SHOULDER MUSCLE ELECTROMYOGRAPHY DURING DIAGONAL AND STRAIGHT PLANE PATTERNS OF MOVEMENT

THESIS

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By

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The purpose of this study was to further investigate the relationship between patterns of shoulder movement and muscular response. Thirteen females were tested against maximal manual resistance in twelve different patterns, eight straight plane, and four diagonal. Five of the six subjects who met established kinematic criteria were used for electromyographic (EMG) analysis of the anterior deltoid (AD), the middle deltoid, the posteroir deltoid (PD), and the pectoralis major. No significant differences were found between number of muscles solicited or duration of muscular effort during the different movements. Maximal EMG was significantly higher for the AD in abduction and in flexion than in the other patterns, and for the PD in diagonal flexion with abduction and in transverse abduction.

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CHAPTER I

INTRODUCTION

Proprioceptive neuromuscular facilitation (PNF) is a multifaceted rehabilitation approach which is based upon the principles of normal motor behavior and motor learning (Voss, 1967). To put it in very simplified terms, it is a philosophy based upon the concept that all human action is in response to demand, and that potential exists for further development of those responses (Knott & Voss, 1968).

The concept of relationships between varied demands and muscular response is applicable to many areas of human performance, including those concerned with skill, endurance, relaxation, power, strength, and rehabilitation. The more definitive the relationship between demand variables and the motor response, the more definitive the rehabilitation or training protocol can be, and thus, the more likely it is to achieve the desired results.

While many of the factors affecting muscular response have been well documented, the direction, or pattern, of movement has received relatively little attention, except in regards to treating patients with neurological dysfunction. This aspect of facilitating for muscular response has the potential for application to other populations.

Proprioceptive neuromuscular facilitation is unique in its use of spiral, diagonal patterns of movement. Each pattern has three components of motion for each joint involved. These include a flexion or extension component, an abduction or adduction component, and a rotation component. These patterns were designed in consideration of anatomical features, so that demand could be placed upon specific muscles, in order that irradiation, or recruitment of associated muscles, could be maximized.

It was Kabat (1950) who developed PNF as a rehabilitation technique which utilized three primary methods of facilitation: maximal resistance; mass movement patterns; and stretch. He based his concepts on his knowledge of physiology, and also on the work of Gellhorn (1949, 1950) and Gellhorn and Johnson (1950). Their research with electrical stimulation of the motor cortex of monkeys demonstrated resistance as being an effective source of central facilitation, and also the importance of mass movement patterns.

The patterns of movement and techniques were further refined by Knott and Voss (1968), who defined the patterns as being "optimal" for certain muscle groups. Snyder and Forward (1972) compared electromyography (EMG) of some of the lower extremity muscles during various patterns of knee flexion and extension and failed to support the PNF patterns as more capable of eliciting motor unit activity.

Sullivan and Portney (1980) looked at the shoulder and the EMG results from performance of the four upper extremity PNF patterns. Their results did support the concept that individual muscles do have optimal patterns for recruitment within that muscle.

Ferdinand (1979) compared isometric EMG data from PNF and planar patterns of movement, and again found support for the PNF patterns as being specifically optimal. However, he found no support for the PNF isometric as being superior to the planar pattern isometric in eliciting EMG activity.

If, as the developers of PNF claim, the PNF patterns of movement are such that, with resistance, they provide optimal sequencing of muscle recruitment, it would seem that they would be the movement patterns of choice when maximal muscular effort is desired, such as when training for power or strength. Although PNF patterns are commonly used for development of strength in populations without neurological impairment, documentation is needed to support resisted PNF as being capable of eliciting greater muscular response within the muscles of a single joint than straight plane resisted motions in normal subjects.

Purpose of the Study

It was the purpose of this study to look specifically at the muscles of the shoulder and their EMG response to maximal resistance given to straight plane and PNF patterns of movement. An attempt was made to find relationships between (a) the pattern of movement and the number of muscles recruited, (b) the pattern of movement and the extent of recruitment of each muscle, and (c) the pattern of movement and the duration of recruitment of each muscle.

Definition of Terms

The definitions of movement patterns are provided, not because they vary from the accepted definitions, but simply to assure consistency in interpretation. The information is presented in Table 1 and Table 2 for brevity.

Hypotheses of the Study

The following hypotheses were made regarding the relationships between the EMG results and the pattern of movement:

1. The anterior deltoid would demonstrate greater anisometric EMG in the D1F pattern than in other diagonal or straight plane patterns of movement.

2. The middle deltoid would demonstrate greater anisometric EMG in the D2F pattern than in other diagonal straight plane patterns of movement.

3. The posterior deltoid would demonstrate greater anisometric EMG in the D1E pattern than in other diagonal or straight plane patterns of movement.

Table 1

Definition of Patterns for Upper Extremity Movement: Straight Plane Patterns

Pattern	Description
Flexion . . . (FLEX)	Superior movement in the sagittal plane
Extension . . (EXT)	Inferior movement in the sagittal plane
Abduction . . (ABD)	Superior movement in the frontal plane
Adduction . . (ADD)	Inferior movement in the frontal plane
Transverse Abduction . . (TABD)	Movement away from the midline in the transverse plane
Transverse Adduction . . (TADD)	Movement towards the midline in the transverse plane
Internal Rotation . . (IR)	Shoulder ABD to 90 degrees, elbow flexed to 90 degrees, inferior movement of the forearm in the sagittal plane
External Rotation . . (ER)	Shoulder ABD to 90 degrees, elbow flexed to 90 degrees, superior movement of the forearm in the sagittal plane

Table 2

Definition of Patterns for Upper Extremity Movement: Diagonal Plane Patterns

Pattern	Description
Diagonal Flexion 1 . . (D1F)	Starting position of shoulder EXT, ABD, and IR. Movement into position of FLEX, ADD, and ER
Diagonal Extension 1 . (D1E)	Starting position of shoulder FLEX, ADD, and ER. Movement into position of EXT, ABD, and IR
Diagonal Flexion 2 . . (D2F)	Starting position of shoulder EXT, ADD, and IR. Movement into position of FLEX, ABD, and ER
Diagonal Extension 2 . (D2E)	Starting position of shoulder FLEX, ABD, and ER. Movement into position of EXT, ADD, and IR

4. The pectoralis major would demonstrate greater anisometric EMG in the D2E pattern than in other diagonal or straight plane patterns of movement.

5. The diagonal PNF patterns would solicit a lesser number of the four muscles to be highly active during the movement, than would the straight plane patterns.

6. The diagonal patterns would allow the active muscles to function during a greater portion of the movement.

Delimitations of the Study

The following steps were taken to delimit this study:

1. EMG data was collected on four muscles of the shoulder: the anterior deltoid (AD); the middle deltoid (MD); the posteroir deltoid (PD); and the sternal portion of the pectoralis major (PM).

2. Maximal manual resistance was given by a physical therapist, experienced in PNF techniques.

3. Subjects were physical therapy students familiar with, but inexperienced in the techniques of PNF. They were unaware on the purpose of this study.

4. Comparisons were made between the EMG activity occurring in twelve defined patterns of movement.

Limitations of the Study

The limitations of the study included the following:

1. The markers used for landmark identification were affixed to the skin and actually represented points in space outside the body.

2. The limitations of surface electromyographic (EMG) data collection, such as noise and overflow, were recognized.

CHAPTER II

REVIEW OF LITERATURE

Proprioceptive neuromuscular facilitation (PNF) is defined as a "method of promoting or hastening the response of the neuromuscular mechanism through stimulation of the proprioceptors" (Knott & Voss, 1968). It is Herman Kabat, M.D. who is credited with the development of PNF as a treatment technique at the Kabat-Kaiser Institute from 1946 to 1951. The work of Sherrington (1940), Gellhorn (1949, 1950) and others provided the supportive evidence for Kabat's theory of central facilitation.

Kabat believed that central mechanisms are highly responsible for determining muscular response to voluntary movement (Kabat, 1950). He stated that the goal of neuromuscular reeducation should be to activate all available motor units with each contraction, since the number of active motor units is the primary determinant of the strength of muscular contraction. Kabat then reasoned that the activation of all available motor units would result in the benefits of muscular hypertrophy and ease of nervous system impulse transmission. Therefore, the primary principle of Kabat's concept of treatment was to utilize the central motor mechanisms to promote maximal excitation.

The degree of excitation of the anterior horn cells determines the number of motor units activated in a voluntary contraction. The anterior horn cells are influenced, not only by impulses from the motor cortex, but also by proprioceptive and postural reflexes, by impulses from the cerebellum, the basal ganglia, and brain stem, and by spinal reflexes (Kabat, 1952). It is the sum stimulus from all of these areas that determines the level of the resulting response. The key to PNF is the use of proprioceptive facilitation to maximize excitation of the motor units.

Three of the primary methods used for facilitation are maximal resistance, mass movement patterns and stretch. It was Gellhorn (1949) who, from her research on monkeys, provided the support for using resistance. She demonstrated that a fixed joint provided increased tension within a muscle as compared to the tension produced in a free moving joint. She explained that this increased tension provides increased proprioceptive stimuli and therefore results in increased motor unit firing.

She also examined cortical representation of movement, again on monkeys (Gellhorn, 1950). Using electrical stimulation of the motor cortex, she found movement to occur as the response of groups of muscles which were functionally interrelated, or synergistic. She believed that this multiplicity of cortical representation of movements provides the basis of coordinated movements.

With Johnson (Gellhorn & Johnson, 1950), she demonstrated irradiation. This occurs as the result of a strong stimulus, such as maximal resistance, and is defined as the spread of excitation in the central nervous system, causing the contraction of synergistic muscles in a specific pattern. The EMG results demonstrated, not only the increased activity in functionally related muscles, but also the decreased activity in the antagonistic muscles. PNF treatment techniques utilize the selection of irradiation patterns so that maximal resistance to a stronger movement acts as a source of facilitation for weaker associated movements.

This was demonstrated in a study by Partridge (1954) using a subject diagnosed as having poliomyelitis. The subject had a very weak anterior tibialis muscle which was capable of eliciting some EMG activity with a maximal voluntary contraction, but was incapable of initiating ankle movement. Giving resistance to the hip flexors on the same side reflexivly induced EMG activity within the anterior tibialis which was greater than that achieved with a maximal voluntary effort. It is the maximal resistance which provides the irradiation.

Kabat (1950) stated that mass movement patterns should be spiral and diagonal in nature. Knott and Voss (1968) further defined the details of PNF as a treatment technique and selected patterns consistent with those patterns of movement seen in sports and work activities. The patterns are also consistent with the spiral and rotary characteristics of the muscles from origin to insertion, and the structural characteristics of the individual muscles. Each pattern is made up of three components: flexion or extension, abduction or adduction, and rotation. Knott and Voss (1968) claimed that these patterns of spiral and diagonal movement provide for the optimal contraction of the major muscles involved. That is, the muscles are allowed to contract from their completely lengthened state to their completely shortened state.

Stretch was identified earlier in this paper as a primary tool in PNF application. The starting position for movement in a pattern is one in which the muscles involved are placed in their lengthened state. A quick stretch is also often manually applied at the initiation of motion for the benefit of the facilitation of strength and quickness of response, and of the effect on synergistic muscles and allied reflexes through immediate induction (Knott & Voss, 1968).

Hellebrandt, Waterland, and others provided research on normal human subjects to support the concept of irradiation (Hellebrandt, Houtz, Partridge & Walters, 1956; Hellebrandt & Waterland, 1962; Hellebrandt, 1963; Waterland & Munson, 1964;

Waterland & Hellebrandt, 1964; Waterland, 1967). They showed that maximal effort in isolated muscle groups results in patterned recruitment of muscles on the same side of the body, and also electrical activity in muscles on the opposite side of the body. To this point, patterns of movement were being quantified as responses, not as a means of facilitation.

In 1972, Snyder and Forward presented results looking specifically at the effect of different patterns of movement on the muscles acting on the lower extremity. They used EMG to compare the motor unit activity of the vastus medialis, the rectus femoris, the gluteus maximus, the medial hamstring group, and the adductors. The patterns of knee movement used were: sagittal flexion; sagittal extension; diagonal flexion with abduction or adduction and rotation of the hip; and diagonal extension with abduction or adduction and rotation of the hip. Hip flexion was maintained at 90 degrees. All motion was performed without resistance. Their results showed the muscles of interest to be less active in the diagonal patterns (with the exception of the adductors). Their conclusion, then, was that the assumption that diagonal movement provides greater motor unit activity lacks justification (Snyder & Forward, 1972). It should be noted, however, that the hip was not allowed to move into flexion or extension and thus the total pattern was not performed. Also, the lack of resistance might have contributed to the fact that the diagonal movement failed to produce greater muscle activity.

Ferdinand (1979) used both indwelling and surface electrodes on the anterior, middle, and posterior deltoid muscles of eleven normal subjects to confirm the theory that muscles will have greater motor unit activity in their optimal PNF pattern of movement, as defined by Knott and Voss (1968), than in other PNF patterns or in sagittal plane patterns of movement. The results tended to support the concept that muscles do have optimal PNF patterns for motor unit recruitment. The analysis also demonstrated that the motor unit activity of a normal muscle was not significantly different during an isometric contraction in the shortened range of its optimal PNF patterns and during a similar contraction in a sagittal plane. Comparison of the EMG values from the two types of electrodes supported surface electrodes as being suitable for that type of study. The conclusions drawn from the results of that study are limited by the fact that analysis was based solely on isometric contractions. The authors elected not to analyze anisometric performance of the patterns due to their inability to control for speed of movement.

