THE UNIVERSITY OF MANITOBA

A METHOD OF ELECTROMYOGRAPHIC ANALYSIS OF NORMAL AND ABNORMAL MOVEMENT IN THE SHOULDER COMPLEX

by

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ABSTRACT

The activity of the shoulder muscles, the anterior, middle and posterior fibres of deltoid, trapezius and serratus anterior was evaluated during raising and lowering the arm in the scapular plane of abduction in 30 normal subjects. In addition, the activity of the same muscles was evaluated in 21 subjects with hemiplegia and in 18 subjects with a lesion of a glenohumeral joint structure.

The evaluation procedure included an analysis of the electromyographic record of muscle activity. The electromyographic signals were obtained from all subjects by means of bipolar surface electrodes. The signals were recorded for analysis on a pen-writing oscillograph. Information on arm position was obtained from a gravity reference electrogoniometer. The electrogoniometer signal was correlated, at every 10°, with the electromyographic data to indicate the varying muscle contribution during raising and lowering the arm.

The normal subjects showed patterns of progressive activity during raising the arm, with some levelling off of activity as the limb approached the position of maximum elevation.

Descent of the arm produced a progressive decrease in electromyographic activity. Activity levels recorded during arm lowering were less than that obtained during arm raising. The mean age of the normal group was 46.2 years. The ages ranged from 10 to 88 years.

The activity patterns of the muscles of the left shoulder in 16 of the 30 normal subjects was compared with the data obtained from measurements of activity of the right shoulder muscles in the total group of normal

subjects. Analysis of this data demonstrated similar patterns of activity in the muscles of both sides.

A comparison of muscle activity seen in the 15 younger subjects of the normal group of 30 subjects was made with the 15 older subjects. The activity of the two groups was similar.

The activity of the muscles of the shoulder complex was assessed in a group of 21 hemiplegic subjects, Eleven subjects exhibited lesions on the right side and 10 exhibited lesions on the left side.

The age group of the hemiplegic subjects ranged from 28 to 73 years with a mean age of 58.4 years. The analysis of the electromyographic activity in the hemiplegic group showed trapezius and the anterior and middle fibres of deltoid exhibiting patterns of activity similar to normal. The posterior fibres of deltoid showed increased activity, and serratus anterior exhibited decreased activity. The range of movement in the hemiplegic group was less than that seen in the normal group.

In addition to the normal and hemiplegic subjects, the muscle activity was assessed in a group of 18 subjects with lesions of a gleno-humeral joint structure. The age group of these subjects ranged from 39 to 70 years with a mean age of 53.1 years. The analysis of the activity in this soft tissue lesion group showed the middle fibres of deltoid and serratus anterior exhibiting activity similar to that seen in normal subjects. Trapezius showed a slight increase in activity in lesions affecting the left side, but only at the end of the movement. The posterior and anterior fibres of deltoid exhibited increased activity, particularly during arm lowering. Subjects in the group with soft tissue lesions demonstrated limitation of shoulder movement.

The activity of the muscle groups in the 30 normal subjects was compared with the activity of the same muscles of the unaffected shoulder of 10 subjects in the group with hemiplegia and 10 in the group with soft tissue lesions. The hemiplegic group showed patterns of activity similar to that of normal subjects. Subjects with soft tissue lesions showed increased activity in the posterior fibres of deltoid. In these subjects decreased activity levels were identified in serratus anterior. Trapezius, middle and anterior fibres of deltoid showed activity similar to that of the normal group.

The range of movement in the groups with hemiplegia and soft tissue lesions was less than that seen in normals,

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CHAPTER I

INTRODUCTION

The word shoulder is used in the English language with a variety of meanings. It can mean support, and the classical reference is to Atlas who supported the world on his shoulders. In another context the word means to give personal assistance, as is illustrated by the phrase 'shoulder to the wheel'. In anatomical terminology the term is applied to the mechanism by which the upper extremity is attached to the trunk (Moseley, 1969).

The upper limb provides man with a unique mechanism to interact with his environment. At the end of the upper extremity the hand can carry out a wide variety of prehensile and non-prehensile acts. In a functional sense the upper limb is organized about the hand as the principal feature of the system. A primary function of the upper limb is to position the hand for its sensory, contacting and connective uses (Dempster, 1965). The positioning of the upper extremity with respect to the head allows for a visual and aiming control which cannot be duplicated elsewhere in the body (Kelly, 1971).

Considerable research has been done on the mechanism of the shoulder complex, and several analyses describe the muscle and joint activity in movements of the arm (Duvall, 1955; Bearn, 1961; Saario, 1963; Dempster, 1965; Shevin et al, 1969; Long, 1970; Jones, 1970 and Lucas, 1973). The most recent studies have correlated precisely arm position with the phasic activity of the muscles acting on the scapula and glenohumeral joints in normal subjects.

There is a considerable volume of literature on the numerous clinical lesions which affect the shoulder complex (Moseley, 1969; Cyriax, 1969; Brunnstrom, 1970; Bateman, 1972; De Palma, 1973). Kent (1971) states "probably more volumes of material are written about the shoulder complex and resulting disabilities in this area than about any other joint in the body".

Standard texts in medicine describe the clinical lesions of the shoulder complex in detail. The literature abounds with comments on lesions which produce limitation of shoulder movement and descriptions of the changes in movement patterns, but a review of the literature indicates a lack of detailed analysis of the muscle groups acting on the shoulder complex in the abnormal state.

In rehabilitation medicine the patient with chronically limited shoulder mobility presents serious medical, social and economic problems. A limitation of shoulder movement can severely limit the effective use of the hand.

In clinical practise the major emphasis has been directed towards the accurate identification of the lesion. Musculoskeletal lesions of the shoulder have been particularly difficult to identify and classify (Bateman, 1972). There is some disagreement in the literature on the most appropriate method of classification of soft tissue lesions affecting the shoulder complex. This is in part due to the intricate structure of the shoulder region. Many accounts exist describing the mechanisms in hemiplegia involved in the production of the abnormal muscle movement patterns which can severely affect voluntary function (Kabat, 1965; Bobath, 1970; Brunnstrom, 1970).

Apart from the accurate identification of the lesion producing the disability, the main interest has been directed towards the treatment and rehabilitation of the lesion. Treatment has been directed towards an improvement in function, and the development of quantitative analyses that might have assisted in objective evaluation of the disability have not been developed.

The group muscle action in shoulder lesions has not been explored to the same extent as normal shoulder activity, although it would appear that a better understanding of the muscle activity in the abnormal would improve the level of understanding of the disability.

The present study attempts to examine the phasic activity of three major muscles acting on the shoulder complex during elevation of the arm. The phasic activity is correlated with limb position so that each muscle's contribution to the movement in its various stages can be analysed. The information from the study of two abnormal groups is compared with the phasic activity in the same muscle groups in normal subjects. The first group consists of hemiplegic subjects. The second abnormal group consists of subjects with a lesion of a glenohumeral joint structure. In both abnormal groups, limitation of shoulder movement is present.

Electromyography was the technique of choice, using apparatus which would not interfere with the movement under examination. The electromyographic unit and electrogoniometric system developed at the Department of Anatomy, University of Manitoba and the Biomedical Engineering Research Department, Shriners Hospital, Winnipeg, provided the technology required.

The ultimate objective of the study is to devise a method of evaluating muscle contribution to abnormal patterns. The evaluation will be applied to an assessment of the therapeutic procedures as well as an assessment of the degree of disability. This assessment will provide additional and clinically relevant information on the methods currently being used in the rehabilitation of two common types of shoulder lesions.

CHAPTER II

REVIEW OF THE LITERATURE

INTRODUCTION

This section consists of a review of literature related to the study. The evolution of the shoulder is discussed first, followed by a description of the structure of the normal shoulder complex. Following this is a review of the literature concerning the abnormal shoulder in hemiplegia and soft tissue lesions. The last part of the chapter deals with methods of motion analysis.

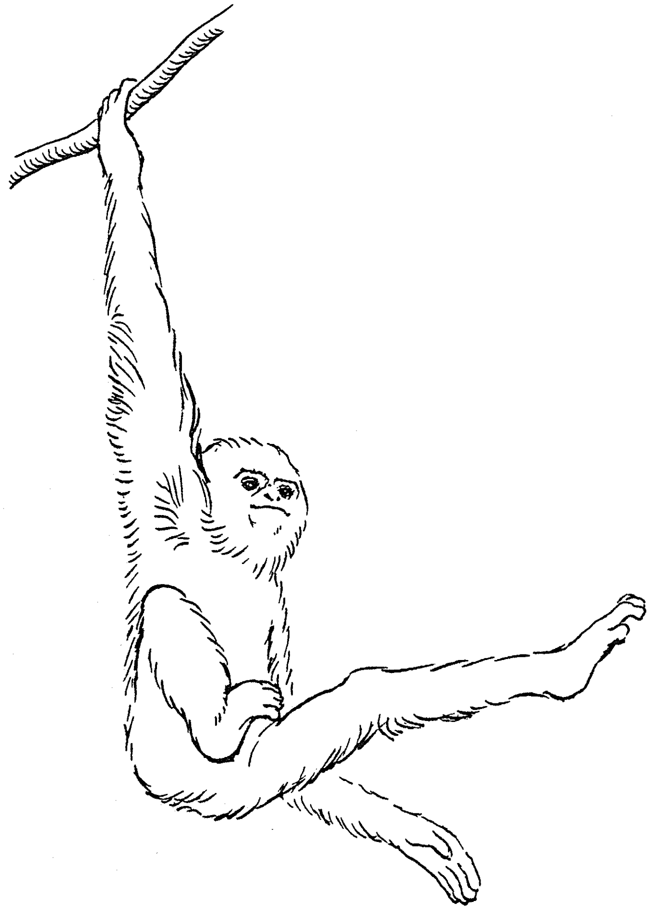
EVOLUTION OF THE SHOULDER

The shoulder is a region which, in primates, functions in different ways in different groups (Napier, 1956; Oxonard, 1967). The shoulder function can be related to locomotion, when the shoulder is weight bearing, or to brachiation, when the body weight is suspended from above (Fig. 2.1).

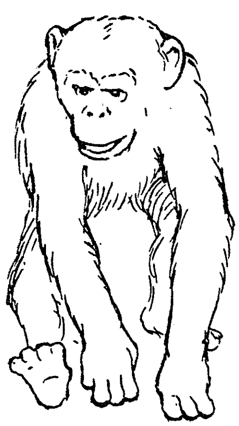
Changes in posture provided the stimulus that initiated the numerous morphological changes (De Palma, 1973). Bateman (1955) states "the shoulder is a prime example of purposeful evolution". Recent fossil discoveries and comparative anatomical studies support the hypothesis that man evolved from a large-bodied arboreal ape that adapted to some degree of hind limb locomotion. It has been suggested that the change in shoulder structure from ape to man may have occurred because of a change in the use of the forelimb (Tuttle, 1969).

Skeleton

An examination of the skeletal elements of primates which have freed the forelimb for prehensile purposes demonstrates certain very striking trends (Inman et al, 1944; Oxonard and Neely, 1969).



Brachiation



Knuckle-walking

Fig 2.1 Shoulder Function in Weight Bearing and Separation Stress.

The scapula, a bone largely suspended by the muscles acting upon it, shows morphological development brought about by specialized functional demands (Inman et al, 1944; Napier, 1956). The adaptive development of this bone has resulted in the upper limb becoming a mobile yet powerful structure (Kent, 1971). The most striking scapular change is the alteration in shape. The change in shape is almost exclusively confined to that portion of the scapula which lies below the spine of the scapula, the infraspinous fossa. This part of the bone in man is larger than that seen in primates. The enlargement of the fossa and development of the lateral border of the scapula changes the direction of the attached muscles (Oxonard, 1967; Oxonard and Neely, 1969; Bateman, 1972). Other changes of particular significance in the primate series are those associated with morphological alterations in the size and extent of the acromion process. The acromion in more primitive forms is short and delicate, projecting for only a short distance over the humeral head. In anthropoids the acromion increases in size and projects laterally over the head of the humerus (Oxonard, 1967).

The mammals which have freed the forelimb exhibit similar changes (Inman et al, 1944), for example, enlargement of the infraspinous fossa, a change related to the functional requirements of the attached muscles. Another development, the enlargement of the acromion is also related to the development of associated musculature, particularly to the more dominant position occupied by deltoid (Inman et al, 1944).

Morphological development of the scapula can be expressed by a scapular index, a ratio of the breadth, measured along the base of the spine, to the length, measured from the superior to the inferior angle.

The scapular index is high in lower forms in which the scapula is long, narrow and slender. The index progressively decreases in successive stages of development approaching man (Inman et al, 1944; De Palma, 1973) (Fig. 2.2).

Inman et al (1944) observed that the lengthening of the scapula, below the spine, changes the relation of the axillary border of the scapula to the glenoid fossa, thereby altering the angle of pull of the muscles in this region.

The humerus, like the scapula, has an identifiable progressive morphology. One of the major alterations is the progressive distal migration of the point of insertion of deltoid (Inman et al, 1944; Ashton and Oxonard, 1961; Oxonard, 1967). The shift in deltoid insertion and the increase in size of the acromion process increases the functional capability of the muscle. Inman et al (1944) states "this is a reflection of the increasing importance which the deltoid will progressively assume in the mechanism of the free limb".

In addition to the change in deltoid position, the humerus shows changes in the humeral shaft. In quadrupeds the articular surface of the head is directed dorsally, and the epicondyles at the inferior end of the bone lie in the coronal plane. The axis of the head makes an angle of 90° with an imaginary line connecting the epicondyles. As the thoracic cage flattens out with the erect posture, the scapula is rotated dorsally. The humeral head has to follow the scapula in its displacement on the chest wall. The humerus thus undergoes torsion. The axes already mentioned now come, in man, to make an angle of approximately 164° (Inman et al, 1944). This change also affects the position and size of the

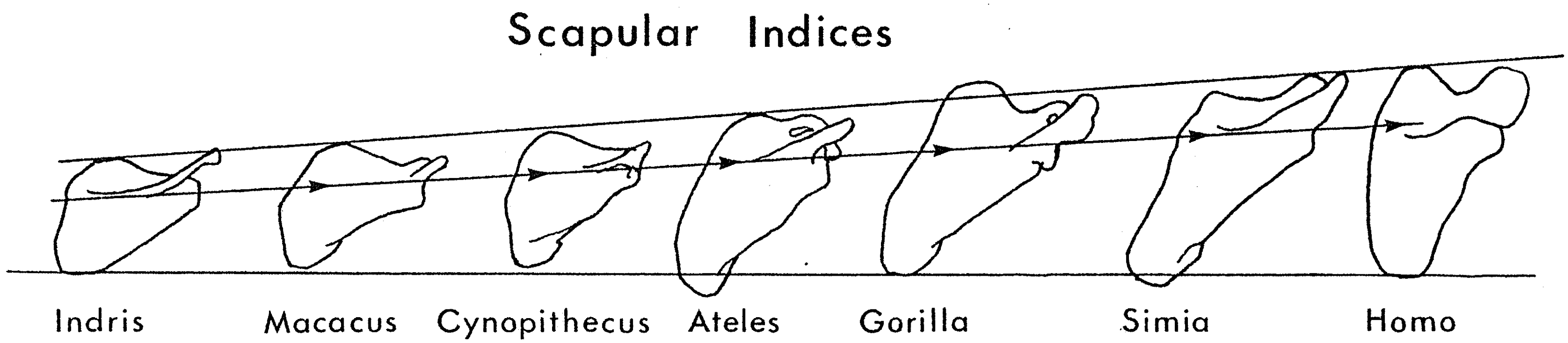


Fig 2.2 Alterations in the Length of the Scapula in Successive Stages of Development Approaching Man.

(Redrawn from Inman, 1944)

humeral tubercles. In primitive forms the intertubercular groove lies midway between two tubercles of almost equal size. The humeral torsion displaces the intertubercular groove medially reducing the size of the lesser tubercle (Inman et al, 1944; De Palma, 1973). The marked reduction in the size of the lesser tubercle is a characteristic feature of the higher primates (Inman et al, 1944).

