. Before the testing began, the subjects randomly assigned the order of the 3 grip width positions.

The subject lifted the bar off the standards and supported the weight with the arms. Once the subject was set, the first electrical

stimulus was administered (Figure 16) indicating to the subject to begin the lowering phase (eccentric contraction). The subject lowered the bar until the bar touched the chest. The bar was paused on the chest for approximately 1 second, or until all motion was stopped (refer to Figures 6, 7, 8, and 9). At that moment the 35 mm camera was used to photograph the shoulder joint angle. The photograph of the shoulder joint angle was recorded to determine changes in the shoulder joint angles of the 3 grip width positions. The second electrical stimulus was administered following the photograph (Figure 16). This indicated to the subject to begin the pressing phase (concentric contraction).

The EMG recording began prior to the first stimulus and continued throughout the lift at a speed of 2 cm per second. The EMG recording was terminated at the moment the elbow joint reached complete extension. This procedure was followed 4 times. The first time using the normal training grip width, to determine the maximal voluntary contraction for each muscle group. The remaining 3 times using the randomly assigned wide, medium, and narrow grip width positions at 85% of the maximal weightload. Prior to the testing, the subject was required at least 1 day of rest after a bench press workout to prevent the effects of fatigue.

Statistical Treatment of the Data

A Two-way Analysis of Variance (ANOVA) was the statistical treatment used to analyze the ratio of EMG muscle activity obtained.

from the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii, while using a wide, medium, and narrow grip width position. A Scheffe' post hoc test was used to determine significance of the F score at the .05 level of significance.

A Pearsons Product Moment Coefficient Correlation (Pearsons r) was used to determine if a significant correlation existed between the shoulder joint angle and the EMG activity for the muscles analyzed in the study. In addition, a Pearsons r was used to determine if a significant correlation existed between EMG activity and the grip width position, and the arm length and grip width position.

The Friedman Two-way Analysis of Variance by Ranks was used to determine if there was a significant difference between the recruitment patterns of the muscle groups studied, and to determine a significant difference between the EMG activity produced by the muscle groups analyzed. The multiple comparison procedure for the Friedman test was used to determine where the significance existed between muscle and grip width comparisons. The .05 level of significance was used.

CHAPTER IV
RESULTS AND DISCUSSION

Introduction

The electromyograph has been utilized as a method to determine the muscle activity of the muscle groups involved in a movement. When a muscle contracts, the resulting EMG activity is a function of the increase in muscle tension. The bench press involves both eccentric and concentric contractions of the muscles in which changes in muscle length occur. Although the components of the muscle response to eccentric and concentric contractions were not distinguished in this investigation, the different effects of the eccentric and concentric contraction are manifested in the EMG recordings of this investigation.

The purpose of this investigation was to determine how a wide, medium, and narrow grip width effects the muscle activity elicited by the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps brachii during the performance of the bench press exercise. A Two-way ANOVA was calculated to determine significant differences between the ratio of EMG activity and the wide, medium, and narrow grip widths, and between the ratio of EMG activity and the 4 muscle groups analyzed.

It was also of interest to differentiate between the recruitment order of the muscles involved, and which muscle produced the greatest EMG activity during the performance of the bench press exercise. The

Friedman Two-way ANOVA by ranks was calculated to determine if a significant difference existed between the recruitment order of the muscle groups analyzed, and to determine the difference between the EMG activity produced by the muscle groups analyzed.

In addition, another purpose of the study was to address the question of the relationship between the shoulder joint angle and the muscle activity produced by the muscles analyzed in the study. Correlation coefficients were determined to explicate the relationship between the shoulder joint angle and the muscle activity.

This chapter will present the statistical analysis of the data. The results will be presented first, followed by a discussion.

Subjects

The subjects involved in this study consisted of 28 trained male volunteers. Each subject was required to have at least 1 year experience performing the bench press exercise. All subjects met twice during the study. The first meeting was to determine the 1RM. The second meeting was for the actual testing in which the subjects performed the 1RM to determine maximal EMG activity, and 85% of the 1RM for the wide, medium, and narrow grip widths. Table 1 presents the means and standard deviations for the subject's physical characteristics.

EMG Ratio Measurements

Table 2 presents the mean EMG ratios and standard deviations for each muscle when using a wide, medium, and narrow grip width position during the eccentric (Ec.) and concentric (Con.) muscle contraction.

Table 1

Means and standard deviations for the physical characteristics,
the 1 RM, and the 85% RM for the subjects involved in the bench press study.

Variable	Mean	SD
Age (yrs)	22.2	3.18
Height (in)	71.4	3.21
Weight (lbs)	185	2.46
Experience (yrs)	2.50	0.92
Arm Length (in)	23.8	1.22
Chest Size (in)	41.2	2.03
1 RM (lbs)	253	38.6
85% RM (lbs)	214.5	32.5

* N=28

Table 2
Means and standard deviations for the ratios
of EMG activity for the eccentric and concentric contractions.

Variable	Mean		SD	
	Ec.	Con.	Ec.	Con.
Pectoralis Sternal				
Wide	.871	.843	.23	.22
Medium	.779	.826	.20	.19
Narrow	.812	.877	.23	.25
Pectoralis Clavicular				
Wide	.822	.832	.19	.19
Medium	.877	.922	.25	.20
Narrow	1.035	1.050	.40	.30
Anterior Deltoid				
Wide	.812	.837	.18	.19
Medium	.801	.861	.22	.18
Narrow	.820	1.060	.25	.36
Medial Triceps				
Wide	.802	.824	.21	.15
Medium	.801	.829	.22	.16
Narrow	.929	.933	.33	.23

$$\frac{.85 \text{ RM EMG Activity}}{1 \text{ RM}_N \text{ EMG Activity}} = \text{EMG Ratio}$$

Ec. Eccentric Contraction
Con. Concentric Contraction

* N=28

A graphical representation of the mean ratios by muscle and by grip width is presented for the eccentric contraction in Figures 17 and 18, and the concentric contraction in Figures 19 and 20. The EMG activity produced from the 85% RM contractions were recorded for each muscle using a wide, medium, and narrow grip width positions. The EMG ratios used in the analysis were formulated from the 85% RM and the maximal EMG activity (Ratio of EMG Activity = $.85 \text{ RM}/1\text{RM}_N$).

In referring to Table 2, Figures 17 through 20, comparisons were made between the grip widths effects on the mean EMG ratio for each muscle group during the eccentric and concentric contractions. The data recorded in Tables 3 and 4 revealed that significant differences were found for the EMG ratio by grip width Ec. ($p < .05$), Con. ($p < .001$) and by muscle group Ec. ($p < .05$), Con. ($p < .05$), and between mean EMG ratio for grip width and muscle group Ec. ($p < .05$), Con. ($p < .001$). No significant interactions ($p < .05$) were found between grip width and the EMG ratio for each muscle group during the eccentric and concentric contraction.

Table 3. Analysis of variance for the eccentric contraction.

Source of Variation	df	F Ratio	Level of Significance
Grip ratio by muscle ratio	5,324	3.09	.01*
Grip ratio	2,324	3.27	.025*
Muscle ratio	3,324	2.67	.048*
Interaction muscle by grip width	6,324	1.60	.145

*- $p < .05$ level

Table 4. Analysis of variance for the concentric contraction.

Source of Variation	df	F Ratio	Level of Significance
Grip ratio by muscle ratio	5,324	7.001	.001*
Grip by ratio	2,324	13.272	.001*
Muscle by ratio	3,324	2.820	.039*
Interaction muscle by grip	6,324	1.286	.063

* $p < .05$ level

These results indicated that for this sample the grip widths had a significant effect on the EMG activity produced by the muscles analyzed. To determine where the significant differences lay for the pectoralis sternal (PS), pectoralis clavicular (PC), anterior deltoid (AD), and medial triceps (MT); and for the wide (W), medium (M), and narrow (N) grip width positions Scheffe' post hoc analyses were performed (Tables 5 and 6).

Mean EMG ratios by grip widths showed significant differences between the PS and PC muscles Ec. ($p < .05$), Con. ($p < .05$), the PC and AD muscles Ec. ($p < .05$), and the PS and AD muscles Con. ($p < .05$) for the narrow grip width position (Table 5). A value of 6.04 was required for a significant difference at $p < .05$ level.

Mean EMG ratios by muscle groups showed significant differences between the W and N grip widths Ec. ($p < .05$), Con. ($p < .05$) for the PC muscle, the W and N grip widths Con. ($p < .05$) for the AD muscle, and the M and N grip widths Con. ($p < .05$) for the AD muscle (Table 6). A value

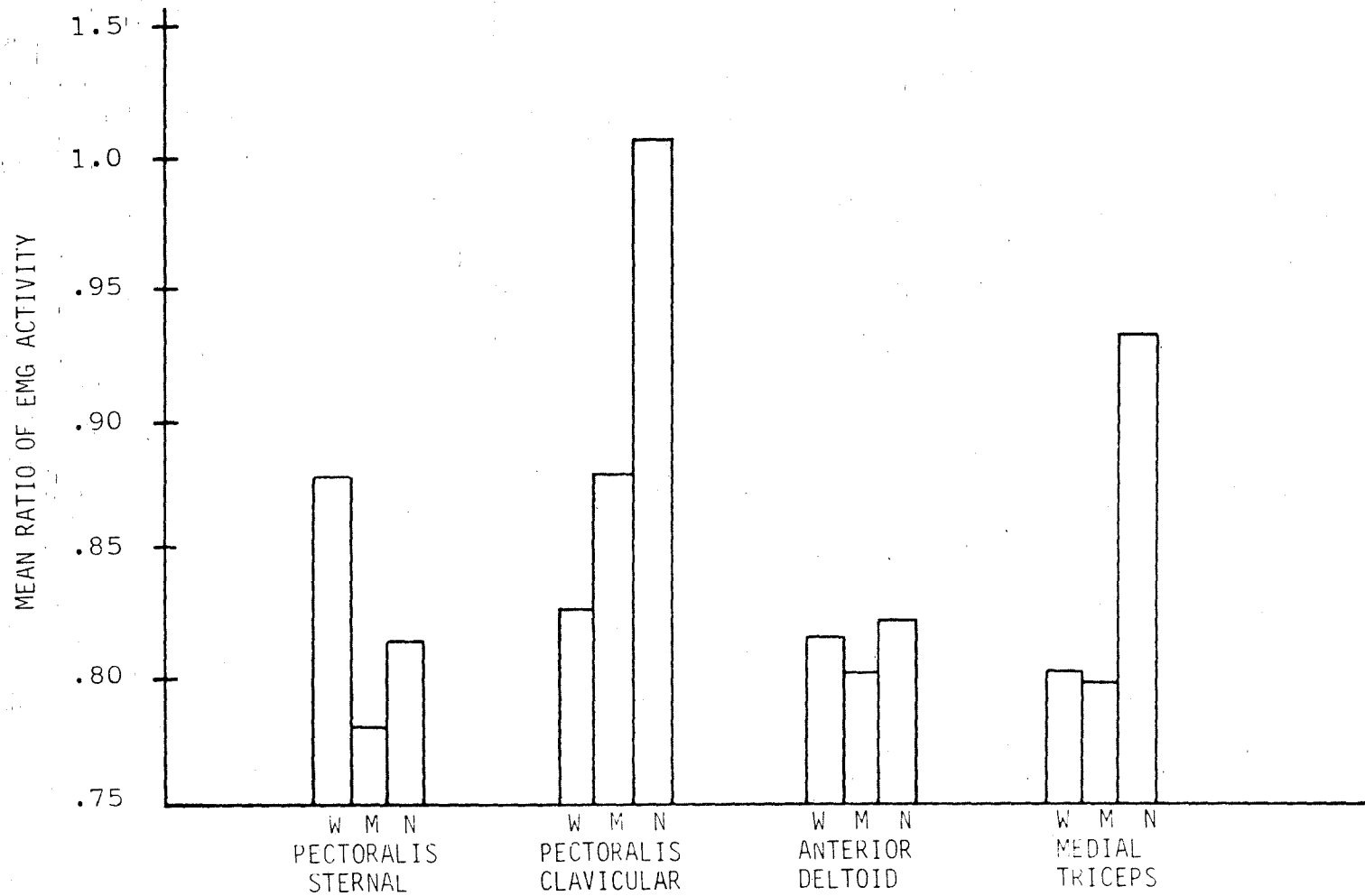


Figure 17. Comparison of the mean ratio of EMG activity by muscle for the eccentric contraction.