Sullivan and Portney (1980) published related research providing support of the optimal patterns for upper extremity (UE) muscles. EMG analysis was performed on 29 normal adult subjects. The muscles involved were the anterior, middle and posterior deltoids, and the sternal portion of the pectoralis major. Although stating the lack of control for speed of movement, the authors analyzed the EMG activity occurring during the four defined UE patterns, performed against manual resistance. Their results supported the concept of optimal patterns, showing the anterior deltoid to be most active during shoulder flexion, adduction, and external rotation; the middle deltoid most active during a pattern of shoulder flexion, abduction, and external rotation; the posterior deltoid most active with shoulder extension, abduction, and internal rotation; and the pectoralis major to be most active during a pattern of shoulder extension, adduction, and internal rotation. Thus, these authors provided support for PNF patterns in isotonic movements, with the limitation of lack of control for speed. However, they failed to provide a comparison of the motor unit activity in isotonic PNF patterns of movement and that of sagittal plane patterns of movement. Considering that resistive exercise is most often performed with movement, and not isometrically, this aspect of PNF needs further research.

There has been some research on the training effects of using UE PNF patterns. Surberg (1977) used three groups and tested reaction time, response time and movement times in a diagonal pattern. Each group trained for six weeks, three times per week. One group utilized weight training, one used ball throwing, and the third received manually resisted PNF. The results showed the group which trained in PNF to have improved response and movement time in performing a PNF type movement. Considering specificity of exercise, these results are not unexpected, and unfortunately, are limited in application.

A more recent study by Nelson, Chambers, McGown and Penrose (1986) utilized measurements of elbow and knee strength, as measured using a CYBEX II isokinetic dynamometer (Lumex Inc., Ronkonkoma, NY), throwing distance, and vertical jump height, to compare the training benefits from weight training and PNF. Three groups; weight training, PNF, and control, were tested before and after eight weeks of training three days per week. The PNF group demonstrated the greatest gains in strength and performance, indicating that PNF might be superior to weight training, not only for rehabilitation, but also for athletic conditioning. From the results of their study, however, it is impossible to say that it is the pattern of movement which makes PNF more beneficial. The possibility exists that manual resistance through the full range of motion (ROM) in a sagittal plane of movement might show equivalent gains in performance. Also, application of their conclusions to the hip or shoulder without further support seems inappropriate considering the increased complexity of the more proximal joints and their muscular interaction.

PNF, originally developed as a rehabilitation tool to be used with those with neurological impairment, is widely accepted as a means of developing strength in those who are not neurologically involved. While the use of resistance and stretch, and their effects on muscular recruitment, have been well documented, the movement patterns have not. If PNF movement patterns are to be claimed as superior to sagittal plane movement in exercise, the differences in motor unit activity between the two needs to be quantified.

CHAPTER III

PROCEDURES

The purpose of this study was to compare the EMG data collected during selected, resisted patterns of shoulder motion. This chapter presents the procedures for collection and analysis of the data.

Subjects

Thirteen physical therapy students familiar with, but inexperienced in the techniques of PNF were used as subjects. They were right-handed females with no history of injury, or known diagnosis which would involve UE function. Only female subjects were analyzed, to maintain homogeneity, and to assure the tester's ability to provide maximal resistance.

Instrumentation

Data collection involved the use of the VICON system (Oxford Metrics, Ltd., Tampa, FL) of determining 3D coordinates in space. This system uses cameras which both emit and detect reflected infrared light. These are interfaced with a DEC PDP-11 computer (Digital Equipment Corporation, Maynard, MA).

Each camera views each marker in only two dimensions (2D). Appendix A provides further detail on the transformation of video signals into 2D coordinates.

When using the VICON system, the X, Y and Z axes, and the point of origin must be established. Once this was done, the location of each camera was measured in each plane. This

The computations used in calibration are presented in Appendix B. Each data capture, which was performed at the control of the operator, was initiated by the push of a button, and involved calculation of the 3D location of reflective markers placed on a subject at rates up to 50 Hz, and for periods of time limited only by the storage capabilities of the computer. The 3D coordinates were determined by the methods defined in Appendix B. These coordinates actually represented the centroids (3D centers) of the markers.

The probability of error due to lens distortion, electronic image drift, and non-linearity of the scan were recognized (Whittle, 1982). The calibration process allowed for the image, and vertical and horizontal scan distortion of each camera to be computed and, therefore, eliminated from the following computations of marker locations. Accuracy is claimed to be better than 0.15 percent of the largest dimension of the experimental volume (VICON User Guide, 1985). With the largest dimension of this study approximating 2 meters, the maximum error should be less than 3.0 mm.

Vicon EMG

The VICON system also allowed for synchronized integration of input from four EMG surface electrodes. Each electrode consisted of three leads: a negative; a positive; and a ground. The data capture for EMG occured simultaneously with that of marker data.

An EMG arises from two distinct electrical activities within the body. One, the signal transmission in motor nerves, and two, the conduction of the electrical signal through the body of the contracting muscle. EMG is made up of thousands of individual electrical pulses, known as "action potentials." Each of these is a part of the series of pulses sent by the peripheral nervous system to create the contraction of individual muscle fibers (Basmajian & DeLuca, 1985).

The contractile force in each fiber is controlled by the rate of pulse transmission. The overall force in a muscle is determined by the number of fibers active. Motor control is, then, achieved as the combined effects of action potential rate and proportion of fibers active. Muscle force increases as the action potential rate and proportion of fibers active increases. These two components of muscular control also

Temporal and spatial integration tends to average, or smooth, the effects of the random timing and distribution of individual action potentials within a muscle. This smoothing is much more significant in surface recordings than in needle recordings (Basmajian & DeLuca, 1985).

There were three primary components to the VICON EMG subsystem: amplifiers (HDX-82) and electrodes; a subject-borne preprocessor; and a power supply and safety isolation. The amplifiers were designed to compensate for the poor conductive properties of skin, so that skin preparation was greatly simplified. Most importantly, it amplified the EMG by a factor of 1,000 times (VICON User Guide, 1985).

Because the larger the bandwidth, the larger the susceptibility to interference, the bandwidth was reduced in the subject-borne preprocessor, as close as possible to the site of measurement. The bandwidth of EMG measurement was 1,600 Hz. The preprocessor extracted the components within a frequency band from zero to 25 Hz using low-pass filtering (Usui & Amidror, 1982). The VICON User Guide (1985) suggests that the majority of surface EMG recordings lie between 10 and 100 Hz, and that preprocessing down to the lower frequency band virtually eliminates the problem of distinguishing noise from the signal.

The preprocessing signal was then sent, via cable, to the Interface Module. Analogue-to-digital conversion allowed the data to be stored within the PDP-11. This system of EMG signal transmission is claimed to be virtually free from interference for three reasons. One, the signal voltages are an amplification of the original EMG by 1,000 times. Secondly, the signal bandwidth is a reduction of the original EMG by 60 times. And thirdly, the cable is insulated against external noise, and is of low electrical impedence (VICON User Guide, 1985).

The VICON EMG Interface Module had fixed gain and bandwidth. The reasons given for this are as follows: the system is pre-calibrated with guaranteed accuracy; the system signal-to-noise ratio is so high that quality data can be collected without changes of gain even in the smallest and largest of signals; and, the VICON software allows for variation in the scaling for display (VICON User Guide, 1985).

Testing Procedures

All testing took place over two one week periods in the Motion Analysis Laboratory of the Oklahoma City Veterans Administration Hospital. The X, Y, and Z axes, and the origin were defined within the laboratory. Five cameras were set up and calibrated in the laboratory prior to the arrival of subjects. Figure 1 shows the placement of the subject and cameras relative to the laboratory axes.

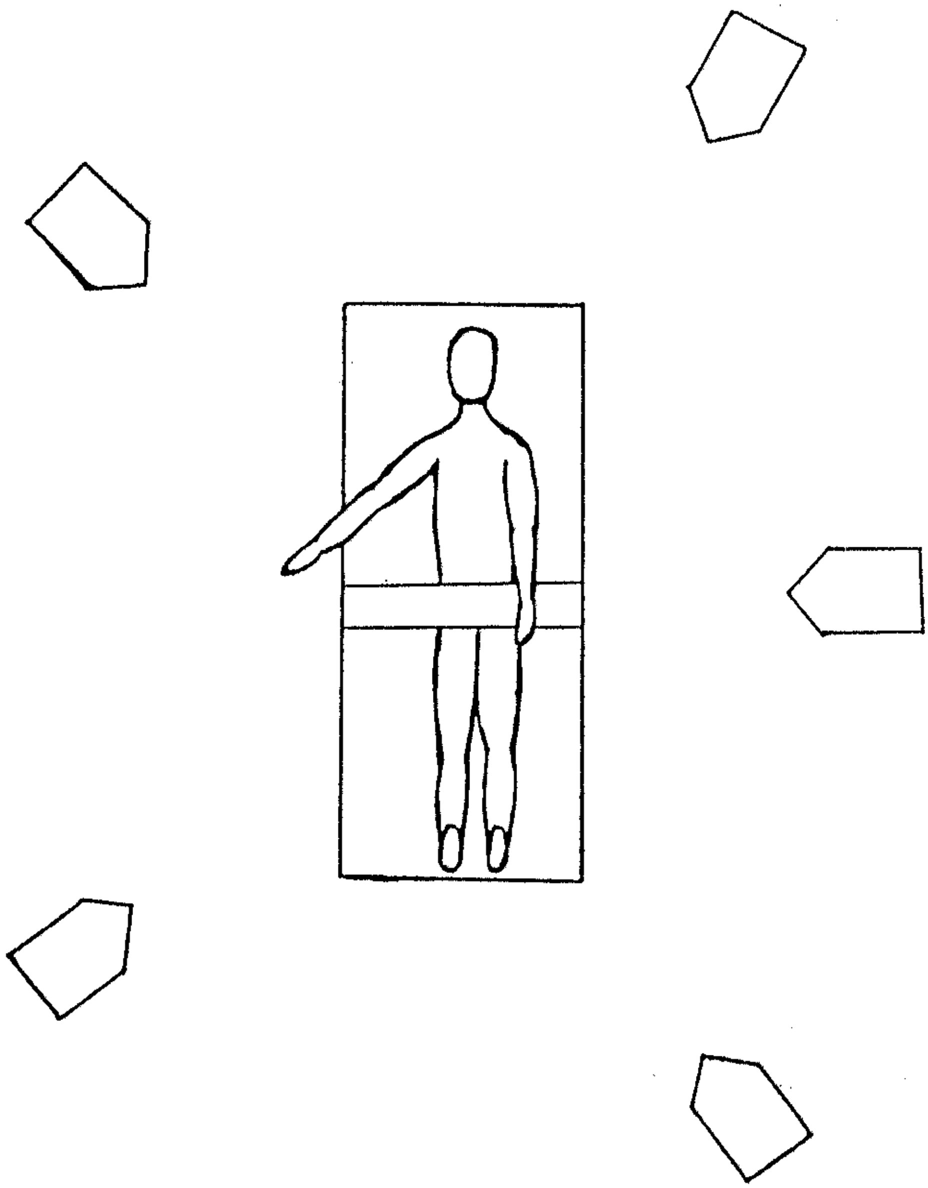


Figure 1. Camera Placement and Subject Positioning.

The muscles of interest were the anterior deltoid (AD), the middle deltoid (MD), the posterior deltoid (PD), and the sternal portion of the pectoralis major (PM). These muscles were selected because of their ability to function in several different directions of movement (Sheving & Pauly, 1959). The work of Inman, Saunders, and Abbott (1944) and others (Yamshon, 1949; Sigerseth & McCloy, 1956), supports the AD, MD, PD, and PM as being less specific in action than other shoulder muscles.

Surface electrodes were placed over the muscle belly of each of these four muscles. The shoulder area was exposed and cleansed with alcohol (VICON User Guide, 1985). The electrodes, filled with conductive gel, were applied with tape along the length of the muscle belly. The positive and negative leads were within six centimeters of each other. The ground leads were placed away from the active muscles (VICON User Guide, 1985; Basmajian & DeLuca, 1985).

Each subject was positioned supine, on a treatment table, with the legs extended. This treatment table was parallel to the X axis. An egg-crate mattress, which had been cut out in the area of the right scapula, was placed between the subject and the treatment table to allow free movement of the scapula. The pelvis was stabilized with a strap across the ASIS. The preprocessor unit was placed on the table, above the subject's right shoulder. All electrode cables were secured to the subject's arm.

Four reflective limb markers were used to determine the right shoulder movement pattern and velocity. The locations of these markers were (a) the insertion of the MD, (b) the lateral humeral epicondyle, (c) the medial humeral epicondyle, and (d) the dorsal wrist at the base of the third metacarpal. These positions all refer to the right side of the subject's body. Figure 2 illustrates marker location.

Prior to testing, the twelve patterns to be performed were demonstrated to the subject. The subject was allowed, then, to warmup by performing those movements actively, without resistance, five times each.

Subjects were tested individually, with all trials performed consecutively. Each subject performed six trials, each involving two of the twelve patterns defined in Table 1 and 2. The order of the trials was counterbalanced between subjects to disallow for the effects of learning or fatique.

Table 1, presented in Chapter I, provides the patterns of movement most frequently used to define shoulder movement. These involve movement in one primary plane. Elbow flexion/ extension was not allowed to occur during these patterns of movement.