The clavicle is absent in animals in which the forelimbs are used principally or entirely for progression, but is well developed where the limb is used for holding, grasping and climbing e.g. many rodents, the primates and man (Bateman, 1955; Kent, 1971). Morphologically the clavicle is considered to have a number of functions:

1. To hold the humerus away from the body so that the upper limb can move freely (Moseley, 1969; De Palma, 1973).
2. To provide a bony framework for the attachment of muscle (Abbott and Lucas, 1954; Gray, 1973).
3. To provide protection for vessels and nerves (Moseley, 1969; Abbott and Lucas, 1954).
4. To provide the means of transmitting force of the trapezius to the scapula through the coracoclavicular ligament (Moseley, 1969).
5. To provide a mechanism for increasing range of motion at the glenohumeral joint (Moseley, 1958 and 1969).

Muscles

The change in posture and functional activity of a free upper limb were responsible for alterations in the size and points of attachments of muscles in the shoulder region (Inman et al, 1944; Oxonard, 1967;

De Palma, 1973). The extent of the change in any individual muscle becomes apparent when its relative mass is compared with the total mass of the group to which it belongs (Inman et al, 1944; De Palma 1973). Inman et al (1944) defined three topographical muscle groups in the shoulder region (1) those passing from the scapula to the humerus, the scapulo-humeral group, (2) those passing from the trunk to the scapula, the axio-scapular group, and (3) those passing from the trunk to the humerus, the axio-humeral group.

The Scapulo-humeral Group

These connect the scapula to the humerus and consist of supraspinatus, infraspinatus, teres major and minor, subscapularis and deltoid. Of this group, evolving from the lower primates to the anthropoids, the supraspinatus has decreased in relative mass. However, while the supraspinatus has decreased in man, the deltoid muscle has increased very significantly in proportional mass (Inman et al, 1944; Montague, 1947; De Palma, 1973).

The changes in shape of the scapula influenced the morphology of the deltoid so that the portion of the deltoid attached to the region of the inferior angle of the scapula in primitive forms becomes separated from the general mass of the muscle (Inman et al, 1944; Oxonard, 1967). In this way a part of the deltoid is established as a morphologically separate element - the teres minor. This latter muscle is therefore absent in the primitive mammalian form. The power of the deltoid is increased in higher primates and in man by an increase in the relative size of the muscle. In addition, the increased leverage achieved by the development of the acromion and the distal migration of the deltoid insertion enhances the mechanical efficiency of the muscle action (Inman et al, 1944; De Palma, 1973).

In primitive forms the subscapularis is the largest muscle of the scapulo-humeral group. Evolving through the primate group to man the subscapularis has decreased only slightly relative to other muscles in the shoulder group. However, the origin of the muscle becomes more extensive as the scapula enlarges in overall size. As a result of this enlargement the lower fibres of the muscle together with those of teres minor act on the humerus in a downward direction (Inman et al, 1944; Oxonard, 1967; De Palma, 1973).

The infraspinatus has enlarged in the same manner as the subscapularis, by the elongation of the scapula. The subscapularis, teres minor and infraspinatus, because of the morphological and topographical elongation of the scapula, function as a unit. They are rotators and depressors of the humeral head (Inman et al, 1944; Gray, 1973).

The Axio-scapular Group

This group, connecting the trunk with the scapula, includes the trapezius, the rhomboids, the serratus anterior and the levator scapulae. Throughout the primate series, the trapezius has changed very little either in proportionate mass or general morphological arrangement. There has been, however, some concentration of the upper and lower borders of the muscle and a developing deficiency in the intermediate part of the muscle lying opposite the spine of the scapula. The serratus anterior and the levator scapula form a single sheet of muscle in primitive forms. Progressive loss of the middle portion divides the sheet and leads to its division into two separate muscles (Inman et al, 1944; Ashton and Oxonard, 1961; Oxonard, 1967; De Palma, 1973).

There is no significant change in the relative size and position of the rhomboids (Inman et al, 1944; Ashton and Oxonard, 1961).

The Axio-humeral Group

This group connects the humerus with the trunk. It consists of the pectoralis major and minor and latissimus dorsi. The pectoral muscles were originally derived from a single muscle mass which underwent separation into superficial and deep layers (Inman et al, 1944; Ashton and Oxonard, 1961; De Palma, 1973). The superficial layer is the pectoralis major. Part of the origin of this muscle has migrated in a cephalic direction, thus establishing the clavicular head of the muscle. The deep layer gives rise to pectoralis minor. The latter muscle has undergone progressive transference of its attachment to the coracoid process of the scapula. Inman et al (1944) states that the shift in pectoralis minor attachment is related to the increase in freedom of the forelimb and the enlargement of the acromial arch. The latter development results in the appearance of the subacromial bursa in the upper primates and man.

The latissimus dorsi and the teres major do not show any significant morphological changes (Ashton and Oxonard, 1961).

PRENATAL DEVELOPMENT

The embryonic period in prenatal development extends until the end of the seventh week. At the end of this period the beginnings of all major structures are present (Gardner, 1963; Moore, 1973). At this stage the embryo is 28 to 30 mm in crown-rump length. The fetal period extends from the eighth week to birth and during this time important developmental changes continue (Moore, 1973).

Embryonic Period

The limb buds first appear as small swellings on the ventrolateral body wall towards the end of the fourth week (Gardner, 1963; Hamilton et al, 1972; Moore, 1973; De Palma, 1973). The base of the upper limb bud occupies a position opposite the spinal segments fourth cervical to first thoracic. At this time the upper limb bud consists of undifferentiated mesenchymal tissue. Although the bud contains cells which will later differentiate, no muscles or skeletal elements are seen at this time (De Palma, 1973). Moore (1973) states "each limb bud consists of a mass of mesenchyme derived from the somatic mesoderm and is covered by a layer of ectoderm". The distal end of the upper limb bud flattens into a paddle-like hand and digits differentiate at the margins of these plates (Davies, 1963; Moore, 1973).

As the limbs elongate, the skeletal elements begin to form. There is also an aggregation of myeloblasts, the latter developing into a large muscle mass. The muscle mass separates into dorsal (extensor) and ventral (flexor) components (Moore, 1973).

During the 5th week chondrification proceeds from the proximal to the distal portion of the limb (De Palma, 1973). Towards the end of the 6th week the precartilage concentrations have become sufficiently moulded to indicate the main limb bones (Gardner, 1963; Patten, 1968). During the seventh week it is possible to make out the primordia of many of the smaller bones of the hand (Patten, 1968). Ossification begins in the long bones by the end of the embryonic period. Primary centres have appeared in nearly all bones of the extremities by 12 weeks. The secondary centres appear after birth (Patten, 1968; Moore, 1973).

Initially the limbs are directed caudally, later they extend ventrally and then the developing upper and lower limbs rotate in opposite directions and to different degrees. The arm buds rotate laterally through 90° on their longitudinal axis; thus the future elbows point backward (Moore, 1973).

Joint Development

In the area where a freely moveable joint is to be formed between two bones, there is only a "vaguely outlined precartilage concentration of mesenchyme" (Patten, 1968). As cartilage models of future bones become better defined, the joint becomes localised as an area between them where the mesenchyme is less concentrated (Gardner, 1963; Patten, 1968; De Palma, 1973). Patten 1968 states "the thinning out and final disappearance of the connective tissue from around the epiphysis establishes the joint cavity". Moore (1973) states that in the development of synovial joints the mesenchyme between the developing bones differentiates to give rise to the capsule and ligaments. Centrally the mesenchyme disappears to form the joint cavity and those mesenchymal cells lining the capsule and articular surfaces form the synovial membrane.

The glenohumeral joint follows the pattern of development of synovial joints as described above. At about five weeks in the embryo the central core of the humerus begins to appear but an "interzone" remains between the humerus and scapula (Gardner and Gray, 1953; De Palma, 1973). By six weeks condensation occurs around the glenoid, forming the glenoid lip (Gardner and Gray, 1953). Chondrification in the humerus and scapula continues rapidly. The humeral head enlarges, the greater and lesser tubercles appear, and the head is delineated from the humeral shaft by the neck of the humerus (Gardner and Gray, 1953; De Palma, 1973). At the same time, the scapula increases in size with formation and enlargement of the spine, acromion and coracoid process (Gardner and Gray, 1953). By the sixth or seventh week the joint cavity appears. With the termination of the embryonic period the shoulder joint exhibits the major features of an adult joint (De Palma, 1973).

The sternoclavicular joint also follows the pattern of development of synovial joints. The various components of the joint develop in situ, in the form and arrangement characteristic of the adult, attaining this similarity before the end of the embryonic period. The acromic-clavicular joint however, differs in the rate of development. The joint cavity does not appear until well into the fetal period (Gardner and Gray, 1953).

In the fifth week the scapula occupies a position in relation to the fourth and fifth cervical vertebrae. At six weeks the scapula enlarges, extending from the fourth cervical to the first thoracic vertebra. At the end of the seventh week the greater portion of the scapula is located below the first rib. At the end of the embryonic period only a small portion of the scapula lies above the first rib and the inferior angle is in relation to the fifth intercostal space (Lewis, 1901; De Palma, 1973).

There are certain periods during development when the embryo is particularly susceptible to disturbances of either hereditary or environmental origin (Gardner, 1963). These sensitive periods are usually termed 'critical periods'. The critical period in the development of the upper limb extends from midway in the fourth week to the end of the eighth week. The period of the eighth week is the time when the limb is highly sensitive to teratogens (Moore, 1973).

Development of Skeletal Muscle

The muscular system develops almost entirely from the mesoderm. Muscle tissue develops from mesoblasts, primitive cells which are derived from mesenchyme (Moore, 1973). The musculature of the limbs is developed from mesenchyme surrounding the developing bones. There is no migration of mesenchyme from the myotome regions of the somites to form limb muscles (Moore, 1973). Like the skeletal elements, development of premuscle masses to individual muscles follows a definite sequence. Development of the masses most closely associated with the trunk present the earliest advances; next to develop are those connecting the arm with the trunk. The least advanced are the premuscle masses of the arm (Lewis, 1901, De Palma, 1973). As early as the sixth week, premuscle masses are discernible - although they as yet contain no muscle fibres (De Palma, 1973). Gardner (1963) states that the differentiation of muscles begins at about five weeks and is followed by the differentiation of tendons. For example the condensation marking the tendon of the long head of biceps is seen at about five and a half weeks.

There are five premuscle masses in the shoulder region:

1. trapezius and sternomastoid muscles
2. levator scapulae and serratus anterior muscles
3. latissimus dorsi and teres major muscles
4. pectoral muscles
5. rhomboid muscles

At this time no demarcation of muscle masses is present in the arm. Development of the deltoid and smaller muscles connecting the scapula to the humerus follows the major muscle masses described above in the sixth week (Lewis, 1901; Gardner and Gray, 1953; De Palma, 1973). At the end of the embryonic period the deltoid is large and well marked. So also are serratus anterior, trapezius and the smaller shoulder muscles.

Development of Nerve Supply

The nerves of the upper limb which supply the muscles of the shoulder girdle and upper extremity arise from the developing spinal cord segments opposite the limb bud and extend outwards as a sheet. The developing brachial plexus, extending distally as a continuous sheet of fibres, splits into dorsal and ventral divisions. The tips of the developing nerve fibres become attached to the primitive muscle, and follow the muscle, by passing in between the layers of the muscle substance (Bateman, 1972). As the limb grows, nerves from the plexus branch into individual muscles. As the muscle masses develop they draw the nerves along with them to keep pace with the skeletal maturation. Deltoid and serratus anterior are supplied by nerves developing from the brachial plexus. Trapezius, however, develops from a sheet of primitive muscle growing tailward from the occiput to the limb bud. The nerve supply of trapezius (cranial nerve XI) follows the migration of the muscle (Bateman, 1972).

The Fetal Period

During the fetal period, the structures in the shoulder region undergo further maturation and enlargement (De Palma,1973). The joint cavities increase in absolute size while maintaining relative size. At about three to four months, blood vessels begin an extensive invasion of the ligaments and tendons and the epiphyses are being vascularised (Gardner, 1963). The ligaments of the shoulder joint become increasingly fibrous during the fetal period. All the components of the rotator cuff are present at the beginning of the fetal period and continue development during this time (Gardner, 1963).

POSTNATAL DEVELOPMENT OF THE SHOULDER SKELETON

During the period of postnatal development the soft tissue elements increase in size ultimately attaining their adult proportion (De Palma, 1973). Skeletal elements also show development with the appearance of centres of ossification and the fusion of these centres with the rest of the skeletal element (Gray, 1973). The skeletal development is described below.

The Humerus

At birth the upper humeral epiphysis consists of a rounded mass of cartilage with greater and lesser tubercles. Ossification of the upper end of the humerus occurs in three centres. The centre for the head appears between the fourth and sixth month after birth (De Palma, 1973; Gray, 1973). The greater and lesser tubercles begin to ossify in the second and fifth year in males and a year earlier in females. By the sixth year the centres for the head and tubercles have joined to form a single large epiphysis. The upper end of the humerus fuses with the shaft of the humerus about the 20th year in males and about two years earlier in females (Gray, 1973). The upper epiphysis of the humerus joins the shaft later than the lower, and the length of the bone is due mainly to the upper growth cartilage (Bateman, 1972; De Palma, 1973; Gray, 1973).

The Scapula

At birth only the body of the scapula shows ossification. The acromion, coracoid process, vertebral border and inferior angle are cartilaginous (De Palma, 1973). The cartilaginous scapula is ossified from eight or more centres, one in the body, two in the coracoid, two in the acromion, and one each in the medial border, inferior angle and the lower part of the rim of the glenoid cavity (Gray, 1973). The various epiphyses of the scapula have all joined the bone by about the 20th year (Gray, 1973).

The Clavicle

The clavicle is one of the first bones in the body to ossify (De Palma, 1973). The shaft of the bone is ossified in membrane from two primary centres, medial and lateral, which appear in condensed mesenchyme between the fifth and sixth week of intrauterine life and fuse about the 45th day (Gray, 1973). A secondary centre at the sternal end of the clavicle appears in the late teens or early twenties and about two years earlier than this in the female (Gray, 1973).

SHOULDER ARTICULATIONS

The shoulder complex is composed of four independent articulations:

1. the sternoclavicular joint
2. the acromioclavicular joint
3. the scapulothoracic joint
4. the glenohumeral joint

(Inman et al, 1944; Sohier, 1967; Carlin, 1963; Kent, 1971; De Palma, 1973). Although each joint is an independent entity, capable of independent motion, all four contribute their share to total movement in the normal functional mechanism of shoulder activity. The participation of each of these joints in the entire movement is simultaneous and not successive (Inman et al, 1944).

The Sternoclavicular Joint

Entering into the formation of the sternoclavicular joint is the sternal end of the clavicle, the clavicular notch of the manubrium sterni and the cartilage of the first rib (Grant, 1963; Gray, 1973). This joint is the only point of bony attachment of the entire upper limb to the axial skeleton (Kent, 1971). The articular surface of the clavicle is larger than that of the sternum and is covered by a layer of fibrocartilage. It is convex vertically and slightly concave anteroposteriorly, a type of saddle joint (Kent, 1971; Bateman, 1972; De Palma, 1973; Gray, 1973). The clavicular notch of the sternum is reciprocally curved, but the two surfaces are not perfectly congruent. About half of the medial end of the clavicle rises above the slanting sternal notch (Kent, 1971). The joint cavity is completely divided by an articular disc (Gray, 1973).

The ligaments of the sternoclavicular joint are:

1. capsular
2. anterior sternoclavicular
3. posterior sternoclavicular
4. interclavicular
5. costoclavicular

The capsular ligament surrounds the joint and is thicker on the front and back of the joint. The sternoclavicular ligaments lie obliquely on the anterior and posterior aspects of the joint, passing downwards and medially from the clavicle to the manubrium sterni. The interclavicular ligament lies on the superior aspect of the joint and unites the superior aspect of the medial ends of both clavicles. The costoclavicular ligament lies on the inferior aspect of the joint connecting the upper surface of the first rib to the under surface of the medial end of the clavicle. This ligament consists of two laminae, the anterior lamina passing obliquely upwards and laterally, the posterior lamina passing upwards and medially (Gray, 1973). This latter ligament is important in stabilizing the medial end of the clavicle (Kapandji, 1970). The articular disc, lying within the joint cavity, is attached above to the upper and posterior border of the articular surface of the clavicle, and below to the first costal cartilage near the junction with the sternum (Dempster, 1965; Gray, 1973). In addition to binding the clavicle to prevent medial displacement, the disc acts as a hinge and shock absorber upon which the clavicle moves when the shoulder is moved up or down (De Palma, 1973). In elevation and depression, most movement occurs between the clavicle and the disc, while in protrusion and retraction of the scapula, most of the movement occurs between the sternum and the disc (Dempster, 1965). The strength of the joint depends on all ligaments, and on the articular disc (Bearne, 1967; Bateman, 1972; De Palma, 1973; Gray, 1973).