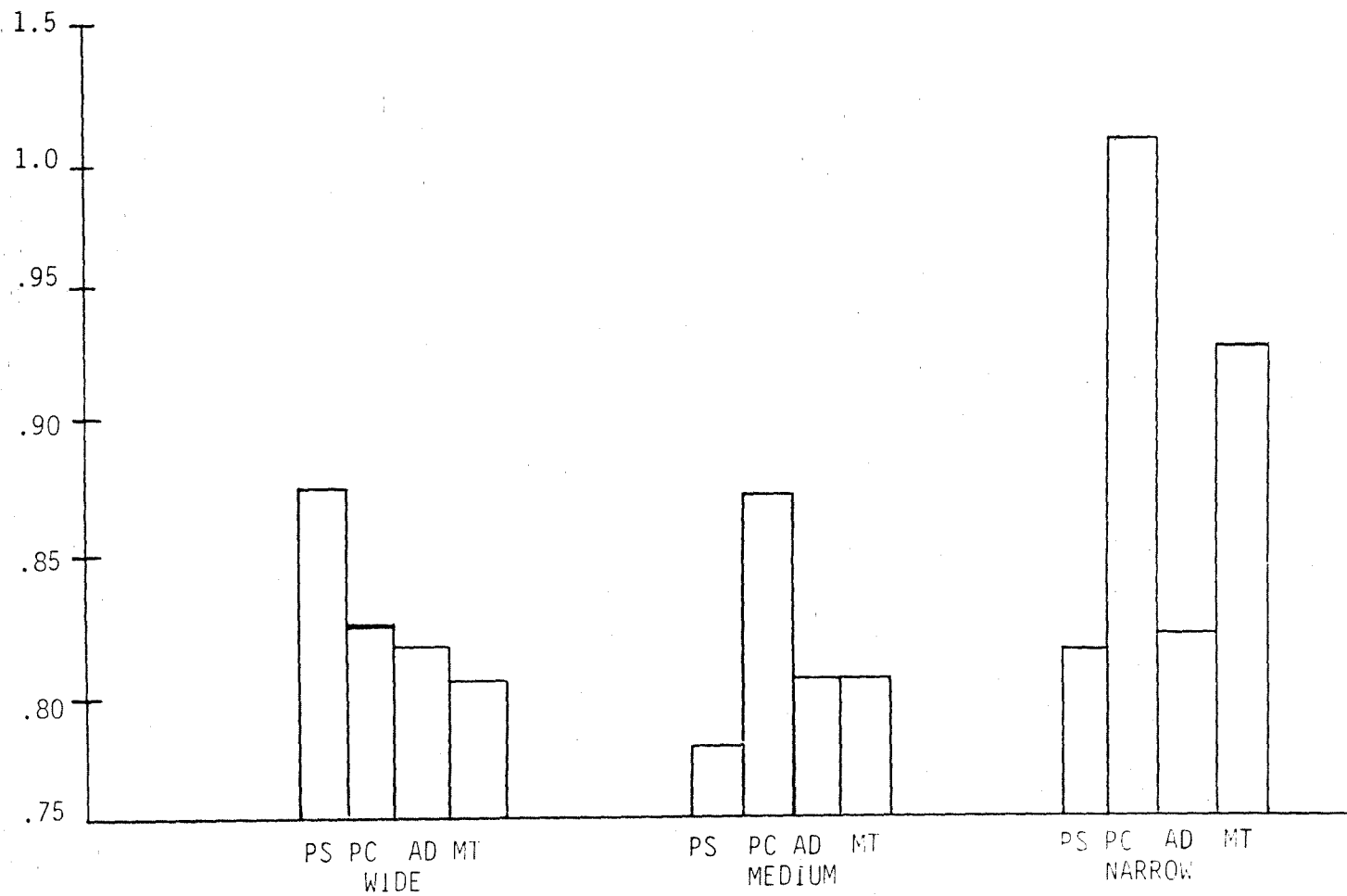


Figure 18. Comparison of the mean ratio of EMG activity by grip width for the eccentric contraction.

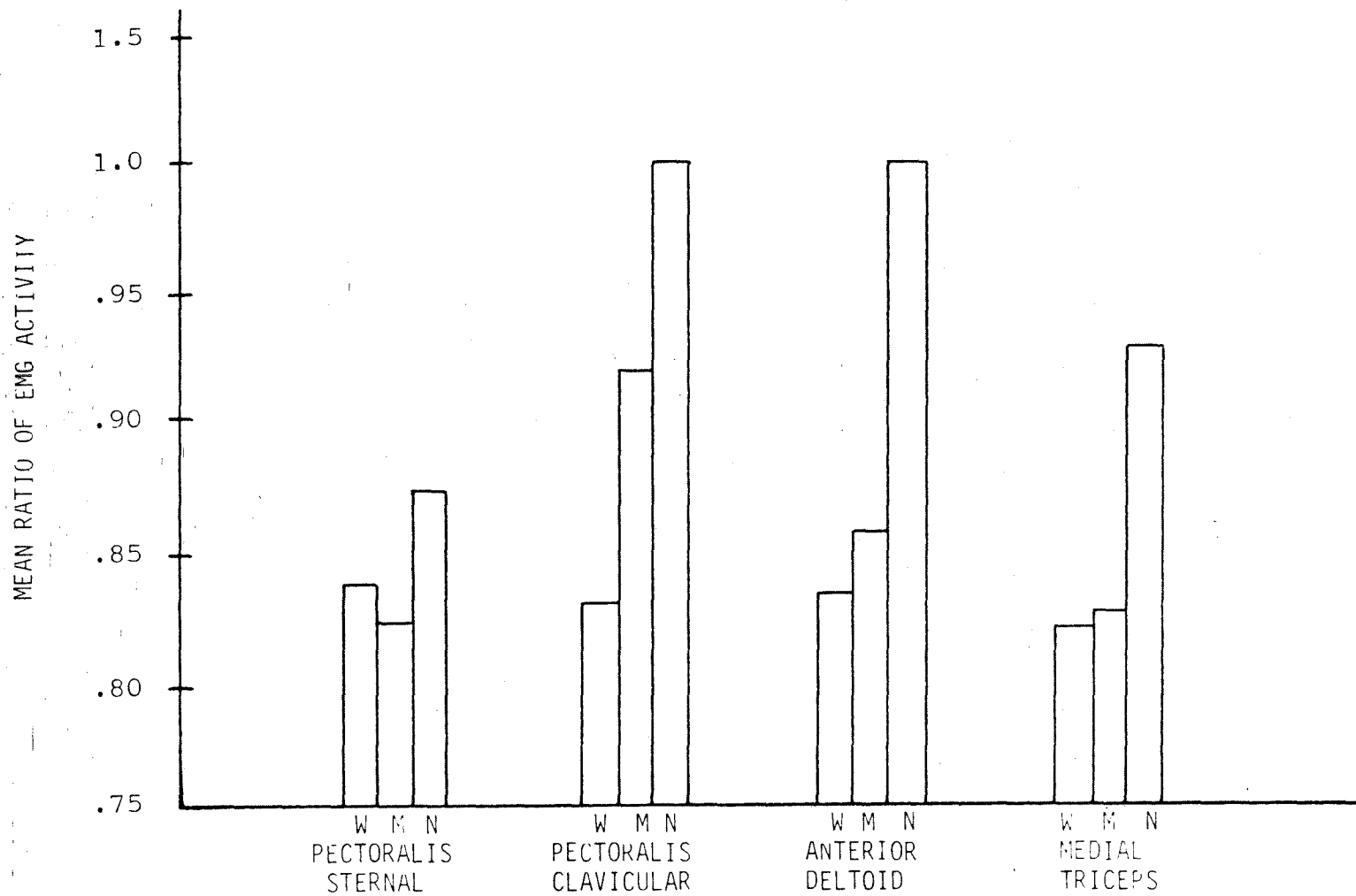


Figure 19. Comparison of the mean ratio of EMG activity by muscle for the concentric contraction.

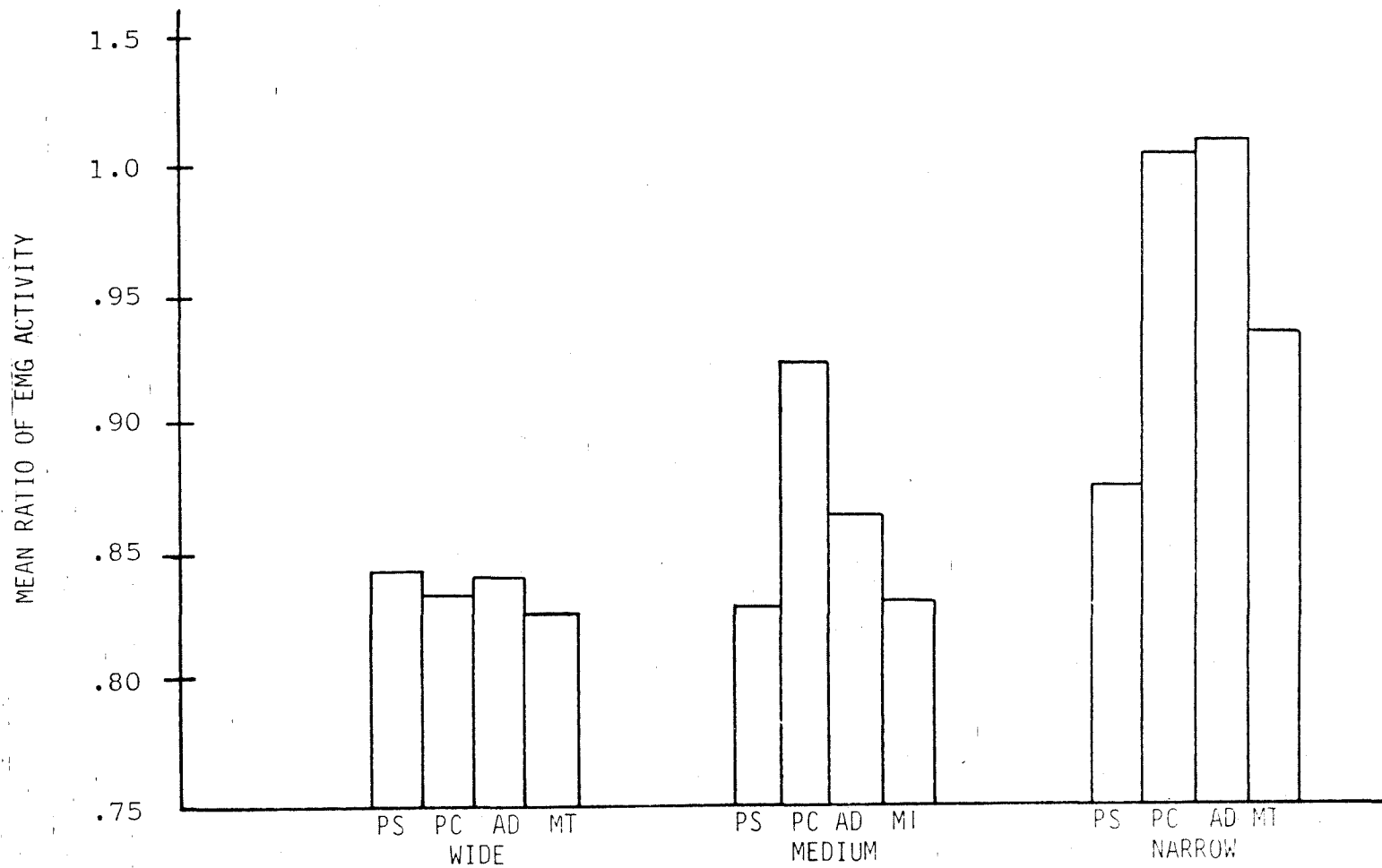


Figure 20. Comparison of the mean ratio of EMG activity by grip for the concentric contraction.

of 9.06 was required for a significant difference at $p < .05$ level.