Table 2 (Chapter I) provides the diagonal patterns of movement defined by Knott & Voss (1968). These patterns

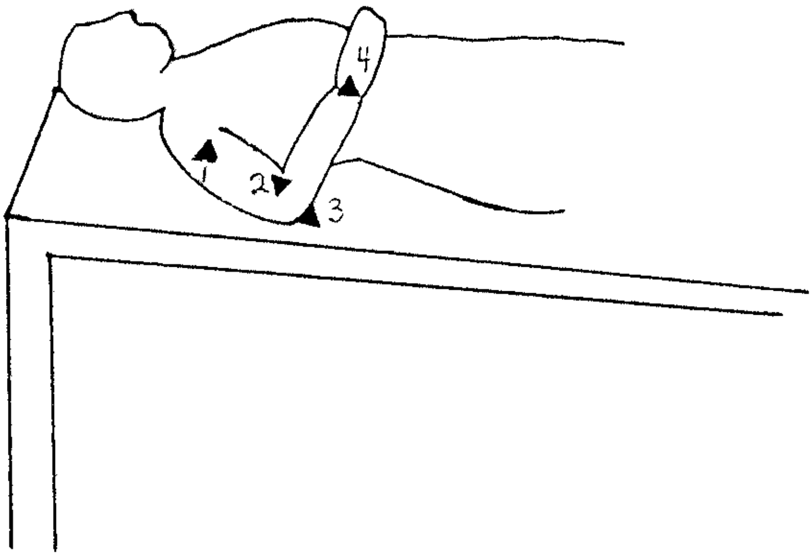


Figure 2. Location of Reflective Markers.

involve movement in all three of the primary planes. Elbow flexion and extension were allowed to occur according to PNF pattern definition.

Each trial consisted of three repetitions of paired patterns of movement. These reciprocal pairs are listed in Table 3. The pairing of patterns was used to simplify testing and reduce fatigue (Knott & Voss, 1968). Prior to collection of data, the subject was taken passively through the range of motion for the desired pattern.

Table 3

Upper Extremity Reciprocal Patterns

Agonist	Antagonist
FLEX	EXT
ABD	ADD
IR	ER
TABD	TADD
D1F	D1E
D2F	D2E

The initial movement of each pattern was preceded by an isometric contraction in the lengthened position. This was to prevent inconsistencies in pre-stretch prior to movement (Komi, 1984). Each pattern was completed with another isometric contraction at the far end of the range of motion. This was to encourage full muscular effort throughout the pattern.

Each pattern within the trial was performed three times. An isometric contraction separated each of the patterns of movement. The third repetition of each pattern was used for analysis. Between trials, the subject was allowed to rest, supine, for two minutes.

The resistance was maximal manual resistance applied by a physical therapist experienced in the techniques of PNF. Maximal resistance is defined as the greatest resistance possible which still allows for continued movement through the entire pattern. This "near isometric" contraction was utilized to maximize motor unit recruitment.

The same therapist provided resistance to all subjects, all trials. The placement of the therapist's hands for application of the resistance was as defined by Knott & Voss (1968). Hand placement was such that, for each pattern, one of the therapist's hands was on the subject's hand, and the other on the distal upper arm, so that resistance was provided opposite to the desired direction of movement. This method of resistance was selected because it was not dependent upon gravity, it allowed for 3D movement, and it allowed for the resistance to accommodate for the changes in the muscles' ability to generate force.

Kinematic Data Acquisition

From the 3D coordinates of the reflective markers, four joint angles of the shoulder were determined; FLEX/EXT, ABD/ADD, IR/ER, and TABD/TADD. Because the subjects were positioned horizontal and parallel to the X axis, and remained in this position throughout all trials, the angles of FLEX/EXT, ABD/ADD, IR/ER, and TABD/TADD for the straight plane movement patterns could be presented as projected in the laboratory planes. The X axis was used as the vector representing the longitudinal axis of the body. This assumed that the laboratory planes adequately represented the anatomical planes. Figure 3 illustrates the relationship between the laboratory and anatomical planes.

Because of the complexity of movement possible by the humerus at the shoulder joint, three landmarks associated with the humerus were used to define its position (Fig. 2). These were; the insertion of the MD (point 1), and the lateral and medial humeral epicondyles (points 2 and 3, respectively).

The marker on the wrist was used for planar IR/ER angle definition. It was also used to aid in visualizing subject position and identification of the markers as represented by each of the cameras.

To calculate projected angles, vectors were defined by the X, Y, and Z coordinates of the two markers associated

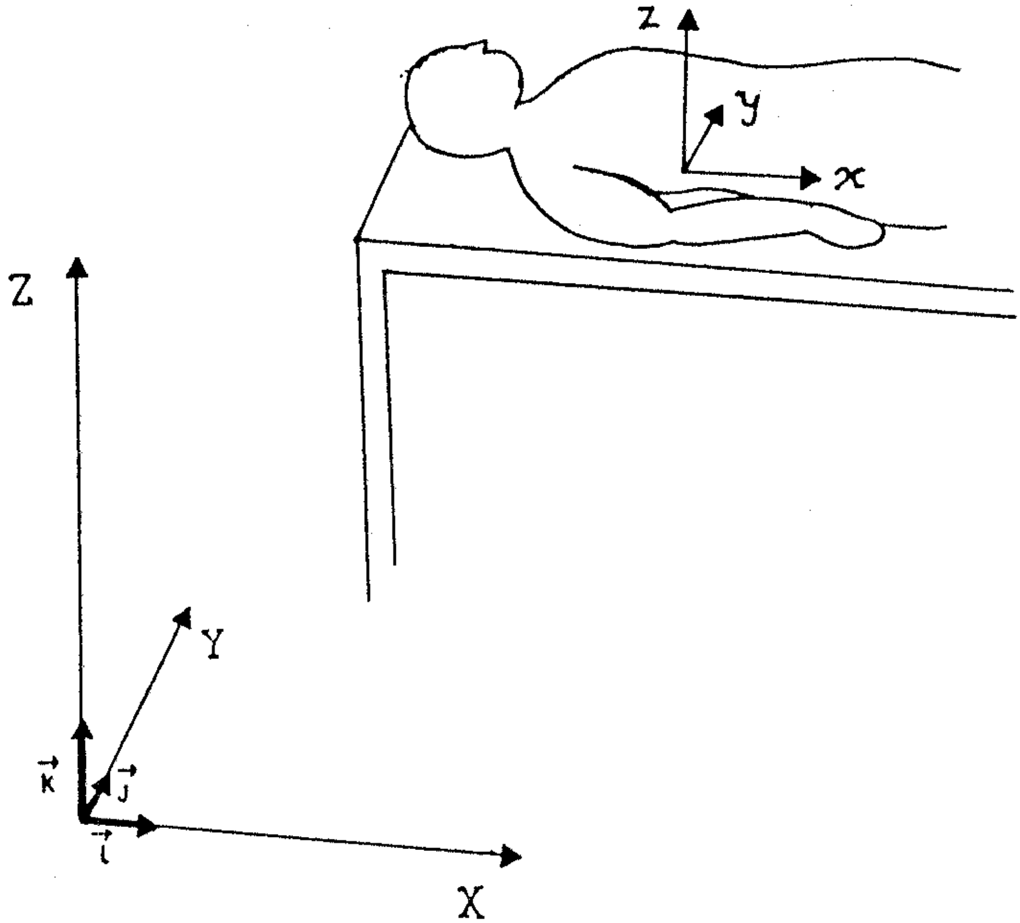


Figure 3. Laboratory (XYZ) and anatomical (xyz) axes.

with each of the segments. The upper arm segment, vector $\underset{\sim}{S_a}$, was defined by markers 1 and 2 as,

$$\underset{\sim}{S_a} = (x2 - x1)\underset{\sim}{i} + (y2 - y1)\underset{\sim}{j} + (z2 - z1)\underset{\sim}{k}, \tag{1}$$

where $\underset{\sim}{i}$, $\underset{\sim}{j}$, and $\underset{\sim}{k}$, are the unit vectors in the X, Y and Z directions, respectively. The epicondyle segment, vector $\underset{\sim}{S_e}$, was defined by markers 2 and 3 as,

$$\underset{\sim}{S_e} = (x3 - x2)\underset{\sim}{i} + (y3 - y2)\underset{\sim}{j} + (z3 - z2)\underset{\sim}{k}. \tag{2}$$

The lower arm segment, vector $\underset{\sim}{S_l}$, was defined by markers 3 and 4 as,

$$\underset{\sim}{S_l} = (x4 - x3)\underset{\sim}{i} + (y4 - y3)\underset{\sim}{j} + (z4 - z3)\underset{\sim}{k}. \tag{3}$$

Although the body should have remained constant in position within the XYZ reference frame, the humerus did not. To be able to define motion occuring in relationship to the humerus, the position of the humerus required further definition. In effect, the humerus was given its own reference frame.

Using the two vectors previously defined, $\underset{\sim}{S_a}$ and $\underset{\sim}{S_e}$, a reference frame for the humerus was developed for each individual output frame. To establish this reference frame, the initial step was to define X' along $\underset{\sim}{S_a}$, and $\underset{\sim}{i}'$ as the unit vector in the X' direction (see Figure 4),

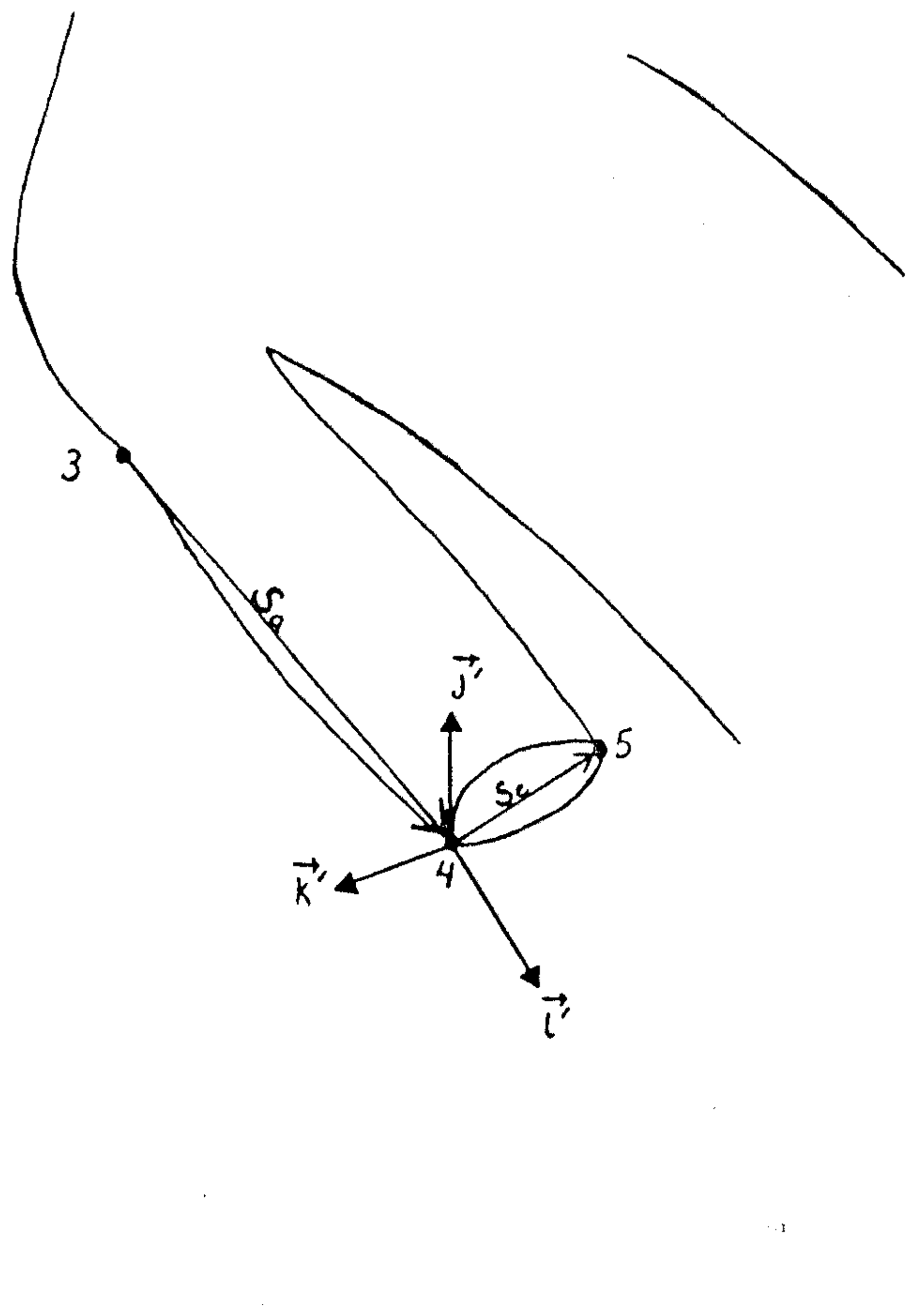


Figure 4. Determination of the humeral reference frame.

$$\underset{\sim}{i}' = \frac{\underset{\sim}{S_a}}{S_a} \tag{4}$$

where S_a is the magnitude of the vector $\underset{\sim}{S_a}$.

The unit vector, $\underset{\sim}{j}'$, in the Y' direction was then defined as the cross product of $\underset{\sim}{i}'$ and the unit vector in the direction of the epicondyle vector, $\underset{\sim}{S_e}$,

$$\underset{\sim}{j}' = \underset{\sim}{i}' \times \frac{\underset{\sim}{S_e}}{S_e} \tag{5}$$

where S_e is the magnitude of the vector $\underset{\sim}{S_e}$. Figure 4 shows this vector, $\underset{\sim}{j}'$, to be perpendicular to the plane formed by the initial two vectors, $\underset{\sim}{S_a}$ and $\underset{\sim}{S_e}$.