The Acromioclavicular Joint

The joint surfaces of the acromial end of the clavicle and the medial margin of the acromion of the scapula are covered with fibrocartilage. The joint surfaces are small, and the axis of the joint runs in an antero-posterior direction (Gray, 1973). The ligaments of the joint are capsular, acromioclavicular and coracoclavicular. The capsule completely surrounds the joint and is strengthened by the acromioclavicular ligament on its superior aspect. Like the sternoclavicular joint this joint has an articular disc, although the disc rarely divides the joint cavity into two (Kent, 1971; Gray, 1973).

The coracoclavicular ligament is an important structure in maintaining the correct scapulo-clavicular relationship (Inman et al, 1944; Kent, 1971). The ligament consists of two parts, conoid and trapezoid. The conoid part is triangular in shape. The base is attached above to the conoid tubercle on the undersurface of the clavicle. The apex is attached to the medial and posterior edge of the root of the coracoid process. The trapezoid part is the anterolateral section of the coracoclavicular ligament. It is attached below to the upper surface of the coracoid process, and above to the inferior surface of the clavicle (Bateman, 1972; Gray, 1973).

Kapandji (1970) states that as the scapula slides forward on the chest and the angle between the scapula and clavicle increases the conoid part of the coracoclavicular ligament is stretched and checks the movement. He also states that the trapezoid ligament becomes stretched as the angle between the clavicle and scapula decreases. Bateman (1972) suggests that the coracoclavicular ligament has a 'powerful hold' on the scapula, uniting it to the clavicle. He also suggests that the trapezoid part of the ligament prevents forward tilting of the scapula.

The Scapulothoracic Joint

The scapulothoracic joint is not a true joint but instead is the riding of the scapula on the posterolateral surface of the thoracic cage (Kelly, 1971; De Palma, 1973). The scapula's anterior surface is concave, corresponding to the convex surface of the rib cage. The scapula remains largely suspended by muscular action (Gray, 1973). Bateman (1972) states "the contribution of the scapula to shoulder function is one of the most ingenious mechanisms of the body". The scapula acts as a base or platform for the upper extremity. The scapula takes part in movement of the whole shoulder girdle in addition to enhancing movements of the glenohumeral joint. Movements made possible by the scapulothoracic mechanism are discussed in detail in the section dealing with movements of the shoulder complex (pages 32 to 43).

The Glenohumeral Joint

The glenohumeral joint is a multiaxial ball and socket joint (Gray, 1973). In the adult, the head of the humerus represents almost half a sphere, or at least two-fifths of it (Steindler, 1970). The neck and head of the humerus are angulated against the shaft 45° - 50° in the frontal plane. In the transverse plane the head and neck of the humerus are twisted backwards or internally against the shaft so that the axis of the elbow joint becomes oblique in relation to the axis of the head of the humerus (Steindler, 1970; De Palma, 1973). Kapandji (1970) states that the head of the humerus represents a third of a sphere of a diameter of 3 cm and is directed superiorly, medially and posteriorly. The axis of the head forms, with the axis of the shaft, an angle of 135°, and with the frontal plane, an angle of 30°. The glenoid fossa of the scapula has a smaller surface area than the articular area of the humeral head. Only part of the humeral head can be in articulation with the glenoid surface at any one time (Gray, 1973)(Fig. 2.3).

The articular surfaces are reciprocally curved. The head of the humerus, roughly hemispherical, articulates with the pear-shaped concave glenoid cavity of the scapula. Structurally the shoulder joint is weak. For stability it depends on the muscles and ligaments surrounding the joint. The joint is also protected to a large extent by the coraco-acromial arch which lies above the joint and consists of the coracoid process, the acromion process and the coracoacromial ligament (Inman et al,

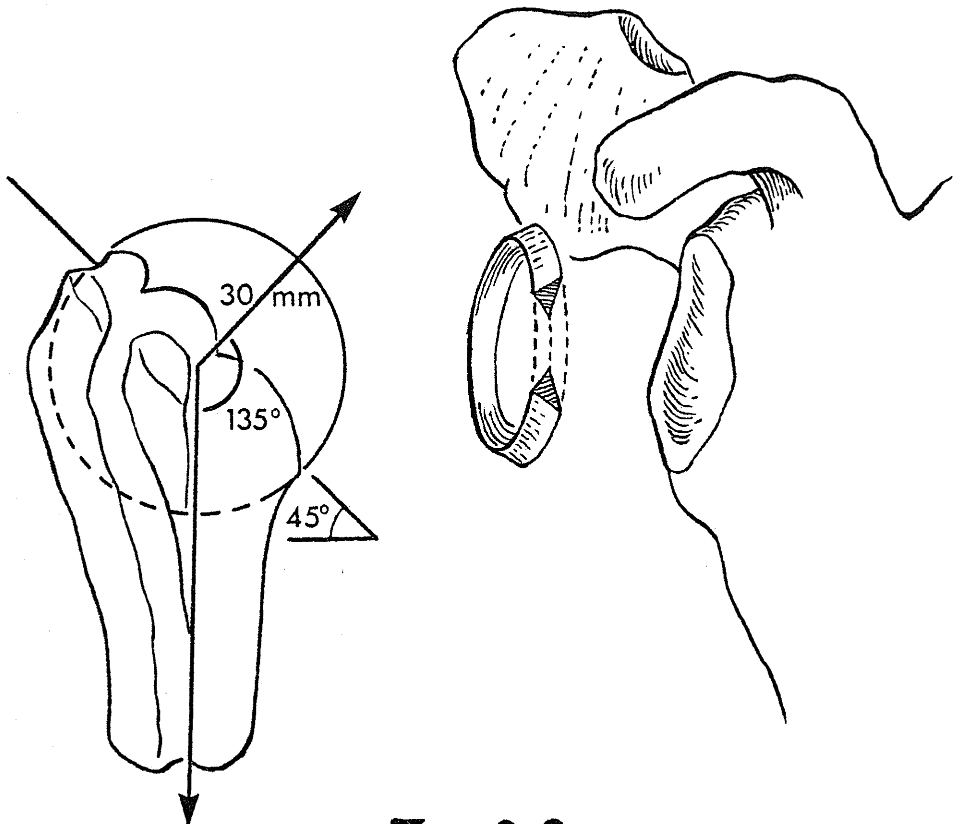


Fig. 2.3

THE UPPER END OF THE HUMERUS AND GLENOID CAVITY

(Redrawn from Kapandji 1970)

1944; Carlin, 1963; De Palma, 1973; Gray, 1973).

The ligaments of the glenohumeral articulation are the capsular, the glenohumeral, the coracohumeral, and the transverse humeral (Gray, 1973).

The fibrous capsule is attached medially to the circumference of the glenoid cavity beyond the glenoid labrum. Laterally it is attached to the circumference of the anatomical neck of the humerus, except inferiorly where it descends for about one cm onto the shaft of the humerus. The capsule is loose and lax. This laxity is related to the great range of movement which is possible in the glenohumeral joint (Gray, 1973).

Rotator Cuff

The tendons of the subscapularis, supraspinatus, teres minor and infraspinatus end in flat tendons whose fibres fuse with those of the fibrous capsule (Cyriax, 1963; Gray, 1973). De Palma (1973) uses the term 'musculotendinous cuff'. He also states that "so complete is the interlacing of tendon and capsular fibres that it is impossible to separate the two structures by sharp dissection". The rotator cuff serves to support the glenohumeral joint (Bateman, 1972). It also functions as a suspensory structure for the humeral head (De Palma, 1973).

The Glenohumeral Ligaments

Three thickenings, the glenohumeral ligaments, strengthen the capsule. They are attached to the upper part of the medial margin of the glenoid cavity. The superior band passes to a small depression on the lesser tubercle of the humerus, the middle band passes to the lower part of the lesser tubercle and the inferior band extends to the lower part of the anatomical neck (Grant, 1963; Gray, 1973). In addition to the glenohumeral ligaments the capsule is strengthened anteriorly by the tendon of pectoralis major (De Palma, 1973; Gray, 1973). The middle and inferior glenohumeral ligaments become taut in abduction. All three ligaments are taut in lateral rotation of the arm (Kapandji, 1970). Lucas (1973) states that the glenohumeral ligaments are in fact pleat-like folds in the capsular ligament.

The Coracohumeral Ligament

The coracohumeral ligament can, in addition to the structures mentioned above, be considered an important part of the rotator cuff (De Palma, 1973). It strengthens the upper part of the capsule, passing from the lateral border of the root of the coracoid process downwards and laterally to the front of the greater tubercle of the humerus (De Palma, 1973; Gray, 1973). Kapandji (1970) states that a small slip also passes to the lesser tubercle. The anterior part of the coracohumeral ligament becomes taut in extension. The posterior part of the ligament becomes taut in flexion of the glenohumeral joint (Kapandji, 1970). The coracohumeral ligament is thought to represent the morphologically older attachment of pectoralis minor on the humerus. In 15% of cadavers a part of the pectoralis minor tendon still crosses the coracoid process to insert on the humeral head (Lucas, 1973).

The Glenoid Labrum

The labrum is a fibrocartilagenous rim, triangular in cross section, attached to the margin of the glenoid cavity. It assists in deepening the concavity for the reception of the humeral head (Gray, 1973).

Coracoacromial Arch

The coracoacromial ligament bridges the gap between the acromion and coracoid process (Carlin, 1963; Gray, 1973). This arch provides a stabilizing influence on the glenohumeral joint by limiting the upward displacement of the humerus. This function is particularly significant following tears and attrition lesions of the rotator cuff (Lucas, 1973).

Subdeltoid Bursa

Superficial to the rotator cuff is the subdeltoid bursa, which provides two smooth serosal layers, one of which is adherent to the overlying deltoid muscle and the other to the underlying rotator cuff (Lucas, 1973). The bursa allows the rotator cuff to glide easily beneath the deltoid and acromion as the arm is elevated (Gray, 1973, Lucas, 1973).

Biceps

Separating the greater and lesser tubercles is the anteriorly placed intertubercular groove, occupied by the tendon of the long head of biceps. As the tendon passes over the humeral head from the supraglenoid tubercle it makes a right angled turn over the head to enter the intertubercular groove. The tendon assists in stabilizing the glenohumeral joint (Gray, 1973; Lucas, 1973).

MOVEMENTS OF THE SHOULDER COMPLEX

The shoulder complex is an integral portion of the upper limb, the shoulder structures making up about half the mass of the upper limb (Dempster, 1965).

Shoulder movements include all the relative motions that can occur between the trunk and the shoulder girdle, and shoulder girdle and arm (Dempster, 1965). De Palma (1973) states "in the shoulder girdle man has evolved a delicate intricate mechanism which permits the prehensile hand to be placed in any desired position in relation to the trunk". The working limb utilises three systems of joints to position the hand. First, the wrist and forearm for positioning the palmar surface of the hand. Second, the elbow for positioning the hand relative to the body and surrounding work space (Dempster et al, 1959). Third, the shoulder complex for determining the position of the humerus (Dempster, 1965).

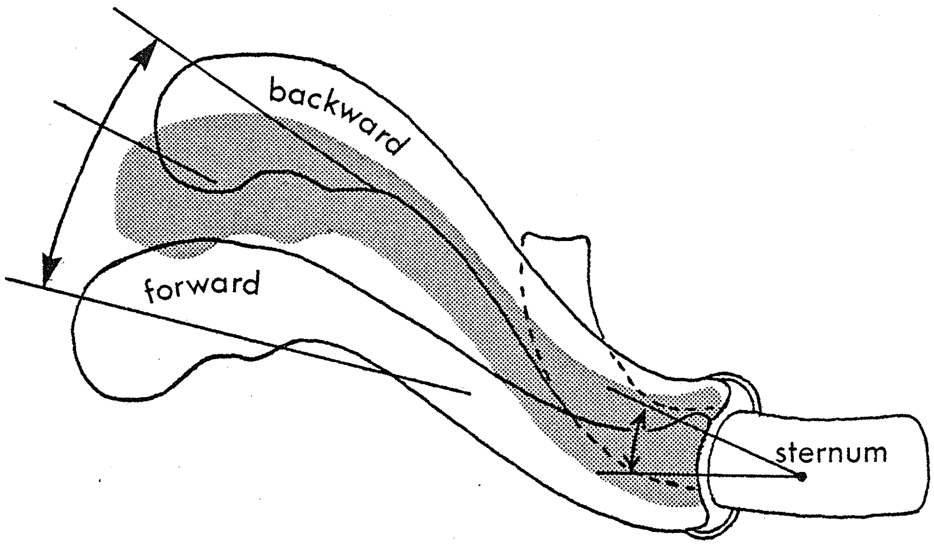
Movements of the arm are a combination of activity in the joints of the shoulder girdle: the clavicular joints, the scapulothoracic joint and the glenohumeral joint (Gray, 1973).

The clavicle can be moved upwards and downwards, forwards and backwards, and circumducted elliptically (Kapandji, 1970; Kelly, 1971). Upward and downward movements are accompanied by rotation about the long axis of the clavicle (Kelly, 1971). When the clavicle is lifted sufficiently upwards its upper surface rolls slightly posteriorly. The range of movement of the lateral end of the clavicle exceeds that of the sternal end (Kapandji, 1970). The forward and backward movements of the clavicle occur in the horizontal plane. Kapandji (1970) states that the axis of movement is located medial to the sternoclavicular joint. The upward and downward movement occurs in the frontal plane, the axis of movement being located at the clavicular attachment of the costoclavicular ligament (Kapandji, 1970)(Fig. 2.4).

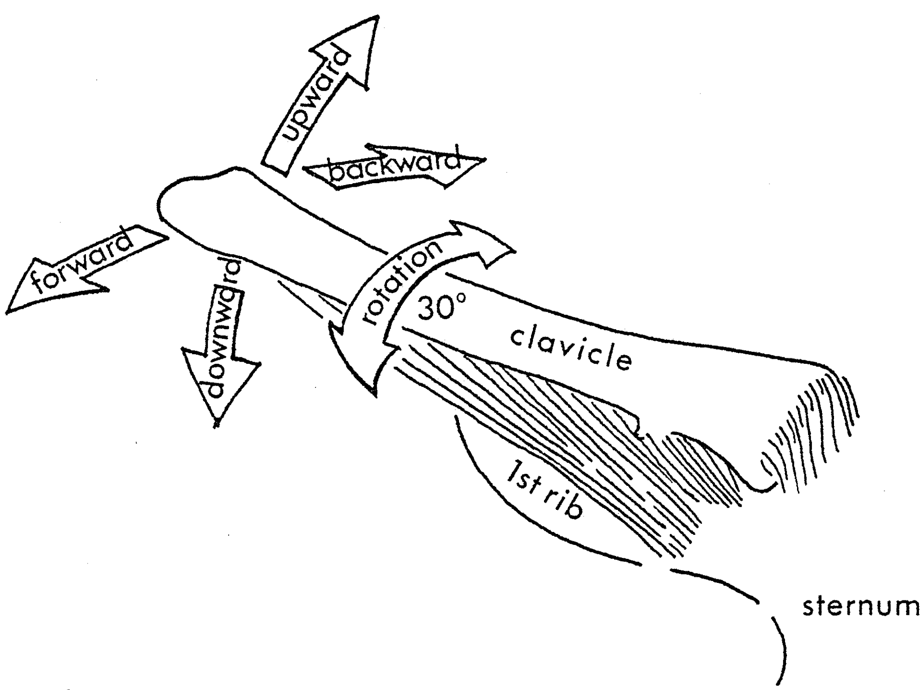
The acromioclavicular joint allows the acromion, and thus the entire scapula to glide forward and backward and to rotate on the clavicle. The range of scapular movements is increased further by associated movements at the sternoclavicular joint (Conway, 1961; Kelly, 1971; Bateman, 1972; Gray, 1973).