Table 5. Scheffe' post hoc analysis comparison of EMG ratio by grip for the eccentric and concentric contractions.

Grip	Muscle Comparison	F Ratio	
		Ec.	Con.
Wide	PS vs PC	0.533	0.032
	PS vs AD	0.773	0.013
	PS vs MT	1.058	0.097
	PC vs AD	0.022	0.007
	PC vs MT	0.089	0.020
	AD vs MT	0.022	0.055
Medium	PS vs PC	2.130	2.481
	PS vs AD	0.107	0.328
	PS vs MT	0.107	0.002
	PC vs AD	1.283	1.001
	PC vs MT	1.283	2.328
	AD vs MT	0.000	0.276
Narrow	PS vs PC	10.561*	8.058*
	PS vs AD	0.014	9.016*
	PS vs MT	3.042	0.844
	PC vs AD	9.800*	0.027
	PC vs MT	2.267	3.685
	AD vs MT	2.640	4.342

* $p < .05$, df 2,324

During the performance of the bench press exercise, the muscles being analyzed were required to contract eccentrically and concentrically. As these muscles contract against a resistance, the muscles undergo changes in length while creating tension. To determine the function of these muscles during the bench press exercise, it is important to determine how well EMG activity predicts tension developed by a muscle. When the muscles contracted against a resistance, the EMG amplitude increased with an increase in tension during shortening of the muscle fibers, and a decrease in tension and EMG activity during lengthening

of the muscle fibers. The results showed that the EMG amplitude indicated the state or level of the contracting muscle. The analysis of the bench press exercise revealed that the EMG amplitude produced during the eccentric contraction (muscle lengthening) was less than the EMG amplitude produced during the concentric contraction (muscle shortening).

Table 6. Scheffe' post hoc analysis comparison of the EMG ratio by muscle for the eccentric and concentric contractions.

Muscle	Comparison	F Ratio	
		Ec.	Con.
Pectoralis Sternal	W vs M	1.881	0.078
	W vs N	0.773	0.311
	M vs N	0.242	0.700
Pectoralis Clavicular	W vs M	0.672	2.181
	W vs N	9.614*	12.795*
	M vs N	5.202	4.411
Anterior Deltoid	W vs M	0.027	0.155
	W vs N	0.014	13.389*
	M vs N	0.080	10.662*
Medial Triceps	W vs M	0.000	0.007
	W vs N	3.584	3.199
	M vs N	3.641	2.912

* $p < .05$, df 3,324

The increase or decrease in muscle tension during an eccentric and concentric contraction is due to the change in the structure of the myofibrils at the sarcomere level (Gordon, Huxley, and Julian, 1966). It was stated that at a resting muscle length, there is a maximum number of cross-bridges between filaments and maximum tension is possible. As the muscle lengthens, the filaments are pulled apart

and the number of cross-bridges are reduced, resulting in decreased tension. When a muscle is fully lengthened, there are no cross-bridges and tension is zero. As the muscle begins to shorten from the lengthened position there is an increase in muscle tension. If the muscle shortens to less than resting length, there is an overlapping of the cross-bridges and an interference takes place. This interference results in a decrease in muscle tension (Gordon et al., 1966).

The findings of this bench press exercise were in agreement with what Komi (1973) had stated. The ratio of EMG activity was found to be lower in the 4 muscle groups for the eccentric contraction (lowering phase) than for the concentric contraction (pressing phase) when lifting the same weightload. These results were similar to an earlier report by Santiomeir (1971) for the pectoralis major. Santiomeir indicated that the EMG activity was greater for the concentric contraction than the eccentric contraction during the bench press exercise. In this study, the increase in EMG muscle activity can be associated with an increase in muscle tension. The tension developed by the 4 muscle groups, which may be represented by the amplitude of EMG activity, was shown to be greater for the concentric contraction. This indicated that during the concentric contraction of the bench press, a greater demand was placed on the muscle analyzed, than during the eccentric muscle contraction.

The amplitude of the EMG activity produced by the muscles analyzed may also be associated with the recruitment of motor units and an increased firing rate. As the EMG activity in a muscle increases during

a contraction, there is an increase in the firing rates of the active motor units and an increase in the recruitment of new motor units.

The EMG record showed that there was a greater recruitment and greater firing rates in the motor units for the concentric contraction than for the eccentric contraction of the bench press exercise.

In this study, it was observed from the EMG recordings that during the concentric contraction, the frequency of the EMG activity increased at the same point during the recording that the amplitude increased. The measurements used for the analysis were measured from the point where the EMG amplitude was the greatest. This data may indicate that at the point of the greatest amplitude of EMG activity, the muscle groups involved in the bench press exercise produced the greatest tension and contraction force for the concentric contraction. In 1976 Komi et al. determined that the number of the action potential spikes increased in a linear manner with the increase of the contraction force. The increase in EMG activity during a muscle contraction is due to both the recruitment of new motor units and the increase in the firing rates of already active motor units (DeVries, 1980; Basmajian, 1979; Winter, 1979; Ruch et al., 1973; Woodbury et al., 1965; Adrian et al., 1929). Therefore, it may be concluded that the EMG activity is representative of the tension produced in a muscle.

The development of tension in a muscle is considered a controversial issue by researchers involved in EMG analysis. In the past, it has been difficult to determine when a muscle produces its greatest tension. It has been stated that during a concentric contraction, the tension development in a muscle was greatest at the beginning of the contraction

(komi, 1973). However, during the concentric contraction of the bench press, the muscle groups analyzed did not follow this pattern. It was observed that the PS developed its greatest EMG amplitude (tension) during the first half of the concentric contraction for all grip widths. The PC produced its greatest EMG amplitude (tension) approximately at the midpoint of the contraction. As for the AD, its greatest EMG activity was developed initially after the concentric contraction began, and the MT developed its greatest EMG amplitude towards the end of the contraction. A need exists to determine the precise position of each muscle, during the performance of the bench press, in which the greatest EMG activity is produced. This information would indicate accurately the position of the muscle during the lift in which the greatest tension occurs.

When comparing the mean ratio of EMG activity (85% of 1RM) by grip width for the eccentric contraction (Figure 17) the wide grip produced the greatest EMG activity in the PS muscle, indicating that the PS produces the greatest tension of the 4 muscle groups during the eccentric contraction. When using the medium grip width, the PC produced the greatest ratio of EMG activity. As for the narrow grip width, the PC produced the greatest ratio of EMG activity followed closely by the MT.

When comparing the mean ratio of EMG activity for the concentric contraction (Figures 19 and 20), the narrow grip width produced the greatest ratio of EMG activity for the muscle groups studied. This indicated that the narrow grip width produced the greatest ratio of EMG activity for all 4 muscles. These results may be related to the tension developed by these muscles.

It has been theorized by Algra (1982), Gillett (1980), and Starr (1976) that the wide grip width produced greater tension in the PS than any other grip width. However, the results of this study showed that the PS produced the greatest ratio of EMG activity when using the narrow grip width. When using the wide grip width, the PS produced the greatest ratio of EMG activity when compared to other muscles for that grip width. This indicated that when a wide grip width is preferred for training, the PS may produce the greatest tension. The PC produced the greatest ratio of EMG activity when using the medium grip width. As for the narrow grip width, the AD produced the greatest ratio of EMG activity followed closely by the PC.

The development of strength in a muscle is related to the amount of tension developed by a muscle during a contraction. The greater the overload placed on a muscle, the greater the tension developed by the muscle, and as a result, greater strength development occurs (Mathews and Fox, 1976; DeLorme, 1949). As the overload increases, there is a greater recruitment and firing of motor units. As a result, there is an increase in the EMG activity for the muscles involved in the contraction against a weight. The increase in recruitment and firing of motor units may be associated with an increase in the tension developed by the muscle. As strength increases in a muscle, the potential for developing greater amounts of tension also increases and as a result, a greater overload may be used.

In this analysis of the bench press, the wide grip width demonstrated less EMG activity than the other grip widths. This could be

attributed to the effects of ECA. The subjects involved in the study were experienced and trained in the bench press. A high percentage of the subjects trained using a relatively wide grip width (30 to 32 in.) which was similar to the wide grip width (\bar{X} =34.5 in.) used in the study. Therefore, greater training and strength development occurred in the muscles specifically for the wide grip width. This meant that the muscles analyzed may have contracted with greater efficiency when using a wide grip width, rather than a medium or narrow grip when contracting against 85% of the maximal weightload. This conclusion may be attributed to the lower EMG activity produced by the wide grip width as compared to the greatest EMG activity for the medium and narrow grips.

It is evident from the mean ratio of EMG activity produced by the eccentric and concentric contractions, that a difference exists between the grip widths and the muscle activity of each muscle. Therefore, demonstrating that the EMG activity (tension) developed in the PS, PC, AD, and MT is effected by the grip width position used to perform the bench press exercise.

As discussed above, the amplitude of EMG activity is linearly related to the tension developed in a muscle during a contraction. When the tension in a muscle increases, the amplitude of EMG activity will also increase. It can be theorized, to increase the strength in the muscle groups involved in the bench press exercise, the grip width which produces the greatest EMG activity should be used. However, to develop overall strength in the muscles involved in the bench press, it is suggested that a variation of grip widths (wide, medium, and narrow) be used and incorporated into the training program. This will improve

the performance of all the muscles involved in the bench press rather than the muscles primarily involved in a specific grip width position.

Muscle Recruitment Order

A Friedman Two-way analysis of variance by ranks was used to determine if a significant difference existed between the sums of the muscle group ranks. The results showed a significant difference at the $p .05$ level for the sums of the muscle group ranks for the wide, medium, narrow, and normal grip width positions during the concentric contraction (Table 7).

Table 7. Friedman analysis of variance by ranks for the muscle recruitment order for the concentric contraction.

Contraction	Group	Xr^2 Ratio	Level of Significance
Concentric	W	20.94	.001*
	M	27.04	.001*
	N	27.73	.001*
	No.	29.85	.001*

Significance of the Xr^2 is based on the degree of freedom (df,3) and the level of significance from the X^2 table. The Xr^2 value must be larger than 7.815 to be significant at the $p < .05$ level.
No. = Normal Grip Width.