Figure 5 shows the relationship between the humeral reference frame, X'Y'Z', and the laboratory axes, XYZ. The unit vector in the Z' direction, $\underset{\sim}{k}'$, was then defined by the cross product of $\underset{\sim}{i}'$ and $\underset{\sim}{j}'$ as,

$$\underset{\sim}{k}' = \underset{\sim}{i}' \times \underset{\sim}{j}'. \tag{6}$$

To find the angle of ABD/ADD of the shoulder, the unit vector describing the long axis of the upper arm, $\underset{\sim}{i}'$, was projected into the XY plane. Figure 6 illustrates this projection. The projected vector is given as $\underset{\sim}{P_a}$.

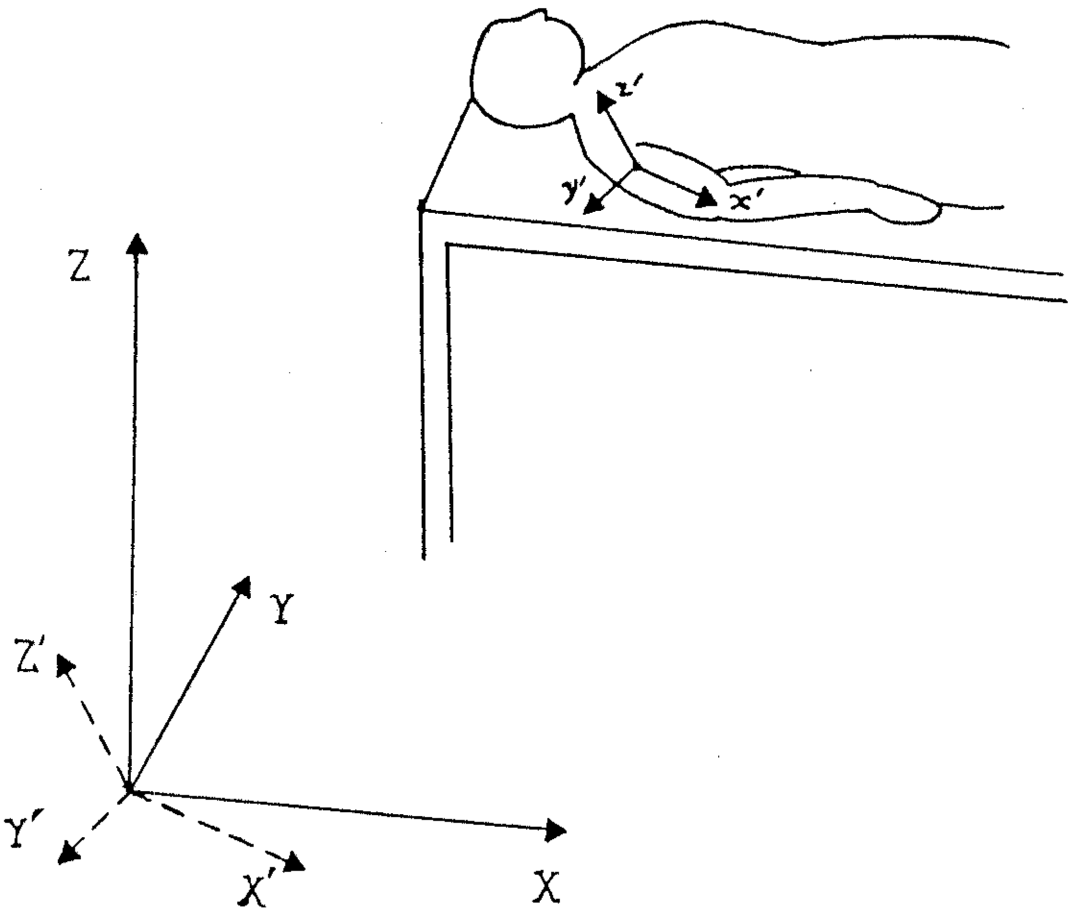
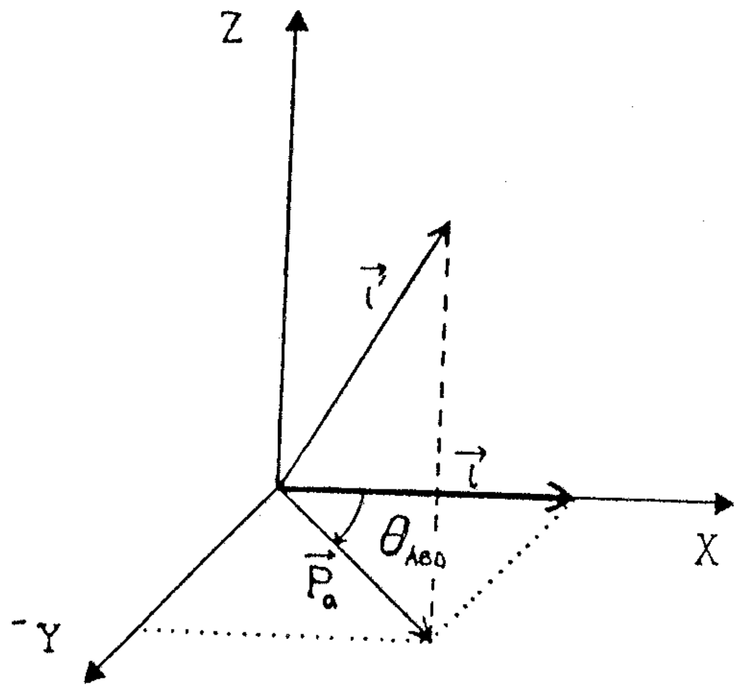


Figure 5. Humeral reference frame relative to the laboratory axes.



<u>Figure 6</u>. Projection of the upper arm segment into the XY plane for determination of the ABD/ADD angle.

The angle of this segment relative to the X axis was then calculated as,

$$\theta ABD = \cos^{-1} \frac{\tilde{P}_a \cdot i}{P_a} \qquad (7)$$

where P_a is the magnitude of the vector $\tilde{P}_a$.

Looking at Figure 7, the upper arm long axis is again represented as i'. For finding the shoulder angle of FLEX/EXT, the projection of this segment was made into the XZ plane. $\tilde{P}_f$ represents the projection of the upper arm segment.

The determination of the upper arm angle relative to the X axis, in the XZ plane, utilized,

$$\theta FLEX = \cos^{-1} \frac{\tilde{P}_f \cdot i}{P_f} \qquad (8)$$

where P_f is the magnitude of the vector $\tilde{P}_f$. If $\tilde{i}'$ is parallel to $\tilde{i}$, θABD or $\theta FLEX$ will equal zero.

For determining the angle of TABD/TADD, the upper arm segment, i, was projected into the YZ plane. This is shown in Figure 8 where $\tilde{P}_T$ represents the YZ projection. The TABD/TADD angle was calculated as,

$$\theta TABD = \cos^{-1} \frac{\tilde{P}_t \cdot -j}{P_T} \qquad (9)$$

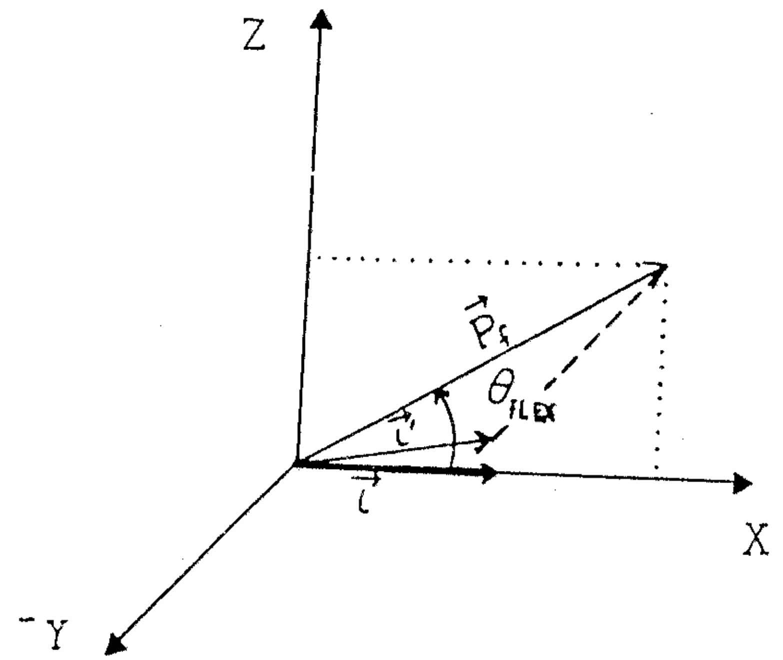


Figure 7. Projection of the upper arm segment into the XZ plane for determination of the shoulder FLEX/EXT angle.

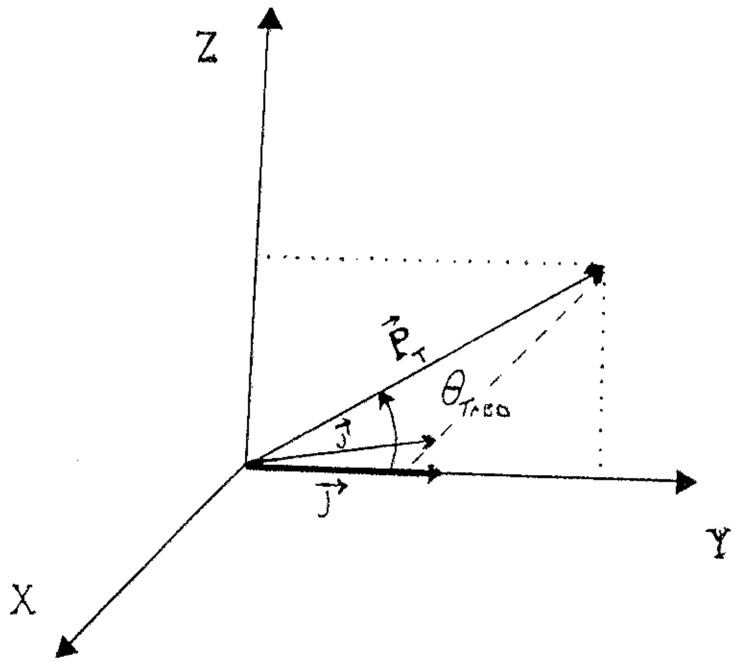


Figure 8. Projection of the upper arm segment into the YZ plane for determination of the shoulder TABD/TADD angle.

where P_T is the magnitude of $\underset{\sim}{P}_T$. If P_T is parallel to $-\underset{\sim}{j}$ then $\theta TABD$ will equal zero degrees. This same technique of calculating a projected angle, as applied to IR/ER, utilizes the vector $\underset{\sim}{S}_1$ which represents the lower arm segment. The projection of this vector into the XZ plane and the determination of its relationship to the Z axis, will give the IR/ER angle. However, this is not the method of preference, as it requires that the humerus remain parallel to the Y axis throughout the movement, and that the angle of elbow flexion/extension remain constant for all measurements. Also, depending upon the landmark chosen, supination/pronation of the lower arm can affect the measurement. In performance of PNF patterns, the entire extremity contributes to the pattern of movement. Therefore, supination/pronation and FLEX/EXT of the elbow were expected. Also, because movement out of the laboratory planes was at times extreme, the error from projection could be great. For these reasons, the method of Hinrichs (1982) was used to compute long axis rotations. The IR/ER angle was defined, using the reference frame, X'Y'Z', as the rotation of $\underset{\sim}{j}'$ about the long axis of $\underset{\sim}{i}'$.

To determine rotation, a neutral, or zero, position was first designated. This was done by preceding all trial movements with passive placement of the right upper extremity into a measured position of 90 degrees of shoulder ABD, 90 degrees of elbow FLEX, and zero degrees of IR/ER. Rotation was then defined in terms of relative movment between frames. This was done by first defining the relative movement of $\tilde{i}'$, the long axis about which rotation occurred. Using n to represent frame number, Figure 9 demonstrates finding the angle β_n, and the vector $\tilde{a}_n$. In this figure, β_n represents the angle between $\tilde{i}'_{n-1}$ and $\tilde{i}'_{n+1}$,

$$\beta_n = \sin^{-1} \quad (\tilde{i}'_{n-1} \times \tilde{i}'_{n+1}). \tag{10}$$

The unit vector $\tilde{a}_n$ represents the direction of the angular velocity,

$$\tilde{a}_n = \frac{\tilde{i}'_{n-1} \times \tilde{i}'_{n+1}}{| i'_{n-1} \times i'_{n+1} |}. \tag{11}$$

The angular velocity at frame n, $\tilde{\omega}_n$, was defined as,

$$\tilde{\omega}_n = \frac{\tilde{a}_n \ \beta_n}{2 \ \Delta t} \tag{12}$$

where Δt is the time interval between successive frames.

This, $\tilde{\omega}$, represents the angular velocity of the long axis of the humerus inherent in its FLEX/EXT and ABD/ADD movements. It represents the three dimensional angular velocity vector of the humerus disregarding any rotation about its long axis. The angular velocity of each pattern was used as a means of control in the analysis. This is detailed later in this chapter.

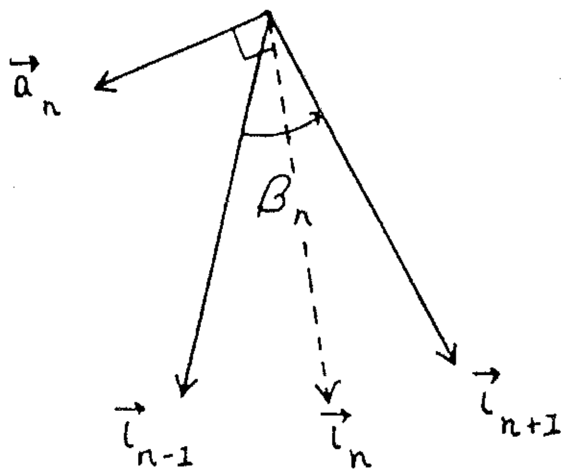


Figure 9. Definition of β_n and $\underset{\sim}{a}_n$.