Movement occurs in the acromioclavicular joint in nearly all movements of the arm (Conway, 1961; Bateman, 1972). The joint surfaces when viewed from above are curved or crescent-shaped so that the acromion may swing in an arc around the clavicle. In elevation of the arm, motion in this joint occurs in two phases; part of the movement takes place in the first 30° and the remainder after 135° of elevation (Inman et al, 1944). In addition to the movements described above, the clavicle also rotates in its long axis during elevation. The acromioclavicular joint allows three types of movement (Kent, 1971). The first is about a vertical axis and is the movement of the scapula on the outer end of the clavicle. This enables the vertebral border of the scapula to move away from the chest about 30° to 50°. This has been termed 'winging' of the scapula (Moseley, 1958; Steindler, 1970; Kent, 1971). The second type of motion, about an anteroposterior axis, enables the scapula to rotate forward on the chest wall. This produces about 20° to 30° of movement (Moseley, 1958; Kent, 1971). The third motion is tilting the inferior angle of the scapula away from the chest wall. This occurs about an axis that lies in

Fig. 2.4
MOVEMENTS OF THE CLAVICLE



A. Clavicle viewed from above - Horizontal movements



B. Clavicle viewed from the front - Movements of the lateral end of the clavicle.

(Redrawn from Kapandji, 1970)

the frontal plane and permits about 30° of motion (Moseley, 1958; Kent, 1971) (Fig. 2.5).

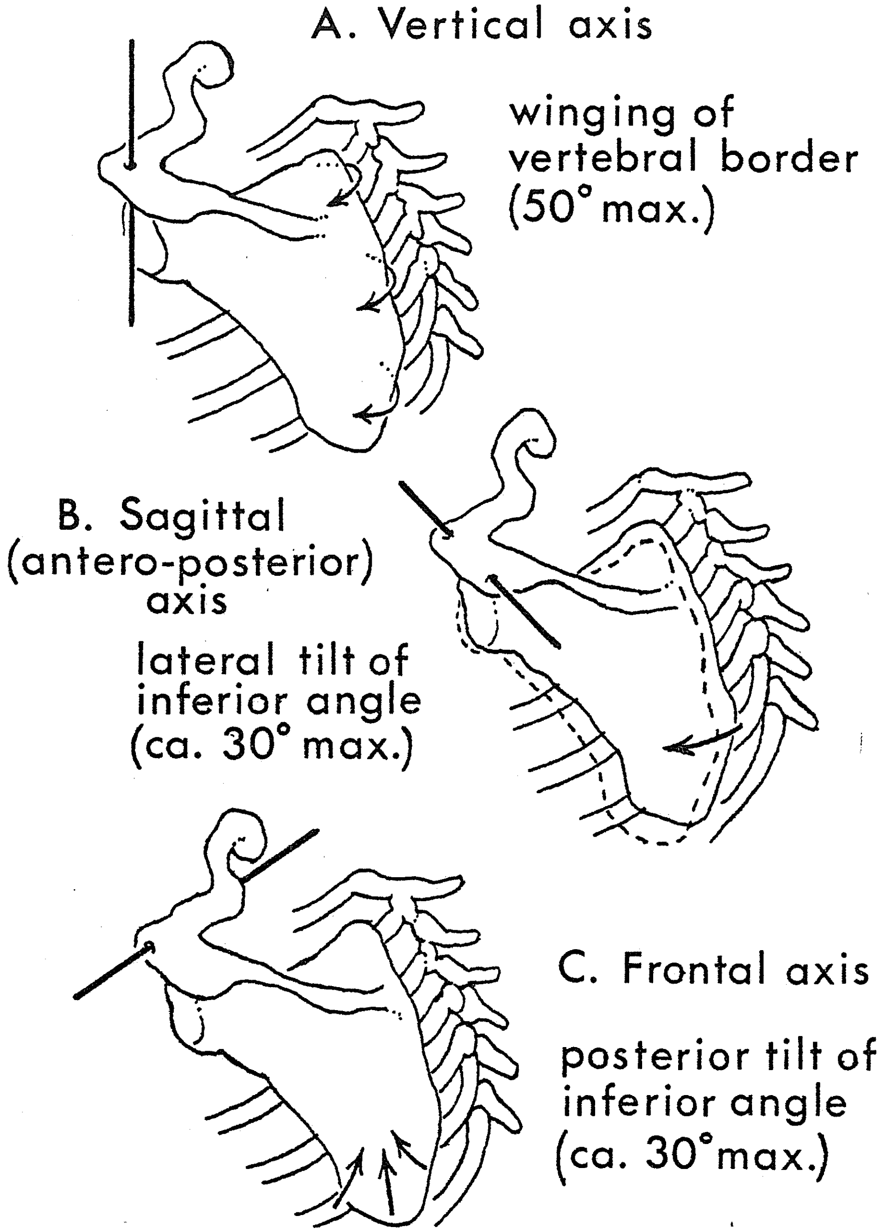
The movements at the sternoclavicular joint resemble the movements of a ball and socket joint more than those occurring in a plane joint (Kent, 1971). The movements occurring in the joint are elevation and depression, approximately 45° to 60° of elevation and 5° of depression (Moseley, 1958; Basmajian, 1963). Forward movement or protraction and backward movement or retraction each permit 15° from the resting position (Moseley, 1958; Basmajian, 1963; Steindler, 1970). Rotation of the clavicle in its long axis is approximately 30° to 50° (Abbott and Lucas, 1954; Moseley, 1958; Conway, 1961; Basmajian, 1963) (Fig. 2.6).

The movements of the clavicular joints are then primarily related to the movements of the scapula. These movements can be classified as follows:

1. elevation and depression of the scapula
2. protraction or forward movement of the scapula
3. retraction or backward movement of the scapula
4. forward or upward rotation of the scapula
5. return or downward rotation of the scapula

(Kelly, 1971)

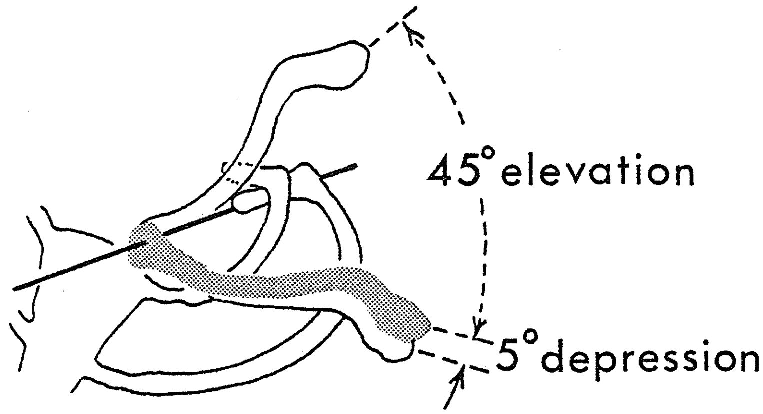
The scapula does not lie in a frontal plane but lies obliquely on the chest wall forming an angle of 30° with the frontal plane (Kapandji, 1970; Kelly, 1971). The clavicle runs obliquely in a posterolateral direction and forms an angle of 60° with the scapula. The scapula in its normal position lies on the posterolateral aspect of the chest from the level of the second to the seventh rib. The inferior angle lies opposite



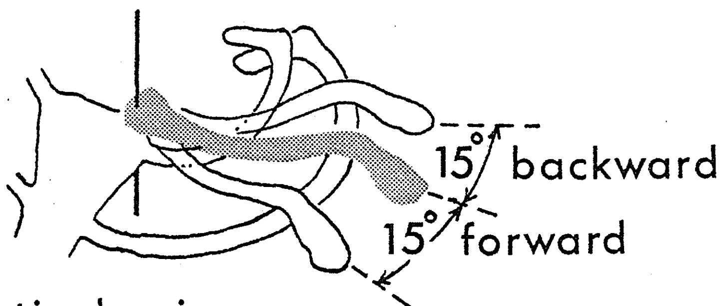
AXES OF MOTION AT THE ACROMIOCLAVICULAR JOINT

Fig. 2.5

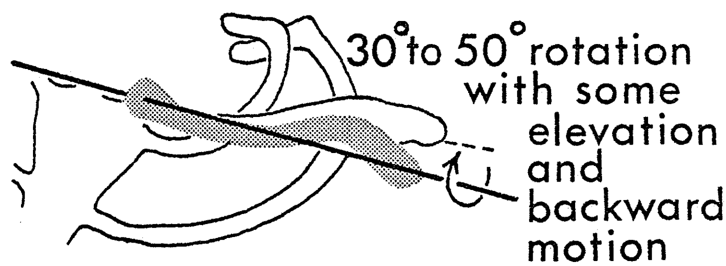
(Redrawn from Kent, 1971)



A. Horizontal (antero-posterior) axis



B. Vertical axis



C. Axis of rotation

AXES OF MOTION AT THE STERNOCLAVICULAR JOINT

Fig 2.6

(Redrawn from Kent, 1971)

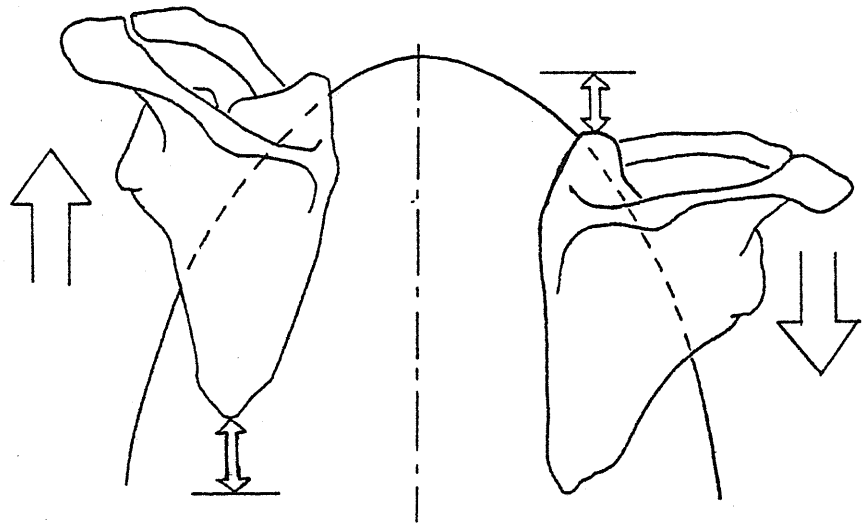
the spine of the seventh or eighth thoracic spine. The medial border of the scapula lies five to six cms lateral to the thoracic spines (Kapandji, 1970).

Elevation

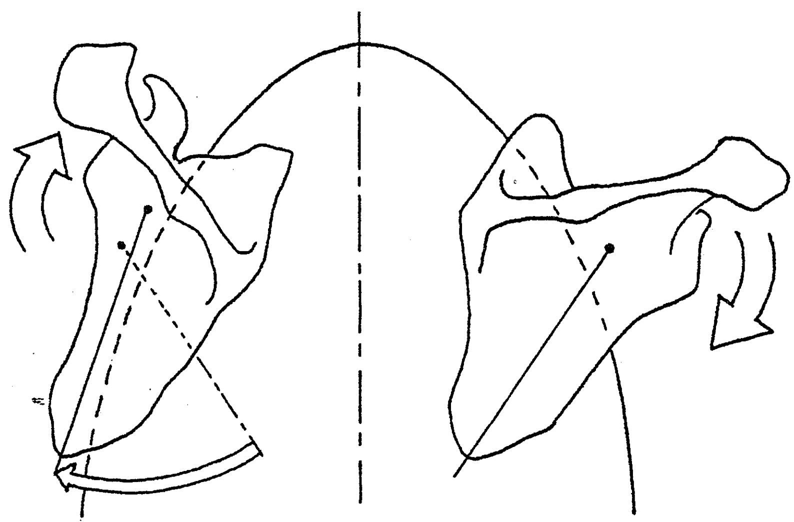
Elevation and depression, illustrated by shrugging the shoulders, does not necessarily imply movement at the glenohumeral joint (Gray, 1973). During elevation the scapula moves upwards without changing the orientation of its vertebral border (Kelly, 1971). During elevation only a slight degree of angular movement occurs at the acromioclavicular joint but the sternal end of the clavicle slides downwards over the surface of the articular disc (Gray, 1973). This movement at the sternoclavicular joint is checked by tension of the antagonist muscles, the costoclavicular ligament and the lower part of the capsule (Steindler, 1970; Gray, 1973) (Fig. 2.7).

Depression

Depression of the scapula occurs in the return from elevation. Depression beyond the neutral position is quite limited because further downward excursion of the clavicle is prevented by the first rib (Kelly, 1971). In depression there is a little angular movement at the sternoclavicular joint; the clavicle slides upward on the disc. The movement is checked by the interclavicular and sternoclavicular ligaments and the articular disc (Bearn, 1967; Steindler, 1970; Gray, 1973)(Fig. 2.7).



A. ELEVATION AND DEPRESSION



B. ROTATION

Fig 2.7 Movements of the Scapula

(Redrawn from Kapandji, 1970)

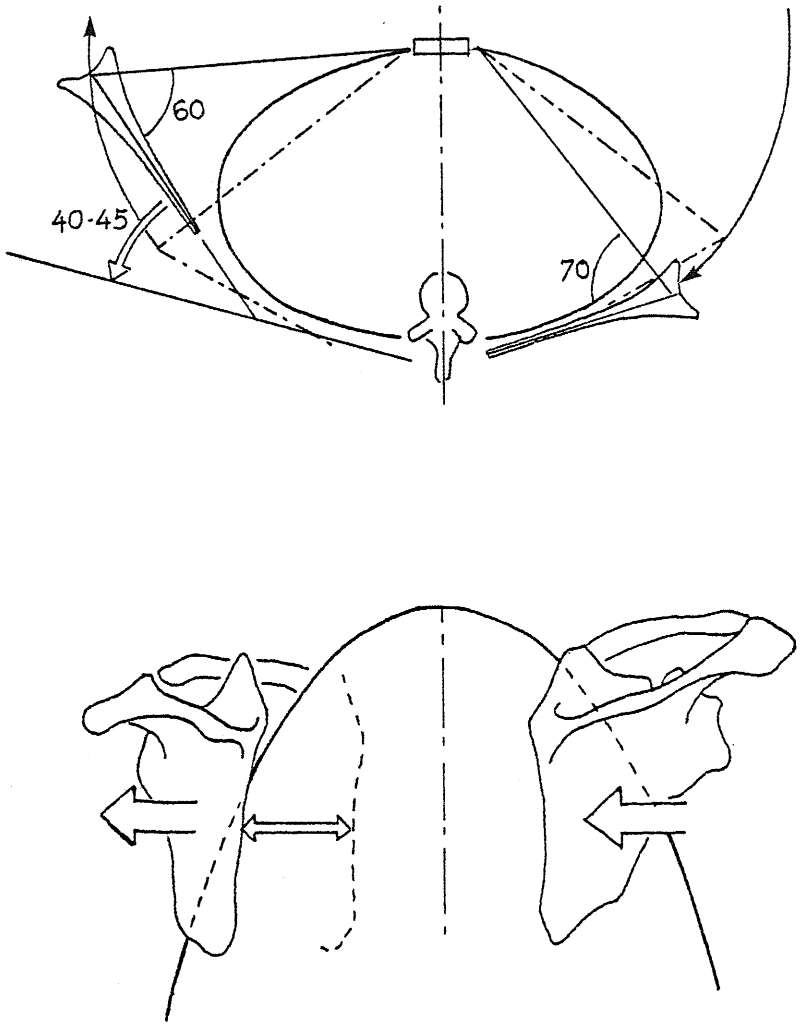
Protraction

Protraction moves the scapula laterally. Kelly (1971) states "because the scapula hugs the curved rib cage during most of its movements, the resulting action is not limited to the frontal plane but resembles the movement of an open hand sliding around the surface of a basketball". This movement of the scapula occurs in all forward, pushing, thrusting and reaching movements (Gray, 1973). Thus the glenoid cavity will face more anteriorly than it does in its neutral position (Kelly, 1971; De Palma, 1973). During the movement of protraction the acromion moves forward over the clavicular facets to the limits of its range of movement, and at the same time the point of the shoulder is advanced further by a forward movement of the lateral end of the clavicle, associated with a backward swing of the sternal end of the bone (Steindler, 1970; Gray, 1973). The movement is restricted by the posterior part of the interclavicular ligament and the posterior sternoclavicular ligament and posterior part of the costoclavicular ligament (Dempster, 1965)(Fig. 2.8).

Retraction

This is the return from protraction and a continuation of the movement beyond the normal neutral position toward the vertebral column (Kelly, 1971). In the terminally retracted position the glenoid cavity faces laterally, with the scapula lying in the frontal plane (Kelly, 1971; Gray, 1973).

When the scapula moves medially it comes to lie more and more in a frontal plane, the glenoid cavity facing more laterally. When the scapula moves laterally it comes to lie more and more in a sagittal plane. The



PROTRACTION AND RETRACTION

Fig. 2.8 Movements of the Scapula

(Redrawn from Kapandji, 1970)

position of the scapula between extremes of protraction and retraction make an angle of 45° (Kapandji, 1970). The movement of retraction is limited by the anterior sternoclavicular ligament, the anterior part of the capsular ligament and the anterior layer of the costoclavicular ligament (Dempster, 1965).