Table 7 shows that a significant difference exists between the sums of ranks between each muscle group for all grip widths. Differences between the rank sums were so large that they cannot be attributed to sampling variability. A multiple-comparison procedure for use with the Friedman analysis was conducted to determine where the differences

between the muscle groups occurred (Table 8).

The multiple comparison analysis for the concentric contraction showed differences between the PS and AD, PC and MT, and the AD and MT muscles for the wide, medium and normal grip widths. As for the narrow grip width, differences were found between the PS and MT, PC and MT, and the AD and MT muscles.

Table 8. Multiple comparison of the muscle groups for the concentric contraction.

Grip	Muscle Comparison	Multiple Comparison Value
Wide	PS vs PC	14
	PS vs AD	32*
	PS vs MT	13
	PC vs AD	18
	PC vs MT	27*
	AD vs MT	45*
Medium	PS vs PC	20
	PS vs AD	31*
	PS vs MT	15
	PC vs AD	11
	PC vs MT	35*
	AD vs MT	46*
Narrow	PS vs PC	17
	PS vs AD	04
	PS vs MT	33*
	PC vs AD	21
	PC vs MT	50*
	AD vs MT	29*
Normal	PS vs PC	19
	PS vs AD	35*
	PS vs MT	17
	PC vs AD	16
	PC vs MT	36*
	AD vs MT	52*

* Multiple comparison value must be greater than the critical value of 25.4 to show significant differences.

When comparing the rank sums for the concentric contraction (pressing phase) for the wide, medium, and normal grip widths, the AD was determined as being recruited first, followed by the PC, the PS, and the MT. As for the narrow grip width, the PC was determined as being recruited first, followed by the PS, the AD, and the MT (Appendix D). The change in the shoulder joint angle or position from a large angle to a smaller angle seemed to alter the muscle recruitment order.

The eccentric contraction showed continuous muscle activity for the MT and the PS muscles throughout the entire lowering phase. The PC and AD muscle activity was quiet during the support of the bar by the arms. As the lowering phase began, both the PC and the AD were recruited. Overall, during the eccentric contraction the AD was recruited first followed by the PC.

The recruitment order for the wide, medium, and normal grip widths for the concentric contraction seemed to show a specific pattern. It could be theorized that the recruitment pattern for the muscles involved in shoulder flexion may be associated with the size of the muscle, with the smaller muscle being recruited first, followed by the larger muscles. The AD, which was the smallest muscle involved in shoulder flexion for this study, was recruited first for the concentric contraction of the bench press. The PC was recruited second followed by the PS which was the largest muscle analyzed.

Several theories could exist as to why the muscles were recruited in such an order. One theory involves the position of the shoulder joint. When the shoulder joint is positioned at a specific angle the AD, PC, and the PS which are involved in shoulder flexion are placed in

a specific line of pull. When a specific shoulder joint angle was used, as in the bench press exercise, the muscles involved in shoulder flexion are lengthened to varying lengths, and the muscles do not shorten simultaneously during the contraction.

When using a wide, medium, and normal grip width position, the shoulder joint angle was in a position that when the contraction was initiated, the tension was produced first by the AD muscle. The PC was the next muscle in position to assist in the contraction, followed by the PS. However, when the shoulder joint angle was significantly altered, as when using the narrow grip width to perform the bench press, there was a change in the line of pull for the muscles involved in the study. Therefore, the change in the shoulder joint angle may be responsible for the change in the recruitment pattern of the muscles involved in the narrow grip width.

The inquiry into the recruitment pattern of the muscle groups involved in the bench press has interested individuals who perform the bench press for some time. Many opinions have been formulated through observations of the muscles involved in the bench press (Algra, 1982; Gillett, 1980). Without the use of electromyography, the arrival of neural stimulation to the muscles cannot be determined accurately. From the results of the Friedman analysis of variance (Table 7) it can be observed that the differences between the sum ranks are very large. It may be concluded from these results that a definite difference exists between the order in which the muscles become involved during the concentric contraction of the bench press exercise.

Absolute EMG Activity

One concern of the individuals who perform the bench press exercise is the involvement of the muscle groups contributing to the eccentric and concentric contractions. A Friedman two-way analysis of variance by ranks was used to determine if a difference existed between the sums of the ranks for the absolute EMG activity. This analysis indicated which muscle group produced the greatest absolute EMG activity. Table 9 shows the results of the analysis using absolute EMG data.

Table 9. Friedman two-way analysis of variance for the absolute EMG activity for the eccentric and concentric contractions.

Contraction	Grip Widths	Xr^2 Ratio	Level of Significance
Eccentric	Wide	19.94	.001
	Medium	16.83	.001
	Narrow	24.80	.001
	Normal	25.10	.001
Concentric	Wide	21.03	.001
	Medium	14.00	.01
	Narrow	39.05	.001
	Normal	16.99	.001

Significance of the Xr^2 is based on the degrees of freedom (df,3) and the level of significance from the X^2 table. The Xr^2 value must be larger than 7.815 to be significant at the $p < .05$ level.

The results indicated that significant differences ($p < .05$) were found between the sums of the muscle group ranks for the wide, medium, narrow, and normal grip width positions during the eccentric and concentric contractions. A multiple comparison procedure was performed to determine where the differences between muscle groups were located (Table 10.)

Table 10. Multiple comparison of the absolute EMG activity.

Grip	Muscle Comparison	Multiple Comparison	
		Ec.	Con.
Wide	PS vs PC	15.5	16.0
	PS vs AD	42.5*	39.5*
	PS vs MT	22.0	34.5*
	PC vs AD	27.0*	23.5
	PC vs MT	6.5	18.5
	AD vs MT	20.5	5.0
Medium	PS vs PC	25.0	25.5*
	PS vs AD	41.5*	41.5*
	PS vs MT	30.5*	31.0*
	PC vs AD	16.5	16.0
	PC vs MT	5.5	5.5
	AD vs MT	11.0	10.5
Narrow	PS vs PC	45.0*	28.5*
	PS vs AD	41.5*	52.0*
	PS vs MT	36.5*	34.5*
	PC vs AD	3.5	23.5
	PC vs MT	8.5	6.0
	AD vs MT	5.0	17.5
Normal	PS vs PC	20.5	15.0
	PS vs AD	46.5*	35.0*
	PS vs MT	33.0*	32.0*
	PC vs AD	26.0*	20.0
	PC vs MT	12.5	17.0
	AD vs MT	13.5	3.0

* Multiple comparison value must be greater than the critical value of 25.4 to show a significant difference for the muscle groups and amount of EMG activity.

Table 11 presents the means and standard deviations for the absolute EMG data produced by the PS, PC, AD, and MT. A graphical representation of the mean absolute EMG activity by grip and muscle for the eccentric and concentric contraction is presented in Figures 21 through 24.

Table 11

Means and standard deviations for the absolute EMG activity for the eccentric and concentric contraction.

Variable	Mean		SD	
	Ec.	Con.	Ec.	Con.
Pectoralis Sternal				
Wide	1.91	2.39	.87	1.04
Medium	1.71	2.25	.86	.99
Narrow	1.77	2.51	.77	1.13
Normal	2.27	2.96	1.02	1.36
Pectoralis Clavicular				
Wide	2.16	2.70	.69	.79
Medium	2.28	3.00	.78	.92
Narrow	2.84	3.39	.93	1.21
Normal	2.70	3.37	.92	1.10
Anterior Deltoid				
Wide	2.77	3.44	.84	1.02
Medium	2.69	3.52	.84	.91
Narrow	2.69	4.22	.69	1.23
Normal	3.45	4.18	.98	1.12
Medial Triceps				
Wide	2.35	3.21	.73	.96
Medium	2.30	3.28	1.00	1.17
Narrow	2.65	3.63	.75	1.11
Normal	3.04	3.96	.99	1.10

Absolute EMG activity measured in Kilo-millivolts
* N=28

Ec. Eccentric Contraction
Con. Concentric Contraction

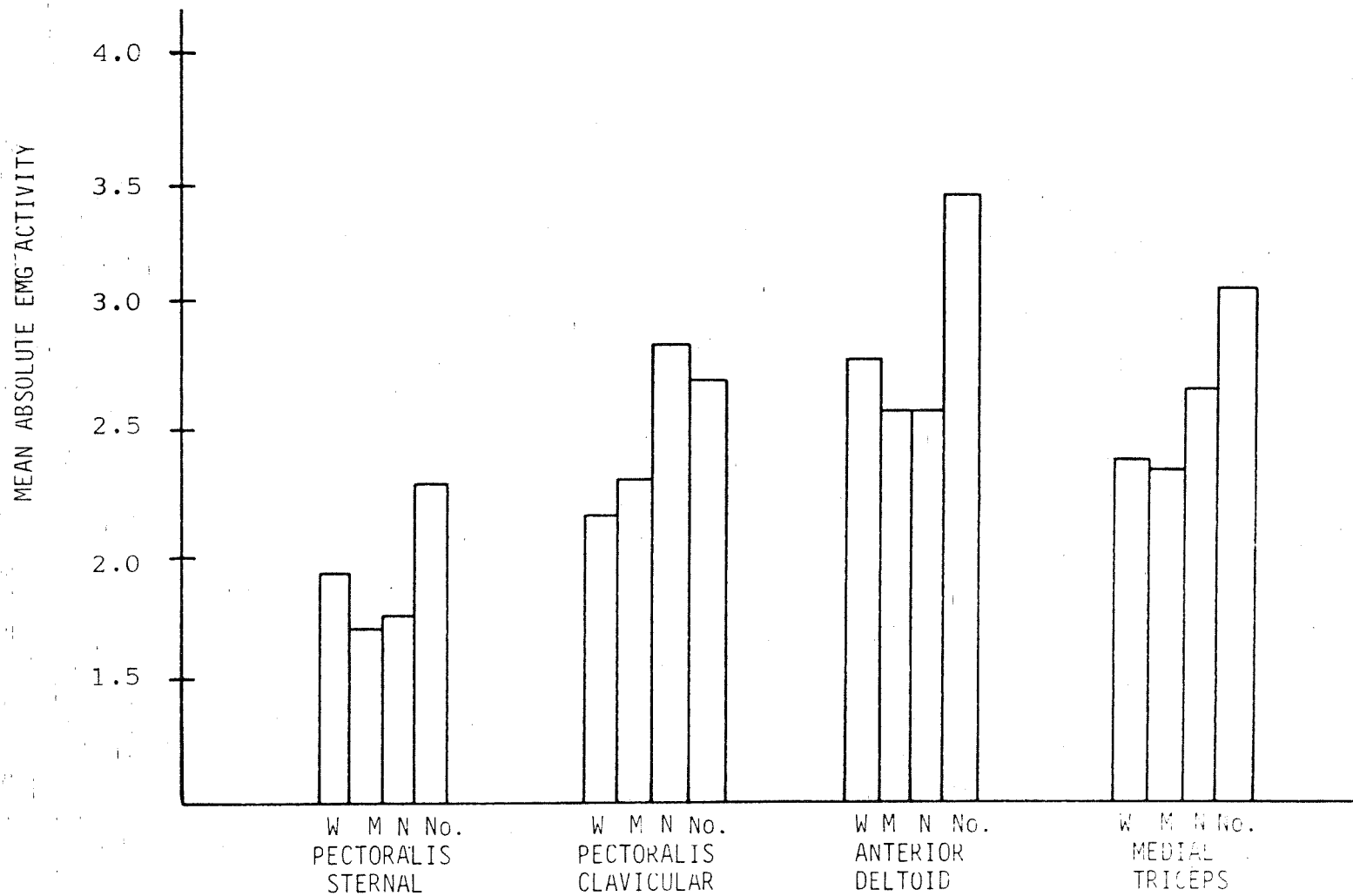


Figure 21. Comparison of the mean absolute EMG activity by muscle for the eccentric contraction.