To go a step further, in quantifying the rotation occurring about the long axis of the humerus, another reference frame was established to represent $\underset{\sim}{i}'_n$ as the long axis for rotation. This required a plane of rotation which was perpendicular to $\underset{\sim}{i}'_n$. The unit vector a_n had already been defined as perpendicular to $\underset{\sim}{i}'_n$. Another unit vector, $\underset{\sim}{b}_n$, was defined perpendicular to $\underset{\sim}{i}'_n$ and $\underset{\sim}{a}_n$, as,

$$\underset{\sim}{b}_n = \underset{\sim}{i}'_n \times \underset{\sim}{a}_n. \tag{13}$$

$\underset{\sim}{a}_n$ and $\underset{\sim}{b}_n$ now define a plane perpendicular to $\underset{\sim}{i}'_n$ in an IAB reference frame. Figure 10 provides illustration of this new reference frame.

Then, the position of the $\underset{\sim}{j}'$ vector was expressed, as it appeared in the IAB reference frame, in the frames n-1 and n+1. Recall that $\underset{\sim}{j}'$ was determined by the epicondyle segment, and is perpendicular to $\underset{\sim}{i}'$. Figure 11 illustrates the location of $\underset{\sim}{j}'_{n-1}$ and $\underset{\sim}{j}'_{n+1}$ in the AB plane.

To make comparisons of positions within this reference frame, $\underset{\sim}{j}'$ had to be transformed into the IAB reference frame at each given frame. This was done using the tranformation matrix $[\,\lambda\,]$,

$$\underset{\sim}{j}'' = [\,\lambda\,]\,\underset{\sim}{j}' \tag{14}$$

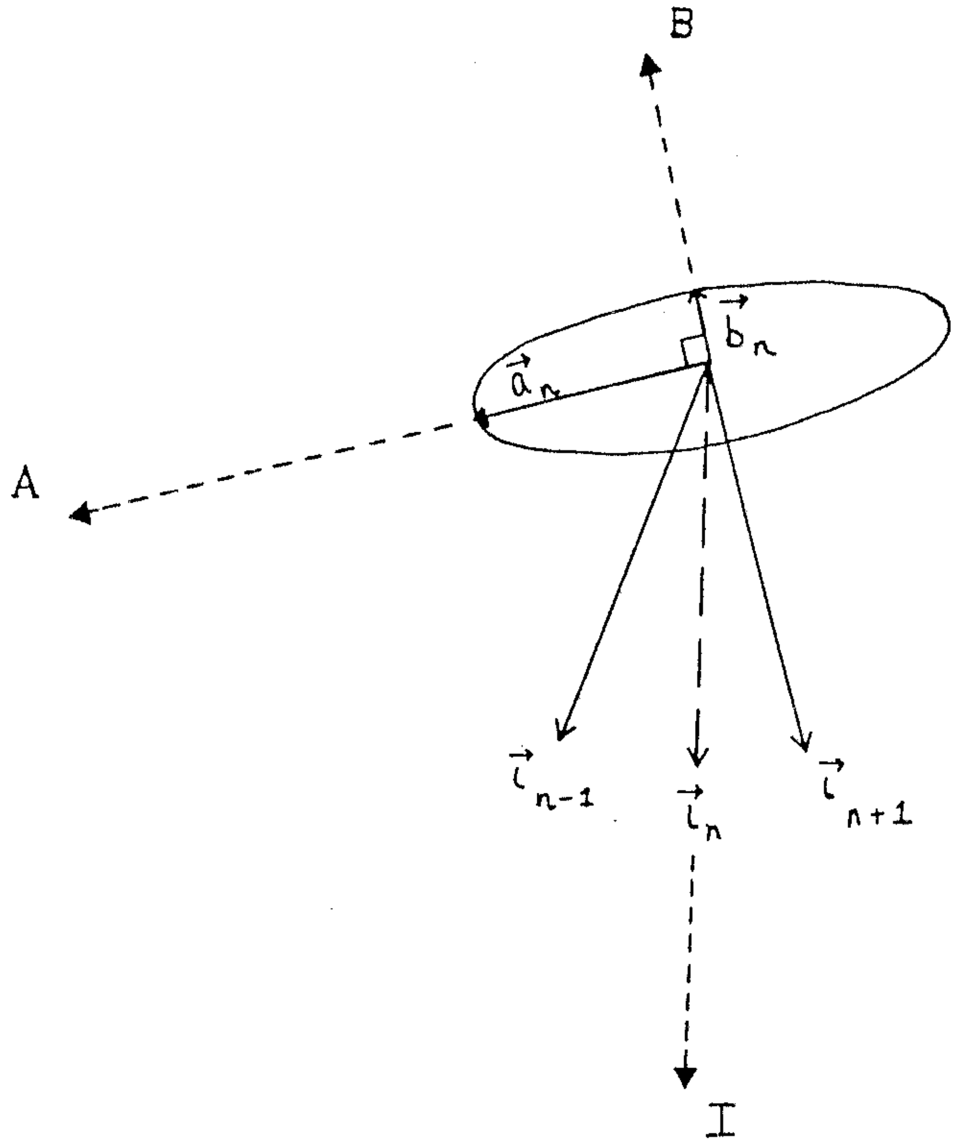


Figure 10. Rotational reference frame.

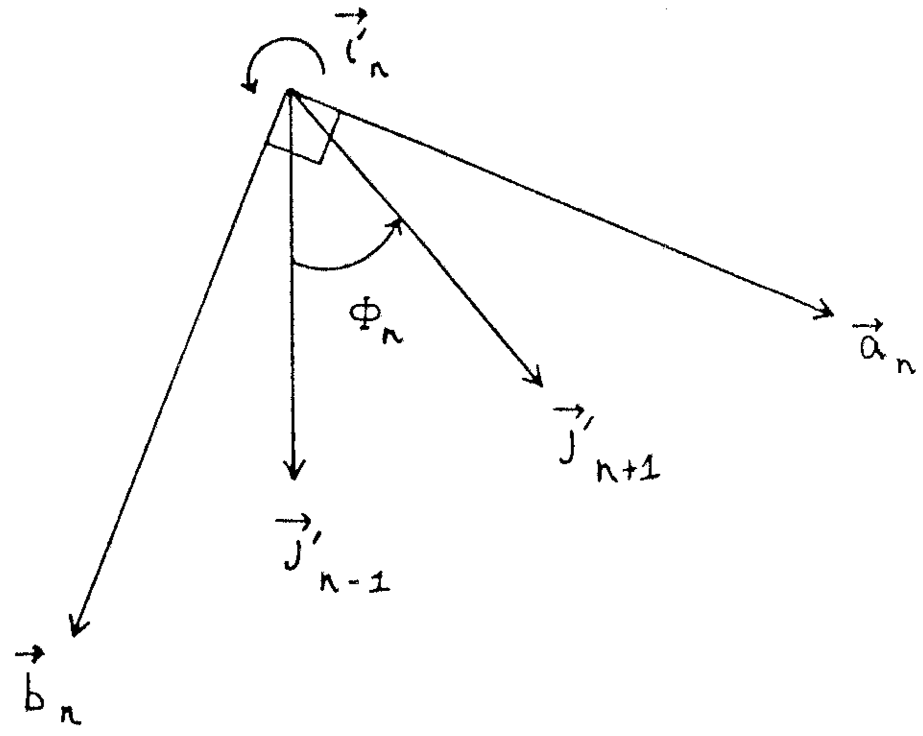


Figure 11. Illustration of $\underset{\sim}{j}'$ within the AB plane.

where,

$$[\lambda] = \begin{vmatrix} i'_{(x)} & i'_{(y)} & i'_{(z)} \\ a_{(x)} & a_{(y)} & a_{(z)} \\ b_{(x)} & b_{(y)} & b_{(z)} \end{vmatrix} . \qquad (15)$$

In this matrix, the subscripts x, y, and z refer to the x, y, or z component, respectively, of that unit vector.

The angle of IR/ER over two frames, Φ_n, was the angle of change in $\tilde{j}''$ between frames n-1 and n+1, such that

$$\Phi_n = \sin^{-1} (|\tilde{j}''_{n-1} \times \tilde{j}''_{n+1}|). \qquad (16)$$

To distinguish the angle Φ_n as positive or negative, the direction of change was determined. Another unit vector, $\tilde{d}''_n$, was defined as,

$$\tilde{d}''_n = \frac{(\tilde{j}''_{n-1} \times \tilde{j}''_{n+1})}{|j''_{n-1} \times j''_{n+1}|} \qquad (17)$$

This unit vector, $\tilde{d}''_n$, had the coordinates (0,0,1) if the rotation occurs clockwise. This would indicate IR. If the rotation was counterclockwise, ER, the coordinates were (0,0,-1). These coordinates were in the IAB reference frame. A constant, C, was set equal to the this third coordinate of $\tilde{d}''_n$ and used in defining the angular velocity of IR/ER , $\tilde{\omega}''$.

$$\underset{\sim}{\omega}''_n = \frac{C \quad \Phi_n}{2 \; \Delta t} \qquad (18)$$

Then, $\underset{\sim}{\omega}''$ represented the velocity of the rotation occurring about the humeral long axis. This, also, was used as a control in the analysis, and is discussed in more detail later in this chapter.

The IR/ER angle data, to this point, has been relative changes between frames, not actual angle values. The angular velocity was been defined for each frame, and from this, then, the IR/ER values were found. This angle, ψ, was defined as 90 degrees for the first frame, n = 1. For subsequent frames ψ_n was defined as,

$$\psi_n = \psi_{n-1} + \underset{\sim}{\omega}''_n \bullet \Delta t, \qquad (19)$$

Δt representing the change in time between frames, or .02 seconds. Following this calculation for the IR/ER angle at each frame, the IR/ER displacement occuring with performance of the pattern was found as,

$$\Delta\psi = \Phi_f - \Phi_i \qquad (20)$$

or, the difference between the final and initial positions. The average angular velocity was found as the sum of ω''_n divided by the total time of pattern performance,

$$\underset{\sim}{\omega}''_{avg} = \frac{\Sigma \; \underset{\sim}{\omega}''}{\Delta t} \qquad (21)$$

Interpretation of Kinematic Data

For each subject, each pattern, angular displacement curves were developed. These curves were normalized using interpolation, so that angular displacement was given as a function of percentage of time of pattern performance, rather than as a function of actual time. With all individual curves then being made up of an equal number of angular displacement values, a mean curve could be developed.

For the straight plane patterns, only the angle of emphasis was used. For example, from the trials of ABD/ADD only the displacement in ABD/ADD was measured. This was to prevent unrealistic data from the projection of segments near perpendicular to the plane of projection. For, as a segment nears perpendicular to the plane of projection, the projection becomes distorted, and angle values unreliable.

For the trials involving the diagonal patterns, angular displacement measurement was made for IR/ER, and for each of the three projected angles; FLEX/EXT, ABD/ADD, and TABD/TADD. Angular displacement was used as a control factor within the study. Comparisons were made between subject angular displacement values at 1, 50, and 100 percent of performance time. Those trials which deviated more than five degrees from the mean in the initial or final position, or more than ten degrees at the midrange point, were not used for

EMG analysis. This was to avoid error due to differences in the movement performed.

The displacement data also allowed the development of mean curves of angular velocity of the humerus about its joint axis, ω, for each pattern. The angular velocity curves in the appropriate direction were found for the straight plane motions. For the diagonal patterns, the angular velocity curves describing humeral displacement, $\underset{\sim}{\omega}$, and the IR/ER angular velocity values, $\underset{\sim}{\omega}''$, were found as described earlier in this chapter.

Each individual angular velocity, at 25, 50, and 75 percent of the time of pattern performance, for each pattern, was used for comparison. Those curves which deviated more than 15 degrees per second from the mean values at these points were not used for analysis. This was to minimize error due to variations in speed of movement.

EMG Data Acquisition

The EMG data were collected in arbitrary units. For comparison, they were normalized (Perry & Bekey, 1981). Comparisons were not made between muscles (Basmajian & DeLuca, 1985).

The original EMG data consisted of a unit value for each muscle, for each sampling interval. These numerical data were typically displayed in the form of envelope curves.

For each subject, normalizing involved expressing all EMG data as percentages of the maximal EMG elicited in the lengthened isometric position most appropriate for each of the four muscles (Daniels & Worthingham, 1972). For the AD, the normalizing contraction maximum (NCM) was that achieved in flexion. For the PD, it was taken from TABD, and for the MD, from ABD. The NCM for the PM was that elicited during TADD. All NCM were taken from the third lengthened state isometric contraction. This NCM EMG unit value was considered to be 100 percent. All other unit value EMG data were compared to the unit value of that muscle's NCM unit value, and were presented as a percentage of that value. All comparisons utilized the third trial.

For each subject, each muscle, and each pattern, the maximum EMG for each of the anisometric patterns was presented and expressed as a perecntage of NCM. With these percentages, a mean anisometric EMG maximum for each muscle in each pattern was determined.

A mean curve of the anisometric EMG values, expressed as a percentage of NCM, as a function of percentage of time of pattern performance, could then be constructed for each pattern, and each muscle. From these mean curves, an average EMG value was found for each condition, as the sum of the EMG percentages divided by 100 (percentage of time). Each individual curve, then, was analyzed to determine the percentage of time in which its EMG values were above the average EMG value.