Upward Rotation

Upward rotation pivots the scapula so that the glenoid fossa is directed upwards. The inferior angle moves away from the vertebral column, while the vertebral border progressively forms a larger, downward opening angle with the vertebral column. Upward rotation and protraction often occur simultaneously (Kelly, 1971). The upward rotation of the scapula serves to increase the range of movement of the humerus, by turning the scapula so that the glenoid cavity faces almost directly upward. This is the position assumed by the scapula when the arm is raised above the head. This movement is always associated with elevation of the humerus and forward movement of the scapula around the chest wall (Gray, 1973).

The sternoclavicular joint permits movement of the lateral end of the clavicle; this movement is almost complete when the arm is abducted to 90° (Steindler, 1970; Gray, 1973). Movement of the acromioclavicular joint occurs in the first 30° of abduction at which point the coracoclavicular ligament (conoid part), becomes taut. Following this the movement of abduction of the arm is accompanied by rotation of the clavicle around the longitudinal axis of the bone. Further acromioclavicular movement occurs at the final stages of abduction, after 135° (Inman et al, 1944: Bateman, 1972; Gray, 1973)(Fig. 2.7).

Downward Rotation

Downward rotation is the return of the scapula from upward rotation. It may continue to a small extent beyond the neutral position. Downward rotation and retraction are commonly associated (Kelly, 1971).

GLENOHUMERAL JOINT MOVEMENT

The union between the glenoid fossa of the scapula and the head of the humerus is a synovial ball and socket joint. In contrast to the hip joint, the shoulder joint sacrifices stability for a remarkable degree of mobility (Gray, 1973). The glenoid fossa is smaller in surface area than the humeral head, also the glenoid is not curved as abruptly as the humeral head. Consequently the contact area between the two surfaces is rather small. The position of 'best fit', when the curve of the humeral head best fits the glenoid curvature occurs in terminal abduction and outward rotation of the arm (Kelly, 1971).

The movements of the shoulder girdle accompany those of the shoulder joint to position the glenoid fossa. Also the ability to reposition the scapula within a wide movement range allows it to be stabilized and act as a platform to anchor a number of muscles which move the arm. The temporal relationships of the movements of the shoulder complex have been termed the 'scapulothoracic rhythm' (Kelly, 1971).

The shoulder as a multiaxial ball and socket joint is capable of an infinite variety of swinging and spinning movements. These movements may all be described as rotations of the moving bone about three axes, or the joint may be described as having three degrees of movement (Gray, 1973).

The movements of the glenohumeral joint can be classified as:

1. abduction and adduction
2. flexion and extension
3. medial and lateral rotation
4. circumduction (a combination of the above)

(Kelly, 1971; Gray, 1973).

When the movements of the glenohumeral joint are being analyzed there are two approaches. The first is to consider the movements of the humerus in relation to the scapula rather than to the sagittal and coronal planes of the body. The second approach is to describe the movements as occurring in relation to these primary body planes. Anatomically it would seem preferable to use the former system, as is advocated by Gray (1973). Several others also support this view including Johnston (1937), Saha (1958) and Carlin (1963). It is interesting to note that although structural design does not place the scapula flat on the back of the thorax, several authorities measure the arm movement as if this were indeed so. The analysis of glenohumeral movement in the primary planes is advocated by several authorities including Bateman (1972), De Palma (1973) and the publication of the American Academy of Orthopaedic Surgeons (1965). The latter was established to identify a standard form of measurement of ranges of motion to be used by clinicians. Commenting on the question of shoulder analysis, Doody et al (1970) states "although much of the study of movements of the upper extremity has been concerned with movement in the primary planes of the body human beings seldom move the limb in the coronal or sagittal planes". It is interesting to note that in a paper in the British Journal of Surgery in 1937, Johnston stated "many writers . . . have deplored the confusion arising in connection with the terms applied to the movements at the shoulder, and incidentally they have not lessened the existing confusion by the introduction of a number of new terms". Johnston also suggests many writers do not appreciate the importance of referring shoulder movements to the plane of the scapula. Doody et al (1970) and Lockhart et al (1959) also suggest that abduction of the extremity in the scapular plane is easier and more natural to perform than abduction in the primary plane as little humeral rotation is required.

When the arm is by the side in the resting position the glenoid cavity faces almost equally forwards and laterally and the position of the humerus corresponds to that of the scapula (Gray, 1973). As a result of this position, flexion, in the scapular plane, carries the arm forwards and medially across the front of the chest, and the movement takes place around an axis which passes through the head of the humerus at right angles to the plane of the glenoid cavity (Freedman and Munro, 1966).

Abduction and adduction, when analyzed in the scapular plane, will occur in a plane at right angles to the plane of flexion and extension and the axis passes horizontally through the head of the humerus parallel to the plane of the glenoid cavity (Gray, 1973). Abduction therefore carries the arm forward and laterally away from the body, and the movement occurs in the plane of the body of the scapula (Doody et al, 1970; Gray, 1973)

If the movements of the humerus are considered in relation to the trunk and not the scapula, flexion and extension occur in the sagittal plane and abduction and adduction in the frontal plane.

Rotation occurs around a vertical axis. Rotation of the arm inwards is alternatively termed medial rotation; rotation outwards may be termed lateral rotation (Kelly, 1971).

The mechanical mid-position of the glenohumeral joint occurs when the centre of the articular surface of the humeral head coincides with the centre of the glenoid. In this mid-position the humerus is abducted 45° and flexed 45°. The lesser tuberosity is directed forwards and the arm slightly inwardly rotated (Steindler, 1970). The mid-position is similar to the position chosen when surgical ankylosis of the glenohumeral joint is required. Ankylosis (bony fixation) may be indicated when movement at this joint is seriously affected by muscular or bony pathology. The position of ankylosis is 45° to 60° of abduction, and 45° forward flexion, from the frontal plane. This position takes advantage of scapulothoracic motion. In the position of function the arm can move in all directions, although the range in each direction is limited. Following ankylosis the arm can still occupy a position of rest at the side of the body but cannot be extended over the head. The scapulothoracic motion necessary for shoulder function in ankylosis is greater in range than in the normal (Brantigan, 1963).

RANGES OF MOTION IN THE GLENOHUMERAL JOINT

The degree or range of motion of the arm is determined by the contribution of the four joints involved in the shoulder complex: sternoclavicular, acromioclavicular, scapulothoracic and glenohumeral. While each of these is capable of independent movement all contribute their share to the total in the normal functional mechanism of the arm (Inman et al, 1944;

Kernwein et al (1957) and Sohier (1967).

Abduction

The movement of abduction, in the scapular plane, varies from 100° to 120°; this is movement which occurs at the glenohumeral joint (Inman et al, 1944; Gray, 1973). When the arm is raised above the head an additional 55° to 65° are obtained by forward rotation of the scapula. The total arm movement in abduction is therefore 170° to 180° (Inman et al, 1944; Kelly, 1971; Bateman, 1972; Gray, 1973). The publication of the American Academy of Orthopaedic Surgeons (1965) states that the range of abduction in the coronal plane is 180°. It should be noted that glenohumeral movement is simultaneously accompanied by scapulothoracic movement. Codman (1934) termed this combined activity 'scapulo-humeral rhythm'.

Inman et al (1944) state that in the first 30° of abduction the scapula may remain fixed or it may shift slightly medially or laterally. This early phase of motion is highly irregular and is characteristic for each individual. The position adopted by the scapula in the first 30° of abduction of the arm seems to depend upon the habitual posture which the scapula occupies in the subject at rest. Inman et al (1944) termed this the 'setting phase'. This 'trembling' or 'waving' of the inferior angle was also noted by Bateman (1971). Once 30° of abduction has been reached the relationship of scapular to humeral motion remains remarkably constant. Thereafter a ratio of 2° of humeral to 1° of scapular motion takes place. Between 30° and 180° of abduction, for every 15° of motion, 10° occurs at the glenohumeral joint and 5° are due to scapular rotation on the thorax (Inman et al, 1944; Grant, 1963; Singleton, 1966; Gray, 1973). Duvall (1955) suggests that the greatest part of scapular rotation occurs in the middle part of abduction, when the arm is between 60° and 115°.

As the humerus abducts it also laterally rotates. The amount of lateral rotation is in the region of 90° (Saha, 1958; Steindler, 1970). This rotation of the humerus is of the greatest importance in that it allows the greater tuberosity of the humerus to move under the anterior edge of the acromion as the arm is abducted (Steindler, 1970). Lesions of the lateral rotators of the humerus may prevent the head of the humerus moving out of the way of the obstructing overhang, and impingement may occur (Bateman, 1972; De Palma, 1973).

Movements of the scapula and glenohumeral joints normally occur simultaneously. However under special and abnormal conditions the motions of these joints can occur independently. When the scapula is fixed it is possible to raise the arm actively to 90° and passively to 120° (Inman et al, 1944; Lucas, 1973). Inman et al (1944) showed that the lack of scapular movement in abduction alters the effective bone leverage for muscle action and consequently diminishes power by one-third.

Clavicular Movement in Abduction

Elevation of the arm is accompanied by movements of the clavicle at the sternoclavicular joint. This movement begins early and is almost complete during the first 90°, when for every 10° of elevation of the arm there are 4° of elevation of the clavicle. Above 90°, movement of the clavicle is almost negligible (Inman et al, 1944). Motion at the acromioclavicular joint is approximately 20° and occurs early in the first 30°

of abduction, and late, after 135° of elevation. The sum of the movements at the clavicular joints is equal to the range of movement permitted at the scapula (Inman et al, 1944; Doody et al, 1970). Doody et al (1970) examined scapular movement and recorded a mean scapular movement of 58.2° during abduction:

Acromioclavicular movement (20°) + Sternoclavicular movement (40°)

is equal to

Total scapular movement (60°)

Rotation of the clavicle in its long axis also occurs. The rotation is accomplished by the coracoclavicular ligament. This ligament is attached to the posterior border of the clavicle and medial border of the coracoid process. As the scapula rotates the medial border of the coracoid drops down and laterally. In doing so the coracoclavicular ligament pulls strongly on the posterior clavicle thus causing rotation about a longitudinal axis (Kent, 1971).

Without clavicular rotation, abduction of the arm is restricted. Dysfunction of the clavicular mechanism, restricting rotation, results in impaired function and impaired scapulohumeral rhythm (Inman and Saunders, 1946).

Adduction

This movement of the humerus brings the arm back from the abducted position to the resting position by the side. From 180° elevation the arm may be lowered to the side and at the end of the excursion carried behind the back 5° to 10° further (Bateman, 1972). The manual on range of motion testing produced by the American Academy of Orthopaedic Surgeons (1965) states that 75° of adduction from the neutral or resting position is possible when the arm is carried across in front of the body in the frontal plane towards the opposite side.

Flexion

In flexion the humerus moves in a plane at right angles to the plane of the body of the scapula (Gray, 1973). Inman et al (1944) observed that during the first 60° of forward flexion the scapula becomes 'set', a mechanism previously described as occurring in the first 30° of abduction. Once the 60° of forward flexion has been reached the relationship of humeral to scapular motion occurs in the ratio of 2:1. Bateman (1972) states that the arm can be raised in flexion 180° and the scapula although fixed on the chest initially moves forward around the chest wall during the second 90° of elevation. Bateman also suggests that in this movement the scapula moves further forward on the chest wall than it does in abduction. The publication of the American Academy of Orthopaedic Surgeons (1965) states that 180° of flexion in the sagittal plane is possible. In flexion the head of the humerus does not encounter the same obstruction from the coracoacromial arch that occurs in abduction. Kapandji (1970) and De Palma (1973) also report 180° of flexion in the sagittal plane. Steindler (1970) states the range of glenohumeral movement in flexion of the arm to be between 100° and 150°. Kent (1971) states that in flexion of the arm in the sagittal plane approximately 120° of movement occurs at the glenohumeral joint, the remaining elevation being the product of scapular rotation.

The movement of flexion is checked by the posterior capsule and the posterior part of the coracohumeral ligament, teres minor and infraspinatus (Steindler, 1970).

Extension

In extension the arm is swung backwards at the shoulder behind the line of the body in the sagittal plane, for 30° (Bateman, 1972). In this action the clavicle rotates downwards a little in its long axis and moves backwards with the sternoclavicular joint as its fulcrum. The publication of the American Academy of Orthopaedic Surgeons (1965) and De Palma (1973) state that extension in the sagittal plane is approximately 60°. Kent (1971) states that 55° of 'hyperextension' occurs at the glenohumeral joint. Extension of the glenohumeral joint is often accompanied by retraction of the scapula (Steindler, 1970). The movement of extension is limited by the superior and anterior parts of the shoulder capsule, the anterior part of the coracohumeral ligament and supraspinatus and subscapularis (Steindler, 1970).

Lateral Rotation

External or lateral rotation occurs about a vertical axis. From the midposition with the arm at the side, or abducted horizontally, the shoulder may be externally rotated almost 90°, nearly all the movement occurring at the glenohumeral joint (Bateman, 1972). Gray (1973) states that the humerus revolves for about one-quarter of a circle about a vertical axis, the range being greatest when the arm is by the side. The manual of the American Academy of Orthopaedic Surgeons (1965) states that rotation in abduction is slightly less than with the arm by the side of the body. De Palma (1973) states that as the arm is elevated, the range of rotation gradually diminishes until the arm is in full elevation. Kelly (1971) states that inward and outward rotations both have ranges of nearly 70^{o}. Steindler (1970) states however that the greatest length rotation of the humerus occurs when the arm is in 90^{o} of abduction. Steindler states that the reason for this is that in the position with the arm by the side, outward rotation is checked by impingement of the greater tuberosity against the posterior rim of the glenoid. When the arm is raised to 90^{o} abduction this impingement does not occur and the movement is checked by the ligaments and muscles of the rotator cuff.

External rotation is vital for normal function, if this movement is restricted or lost shoulder action is severely impaired (Bateman, 1972).

Medial Rotation

The arm may be turned inwards a little more than 90^{o} in both horizontal and vertical planes. The movement occurs at the glenohumeral joint (Bateman, 1972; Gray, 1973). The arm can be rotated behind the trunk, as in touching the back over the lumbar spine. This motion is always accompanied by varying degrees of retraction of the shoulder girdle (De Palma, 1973). Medial rotation is checked by the impingement of the lesser tuberosity against the anterior rim of the glenoid (Steindler, 1970).

Regardless of the plane in which the arm ascends to reach complete elevation, the ultimate position of the humeral head in relation to the glenoid cavity, the coracoid process and the acromion is the same (De Palma, 1973). Codman (1934) designated this the 'pivotal position'. In the position of complete elevation no rotation is possible.

Circumduction

Circumduction results from a succession of the foregoing movements; flexion, extension, abduction, adduction and rotation. In circumduction the lower end of the humerus describes the base of a cone, the apex of which is at the head of the humerus. The range of motion in circumduction is increased by scapular movements (Gray, 1973). The movement of circumduction can be illustrated by the movements of the arm in describing a circle in the air, or drawing a circle on a blackboard. The succession of movements is as follows: starting from a position in which the arm is adducted and forward flexed, the arm goes into forward flexion, abduction, lateral rotation, backward extension, adduction, medial rotation and forward flexion again (Steindler, 1970).

RANGE OF MOTION AT VARIOUS AGES

Saario (1963) reported on a survey of 1280 healthy subjects in whom range of motion of the shoulder had been recorded. The subjects ranged in age from below 16 years to above 70 years. The results of this survey showed a reduction in mobility as age progressed.

Flexion and extension, below 16 years of age showed a total range of movement of 240°. In the above 70 age group the range of motion had decreased to 190°. This is a reduction, through aging, of 50° or 21%. Abduction and adduction in the below 16 age group showed 166°. In the over 70 age group this was reduced to 116°. This is a reduction of 50° or 30%. Rotation in the below 16 years age group showed 175°, above 70 years of age this was reduced to 125°, a reduction of 50° or 38%.

MUSCLES OF THE SHOULDER

This thesis is limited to an examination of the activity of deltoid, trapezius and serratus anterior.

Inman et al (1944) showed that equilibrium at the glenohumeral joint, regardless of the position of the arm, was the result of three forces:

1. The weight of the extremity, acting at the centre of gravity.
2. Muscular masses responsible for abduction.
3. The resultant of the above two forces, acting through a centre of rotation, but in a direction opposite to that of deltoid.