* EMG amplitude measured in Kilo-millivolts

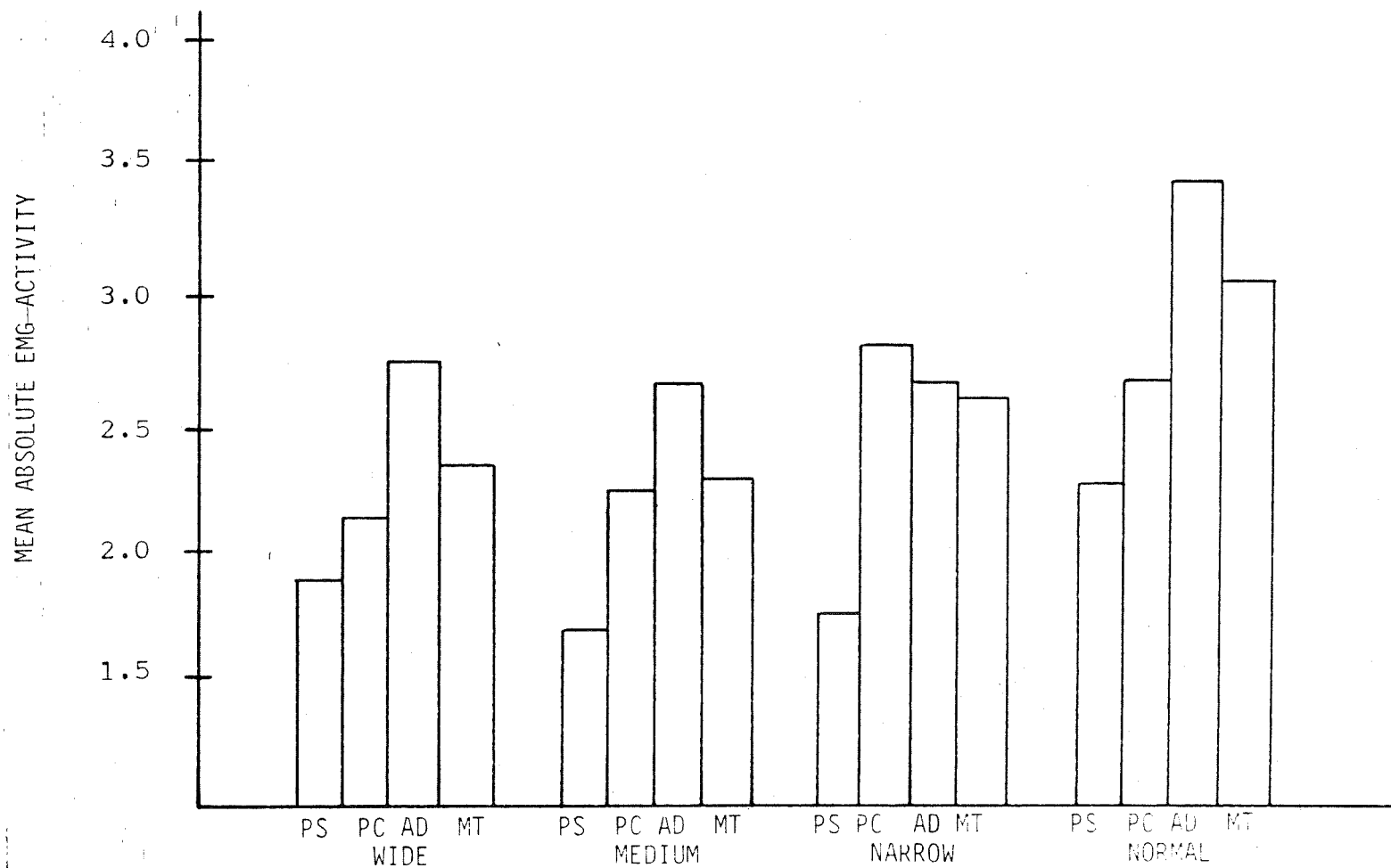


Figure 22. Comparison of the mean absolute EMG activity by grip width for the eccentric contraction.

* EMG amplitude measured in Kilo-millivolts

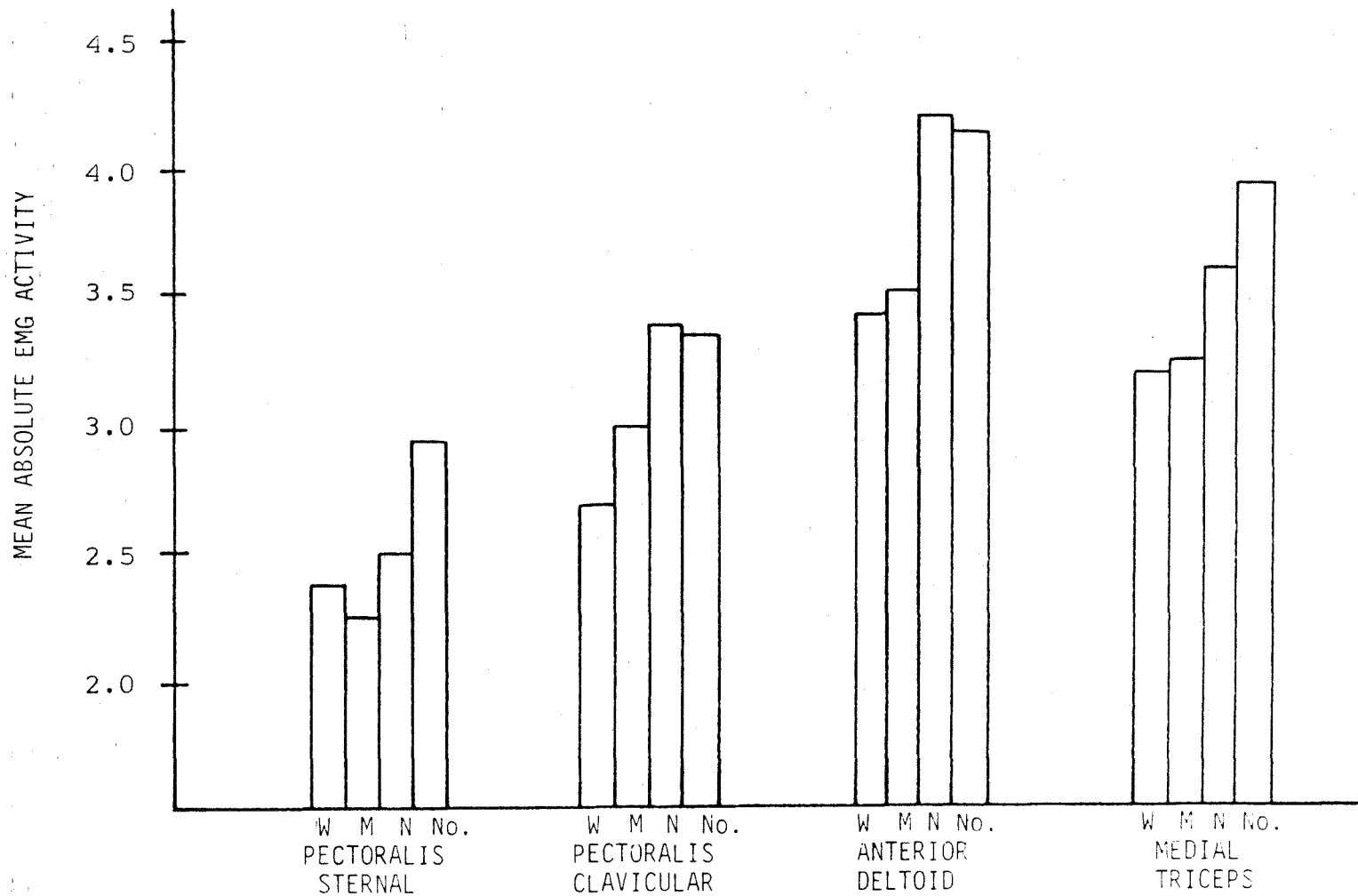


Figure 23. Comparison of the mean absolute EMG activity by muscle for the concentric contraction.

* EMG amplitude measured in Kilo-millivolts

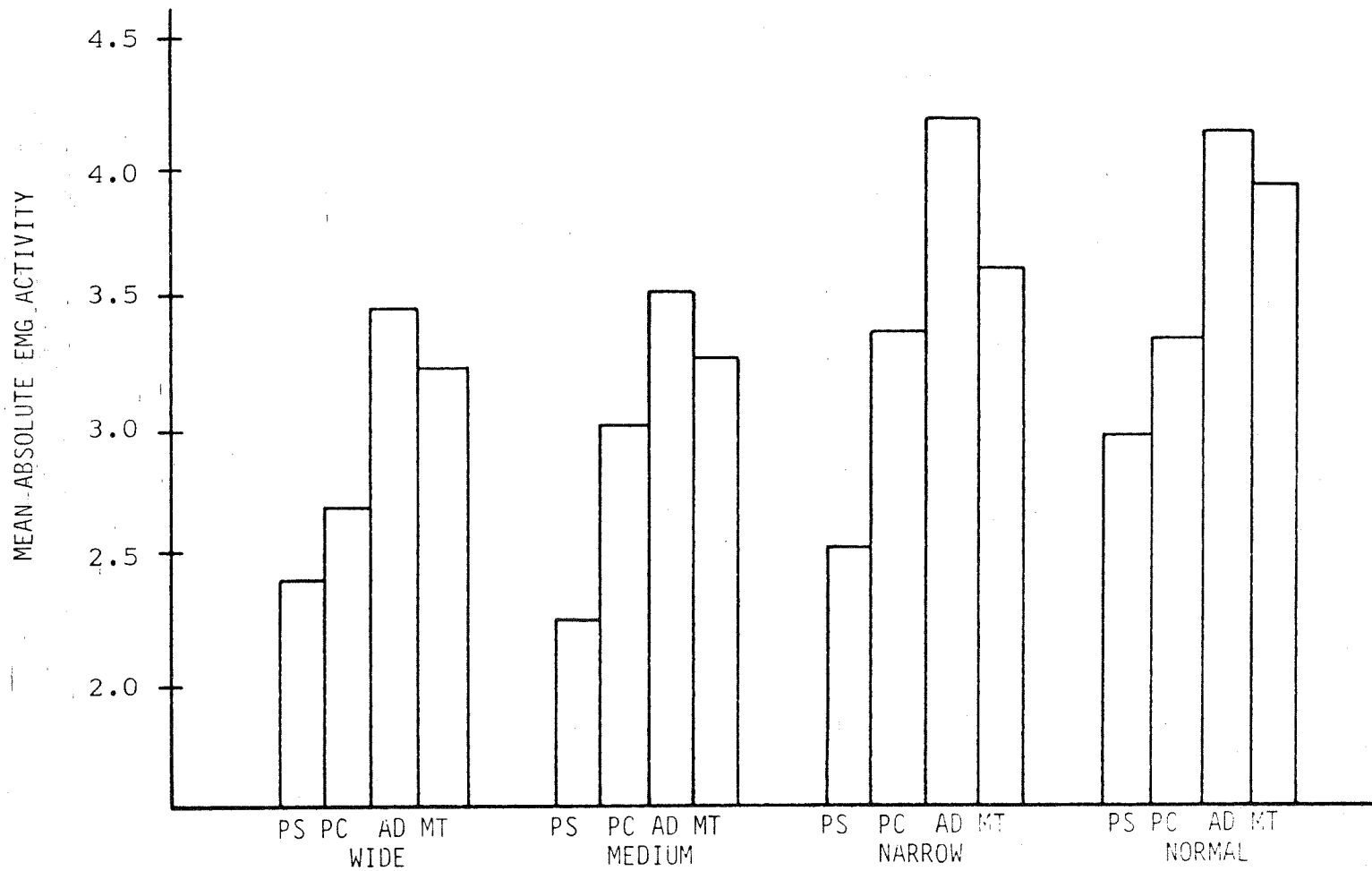


Figure 24. Comparison of the mean absolute EMG activity by grip width for the concentric contraction.