Statistical Analysis of EMG Data

EMG served as the measured variable for each condition. Table 4 lists the dependent variables derived from the data and used for statistical analysis.

Table 4

Dependent Variables for Statistical Analysis

Variable	Description
Maximal anisometric EMG	maximal anisometric EMG for each pattern, for muscle
TAMA	time above the mean average EMG for each pattern, for each muscle
Number of muscles	number of muscles with above average EMG for at least 25 percent of the time of movement, for each pattern

A one-factor analysis of variance with repeated measures was used to determine if significant differences existed between levels of the independent variable, pattern, as shown in Table 5. For those variables in which significant effects appeared, a post hoc analysis using simultaneous confidence intervals was used to indicate specific condition differences. The level of significance was .01 for all tests.

Table 5

Levels of the Independent Variable: Pattern

Level	Pattern
1.	FLEX
2.	EXT
3.	ABD
4.	ADD
5.	TABD
6.	TADD
7.	IR
8.	ER
9.	D1F
10.	D1E
11.	D2F
12.	D2E

CHAPTER IV

RESULTS

The focus of this study was on the activity of four shoulder muscles during specific patterns of movement. This chapter includes first, the results of the kinematic analysis of the movements, and second, the results of the analysis of the EMG activity of the muscles during those movements.

Kinematic Data Analysis

The kinematic parameters of angular position and velocity computed for this study defined the movements performed by the subjects. These data were not used for statistical analysis, but for selection of subjects with similar performances. Kinematic analysis was complicated by the impairment of marker visability by the tester's position in providing resistance. The medial epicondyle position was found to be unreliable in angle calculation. It was often obstructed from view and required interpolation. The error associated with the interpolation, in combination with the error associated with skin movement, was considerable in attempting to use the epicondylar segment to define humeral rotation. Because of this, the projected angle of the lower arm was used to define IR/ER in the two straight plane rotation patterns.

For the diagonal patterns, IR/ER angles could not be quantified because of the inability to accurately define the humeral reference frame. Because the humerus moved in each of the three primary axes during diagonal patterns, and not in any one plane, projection error was inherent in the calculation of the FLEX/EXT, ABD/ADD, and TABD/TADD angles. The least amount of movement out of the plane, and thus the least amount of projection error, occurred with FLEX/EXT. This angle was chosen to define the diagonal movement patterns.

Of the 13 subjects tested, six had complete kinematic data and met the control conditions for the kinematic parameters. There was marker obstruction in at least one of the patterns for five of the subjects, to the degree that the data for those subjects were not eligible for analysis. Table 6 shows the mean values for the angular position criteria detailed in Chapter III. Listed for each pattern of movement is the mean angular position for the initial frame, the final frame, and the frame representing 50% of movement time. The six subjects that met the kinematic criteria fell within five degrees of the mean position in the initial and final frames, and within ten degrees at the 50% of time mark.

The ranges of motion reported here are not meant for comparison to other published range of motion values for normal subjects. The values presented in Table 6 do not necessarily represent the full range of motion available in these subjects, but rather the range of motion used for EMG analysis in this study. The angular position values for the initial and final frames for each movement pattern tend to indicate that the range used for analysis was less than the actual range available for these subjects. This difference is reflective of the performance of the isometric contraction at the beginning and end of the range of motion.

Table 6

Mean Angular Position for the Twelve Movement Patterns

	Angular Position (degrees)		
Pattern	Initial Frame	Middle Frame	Final Frame
FLEX	0	62	143
EXT	160	85	5
ABD	11	69	145
ADD	165	98	26
IR	-48	18	68
ER	65	3	-71
TABD	99	58	1
TADD	27	79	124
D1F	1	52	82
D1E	91	61	4
D2F	30	80	137
D2E	146	86	17

The second kinematic control parameter was angular velocity. The same six subjects were within 15 degrees per second of the mean angular velocity at 25, 50, and 75% of the movement time. Table 7 shows the angular velocity means for each of the twelve patterns.

Table 7

Mean Angular Velocities for the Twelve Movement Patterns

Performance Pattern	Angular Velocity (degrees per second) 25% Performance time	50% Performance time	75% time
FLEX	35	24	45
EXT	31	40	43
ABD	45	35	49
ADD	37	30	31
IR	56	50	38
ER	33	41	50
TABD	35	42	50
TADD	36	35	30
D1F	38	33	23
D1E	18	23	29
D2F	28	24	24
D2E	35	33	34

EMG Data Analysis

Only five of the six subjects whose kinematic parameters qualified them for EMG analysis were used in the statistical analysis. The EMG data for the sixth appeared nonnvalid in that many of the trials demonstrated identical maximum EMG values. All statistical EMG analysis was therefore based upon a subject number of five. This small number undoubtedly limited the probability of statistical findings.

The first EMG data presented, in Table 8, are those for the maximal EMG measured during the patterns of movement. These values were analyzed using ANOVA for repeated measures for significant variance between the different patterns at the .01 level.

Table 8 shows the mean for the maximal EMG values for the anterior deltoid during the twelve different movements. They are listed here in order of magnitude for ease of interpretation.

Table 8

AD Mean Maximal Anisometri EMG

Pattern	% Isometric EMG	± SD
ABD	150*	(± 29)
FLEX	141*	(± 21)
D1F	119	(± 37)
TADD	101	(± 82)
D2F	88	(± 36)
ADD	78	(± 81)
ER	77	(± 19)
TABD	73	(± 27)
D1E	68	(± 42)
EXT	64	(± 53)
D2E	62	(± 30)
IR	39	(± 45)

* significant at 0.01

The ANOVA did show significant variance associated with pattern ($p <= .01$). Further analysis with the Duncan Multiple Range Test for one-way analysis defined the patterns of abduction and flexion as having maximum EMG mean values which were significantly larger ($p <= .01$) than those achieved in the other patterns of movement.

In Chapter I, the hypothesis was made that of the 12 patterns tested, D1F would be shown to be associated with the largest anisometric EMG. The EMG results for the anterior deltoid failed to support this hypothesis.

There were no significant differences found between the maximum EMG values of the middle deltoid in the various patterns of movement. Table 9 shows the mean maximum values for the middle deltoid.

Table 9

MD Mean Maximal Anisometric EMG

Pattern	% Isometric EMG	± SD
FLEX	161	(± 38)
ABD	152	(± 57)
TABD	146	(± 51)
D2F	143	(± 76)
D1E	134	(± 50)
ER	122	(± 57)
D1F	97	(± 43)
TADD	88	(± 79)
ADD	94	(± 81)
EXT	67	(± 74)
D2	75	(± 48)
IR	58	(± 53)

Although no significant variance was found between the maximal EMG in the different patterns, the magnitude was, as with the

AD, greater in FLEX and ABD, two of the patterns involving elevation.

The second hypothesis stated in Chapter I was that D2F would be the pattern, between both the straight and diagonal patterns,with the greatest MD maximal anisometric EMG values. This study failed to support that hypothesis.

The posterior deltoid was the second muscle to demonstrate statistically significant differences in maximal EMG measurement between patterns. Table 10 provides the actual mean maximum anisometric EMG values for the posterior deltoid for each of the movements.

Table 10

PD Mean Maximal Anisometric EMG

Pattern	% Isometric EMG	± SD
D1E	308*	(± 92)
TABD	295*	(± 98)
D2F	270	(± 452)
ER	256	(± 112)
FLEX	256	(± 77)
IR	212	(± 172)
EXT	209	(± 64)
ABD	192	(± 55)
ADD	183	(± 44)
D2E	129	(± 57)
D1F	107	(± 31)
TADD	105	(± 73)

* significant at 0.01

The ANOVA defined this non-error variance to be significant at the 002 level. The same post-hoc test described earlier identified the EMG values from D1E and TABD as significantly greater than the mean ($\underline{p} <= .01$).

The PD was the only muscle to show a diagonal pattern to be associated with significantly higher maximal EMG. This is partial support for the hypothesis given in Chapter I which stated that greatest maximal EMG would be elicited with the D1E pattern. However, D1E was not shown to besignificantly higher than TABD.

The fourth muscle of analysis is the pectoralis major. No significant differences associated with pattern were found in the maximal EMG values. Table 11 provides the mean maximal EMG values for the pectoralis major for each pattern of movement.

The fourth hypothesis given in Chapter I stated that D2E would be the pattern with the largest EMG for the PM. Although D2E is associated with the greatest EMG values for the PM, the statistical support for that hypothesis is absent.

The second parameter used for statistical analysis was the time for which the EMG was above the mean average (TAMA). For each pattern, an average EMG was calculated for each muscle. The mean average refers to the mean of the average anisometric EMG for each of the five subjects.

Table 11

PM Mean Maximal Anisometric EMG

Pattern	% Isometric EMG	± SD
D2E	433	(± 456)
FLEX	427	(± 426)
D1F	424	(± 371)
TADD	419	(± 336)
D2F	399	(± 452)
D1E	344	(± 456)
ABD	308	(± 289)
EXT	290	(± 234)
TABD	281	(± 358)
ADD	279	(± 195)
IR	245	(± 194)
ER	212	(± 231)

Each individual set of EMG data was then compared to this mean average to determine the percentage of the movement time when the EMG was above the mean average for that muscle in that pattern. Table 12 presents the mean time above average for each muscle for each pattern.

The ANOVA failed to show any significant variance in the TAMA EMG associated with pattern at the 0.01 or the 0.05 level. The sixth hypothesis given in Chapter I predicted that the diagonal patterns would be associated with longer durations of muscle activity than the straight plane patterns. This was not the case, as the statistical analysis supported the null hypothesis.

Table 12

Mean Time Above Mean Average EMG

	performance time (%) (± SD)			
Pattern	AD	MD	PD	PM
FLEX	54 (± 27)	46 (± 36)	53 (± 31)	27 (± 42)
EXT	21 (± 44)	20 (± 45)	47 (± 30)	43 (± 44)
ABD	47 (± 17)	45 (± 44)	46 (± 35)	36 (± 40)
ADD	22 (± 44)	26 (± 42)	47 (± 24)	29 (± 42)
IR	24 (± 43)	23 (± 43)	39 (± 39)	42 (± 48)
ER	41 (± 36)	41 (± 42)	41 (± 40)	29 (± 43)
TABD	23 (± 43)	40 (± 35)	51 (± 40)	21 (± 44)
TADD	48 (± 46)	34 (± 47)	41 (± 46)	50 (± 38)
D1F	64 (± 33)	38 (± 50)	46 (± 37)	26 (± 29)
D1E	25 (± 43)	37 (± 39)	52 (± 29)	26 (± 38)
D2F	37 (± 42)	44 (± 39)	46 (± 27)	29 (± 27)
D2E	22 (± 44)	21 (± 44)	36 (± 42)	34 (± 35)

The final parameter used for statistical analylsis was the number of muscles with EMG values above the mean average for at least 25% of the time of movement. Table 13 shows the number of the four muscles of interest which were active for the desired duration. The fifth hypothesis stated in Chapter I was that the diagonal patterns would recruit a lesser number of muscles, since the primary mover was being encouraged to move in a plane more closely following the muscle's line of action. The results of this study failed to support that hypothesis. The ANOVA failed to show any significant variance in this parameter at the .01 or .05 level, and thus supported the null hypothesis.

Table 13

Number of Muscles With EMG Values Above the Mean Average EMG for 25% or More of the Time of Pattern Performance

Pattern	Number of Muscles	± SD
FLEX	2.6	(± 0.89)
EXT	1.8	(± 1.48)
ABD	2.6	(± 1.14)
ADD	1.6	(± 1.52)
IR	1.4	(± 1.14)
ER	2.2	(± 1.30)
TABD	1.6	(± 0.55)
TADD	2.4	(± 1.82)
D1F	2.6	(± 1.14)
D1E	1.8	(± 0.84)
D2F	2.2	(± 1.48)
D2E	1.4	(± 1.14)

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion

This chapter presents further discussion of the EMG results outlined in Chapter IV. An obvious detriment to the statistical analysis was the small number of subjects. The design of the study planned for a minimum of 12 subjects, with the understanding that not all would meet the kinematic criteria. Unfortunately, only the data from five subjects could be used. A review of the data previously displayed in Tables 8 through 11 shows the magnitude of muscle activity to be intuitively consistent with the patterns in which we would expect the greatest activity. However, with this small number of subjects, it was predictably difficult to establish significant variance between conditions.

There are other considerations within this study which may account for some of the lack of expected EMG findings. One obvious consideration is the use of surface electrodes. It is highly likely that as the subjects moved through the patterns, the skin movement created alteration in the relationship of the electrodes to the muscle belly. This movement may have resulted in the electrodes being moved away from the muscle belly, or being moved towards an area of greater overflow from other muscles.

Another consideration in the EMG results in this study is the fact that all patterns were performed against maximal resistance. The literature documents the effects of maximal resistance in facilitation of synergistic muscles (Hellebrandt, Houtz, Partridge, & Walters, 1956; Hellebrandt & Waterland, 1962; Hellebrandt, 1963; Waterland & Munson, 1964; Waterland & Hellebrandt, 1964; Waterland, 1967). It may be that the facilitory overflow into the secondary muscles overshadows differences related to pattern. The possible effects of skin movement and overflow were discussed also by Ferdinand (1979) in his comparison of surface and needle electrodes in shoulder EMG.