The third force has two components, the pressure and friction of the head of the humerus at the glenoid cavity and the downward pull of the rotator cuff muscles.

The force of elevation, the pull of deltoid, together with the active component of the third force, the downward pull of the short rotators, establishes the 'muscle force couple' necessary for elevation of the limb (Inman et al, 1944; De Palma, 1973).

A force couple is two equal but oppositely directed forces. The direction of the deltoid is upward and outward with respect to the humerus, with the arm by the side. Whereas the force of the short rotators, infraspinatus, teres minor and subscapularis, is downward and inward. The force of deltoid acting below the centre of rotation is opposite in direction to the force of the infraspinous muscles, which is applied above the centre of rotation. These forces acting in opposite directions on either side of the centre of rotation produce a powerful force couple. The deltoid acting alone produces only an upward subluxation of the humeral head. Similarly if the short rotators work alone they will depress the head of the humerus (Lucas, 1973).

The magnitude of the force required to bring the limb to 90° of elevation is 8.2 times the weight of the extremity (Inman et al, 1944). Beyond 90° the force requirement decreases progressively, reaching zero at 180°. The force requirements of the lower component of the muscle force couple reaches maximum at 60° abduction, at which time the force requirements are 9.6 times the weight of the limb. Beyond 90° a progressive decrease of the magnitude of the force occurs, reaching zero at 135° (Inman et al, 1944; Kent, 1971; De Palma, 1973).

Electromyographic studies have demonstrated that the activity of deltoid increases progressively and becomes greatest between 90° and 180° of elevation (Wertheimer and Ferrez, 1958; Basmajian, 1974). The depressors of the head of the humerus, the infraspinous muscles, have two peaks of activity, one at 110° to 120°, and another at 60° to 80° (Inman et al, 1944; Basmajian, 1974).

Deltoid

Anatomy texts (Lockhart et al, 1959; Grant, 1963; Gray, 1973) describe deltoid as a large thick triangular muscle which covers the shoulder joint anteriorly, laterally and posteriorly. The base of the triangular mass is attached to the anterior border and superior surface of the lateral third of the clavicle, the lateral margin and superior surface of the acromion and the lower edge of the crest of the spine of the scapula, as far as the smooth triangular surface at its medial end.

The muscle converges into a short and substantial tendon attached to the deltoid tuberosity on the lateral aspect of the humeral shaft.

The anterior and posterior fibres descend obliquely without interruption into the tendon of insertion. The intermediate portion of the muscle is multipennate; four intramuscular septa descend from the acromion to interdigitate with septa which ascend from the deltoid tuberosity. The short fibres of this portion of the muscle provide a short but powerful pull (Grant, 1963).

The muscle is innervated by fibres from the 5th and 6th cervical nerves through the axillary nerve.

Before the work by Duchenne in 1867 (Kaplan, 1959) it was assumed that deltoid was the principal elevator of the arm. By electrical stimulation of all three parts of the muscle Duchenne noted the tendency to humeral subluxation. This experiment demonstrated that movement by isolated muscle contraction "is not the nature of things". Duchenne also noted that serratus anterior and trapezius were involved in the mechanism of abduction. Examination of the electrical activity of deltoid by electromyography demonstrated that the activity increases progressively and becomes greatest between 90° and 180° of abduction (Basmajian, 1974).

Yamshon and Bierman (1949) and Scheving and Pauly (1959) noted that the three parts of the deltoid are active in all movements of the shoulder, they noted that in flexion and medial rotation the anterior part is most active; in extension and lateral rotation the posterior part is most active; in abduction the middle fibres are most active. Scheving and Pauly (1959) suggest that although one part of deltoid is functioning as the prime mover the other parts function to stabilize the glenohumeral joint.

Basmajian (1974) translated the Brazilian study of Wertheimer and Ferrez (1958). These researchers found that the anterior part of deltoid showed its main action in flexion of the shoulder joint but it also participated in elevation and abduction. Deltoid did not act in medial rotation. In addition it was also stated that the intermediate portion of the muscle worked strongly in abduction, flexion and extension. The posterior part had its principal action in extension. Schevin et al (1969) examined deltoid activity during isometric contraction. The anterior, posterior and middle fibres all functioned in abduction.

When the limb is in the dependent position by the side deltoid is inactive. It might be supposed that deltoid acts in a supportive manner preventing the weight of the arm subluxating the shoulder. The work of Basmajian and Bazant (1959) demonstrated however that downward dislocation is prevented by supraspinatus and the superior part of the capsule. Bearn (1961) confirmed the findings that deltoid is inactive as a postural muscle for the dependent arm.

Trapezius

The trapezius is a flat triangular muscle extending over the back of the neck and upper thorax. It is attached to the medial one-third of the superior nuchal line of the occipital bone, the external occipital protuberance, the ligamentum nuchae, the seventh cervical and all the thoracic vertebral spinous processes, and the corresponding supraspinous ligaments (Gray, 1973). The superior fibres pass downwards and laterally to be attached to the posterior border of the lateral third of the clavicle. The middle fibres pass horizontally to be attached to the medial margin of the acromion and superior lip of the crest of the spine of the scapula. The inferior fibres pass upwards to end in an aponeurosis which glides over the smooth triangular surface at the medial end of the spine of the scapula (Gray, 1973).

The muscle is supplied by motor fibres from the accessory nerve and proprioceptive fibres from branches of the 3rd and 4th cervical nerves (Gray, 1973).

The trapezius is part of a functional group of muscles which includes the rhomboids, serratus anterior and levator scapulae (Gardner et al, 1960; Grant, 1963; Gray, 1973). Inman et al (1944) was the first to use electromyography to examine the function of trapezius. It was found that the muscle is active during elevation and retraction of the shoulder and during flexion and abduction of the humerus. Yamshon and Bierman (1948) and Wiedenbauer and Mortensen (1952) studied the activity of trapezius during voluntary movements. These studies confirmed the work of Inman et al (1944). The greatest activity was recorded during abduction of the arm. Basmajian (1974) also confirmed these findings. In static loading, Bearn (1961) noted that the upper fibres of trapezius played no active part in the support of the shoulder girdle in relaxed standing upright posture. When weights were held in the hand 75% of subjects could relax trapezius immediately or within two minutes.

Gray (1973) states that trapezius together with other muscles attached to the scapula steadies the bone and controls its position and movements during active use of the upper limb.

Acting with levator scapula, the upper fibres of trapezius elevate the scapula; acting with serratus anterior the muscle rotates the scapula in a forward direction so that the arm can be raised above the head (Kapandji, 1970; Basmajian, 1974).

Serratus Anterior

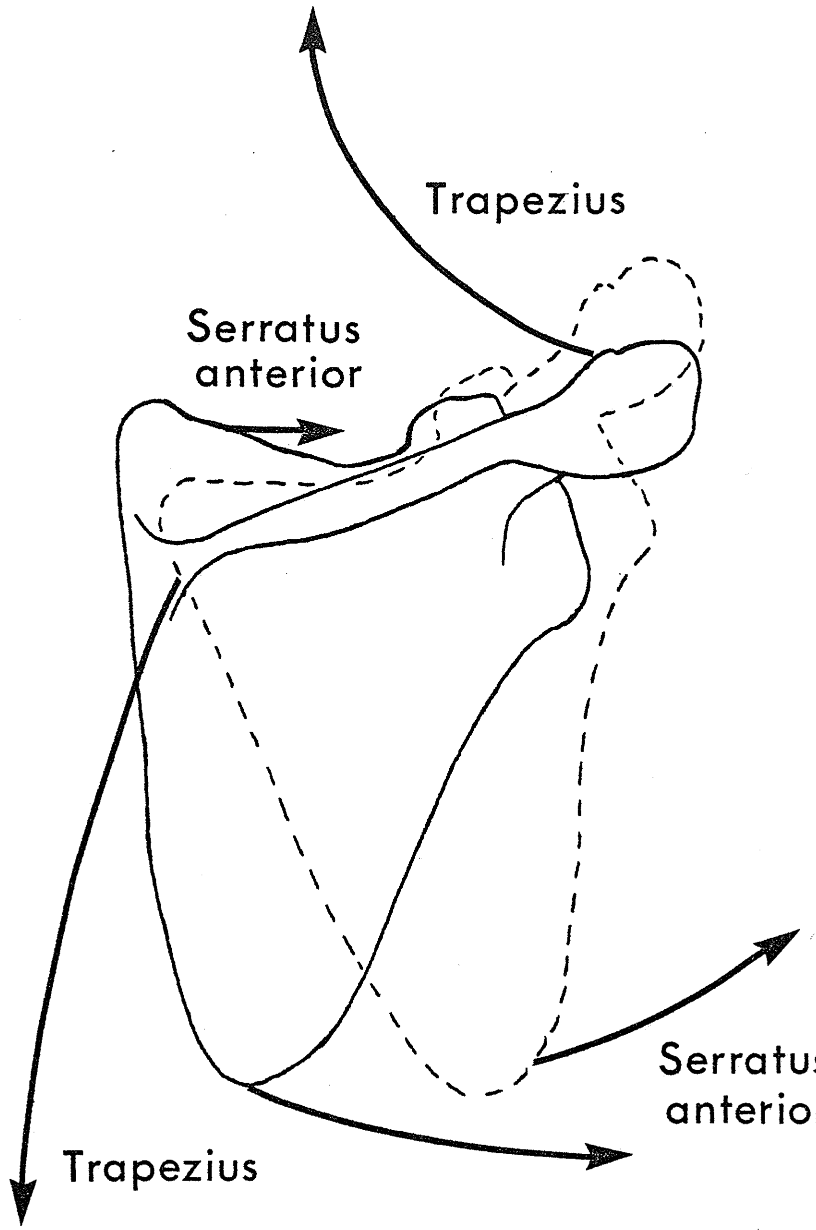
Serratus anterior is a muscular sheet which passes backwards around the thorax from a broad attachment on the ribs to the medial border of the scapula on the costal surface (Grant, 1963; Gray, 1973). The muscle arises by a series of digitations from the outer surfaces and superior borders of the upper eight, nine or ten ribs and from the fascia covering the intervening intercostals. The lower four digitations interdigitate with the fibres of the external abdominal oblique muscle. The muscle passes backwards around the chest wall, between the scapula and ribs. The upper digitation is attached to the costal surface of the superior angle of the scapula, the next two or three digitations spread out to be attached to nearly the whole length of the costal surface of the medial border. The lower four or five digitations converge like a fan to be attached to the costal surface of the inferior angle (Grant, 1963; Gray, 1973).

Serratus anterior is supplied by the fibres from the 5th, 6th and 7th cervical nerves through the long thoracic nerve (Gray, 1973).

Serratus anterior, with pectoralis minor, draws the scapula forward around the chest wall as in reaching, pushing and thrusting movements (Gray, 1973). Inman et al (1944) demonstrated that upper trapezius, levator scapulae and the upper part of serratus anterior constitute a functional unit. This unit supports the scapula, elevates it and acts as the upper component of a force couple mechanism during scapular rotation (Kapandji, 1970; Basmajian, 1974)(Fig. 2.9). The lower trapezius and lower half of serratus anterior constitute the lower part of the rotational force couple. The lower part of trapezius is the more active component of the lower part of the force couple during abduction, but in flexion it is less active than serratus anterior apparently because the scapula must be pulled forwards during flexion (Basmajian, 1974).

In the initial stages of abduction the serratus anterior acts with other scapular muscles to steady the bone so that deltoid is able to exert its action on the humerus and not on the scapula (Gray, 1973). While deltoid is abducting the arm, serratus anterior and trapezius rotate the scapula. During this action the forward pull on the inferior angle of the scapula by the lower digitations is coupled with the upward and medial pull on the base of the scapula spine by the lower fibres of trapezius (Gray, 1973; Basmajian, 1974). Downward rotation of the scapula is produced by the upper fibres of serratus anterior, the rhomboids, pectoralis minor and the middle part of trapezius (Kelly, 1971; Gray, 1973; Basmajian, 1974).

Catton and Gray (1952) demonstrated that serratus anterior does not function as an accessory respiratory muscle. Their study included voluntary deep breathing and forced respiratory acts such as coughing. Jefferson et al (1960) also demonstrated that action potentials were absent, during respiration, from the nerve to serratus anterior. Gray (1973) states that the work by Jefferson (1960) was on respiration in dogs and the study by Catton and Gray (1952) ignored the effect of fixing the scapula by holding on to a fixed object such as a bedrail or railing as asthmatics and athletes



ACTIONS OF TRAPEZIUS AND SERRATUS ANTERIOR IN SCAPULA ROTATION

Fig. 2.9

are seen to do in attitudes of forced respiration. Gray (1973) discussing the question of serratus anterior action in respiration states "this problem is clearly not solved". Basmajian (1974), however, writes of the "final blow" to the concept of serratus anterior function in respiration being struck by Jefferson et al in 1960. Paralysis of serratus anterior results in severe functional disability of the shoulder girdle (De Palma, 1973).

THE SHOULDER IN HEMIPLEGIA

Patients with lesions affecting portions of the vascular system of the brain, mainly the areas supplied by the middle cerebral artery, exhibit motor disturbances in one half of the body. The terms hemiplegia and hemiparesis denote impairment of motor function on one side of the body, specifically the upper and lower limb, and often the lower part of the face. Weakness is termed paresis, a more severe loss of motor function is termed paralysis. Most hemiplegia is the result of 'stroke', the failure of an artery in the brain which may cause loss of upper motor neurones. As many of the motor neurones cross the mid-line of the brain stem the lesion affects the side of the body opposite to the damaged side of the brain (Licht, 1975). In 1965 Hastings estimated that there were 2,000,000 persons in the United States with residual hemiplegia. Hastings suggested that one may expect this disability group to grow larger as the older population increases. Gibson (1974), discussing the epidemiology and patterns of care in stroke patients, states that the incidence of stroke was between 170 and 180 per 100,000 population per year, a figure requiring 2300 acute general hospital days per 100,000 population per year.

A study of the epidemiological features of stroke in Manitoba showed an annual incidence of 138 per 100,000 population (Abu-Zeid, 1975). This rate was slightly lower than that seen in major studies conducted in other parts of North America. Rates identified in Minnesota were 194, 154, and 170 per 100,000. In a study conducted in Massachusetts, rates were 165 and 187 per 100,000. It has been stated that stroke is responsible for the fourth largest category of hospital days in Canada (5.4%). This was identified in the statistical analysis of hospital data compiled by Health and Welfare Canada (1973).

The cerebrovascular accidents producing 'stroke' include cerebral infarction, embolism and haemorrhage. Hemiplegia may also be caused by neoplasm or trauma. Cerebral thrombosis accounts for the largest proportion of stroke cases, followed by cerebral hemorrhage, then embolism (Abu-Zeid et al, 1975). The incidence rates of stroke by sex and age show that the disease occurs more often in men than in women, particularly in people more than 50 years of age. Before the age of 50 there is no sex difference in the incidence of all strokes or specific types (Held, 1975; Abu-Zeid, 1975). The degree of involvement varies from one patient to another. Sensory disturbances are frequently present and, like the motor defects, appear on the body half that is opposite to the side of the lesion (Harrison, 1974). The importance of sensory impulses to the control and production of voluntary movement was demonstrated by Mott and Sherrington (1895). In experiments on monkeys, a complete sensory denervation of the limb by section of the posterior roots of spinal nerves abolished all voluntary movement. Certain automatic motor reactions were observed, but for practical purposes the limb was useless. The experiments by Mott and

Sherrington (1895) were confirmed by similar studies by Lassek (1953), Twitchell (1954) and the clinical observations of Hastings (1965), Pettery (1967), Brunnstrom (1970) and Bobath (1970). Brain and Walton (1969) defined the sensory impairment in hemiplegia. "The appreciation of posture and of passive movement is frequently seriously impaired together with the appreciation of light touch and its accurate localisation and the discrimination of the duality of compass points. The appreciation of size, shape, form, roughness and texture often suffers".

The muscular status of the hemiparetic patient usually is a spastic one although there is an initial stage in which a decrease in reflexes and muscle tone is present (Hastings, 1965; Drachman, 1967). Spasticity can be described as a "condition characterized by increased resistance of muscles to manipulation, by hyperactive deep tendon reflexes and by clonus, all of which are evidence of exaggerated contraction of muscles subjected to stretch" (Hastings, 1965).