* EMG amplitude measured in Kilo-millivolts

The multiple comparison analysis for the eccentric contraction demonstrated a difference between the PS and PC for the narrow grip width; the PS and AD for all grip widths; the PS and the MT for the medium, narrow, and normal grip widths; the PC and AD for the wide and the normal grip widths. For the concentric contraction, the analysis showed a difference between the PS and PC for the medium and narrow grips; the PS and AD for all grip widths; and the PS and MT for all grip widths.

When reviewing the sums of the ranks and the mean absolute EMG activity for the muscles involved in the study, it was determined that a single muscle produced greater overall EMG activity, and therefore had greater involvement for all grip width positions. The eccentric contraction showed that the AD produced the greatest absolute EMG activity for the wide and medium grip widths. The narrow grip width produced the greatest absolute EMG activity in the PC, followed closely by the AD and MT. The concentric contraction demonstrated that the AD produced the greatest absolute EMG activity for all grip width positions. It could be concluded from this study that the AD muscle was predominantly active for all grip widths during the concentric contraction, followed by the MT, PC, and PS. However, each grip width demonstrated a change in absolute EMG activity produced by each muscle group.

It is graphically represented that the absolute EMG activity increases in amplitude from the wide grip to the narrow grip width. This increase in EMG activity may be attributed to the effects of training. These training adaptations to strength, or decreased EMG activity, in the wide grip may be due to hypertrophy (larger cross-sectional area

of fast twitch fibers), neural learning, specificity of training, and EEA. The training adaptations help increase the speed and force of the contraction and the rate at which the muscle develops tension. It has been theorized that muscle adaptation to strength training is specific to the type of exercise (Astrand et al., 1977).

In conclusion, for this sample, the narrow grip width produced the greatest absolute EMG activity in all muscle groups, with an exception to the normal grip width with the maximal weightload. When training at a percentage of your 1RM, it may be beneficial to train at a grip width which involves the greatest recruitment of motor units, the greatest motor unit firing rates, and greatest muscle activity. In addition, overall the 1RM produced the greatest EMG activity. Therefore, for the purpose of strength training, it may be a greater benefit to use a weightload which produces greater EMG activity or muscle involvement to optimally increase the strength of a muscle.

The Relationship Between Shoulder Joint Angle and Muscle Group

The shoulder joint angle formed by an individual performing the bench press may play a role in the success of the lift. Individuals experienced in the performance of the bench press have developed specific styles. These specific movements are learned by the brain and performed the same each time the bench press is performed. The specific movement involves the abduction of the shoulder to a desired position or angle. The specific angle is formed each time a repetition is executed. This specificity of training results in training the muscles to perform optimally at the specific shoulder joint angle, repetition

after repetition. However, if the learned shoulder joint angle is somehow altered during the lift, would the change in the angle effect the degree of muscle involvement?

It was an objective of this study to determine if the positioning of the shoulder joint angle (refer to Figures 6 to 9) had an effect on the degree in which the muscles were involved in the concentric contraction of the bench press exercise. Table 12 presents the means and standard deviations for the shoulder joint angles.

Table 12. Means and standard deviations for the shoulder joint angles.

Grip	Mean (°)	SD
Wide	63.1*	3.84
Medium	54.1*	2.85
Narrow	40.1*	1.91
Normal	57.5	3.84

* Based on elbow joint angle measurements

A Pearsons Product Moment Correlation Coefficient was performed to determine if a relationship existed between the shoulder joint angle and the EMG activity elicited by the muscles being analyzed. Table 13 illustrates the correlation coefficients calculated between shoulder joint angles and EMG muscle activity.

It can be observed that for all shoulder joint angles, correlations were very low and only 2 significant correlations were found. The wide-grip width showed a significant ($p < .05$) negative relationship between

the angle and the PC muscle. The medium grip demonstrated a significant ($p < .05$) positive relationship between shoulder angle and the PS muscle. Due to the findings of this study, illustrated in Table 13, it may be concluded that a weak relationship exists between shoulder joint angles and the EMG activity. The weak relationship between the

Table 13. Correlation coefficient between shoulder angle and EMG muscle activity.

Angle	Muscle	r
Wide	PS	0.06
	PC	-0.39*
	AD	-0.09
	MT	-0.18
Medium	PS	0.39*
	PC	0.04
	AD	0.22
	MT	-0.09
Narrow	PS	0.26
	PC	0.02
	AD	0.10
	MT	0.01
Normal	PS	-0.15
	PC	-0.04
	AD	-0.13
	MT	-0.11

* $p < .05$

shoulder joint angle and EMG activity indicated that the predictability is very low. The weak relationship between shoulder joint angles and EMG activity may be due to the limitations imposed by the study. The primary limitation was the inability to control the shoulder joint angle position for all subjects. Therefore, during the concentric

contraction, there exists a large variation between angles.

In conclusion, it would be beneficial for an individual to determine the shoulder joint angle that produces the greatest EMG activity in the muscles involved in the performance of the bench press exercise. This information will allow an athlete to train using the specific shoulder joint angle. When a specific angle is used, it allows the individual to optimally train the muscles involved in the contraction, and improve the strength and performance of the muscles involved in the bench press exercise.

The Relationship Between EMG Activity and Grip Width

A Pearsons Product Moment Correlation Coefficient was calculated to determine the relationship between the EMG activity produced by the muscles involved in the study and the grip width position. Table 14 illustrates the findings of the correlation.

The results of the correlations showed significant ($p < .05$) positive relationships between the PS and PC, the PS and MT, and the PC and MT muscle groups for the medium, narrow, and normal grip widths. However, in these groups, the correlations were low, indicating that weak relationships were found between the muscle group EMG activity and the grip width position. The wide grip wide showed no significant relationships. The lack of any significant relationships for the wide grip width was most likely due to the fact that the EMG activity produced by the 4 muscle groups were very similar. The AD and MT muscle group comparisons showed a non-significant negative relationship for the wide, medium, and narrow grips.

Table 14. Correlation coefficients between the EMG activity and the grip width position.

Muscle Comparison	Wide r	Medium r	Narrow r	Normal r
PS vs PC	0.03	0.35*	0.38*	0.46*
PS vs AD	0.18	0.25	0.27	0.18
PS vs MT	0.19	0.34*	0.47*	0.39*
PC vs AD	0.28	0.12	0.12	-0.07
PC vs MT	0.19	0.34*	0.44*	0.42*
AD vs MT	-0.19	-0.16	-0.12	0.02

* $p < .05$ level

It was the objective of this study to determine the relationship between the EMG muscle activity and the grip width position. The results of the correlation showed positive relationships between the PS and PC, the PS and AD, the PS and MT, and the PC and AD, the PC and MT for the wide, medium and narrow grip widths. These results indicated that as the EMG activity in one muscle increased the EMG activity in the other muscle also increased. Although these relationships were very low, there was a tendency for a muscle to increase EMG activity as another muscle increased EMG activity. Negative non-significant relationships were found between the AD and MT for the wide, medium and narrow grip widths. Significant relationships were found only in the medium, narrow, and normal grip widths.

It may be concluded from the results of the study that as the EMG activity in a single muscle increased during the concentric contraction,

the EMG activity developed in another muscle group increased proportionally until the object was moved. The increase in EMG activity may be related to the tension developed within the muscles analyzed.

The Relationship Between Arm Length and Grip Width Position

The length of the arm, from the head of the humerus to the ulnar styloid process, is an important factor to be considered for the performance of the bench press exercise. Many individuals do not consider the length of the arm when selecting an appropriate grip width. It has been suggested that individuals with longer arms should select a wider grip width and those with shorter arms should select a closer grip width.

Correlation coefficients were calculated between the arm length measurements and the grip width measurements. The results indicated a significant ($p < .001$) correlation ($r = 0.68$) between arm length and the wide grip width. These results demonstrated a modest relationship between the wide grip width and arm length. The medium grip showed a significant ($p < .05$) correlation ($r = 0.39$) between the arm length and the medium grip width. As for the narrow grip width, the results showed a non-significant correlation ($r = 0.01$) between the arm length and narrow grip width.

Positive correlations were also found between grip widths. The wide and medium grip widths demonstrated a significant ($p < .01$) correlation ($r = 0.58$), whereas the wide and narrow grips showed a non-significant correlation ($r = 0.28$). A significant ($p < .001$) correlation ($r = 0.66$) was found between the medium and narrow grip widths.

It may be concluded from the results of the correlation that individuals with longer arms tend to grip the bar using a wider grip

width than those with shorter arms. In this study the wide, medium, and narrow grip widths were based on the subject's elbow joint angles. Elbow joint angles of 80° for the wide, 60° for the medium, and 40° for the narrow grip were determined. The purpose for using elbow joint angles was to make the grip width distance proportional to the subject's arm length, and keeping the distance the bar must travel for each subject relatively the same. In addition, it may be concluded that as the arm length of the subject increased, the elbow angle also increased, thus increasing the grip width distance.

Shoulder Joint Angle Measurements

The shoulder joint angle, formed when the bar is lowered to the chest and maintained during the pressing phase, may be of some importance to the involvement of the muscle groups analyzed in this bench press study. However, does the change of the shoulder joint angle affect a change in the muscles involved in the muscle contraction?

An analysis of variance was calculated to determine a significant difference between the shoulder joint angles and the grip width positions. The means and standard deviations for the shoulder joint angles and grip widths are located in Table 12 (Appendix E) and Table 15 (Appendix F).

The analysis of the data revealed that significant differences ($F = 53.24$, $df = 3, 108$, $p < .05$) were found between the shoulder joint angles for the wide, medium, narrow, and normal grip widths. To determine where the significant differences lie between shoulder joint angles, Scheffe' post hoc analyses were performed (Table 16).

Table 15. Means and standard deviations for the grip width positions.

Grip	Mean (in)	SD
Wide	34.5	2.85
Medium	26.2	2.29
Narrow	15.4	1.91
Normal	28.3	3.84

By comparing the means of the shoulder joint angles and the grip width positions it can be determined that as the grip width increased, the shoulder joint angle also increased.

Table 16. Scheffe' post hoc analysis of the shoulder joint angle.

Angle Comparison	F Ratio	Level of Significance
W vs M	22.50	0.01
W vs N	146.94	0.001
W vs No	8.71	0.05
M vs N	3.90	NS
M vs No	3.60	NS
N vs No	86.04	0.001

The results may be interpreted by saying that during the performance of the bench press, when a wide grip width is used there is an increase in the shoulder joint angle, and when a narrow grip width is

used there is a decrease in shoulder joint angles. The post hoc analysis showed significant differences between the wide and medium grips, the wide and narrow grips, the wide and normal grips, and the narrow and normal grip widths. The findings showed that as the grip width positioned changed, so did the shoulder joint angle.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, IMPLEMENTATIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to provide electromyographic information for the eccentric and concentric contractions during the performance of the bench press exercise. The EMG analysis of the bench press exercise presents the myoelectrical activity for the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial head of the triceps produced during the eccentric and concentric contractions.