This study revealed two statistically significant differences in shoulder muscle EMG related to the pattern of movement. The first was that the patterns of ABD and FLEX were associated with greater magnitude of AD EMG activity than were the other patterns. The second was that D1E and TABD were associated with greater magnitude of PD EMG activity than were the other patterns. This chapter will discuss these findings.

The findings on the AD were not fully consistent with the findings of Ferdinand (1979) in his comparisons of diagonal and straight plane isometric data. This study found D1F to rank third, behind ABD and FLEX. D1F ranked first in his study, above ABD and FLEX, but not significantly higher. This study found the maximal EMG in ABD and FLEX, but not in D1F, to be significantly higher than in all other patterns.

In both studies, D1F is the highest ranked of the diagonal patterns. This ranking is also consistent with the findings of Sullivan and Portney (1980) in their anisometric comparisons of shoulder muscle EMG in the four diagonal patterns.

The results of this study support ABD and FLEX as being the patterns of choice in eliciting a maximal EMG from the anterior deltoid. There is no evidence that either of these two patterns would be preferable to the other.

The second significant finding was also in the analysis of maximal EMG data. The activity of the PD was found to be statistically greater in D1E and TABD than in the other patterns of movement. In comparison to the isometric results of Ferdinand (1979) the ranking of D1E and TABD is reversed, but in both cases, these two patterns were found to be significantly higher in their maximal EMG values than the other patterns. D2F was ranked third in both studies,but significantly different only for Ferdinand, and not for this study.

The results of this study again support the anisometric comparisons of diagonal patterns made by Sullivan and Portney

(1980). They found the PD maximal EMG to be statistically higher in D1E than in the other diagonal patterns. These findings suggest D1E and TABD as the movement patterns of choice for eliciting maximal EMG activity from the posterior deltoid. There is no statistical support for selecting one of these two patterns over the other.

Missing from this study is support for significant differences in MD and PM maximal EMG activity associated with pattern which were found by both Ferdinand (1979) and Sullivan and Portney (1980). However, Ferdinand made his comparisons on isometric data only, which introduces the possibility of performance differences between isometric and anisometric testing. Sullivan and Portney made their comparisons on the four diagonal patterns only, while this study utilized these same four in addition to the eight straight plane patterns. These differences between the studies, as well as the small number of subjects for this study, may account for some of the variation in results.

The parameter for time above mean average EMG (TAMA) was included in this study in an effort to broaden the understanding of muscular activity beyond the definition of maximal output. The assumption should not be made that the muscles with the largest magnitude of EMG activity will also be the muscles which are the most active throughout the movement. It is probable that a muscle may be highly recruited in initiation of a movement, and then quickly diminish in its contribution to movement as it loses its mechanical advantage, and/or as the demand placed upon it decreases. In many situations the objective of exercise is to improve muscular output throughout the full range of motion. In this case, it may be preferable to compromise intensity of contraction for a pattern which would strengthen over a greater portion of the muscle's functional length. By looking more closely at this parameter of duration of muscular effort, we can also gain insight as to the function of the muscle. For example, a muscle active through a large part of both flexion and extension is most likely acting as a stabilizer, not a primary mover.

This study found no significant differences in the TAMA between the different patterns. This lack of variance may be partially related to the factors given above, namely the small number of subjects, and the limitations of surface electrodes. For this parameter, it may also be due in part to the definition of the parameter. Each subject's EMG data was compared to the mean average EMG for that movement pattern. Because this variable of mean average EMG was based, first, upon the average EMG for each subject, and secondly, upon the group mean for this average, it was not a very definitive value to be used for individual comparisons. Alternative methods for evaluating duration of muscular effort will be discussed later in this chapter.

Since no significant variance was found between this parameter in the different patterns of movement, no attempt will be made to draw conclusions from the results. This topic of duration of muscular effort in the muscles of the shoulder warrants further investigation.

The final parameter analyzed in this study was the number of muscles which were active above the mean average EMG for at least 25% of the duration of the movement pattern. The maximal number would be four, and the minimum would be zero. Considering the limitations stated earlier, it was not surprising that statistical analysis revealed no significant difference in the number of muscles active.

Conclusions

It would be inappropriate to draw definitive conclusions from the results of this study. The results neither prove nor disprove the advantage of diagonal patterns of movement in strength training for a non-neurological population. Of the two statistically significant parameters, one supports the PNF diagonal as the pattern of choice, the second does not. The rank order of the non-significant parameters suggests the possibility of stronger results with a larger subject population. The differences in the rank order of the muscles with the greatest EMG activity, and those with the longest EMG activity, does indicate a need for further study into this aspect of muscle function.

Recommendations for Further Study

In consideration of further study involving kinematic analysis of the shoulder, another form of application of resistance may be preferable. The benefit of the manual maximal resistance is that the tester can respond to the muscular effort being generated. The resistance can be increased or decreased throughout the range of motion to adapt to the muscular torque generation abilities at any point. The obvious drawback to this form of resistance is that the tester is highly likely to obstruct the bony landmarks from the view of any cameras or other data collection system. It also has some limitation in that the subject population must be defined so that the tester will have the strength to adequately control the movement of the subjects. It is not likely that a female tester would be able to provide maximal resistance to a non-injured male population.

Isokinetic equipment is available which would adequately control for velocity at the lower speed settings. The limitations for this type of equipment are the forced fixed axis of rotation, and the poor representation of diagonal movement.

Another possibility for resistance application would be the use of a constant resistance system. There are several types of equipment available which use hydraulics, pheumatics, or weight stacks, for example, to provide a fairly consistent resistance, with some error due to gravity. However, these systems are also restricted in their ability to adequately allow diagonal movement. The exception to this would be a pulley system which does allow variation in the plane of movement. Unlike manual resistance, a constant resistance system would not be able to accomodate the changing ability of the muscles to generate torque. So, there would predictably be portions of the range of motion in which the muscles were not maximally recruited.

Another drawback with this type of resistance would be the lack of control for speed of movement. Some pretest would need to be performed to provide an estimation of each subject's ability to perform in each direction. From these pretest values, resistances would have to be selected individually for each subject so that between test and between subject velocities would be within an exceptable range.

I would recommend in future related studies, that the method of resistance application be one other than manual resistance. Although the limitations of other methods detract from the overall concepts of PNF, the differences in pattern of movement could still be established. Also, in non-neurological shoulder patients, the strength is often adequate to indicate other methods of resistance as being clinically appropriate. Research findings based upon the methods commonly used in the clinical setting might allow greater inference of the results to clinical practice. The second recommendation for further study deals with the interpretation of the EMG data. As mentioned earlier, information regarding the duration of muscular activity throughout the range of motion can be as clinically meaningful as the maximum activity achieved. I would suggest that future studies use a parameter other than time above mean average. Comparison of individual anisometric EMG data to that individual's own isometric maximum EMG would give a better indication of performance. For example, the percentage of time in which the EMG was greater than fifty percent of that individual's maximum isometric EMG, would be more descriptive of that individual's muscular effort.

APPENDIX A

VICON Marker Location Identification

The VICON system has the capabilities of collecting data from up to seven television (TV) cameras. Each camera produces a wideband (12 megahertz) video signal which contains over one quarter million defined pixels in each TV frame. The interface extracts relevant coordinate information from the signals from each camera and passes it to the computer.

Any bright points in the TV picture are identified by short pulses in the video signal. Each TV camera is connected to a Marker Detector circuit which picks out these pulses and converts then into digital timing signals. A Coordinate Generator transforms the timing pulses into crystal-controlled counts of the position of each point. The horizontal position may be resolved to one part in 300 at 50 frames per second, or one part in 600 at 25 frames per second (Smith, 1984).

These 2D digitized marker locations are transferred to the computer's disk file for storage as the Raw TV Data File. The size of this file is limited only by the disk space available.

The next step is to produce a Reduced Data File. This involves eliminating any unwanted reflection, labeling the desired points, and reducing them into sets of single coordinate paris corresponding to the centroids. This produces a 2D file with coordinates sorted by camera number, trajectory or marker number, and time or frame number (Smith, 1984).

Software then utilizes all available 2D observations to reconstruct the sequential 3D positions of all points. The details of the calibration process are supplied in Appendix B. When analysis of kinematic data is desired, a subroutine is called which calculates the 3D coordinates of the limb markers using the calibration data collected earlier (Smith, 1984).

APPENDIX B

VICON Calibration

The first steps of calibration are in reference to the horizontal plane. In other words, calibration is initially performed only in the XY plane. First, the equation of the line joining the perspective center of each camera lens to a given marker is determined. Then, the marker's position is given by the point at which the lines from the cameras intersect. This is demonstrated in Figure 12.

The TV data for calibration consists of the horizontal (U) and vertical (V) coordinates of nine calibration markers, from each of two or more cameras. The calibration program is supplied with the 3D coordinates, X, Y, and Z, of each of these markers and the cameras, as measured by the operators, based upon a designated origin.

The program then calculates the line joining each camera to each marker. Table 14 gives the explanation of symbols used in the description of the calculations. If the camera were free from distortion, and the plane of the image tube were at right angles to the X axis, there would be a linear relationship between the horizontal coordinates of the markers on the television image, and the tangents of the angles between the camera and the markers. This is demonstrated in Figure 13 where U is proportional to tan(q).

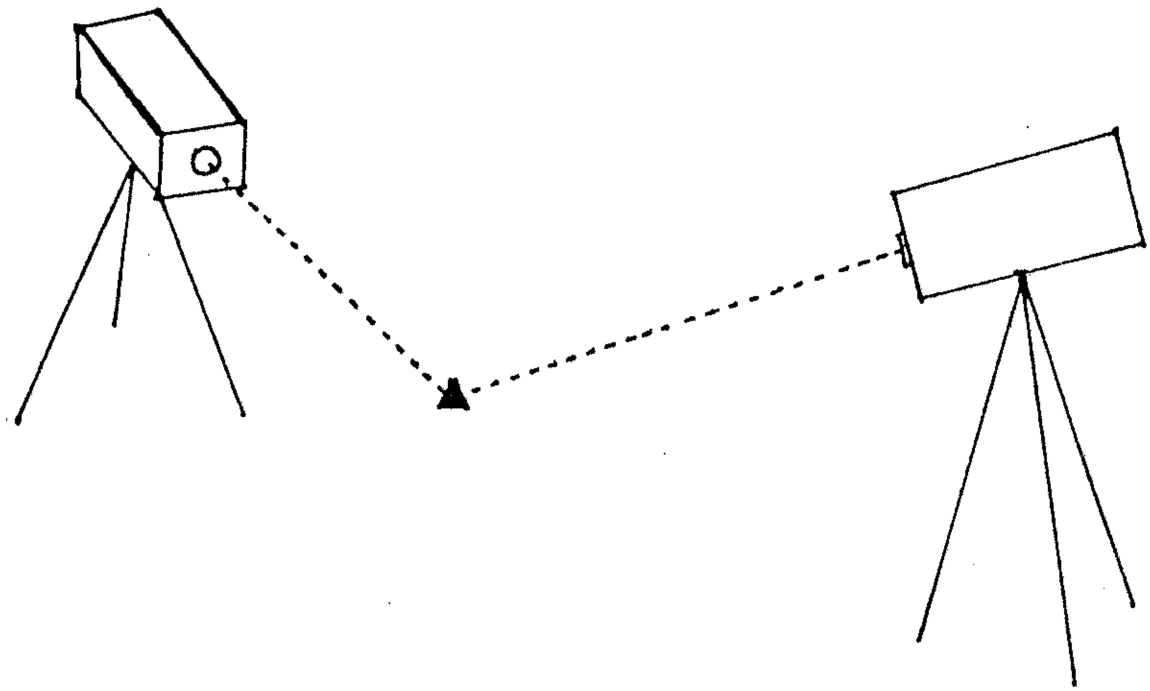


Figure 12. Marker position - as the intersection of the lines from the marker to each camera.

Because the plane of the image tube is generally rotated relative to the X axis, and because scan distortion produces an apparent further rotation of the image plane, it is necessary to add or subtract a fixed "rotation angle" from each of the camera-to-marker angles in order to obtain a linear relationship. This is demonstrated in Figure 14, where U is proportional to tan(q - r).