Bobath (1970) states that four factors interfere with normal motor performance in adult hemiplegia:

1. sensory disturbances
2. spasticity
3. a disorder of the normal postural reflex mechanism
4. loss of selective movement patterns

The recovery of voluntary motion may range from zero to complete (Bard and Hirschberg, 1965). This range of recovery is due to the great variation in the site and nature of the cerebral lesion (Brunnstom, 1970). Wylie (1970) states that rehabilitation can offer a major source of hope for improvement in disabled stroke patients. The shorter the delay between onset of the episode and the initiation of treatment, the better the response.

Hastings (1965) conducted a survey of 116 cases of hemiplegia. Subjects were tested first at weekly, then monthly intervals. Nineteen subjects showed no recovery, 47 partial recovery and 50 full motion. Subjects who recovered full motion had initial motion in the first month, most of these achieving full range of movement within the first month, and all of them by the third month. Those subjects who attained only partial voluntary motion recovered movement slowly, most of them reaching a maximum during the sixth and seventh months. Bobath (1970) suggests that muscle tone does not become stable until about 12 to 18 months after the onset of hemiplegia.

It is during the early spastic period that the hemiplegic limb synergies make their appearance. Whether evoked reflexly or performed voluntarily, the synergies are 'stereotypes' (Brunnstrom, 1970). Synergies consist of either a gross flexion movement, a flexor syngergy, or a gross extensor movement, an extensor synergy. Brunnstrom (1970) suggests that variations do occur, but are related mainly to the relative strength of the synergy components. Neurophysiologically muscles that contract in a synergy are firmly linked together. Two synergies appear in the upper limb (Brunnstrom, 1970):

1. the flexor synergy consists of:
    a. flexion of the elbow
    b. supination of the forearm
    c. abduction of the shoulder
    d. lateral rotation of the shoulder

e. retraction and elevation of the shoulder girdle

2. the extensor synergy consisting of:

   a. extension of the elbow

   b. pronation of the forearm

   c. adduction of the arm

   d. medial rotation of the arm

   e. protraction of the shoulder girdle

The behavior of wrist and fingers varies considerably. Flexion of wrist and fingers may accompany the flexor synergy. Extension of the wrist with closing of the fist may appear with the extensor synergy (Brunnstrom, 1970).

Elbow flexion is the strongest component of the flexor synergy. Abduction of the arm is a weaker component. Abduction may remain permanently weak so that the patient never learns to abduct through full normal range. The maximum range for abduction as part of the synergy is in the region of 90^{o}. When attempting to abduct the patient may obtain limited abduction, extend the shoulder, flex the elbow and retract the scapula [Fig. 2.10(a)] (Pettery, 1967).

The strongest component of the extensor synergy is pectoralis major, producing internal rotation and adduction. Because of the frequency of this arm posture among patients this synergy has been termed a 'typical' arm position in hemiplegia (Brunnstrom, 1970).

ABDUCTION OF THE ARM IN HEMIPLEGIA [Fig. 2.10(a)]

If a patient in the early stage of hemiplegia attempts to raise the arm laterally to a horizontal position some abduction may occur as deltoid

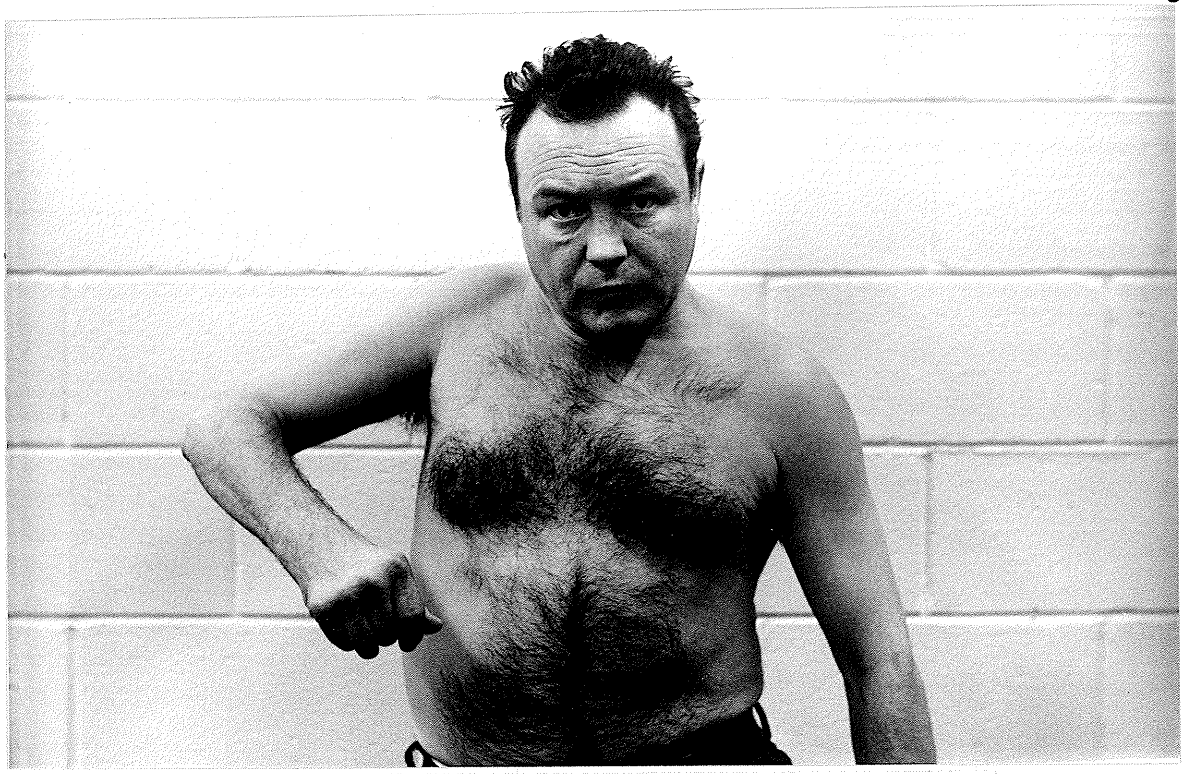


FIGURE 2.10(a).

ATTEMPTED ABDUCTION IN HEMIPLEGIA.

FIGURE 2.10(b).

ATTEMPTED ABDUCTION IN A LESION OF A GLENOHUMERAL JOINT STRUCTURE.

contracts with co-contraction of the short muscles attached to the rotator cuff. However as abduction occurs the elbow tends to flex because of the strong linkage that exists between the flexor muscles of the elbow and the abductor muscles. It is interesting to note that if abduction is to be performed correctly two components of the extensor synergy, extension of the elbow and pronation of the forearm and two components of the flexor synergy, abduction and retraction must occur together (Bobath, 1970; Brunnstrom, 1970). Brunnstrom (1970) states that "such a mixing of the synergy components is not easy for patients with hemiplegia because two competing influences are present and the patients' voluntary effort is insufficient to harmonise muscle action". In patients with hemiplegia, the flexor synergy when complete will show abduction limited to about 90^{o}. In the attempted movement serratus anterior may lie idle. Palpation confirms the contraction of trapezius and deltoid. Brunnstrom (1970) has noted that 'winging' of the scapula, a typical feature of an inactive serratus anterior, occurs when full abduction is attempted. The observations discussed here are based on observation and palpation of muscle groups. The synergy components have not been investigated fully using electromyographic techniques.

Other than spasticity with the limb synergies described above, other superimposed musculoskeletal and neuromuscular complications may be present. Moskowitz (1967 and 1969) listed these as:

1. painful shoulder with or without subluxation
2. reflex muscular dystrophy
3. peripheral nerve lesions

4. extra-articular calcification

5. vascular complications

Electromyography has been used to investigate subluxation of the glenohumeral joint in hemiplegia (Chaco and Wolf, 1971; Basmajian, 1974). When the arm is in the dependent position the stability of the shoulder is due largely to the activity of supraspinatus (Basmajian and Bazant, 1959). This muscle reinforces the horizontal tension of the capsule and holds the head of the humerus in contact with the glenoid cavity. The work of Chaco and Wolf (1971) in investigating the mechanism of subluxation of the shoulder supported the findings of Basmajian and Bazant (1959). Chaco and Wolf found that subluxation of the glenohumeral joint occurred in flaccid hemiplegia. The subluxation did not occur in the early hemiplegic period, within three weeks of onset, as the shoulder capsule continues to hold the head of the humerus in relation to the glenoid cavity. Chaco and Wolf (1971) noted that unless supraspinatus shows a return to activity subluxation of the glenohumeral joint did occur. When spasticity was present subluxation did not occur.

SOFT TISSUE LESIONS OF GLENOHUMERAL JOINT STRUCTURES

There are several causes of pain and limitation of movement in the shoulder region. However a review of the literature does not indicate a generally accepted classification of lesions. Largely due to the difficulty in classification of soft tissue lesions it is not possible to identify an epidemiological pattern. Cailliet (1966) classifies lesions and the causes of pain of musculoskeletal origin as:

1. degenerative
    a. tendinitis
    b. cuff tear

2. traumatic
   a. fracture
   b. dislocation
   c. acromioclavicular separation
   d. biceps tendon tear
3. inflammatory
   a. rheumatoid arthritis
   b. gout
   c. infectious arthritis
4. tumours
   a. bone
   b. soft tissue

Coltart (1963) writing on familiar clinical syndromes in lesions of the shoulder listed the following:

1. degenerative lesions of the supraspinous part of the musculo-tendinous cuff.
2. calcifying lesions in tendon and bursa.
3. complete adherence of the capsule to the head of the humerus.

Compere (1964) gives an extensive classification of causes of shoulder pain:

1. rotator cuff degeneration
2. acute and chronic tears of the rotator cuff with calcium deposits
3. tendinitis: supraspinatus or biceps
4. bursitis
5. rupture of the biceps tendon
6. sprain of the capsular ligaments

7. pericapsulitis, associated with arthritis
8. adhesive capsulitis - also termed 'frozen' shoulder
9. fibromyositis
10. osteogenic pain

Cyriax (1969) states "special difficulties attend identification of the many possible lesions, since the pain is in much the same place whatever the source. In addition double lesions are encountered often". Cyriax (1969) lists the following as possible sources of shoulder-arm pain:

1. capsule of the shoulder
2. sub-deltoid bursa
3. acromioclavicular joint
4. sub-coracoid bursa
5. costo-coracoid fascia
6. subclavian artery
7. supraspinatus tendon
8. infraspinatus tendon
9. subscapularis tendon
10. subclavius muscle
11. biceps tendon
12. triceps tendon

Bateman (1972) discussing lesions producing pain and limitation of movement in the shoulder region lists the following:

1. degenerative tendinitis
2. tendinitis with calcification
3. ruptures of the rotator cuff
4. bicipital lesions

5. acromioclavicular arthritis

6. glenohumeral arthritis

7. frozen shoulder

Excluding fractures, dislocations, inflammatory conditions and tumours of the shoulder complex, it is possible to narrow the group of lesions to those specifically involving glenohumeral joint structures. These lesions, all of which may limit movement, can be identified as:

1. degenerative lesions

2. ruptures of the rotator cuff

3. disorders of the bicipital apparatus

4. arthritis of the glenohumeral joint

5. frozen shoulder

Degenerative Lesions

Degenerative lesions are listed as a common cause of shoulder pain and stiffness. Bateman (1972) states that degenerative lesions constitute 90% of non-traumatic painful lesions. The degenerative soft tissue lesion has been called bursitis, adhesive capsulitis and frozen shoulder (Cailliet, 1966). Since aging is one of the prime factors in the development of degenerative changes, disabling lesions associated with these changes occur after the fourth decade of life (De Palma, 1973). The syndrome, including pain, muscle spasm and restriction of movement, may arise from many structures. It may be impossible in some instances to pinpoint the exact cause of the syndrome by clinical and X-ray examination. The chief obstacle to a specific diagnosis is the compactness of the shoulder region. The intimate relation of many structures in this small area may make it impossible to detect clinically the source of the lesion (De Palma, 1973).

Pain in the shoulder is not always caused by an intrinsic lesion. The cause may be a lesion at some distance from the shoulder. A lesion in the cervical spine, a tumour in the lung, a cardiac disorder or a subdiaphragmatic lesion may cause shoulder pain (De Palma, 1973).

The degenerative processes may involve both the musculotendinous cuff and the tendon of the long head of biceps (Bateman, 1972). Degenerative tendinitis is characterised by pain in the shoulder, then gradual limitation of movement, particularly rotation. No significant episode, accident or acute incident is associated with lesion (Cailliet, 1966; Bateman, 1972). Abduction of the shoulder is limited to 70° or 80° and both medial and lateral rotation is limited [Fig. 2.10(b)]. The patient may also exhibit pain on movement as the arm is raised and rotated, as in attempting to elevate through abduction (Moseley, 1969; Bateman, 1972). The primary changes which occur are due to wear and tear damage of capsular structures. Degeneration starts in the collagen fibres of tendon, bursae may become involved, and ultimately cartilage may be roughed and eroded (Bateman, 1972). It is possible that calcification may also occur in the rotator cuff, most often in the supraspinatus area, although it may also occur in the attachments of infraspinatus, subscapularis and teres minor.

Ruptures of the Rotator Cuff

Deficiencies in cuff substance can occur in all age groups and may result from a traumatic episode. Restriction of movement develops some weeks after the injury and reaches a point at which it is difficult to raise the arm to a right angle either in flexion or abduction. There is also some limitation of rotation (Compere, 1964; Cailliet, 1966).

Disorders of the Bicipital Apparatus

The long head of biceps is intimately related to the glenohumeral joint and is affected by all movements of that joint (Gray, 1973). Disturbances of the bicipital apparatus are not uncommon and can cause severe shoulder dysfunction. The tendon is exposed to friction in everyday life, particularly in heavy manual work when the arm is raised above the head (Bateman, 1972). There is usually a history of trauma in this lesion, either minor repetitive motion or a major injury. The patient may complain of a 'snapping' sensation on movement (Moseley, 1963; Cyriax, 1969; Bateman, 1971). Lesions of the bicipital apparatus may include bicipital tendinitis and tenosynovitis, rupture of the transverse humeral ligament as well as rupture of the biceps tendon (Bateman, 1972).

Arthritis of the Glenohumeral Joint

The shoulder joint is susceptible to post-traumatic and degenerative arthritis. Post-traumatic arthritis is the commonest type of arthritis in the glenohumeral joint. It develops following fractures of the anatomical neck or head of the humerus or fractures of the glenoid fossa. The arthritic lesion may be accompanied by considerable pain and limitation of movement (Moseley, 1963; Bateman, 1972). The degenerative type of arthritis arises from the progressive disturbance initiated by soft tissue injury. Damage to the cuff and biceps tendon alter normal function and introduce obstacles to movement. The frayed or ruptured cuff precipitates degenerative changes in the smooth cartilage. Pain and limitation of movement are characteristic of these degenerative changes (Cyriax, 1969; Bateman, 1972).

Frozen Shoulder

The condition of frozen shoulder may result from any of the musculo-skeletal lesions of the shoulder region previously described. It may be regarded as an end state rather than a primary lesion (Bateman, 1972). It is a collective term indicating a painful shoulder with severe limitation of movement (Neviaser, 1963; Cailliet, 1966; De Palma, 1973). The condition is rarely seen in patients under 40 years of age (De Palma, 1973). The patient complains of pain, aggravated by arm movement. The pain is associated with muscle spasm, which in turn further restricts movement. Motion becomes restricted in all ranges. The arm becomes immobile against the chest wall with the arm adducted, internally rotated and dependent. Any attempt at active or passive movement is restricted and pain occurs when movement is attempted. Varying degrees of limitation exist up to the point where there is total immobility and no active or passive movement is possible. Any movements of the shoulder complex are accompanied by movements of the scapula against the chest wall (Cailliet, 1966; Moseley, 1969; De Palma, 1973).

In the process of development of the frozen shoulder, changes may occur in the joint lining. In an early and acute case the synovium may stick to the articular cartilage. The normal lax inferior folds of the synovial membrane become 'glued together' (Bateman, 1972). The capsule is thickened and contracted, further limiting movement. The shoulder musculature, tense and in spasm from pain stimulation, remains contracted and later atrophies. As the joint structures contract, layer by layer, the freezing process becomes complete. In later stages the adhesions become thick and fixed, the rotator cuff inelastic and the joint cavity dry (Bateman, 1972). De Palma (1973) states that "with time all the soft tissue elements become involved in the process".

De Palma (1973) studied 72 patients with frozen shoulder. The results of the study showed the incidence was highest in patients between 50 and 60 years of age; 72% of subjects were women. Forty-seven subjects had no history of injury and the onset was insidious.