Twenty-eight male volunteers, experienced and trained in the performance of the bench press, were involved in the analysis of the bench press. The subjects met twice for data collection. The first meeting involved determination of the MVC (1RM) for the bench press exercise, and the measurement of elbow joint angles to determine the wide, medium, and narrow grip width positions. The second meeting involved the actual EMG data collection. The experimental design involved 4 trials. Following the warm-up repetitions, the first trial was performed, which included a maximal repetition using the subject's normal training grip width. The 1RM was used to obtain the maximal EMG muscle activity for the 4 muscle groups analyzed. The remaining 3 trials were performed with 85% of the maximal weightload using a wide, medium,

and narrow grip width to record 85% EMG muscle activity. A single repetition was performed for each trial allowing 3 minutes rest between trials. Bipolar surface electrodes were used to detect the myoelectrical activity produced by each muscle studied. The bipolar surface electrodes were placed over the muscle belly in specific areas (refer to Chapter III, electrode placement). A stimulating electrode was used to administer an electrical stimulus to the subject, as a command to indicate initiation of the lowering phase, and the pressing phase of the bench press. The electrical stimulus was also recorded and used as a reference mark for the beginning of the eccentric and concentric contractions. A photograph of the subject's shoulder joint angle was recorded and used to determine changes in shoulder joint angles, in relation to the grip width positions.

The EMG data was analyzed to determine if the wide, medium, and narrow grip width positions affected a change in the EMG activity produced by the muscles involved in the study, and to determine the degree of involvement of each muscle. The recruitment patterns of the muscles during the concentric contractions were also determined from the EMG recordings. The photographs recorded of the subject's shoulder joint angles were used to establish if a relationship existed between the shoulder joint angles and the muscle activity produced.

Research conducted on any type of free weight resistance exercise will provide information useful for its physiological and biomechanical analysis. The information obtained from this research should provide individuals with a greater understanding of the bench press exercise. Hopefully, the research analyzing the bench press exercise will

stimulate further investigations dealing with free weight performed resistance exercises.

Findings

The following findings were formulated from the results of the study:

Ratio of EMG Activity for the Eccentric Contraction

1. There were significant differences ($p < .05$) between the ratios of EMG activity produced by the PS, PC, AD, and MT muscles for all the grip width positions.
2. There was a significant difference ($p < .05$) between the ratio of EMG activity produced by the PS and PC muscles when using the narrow grip width position.
3. There was a significant difference ($p < .05$) between the ratio of EMG activity produced by the PC and AD muscles when using the narrow grip width position.
4. There was a significant difference ($p < .05$) between the ratio of EMG activity produced by the narrow and wide grip width positions for the PC muscle.

Ratio of EMG Activity for the Concentric Contraction

1. There were significant differences ($p < .05$) between the ratios of EMG activity produced by the PS, PC, AD, and MT muscles for all the grip width positions.
2. There was a significant difference ($p \leq .05$) between the ratio of EMG activity produced by the PS and PC muscles when using the narrow grip width position.

3. There was a significant difference ($p < .05$) between the ratio of EMG activity produced by the PS and AD muscles when using the narrow grip width position.

4. There was a significant difference ($p < .05$) between the ratio of EMG activity produced by the narrow and wide grip width positions for the PC muscle.

5. There was a significant difference ($p < .05$) between the ratio of EMG activity produced by the wide and narrow, and the medium and narrow grip widths positions for the AD muscle.

6. There was a significantly greater ratio of EMG activity produced by the AD muscle when using the narrow grip width, than by either the medium or wide grip width positions.

7. While there were greater ratios of EMG activity produced by the PS, PC, AD, and MT muscles when using the narrow grip width, than for the wide or medium grip width positions, these ratios were not significantly different from one another.

8. There was a greater ratio of EMG activity produced by the PS muscle, than by the PC, AD, and MT muscles when using the wide grip width position, these ratios were not significantly different.

9. There was a greater ratio of EMG muscle activity produced by the PS, PC, AD, and MT muscles during the concentric contraction, than during the eccentric contraction, these ratios were not significantly reported.

When analyzing the EMG ratio measurements the findings indicated that the use of a wide, medium, and narrow grip widths produced significant differences between the ratio of EMG activity for the eccentric

and concentric contraction. The pattern and involvement of the EMG activity is effected by the grip width position. Therefore, the hypothesis in Chapter I which stated that there were no differences between the ratio of EMG activity for the grip width was rejected.

Recruitment Analysis for the Concentric Contraction

1. There were significant differences ($p < .05$) in the sums of the recruitment order ranks between the wide, medium, narrow, and normal grip width positions.

2. The AD muscle was determined as being recruited first followed by the PC, PS, and MT muscles for the wide, medium, and normal grip width positions.

3. For the narrow grip width, the order of muscle recruitment was PC, PS, AD, and MT muscles.

Significant differences were found between the sums of the recruitment order ranks for the 4 grip width positions. Specific patterns exist between the order in which the muscles are recruited for the concentric contraction. Therefore, the hypothesis stated in Chapter I dealing with the recruitment order was rejected.

Correlations for the Concentric Contraction

1. There was a significant ($p < .05$) negative relationship between the shoulder joint angle formed by the wide grip width and the EMG activity produced by the PC muscle.

2. There was a significant ($p < .05$) relationship between the shoulder joint angle formed by the medium grip width and the EMG activity produced by the PS muscle.

3. There was an overall weak relationship between the effects of the shoulder joint angle on the pattern of EMG activity produced by the 4 muscle groups.

4. There were significant ($p < .05$) relationships between the PS and PC, the PS and MT, and the PC and MT muscle groups for the medium, narrow, and normal grip width positions.

5. There were overall weak relationships between the effects of the grip width position on the EMG muscle activity produced by the PS, PC, AD, and MT muscle groups.

6. There were significant differences between the shoulder joint angles for the wide and medium ($p < .05$), wide and narrow ($p < .001$), wide and normal ($p < .05$), and the narrow and normal ($p < .001$) grip width positions.

Weak relationships exist between the shoulder joint angles and the pattern of EMG activity. However, the results indicated that the positioning of the shoulder joint did effect the pattern of EMG activity in 2 cases. Therefore, the hypothesis stated in Chapter I which stated that there were no significant differences was rejected.

Absolute EMG Activity Measurements

1. There were significant differences ($p < .05$) between the absolute EMG activity and all the grip width positions.

Eccentric Contraction

2. There was a significant difference ($p < .05$) in the absolute EMG activity between the PS and AD muscles for the wide, medium, narrow, and normal grip width positions.

3. There was a significant difference ($p < .05$) in the absolute EMG activity between the PC and AD muscles for the wide and normal grip width positions.

4. There was a significant difference ($p < .05$) in the absolute EMG activity between the PS and MT muscles for the medium, narrow and normal grip width positions.

5. There was a significant difference ($p < .05$) in the absolute EMG activity between the PS and PC muscles for the narrow grip width position.

Concentric Contraction

6. There was a significant difference ($p < .05$) in the absolute EMG activity between the PS and PC muscles for the wide, medium and narrow grip width positions.

7. There was a significant difference ($p < .05$) in the absolute EMG activity between the PS and AD muscles for all grip width positions.

8. There was a significant difference ($p < .05$) in the absolute EMG activity between the PS and MT for the medium, narrow and normal grip width positions.

9. The AD muscle produced the greatest absolute EMG activity for all grip width positions followed closely by the MT, PC and PS muscles.

10. There was a greater amount of absolute EMG activity produced by the muscles during the concentric contraction than during the eccentric contraction.

Conclusions

1. This investigation provides evidence that the degree of muscle activity and muscle involvement for the PS, PC, AD, and MT muscles is effected by the wide, medium, and narrow grip width position, during the performance of the bench press exercise. The differences in muscle activity are indicative of how the grip width position effects the involvement of the muscles. The patterns of muscle activity produced by the muscles when contracting against a submaximal weightload indicate that the narrow grip width may be more advantageous for developing greater muscle activity.

2. In the analysis of the recruitment order the results revealed that a specific recruitment order does exist for the PS, PC, AD, and MT muscles during the concentric contraction of the bench press exercise. The recruitment order for the muscles involved in the bench press were effected by the changes in the shoulder joint positions. This was shown by the recruitment order remaining constant for the wide, medium, and normal grip widths, and then being altered when the narrow grip width was used which decreased the shoulder joint angle.

3. The results of the correlation between the shoulder joint angle and the EMG activity revealed that the position of the shoulder joint had a slight effect on the degree of muscle activity produced by each muscle group involved. Further research may produce evidence indicating that the shoulder joint angle has a definite effect on the involvement of the muscles during the bench press exercise.

4. It was evident that the grip width position had an effect on the pattern of EMG activity produced by the muscles involved in this

study. Therefore, the selection of a specific grip width position may influence the degree in which a muscle is involved in the bench press exercise.

5. The amplitude of EMG activity produced by the muscles involved in the study is representative of the recruitment of motor units and increased firing rates of motor units. As the EMG activity in a muscle increases, or as the force of the contraction increases there is a increase in the firing rates of active motor units, and an increase in the recruitment of new motor units.

Implementations

The analysis of the wide, medium, and narrow grip width positions during the eccentric and concentric contractions evoked varying responses of the neural and muscular components of the bench press exercise. Although it was not the purpose of this investigation to determine the best overall method of performing the bench press exercise, it was the purpose to provide EMG data on several muscle groups during the performance of the bench press exercise. The following training implementations from this study may be applied to help improve the performance of the bench press, and increase its use as a method of training.

1. When incorporating the bench press exercise into a training program it is necessary to understand the function and involvement of the muscles involved in the exercise. When training with the bench press at submaximal weightloads it may be of a greater benefit to train the muscles using a narrow grip width position. The narrow grip width

position evoked greater muscle activity and involvement from the muscle groups studied, than the wide or medium grip width positions. The narrow grip width was responsible for eliciting a greater recruitment of motor units and an increased firing rate of active motor units.

2. When using the bench press to train specific muscles involved in a specific movement it is recommended that a grip width be used which simulates the position of the arms during the movement. This will ensure greater stimulation of the motor units and increase the strength of the muscles involved for that particular position.

3. When implementing the bench press exercise into a training program it is recommended that a variation in the grip width position be used and incorporated. The use of different grip width positions will stimulate and increase the performance of all the muscle fibers of a specific muscle. In addition, overall strength and performance will increase in all the muscles involved in the bench press exercise.

4. When incorporating the bench press exercise into a strength training program it is suggested to use a weightload which stimulates maximal recruitment and firing rates of involved motor units. The use of a maximal weightload produces greater overall EMG activity in the muscles, and as a result stimulates greater strength development.

Recommendations

The following suggestions are made for future studies:

1. Conduct an electromyographic study separately analyzing the eccentric and concentric contractions of the bench press exercise.