Table 14

Definition of Symbols

Symbol	Definition
X_m	marker coordinate
Y_m	marker coordinate
Z_m	marker coordinate
X_c	camera coordinate
Y_c	camera coordinate
Z_c	camera coorinate
U	horizontal television coordinate
V	horizontal television coordinate
r	horizontal rotation angle
r'	vertical rotation angle
q	horizontal angle between camera and marker
q'	vertical angle between camera marker
a, b, c .	constants from linear regression
d, e, f .	constants from linear regression
D	horizontal camera-to-marker distance

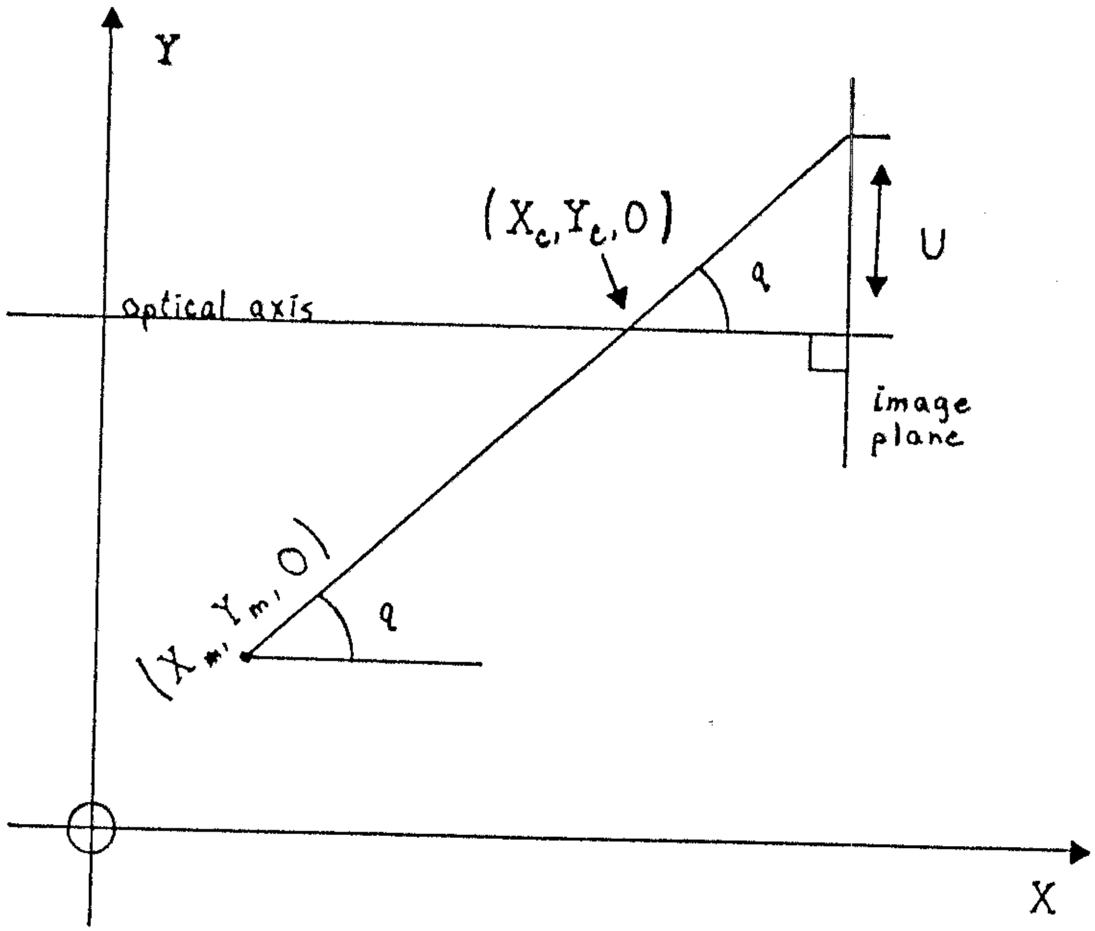


Figure 13. Horizontal calibration: relationship between U.

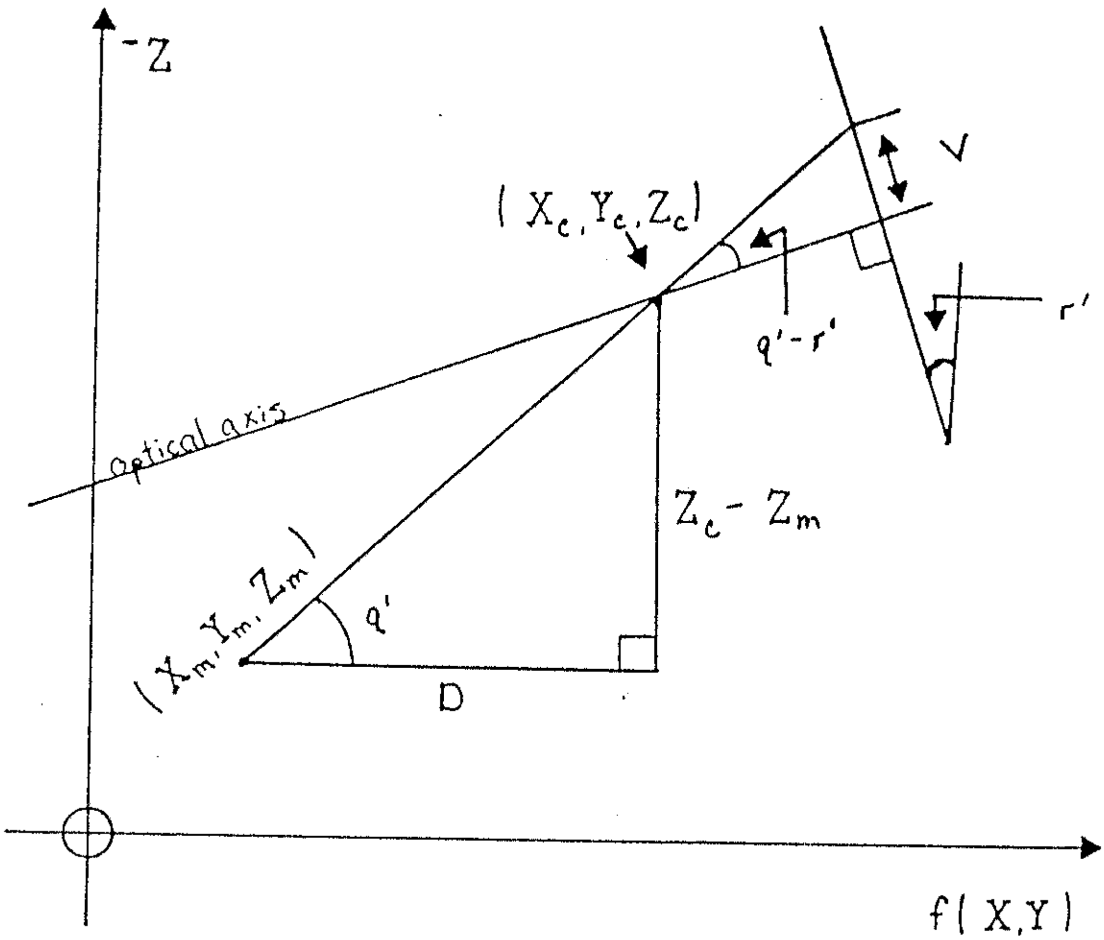


Figure 14. Horizontal calibration: relationship between U and tan(q - r).

An assumption is made for the rotation angle of each camera. The tangents are then calculated for each revised angle. These tangents are then related to the horizontal and vertical TV coordinates in a two-dimensional least squares linear regression procedure which returns constant values for a, b, and c in the equation,

$$\tan(q - r) = aU + bV + c, \tag{B1}$$

where $\tan(q - r)$ is the tangent of the camera-to-marker angle. Relating the tangents to both the horizontal and vertical coordinates prevents errors associated with the image tube not being precisely vertical or horizontal. The constants are next applied to the equation of each camera-to-marker line,

$$Y_m = Y_c - (X_c - X_m)\tan[\tan^{-1}(aU + bV + c) + r]. \tag{B2}$$

Refer again to Figure 13. This is done individually for each camera, which allows for the solution of X_m and Y_m from two equations. Once the values of X_m and Y_m are determined by equation, the calculated and measured X_m and Y_m values for all nine markers are compared, and the root-mean-square (RMS) error of the estimate is calculated. The rotation angle is then incrementaly changed for each camera, in a series of progressively smaller steps, until values have been found for all cameras which give the smallest RMS error of the estimate. A Calibration file is then formed to contain the values for the constants r, a, b, and c, for each camera.

The calibration for the vertical plane is similar to that for horizontal, but simpler because each camera is treated individually. From horizontal plane data, the X and Y coordinates of the markers are used to determine the horizontal distance of each marker to each camera. Figure 15 displays the representation of this distance, D as found by,

$$D = (X_m - X_c)^2 + (Y_m - Y_c)^2. \qquad \text{(B3)}$$

As for the horizontal calibration, the vertical TV coordinate, V, is linearly related to tan(q' - r').

The program again assumes a value for r and calculates tan(q' - r') for each of the markers. A two-dimensional least squares regression, as before, provides the constants e, f, and g in the equation

$$\tan(q' - r') = eU + fV + g. \qquad \text{(B4)}$$

The Z values for individual markers are then calculated from the equation,

$$Z_m = Z_c - D \tan[\tan^{-1}(eU + fV + g) + r']. \qquad \text{(B5)}$$

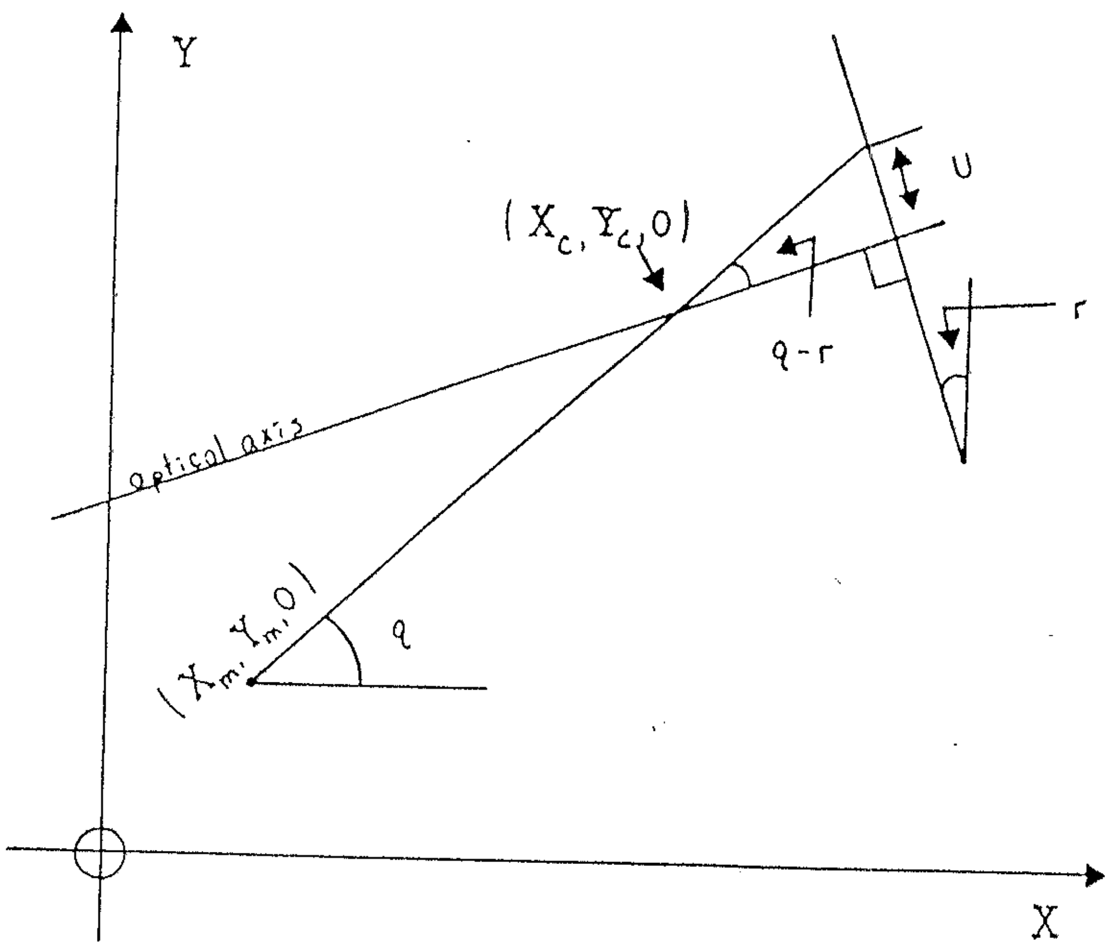


Figure 15. Vertical calibration: relationship between V and tan(q' - r').

The value of r' is again varied in a series of progressively smaller steps until the RMS difference between the actual and calculated z values is minimized. The values of r', e, f, and g are then stored in the calibration file for later use.

APPENDIX C

Table 15

Nomenclature

Symbol	Description
XYZ	Laboratory reference frame, determind by the three axes, X, Y, and Z
xyz	Anatomical reference frame, parallel to XYZ
$\underset{\sim}{i}, \underset{\sim}{j}, \underset{\sim}{k}$	Unit vectors in the directions of X, Y, and Z, respectively
X'Y'Z'	Humeral reference frame, based upon the location of markers 1, 2, and 3
$\underset{\sim}{i'}, \underset{\sim}{j'}, \underset{\sim}{k'}$	Unit vectors in the directions of X', Y', and Z',respectively
$\underset{\sim}{S}_a$	Humeral vector, defined by markers 1 and 2
$\underset{\sim}{S}_e$	Epicondyle vector, defined by markers 2 and 3
$\underset{\sim}{P}_a$	Vector representing the projection of the humeral segment long axis into the XY plane
$\underset{\sim}{P}_f$	Vector representing the projection of the humeral segment long axis into the XZ plane
$\underset{\sim}{P}_t$	Vector representing the projection of the humeral segment long axis into the YZ plane
θ_{ABD}	Angle of humeral abduction, relative to the X axis
θ_{FLEX}	Angle of humeral flexion, relative to the X axis
θ_{TABD}	Angle of humeral transverse abduction, relative to the Y axis
ß	Angle of humeral movement between frames

$\underset{\sim}{a}$ . . . . Unit vector representing normal to the plane of movement of humeral long axis between frames

$\underset{\sim}{b}$ . . . . Unit vector normal to a, and to the plane of movement of humeral long axis between frames

IAB . . . . Reference frame of the humerus, determined by i', a, and b

$\underset{\sim}{\omega}$ . . . . Angular velocity of humeral movement between frames

Φ . . . . Angle of change in the position of rotation between frames

$\underset{\sim}{d}''$ . . . . . . Unit vector in the direction of rotation

C . . . . Constant, either +1, or -1, defining rotation as IR of ER

$\underset{\sim}{\omega}''$ . . . . . . Angular velocity of rotation about the long axis of humerus, IR/ER

ψ . . . . Absolute value of IR/ER at any given frame

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