2. Conduct an EMG analysis of the bench press using inserted wire electrodes and integrated EMG data.

3. Conduct an EMG analysis of the bench press exercise comparing the muscle activity between trained and untrained lifters.
4. Conduct a study specifically analyzing the effects of the shoulder joint angles on the muscle involvement during the performance of the bench press exercise.
5. Conduct a study which determines a maximal repetition for each grip width position, and then compare the maximal EMG activity for each muscle group analyzed.
6. Conduct a study analyzing the bench press using electromyography and cinematography.
7. Conduct a study analyzing the same muscles involved in this bench press study plus additional muscle groups such as; the latissimus dorsi, medial and posterior deltoid, and serratus anterior.

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APPENDIX A

OFFICIAL POWERLIFTING RULES FOR PERFORMING
THE TWO HANDED BENCH PRESS

- A. The lifter may elect to assume one of two positions on the bench press, which must be maintained during the lift.
 - 1. With head, trunk, and legs extended on the bench, knees locked, heels on the bench, or
 - 2. With head, trunk (including buttocks) extended on the bench, feet flat on the floor.
- *B. The signal to begin the lift shall be given when the bar is absolutely motionless at the chest.
- *C. At the signal the bar is pressed vertically to straight arm's length and held motionless for the signal to replace the bar.
- D. The lifter may use any method to bring the bar to the chest preparatory to the uplifting movement.
- *E. The width of the bench shall not be less than 10 inches nor more than 12 inches. The height of the bench shall not be less than 14 inches nor more than 18 inches.
- F. If the lifter's trunk and the bench top are not of sufficient color contrast to enable the officials to detect a possible raising of the buttocks, the bench top shall be covered accordingly.
- G. The spacing of the hands shall not exceed 32 inches measuring between the forefingers.
- H. In this lift, the judges and referees shall station themselves at the best points of vantage.
- I. For those lifters who elect to use position (2) and whose feet do not touch the floor, the platform may be built up to provide firm footing.
- J. Two spotters shall be mandatory.

CAUSES FOR DISQUALIFICATION

- *1. During the uplifting, any change of the elected lifting position.
- *2. Any raising of the lifter's head, shoulders, buttocks, or legs from the bench, no movement of the feet.
- *3. Any shifting of the same.
- *4. Bridging in any form.

- *5. Any heaving or bouncing of the bar from the chest.
 - *6. Allowing the bar to sink excessively into the lifter's chest.
 - *7. Any uneven extension of the arms.
 - *8. Stopping of the bar during the pressing phase.
 - *9. Any touching of the bar by the spotters before the arms are fully extended.
 - *10. Failure to wait for the signal.
 - *11. Bracing against the bench with the feet.
 - *12. Bracing shoulders against uprights of the bench.
 - *13. Hitting the uprights while lifting the bar.
 - *14. Any form of wrapping or bandages on the wrist, elbow or any part of the body is prohibited.
- * Rules that applied to this study.

APPENDIX B

INFORMED CONSENT FORM

TITLE: AN ELECTROMYOGRAPHIC ANALYSIS OF SOME OF THE MUSCLE GROUPS INVOLVED IN THE PERFORMANCE OF THE BENCH PRESS EXERCISE.

PRINCIPAL INVESTIGATOR: WILLIAM J. MICKSCHL

PROCEDURE: I understand that prior to data collection I will be expected to perform several maximum trials to determine a maximum weightload that can be lifted for one repetition, using correct form, for the bench press exercise. Elbow joint angles will be measured to determine appropriate grip widths. I understand that during the actual testing I will be required to perform one repetition at a maximal weightload using a normal training grip width, and one repetition at 85% of the maximal weightload using each of the 3 randomly assigned grip widths, wide, medium and narrow. In preparation for the testing bipolar surface electrodes will be applied to the skin over each of the 4 muscles being analyzed. These muscles include the sternal and clavicular heads of the pectoralis major, the anterior deltoid, and the medial triceps. The muscle analysis will be performed on the dominant side of the body. Skin preparation will be necessary at each site of electrode placement which includes; the removal of any excess body hair, abrasion of the skin with an alcohol swab and fine sandpaper, and application of electrode jell and electrodes. An additional electrode will be placed on the dominant shoulder between the anterior deltoid and the clavicular section of the pectoralis major. This electrode will administer a small electrical stimulus indicating when to initiate the eccentric contraction (lowering phase). A second stimulus will be administered to indicate when to initiate the concentric contraction (pressing phase) of the bench press.

I understand that there exists a possibility of a muscle strain and, or soreness from the execution of the bench press. However, the risk is minimized because a spotter will be assisting for each lift. Momentary skin irritation may result from the electrode jell being applied to the abraded skin. Some discomfort may be experienced from the electrical stimulus, but this is unlikely since the voltage is kept to a minimum.

I, _____, being of sound mind and _____
(Name of Subject)

years of age, do hereby consent to, authorize and request the person named above (and his co-workers) to undertake and perform on me the proposed procedure, treatment, research or investigation (Herein called "Procedure").

I have read the above document, and I have been fully advised of the nature of the procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume voluntarily.

I hereby acknowledge that no representation, warranties, guarantees or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, employees or by anyone acting on behalf of any of them.

I understand that I may withdraw from the study at any time.

Signed at _____ this _____ day of _____, 19____, in the presence of the witnesses whose signatures appear below opposite my signature.

WITNESSED BY:

(Subject)

I, _____, (husband, wife, parent, other) of the aboved-named subject _____, have read the foregoing consent and the document attached hereto and made a part of such consent, and I hereby consent to the said Procedure.

WITNESSED BY:

(Signature)

APPENDIX C

SUBJECT DATA SHEET

Name of Subject _____

Height _____ in. Arm Length _____ in.

Weight _____ lbs. Chest Size _____ in.

Age _____ yrs. Experience _____ yrs.

Predetermined Maximal Repetition _____ lbs.

Dominant Side _____

<u>Elbow Joint Angle</u>	<u>Grip Width</u>	<u>Order</u>
Max _____ °	_____ " (Normal)	<u>1st</u>
40 _____ °	_____ " (Narrow)	_____
60 _____ °	_____ " (Medium)	_____
80 _____ °	_____ " (Wide)	_____

TESTING

Maximal Weight _____ lbs.

85% of Maximum _____ lbs.

EMG Muscle Activity

	<u>PS</u>	<u>PC</u>	<u>AD</u>	<u>MT</u>
MAXIMUM	_____	_____	_____	_____
NARROW	_____	_____	_____	_____
MEDIUM	_____	_____	_____	_____
WIDE	_____	_____	_____	_____

APPENDIX D

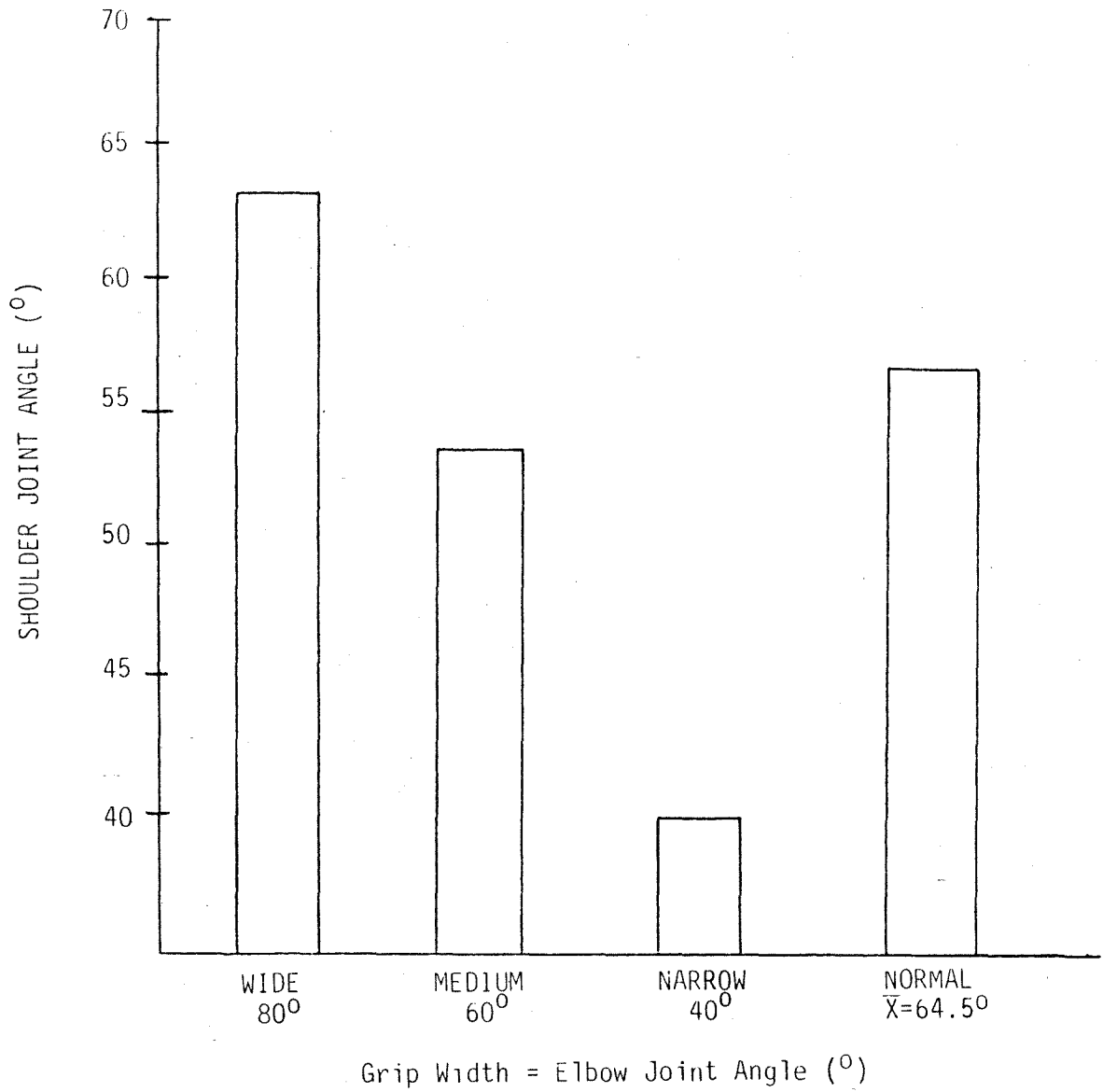
Percentages of Muscle Recruitment Order

Grip	Order	Pectoralis Sternal	Pectoralis Clavicular	Anterior Deltoid	Medial Triceps
Wide	1st	17.8%	14.0%	60.6%*	3.6%
	2nd	7.0%	53.6%*	21.0%	25.0%
	3rd	53.6%*	21.0%	10.7%	14.0%
	4th	21.0%	10.7%	7.0%	57.0%*
Medium	1st	7.0%	17.8%	53.6%*	17.8%
	2nd	21.0%	57.0%*	25.0%	3.6%
	3rd	53.6%*	21.0%	17.8%	3.6%
	4th	17.8%	3.6%	3.6%	75.0%*
Narrow	1st	10.7%	60.7%*	21.0%	3.6%
	2nd	53.0%*	17.8%	17.8%	14.0%
	3rd	32.0%	10.7%	53.0%*	10.7%
	4th	7.0%	10.7%	7.0%	71.0%*
Normal	1st	3.6%	14.0%	71.0%*	10.7%
	2nd	25.0%	60.6%*	10.7%	7.0%
	3rd	57.0%*	21.0%	7.0%	10.7%
	4th	14.0%	3.6%	10.7%	71.0%*

* Indicates the greatest percentage for each muscle group.

APPENDIX E

MEAN SHOULDER JOINT ANGLES



APPENDIX F

MEAN GRIP WIDTHS