In some instances, particularly those with severe pain and muscle spasm the arm shows evidence of vaso-spasm. The hand is puffy and cool and the wrist and joints of the fingers and hand are stiff and painful (De Palma, 1973).

Frozen shoulder runs a specific clinical course; pain and stiffness increase slowly to a certain level of intensity, then after an unpredictable number of months the pain subsides gradually and motion returns (Cyriax, 1969; De Palma, 1973). Moseley (1969) states that the whole process may take from six to 36 months. Cyriax (1969) in describing 'freezing arthritis' states that "at the end of a year" the patient is returning to normal function.

The musculoskeletal degenerative lesions of the shoulder complex produce pain and limitation of shoulder movement, the limitation of movement being directly related to the severity of the lesion. In the normal shoulder complex there is smooth rhythmic movement produced by groups of muscles, prime movers, antagonists and synergists. When muscles or joints are out of their proper working arrangements alterations in this harmonious action will occur (Moseley, 1969).

TECHNIQUES OF MOTION ANALYSIS

Biomechanics is the science that investigates the effect of external and internal forces on human and animal bodies in movement and at rest (Drillis, 1958; Edelstein, 1965). The study of movement can be divided into:

1. Kinematics: The position of a body in space at a particular time.
2. Kinetics: The forces which produce or alter motion.
3. Temporal components: The timing of different parts of the movement pattern. This is related particularly to repeated movements, such as the repetition of the gait cycle in locomotion.
4. Electromyography: The study of the electrical activity in voluntary muscle tissue during contraction.

Photography

One of the most widely used methods of motion analysis involves photographic techniques. There is a variety of techniques ranging from interrupted light photography as used by Marey in 1882 (Steindler, 1970) to the use of television videotape recording for computer analysis (Winter, 1972). Motion photography is a widely used method of studying motion and has been used to analyse the components of many athletic performances (Kelly, 1971). These techniques often involve serial photography and 'slow motion' analysis. The great majority of motion analyses have been in the study of normal movement patterns (Kelly, 1971). Motion analysis of abnormal activity has largely been related to the study of locomotion patterns (Drillis, 1958; Murray et al, 1964; Knutsson, 1972; Richards, 1972). There are few reports of kinematic analysis being applied to the upper extremity, other than the film analysis of arm movements in sport (Kelly, 1971). This is probably due to the complexity involved in shoulder girdle analysis. Arm movement is the product of motion in scapular, clavicular and humeral articulations. Motion analysis by film would only indicate the gross movement of the limb and not the motion occurring in each part of the shoulder complex.

Electrogoniometry

The electrogoniometer consists of two arms of a goniometer with a rheostat substituted for the protractor. A current passes through the rheostat to an oscillograph where voltage changes are recorded in degrees (Tipton et al, 1965; Liberson, 1965; Johnston and Smidt, 1969; Kettlekamp, 1970; Korb, 1970; Perry, 1974). In the study by Liberson (1965) a potentiometer was mounted in long leg braces at the brace joints of hip, knee and ankle. A major problem of this piece of apparatus is the application of the apparatus which may distort the normal pattern of movement of the joint (Winter et al, 1972). Goniometers have been mainly related to the study of locomotion patterns and few reports are available of goniometers designed for upper extremity evaluation (Jones, 1970). The major design constraint in the development of a goniometer which would evaluate arm function is the fact that upper extremity movement is the product of the mobility of several joints. A typical goniometer is placed over the axis of movement of one joint. Ramsey (1960) describes a goniometer used to measure shoulder and elbow movements. Lewertoff (1970 and 1971) describes a goniometer for shoulder joint measurement. This goniometer consists of three functional parts: a stationary member attached to the area over the upper thoracic spine, a moveable member attached to the arm, and an intermediate moveable member. Two potentiometers placed between the three lever arms registered movement. Lewertoff (1971) reporting on the development of the goniometer states "considerable difficulties are encountered, however, in achieving adjustments, that is, proper alignment of the instrument to the subject's body prior to experimentation is still a long process".

Jones (1970) used a gravity reference goniometer with two potentiometers, to measure arm movement in a study of normal muscle action in the shoulder region. This goniometer was a considerable advance on others previously reported in that the force of gravity rotated the potentiometers as the arm moved. The goniometer responded to both angular and rotational movements of the arm. This dispensed with the need for two or more rigid levers fixed to the arm and shoulder girdle. The varying voltage signal from the potentiometers was translated into degrees of movement and subsequently correlated with electromyographic activity.

Electromyography

Electromyography is concerned with the measurement and analysis of muscle action potentials (Licht, 1971). Numerous techniques for recording and various methods of analysing the data have been developed. Kelly (1974) states "the person interested in using electromyography must determine exactly what his objectives are and then what type of instrumentation would best provide valid data". The development of the electromyogram by Inman et al (1944) demonstrated a method of recording muscle contribution to shoulder complex activity. In the experiments by Inman et al (1944), tracking data of moving body parts were recorded by cinematographic techniques and correlated with electromyographic data to determine the relationship between the moving parts and the muscles which produce its movements. In addition to correlating electromyographic information with film records other techniques of correlation can be used. Peat (1974) correlated electromyographic data with footswitch information in an analysis of hemiplegic gait. Perry (1974) used a similar technique in a study of muscle activity in cerebral palsy.

In the analysis of upper extremity activity, the Kinesiology Group at the Highland View Hospital, Cleveland, used cinematography for motion analysis of hand activities. Long (1970) used electromyography and electrogoniometry in an extensive analysis of intrinsic hand muscle action. Taylor and Blaschke (1951) used photography in a kinematic study of shoulder and arm movements. Brandell (1970) used electromyography and cinematography in a study of muscles acting on the index finger. Electromyographic studies of shoulder muscle activity by Scheving and Pauly (1959) and Shevin et al (1969) related electrical activity to gross movements only. No attempt was made to correlate specific joint position with electromyographic activity.

Galvani is considered the originator of the study of electrical activity in muscle. At the end of the eighteenth century Galvani reported his experiments with nerve muscle preparations and electricity (Basmajian, 1974). Galvani believed that muscles stored and discharged electricity received from the nerves (Licht, 1971). No investigation of electrical activity was done, however, until the twentieth century when technological advances permitted the detection and recording of the minute electrical discharges in muscle. At the end of the Second World War a pronounced improvement in technology and the increasing availability of electronic apparatus enabled anatomists, neurologists and physicians to make increasing use of electromyography (Basmajian, 1974). The development of electromyography was stimulated by the work of Adrian and Bronk (1928 and 1929). In 1929, following the development of the coaxial needle electrode, Adrian and Bronk recorded the potential developed by a single muscle fibre. A study by Inman et al (1944) on shoulder muscle activity was one of the first major kinesiological studies which used electromyographic techniques. During the decade of the fifties several electromyographic studies were reported. These, however, were mainly related to the clinical use of electromyography (Basmajian, 1974).

Electromyography has been used as a diagnostic tool in neuromuscular pathology, primarily the study of motor unit activity, motor units working on their own or in small groups (Licht, 1971). In kinesiology the investigators have studied the action of whole muscles rather than individual motor unit activity. Kinesiological studies have been reported by a number of investigators (Slaughter, 1959; Shevin et al, 1969; Jones, 1970; Brandell, 1970; Peat, 1974; Perry, 1974). Many publications have been reported in recent years dealing with advances in the techniques of electromyographic kinesiology. Basmajian (1959; 1963; 1969; 1972; 1972b) has been one of the major contributors.

THE BASIS OF ELECTROMYOGRAPHY

All skeletal muscles are made up of numerous muscle fibres ranging from 10 to 100 microns in diameter. In most cases the fibre extends the whole length of the muscle and is innervated by one neuromuscular junction (Guyton, 1966). On contracting, the muscle fibre shortens to about 57% of its resting length. In normal muscle contraction there is a widespread rapid series of twitches which occur asynchronously among the fibres. The apparent smooth contraction is a summation of the asynchronous twitches (Basmajian, 1972b). The adding together of individual muscle twitches to make strong and concerted muscle movements is termed 'summation' (Guyton, 1966). Summation occurs in two different ways, first, by increasing the number of motor units contracting, and second, by increasing the rapidity of contraction of individual motor units.

Skeletal muscle fibres do not contract as individuals; groups of fibres contract at one time. The constituent fibres of one 'group' of muscle fibres are supplied by the terminal branches of one nerve fibre or axon whose cell body is in the anterior horn of the spinal cord. The nerve cell body, plus the axon, the terminal branches and all the muscle fibres supplied by these branches constitute a motor unit (Karpovich and Sinning, 1971; Kelly, 1971; Basmajian, 1974). Individual motor units contract at frequencies of up to 40 per second, a rate that establishes tetany (Karpovich and Sinning, 1971). Basmajian (1974) states that the motor units contract at various frequencies, usually below 50 per second. There is no single frequency; individual motor units can fire slowly and will increase their frequency of response on demand.

Not all muscles have the same number of fibres in the motor units. The number of muscle fibres served by one axon varies widely. Muscles that react rapidly and function precisely have few muscle fibres in each motor unit and have a large number of nerve fibres supplying each muscle. Feinstein et al (1955) reported nine muscle fibres per motor unit in the human lateral rectus, 25 in platysma, 108 in the first lumbrical, and 2000 in gastrocnemius. The fibres in a motor unit may be scattered and intermingled with fibres of other units. Basmajian (1974) states "the individual muscle bundles one sees in cross section in routine histological preparations of normal striated muscles rarely if ever correspond to individual motor units".

The amount of tension produced by a single motor unit is quite small. Under normal conditions small motor units are recruited early, and as the force is increased larger units are recruited. In addition all the motor units increase their frequency of twitching as the force is increased (Kelly, 1971). When the neural impulses reach the myoneural junction, a wave of contraction spreads over the fibre, resulting in a brief twitch followed by complete relaxation. The duration of this twitch and relaxation varies from a few milliseconds to as much as 0.2 sec., depending on whether the fibre is of the slow or fast conducting type (Basmajian, 1974). During the twitch, a minute electrical potential is generated which is dissipated into the surrounding tissues. This potential has a duration of only one or two msec. (Kelly, 1971; Basmajian, 1974). As all the fibres in a motor unit do not contract at exactly the same instant the electrical activity is extended to about five to 12 msec., with a median duration of nine msec. With fine wire electrodes the potentials recorded are shorter, Basmajian and Cross (1971) finding a mean duration of five msec. The amplitude of the motor unit potentials is around 0.5 millivolts. On the oscilloscope or other recording device the potential is seen as a sharp spike that is usually bi- or tri-phasic although it may have a more complex form. The larger potentials are produced by the larger motor units (Basmajian, 1974). It is important to note that the size of the motor unit potential (MUP) is affected by a number of factors. These factors are related to the techniques used to record the potentials and include the type of apparatus, the type of electrode, and the position of the electrodes in relation to the motor unit (Basmajian, 1974).

In muscle contraction, small potentials appear first with slight contraction, and as the force is increased larger and larger potentials are recruited. In addition, all motor units increase their frequency of firing (Guyton, 1966; Basmajian, 1974). This is termed 'motor unit recruitment'. As volitional contraction increases, more and more units come into action. The resulting overcrowding, on the oscilloscope or recording device, causes overlapping, and some of the potentials summate producing the interference pattern characteristic of full voluntary contraction.

In early EMG studies (Adrian and Bronk, 1928 and 1929), it was accepted that the normal upper limit of activation or motor unit frequency was about 50 per second. Kelly (1971) states that frequency has been found to range from six to 60 per second.

RECORDING OF THE MOTOR UNIT POTENTIAL

Electromyography is concerned with the measurement and analysis of motor unit potentials. The electrical signal from the muscles is picked up by electrodes and transmitted either by a wire or telemetry device to the electromyograph which receives and then records the potentials as electromyograms (Kelly, 1971). As with any other electrical signals, electromyographic potentials can be transmitted either by cables or by FM radio. The latter, which is termed telemetry, is particularly useful when the subject must be completely unfettered by dragging cables, for example in locomotion studies (Peat, 1974; Winter et al, 1974). The signal can be displayed on a variety of devices. One of the most convenient of these is the pen-writing recorder. This unit can record several signals simultaneously on a moving strip of paper. One of the most sophisticated methods of recording uses the multichannel FM tape recorder. Data stored on magnetic tape is then displayed. This data can also be retained for later analysis (Winter et al, 1974).

The electromyographic signal may be displayed on the recording device in its raw or unprocessed state or in some processed form. The system of processing varies, but two types commonly used are the integrated signal, and the signal which has been fullwave rectified and lowpass filtered (Quanbury, 1973). The integrated wave form is a summation of the electrical activity over a specified period of time and presented as the total activity for that time (Fig. 2.11). The signal which is rectified and lowpass filtered has all the rapidly changing components of the wave form removed so that one is left with a record, or 'envelope' as it is

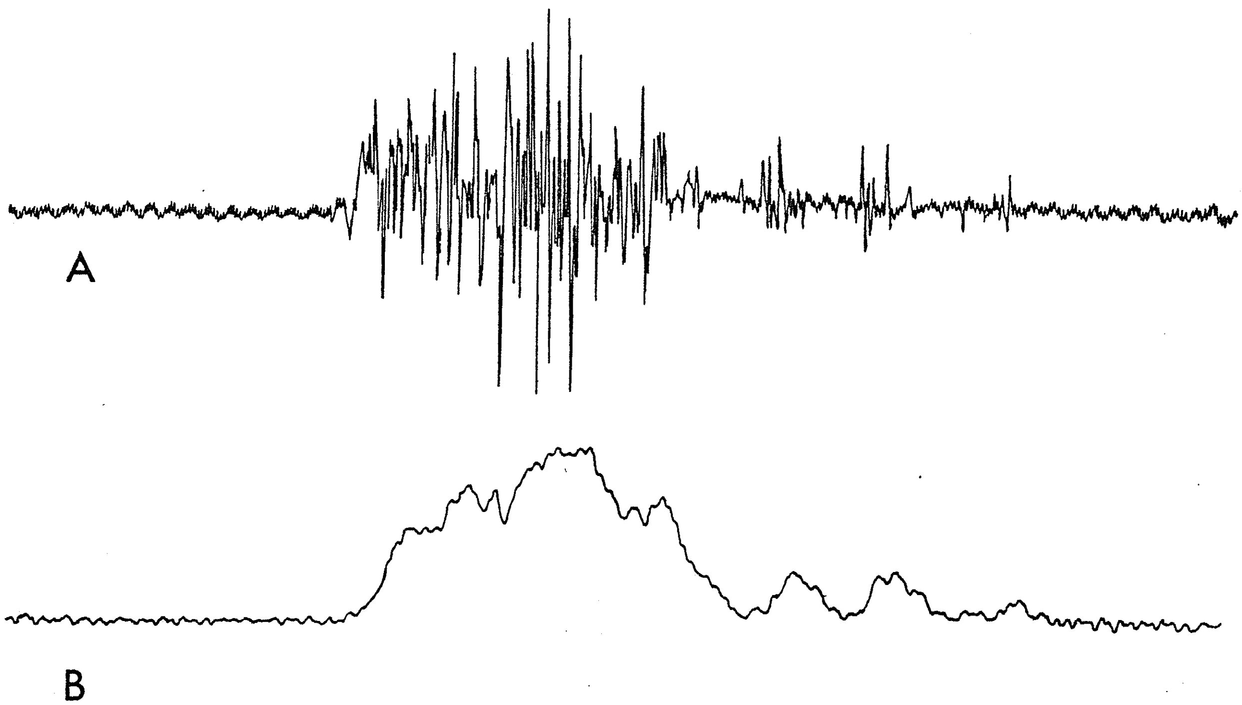


Figure 2.11-Raw EMG (A)
and Processed Signal (B)

termed, which indicates the intensity of activity at each instant of time. As the latter method indicates changes in the wave form as they occur it is a suitable method for the study of phasic muscle activity (Quanbury, 1973). If the investigator is using an envelope for analysis it is useful to have a method also of displaying the raw unprocessed signal as a check of the duration and general configuration of the signal.

The electrical activity from the muscle can be recorded by using electrodes inserted into the muscle belly, or surface electrodes applied over the surface of the muscle. The type of electrode used depends on the objective of the study (Komi and Buskirk, 1970; Kelly, 1971). When the operator is interested in the activity of motor units individually or in a small group, then the choice is an indwelling electrode. When the measurement of the whole muscle or groups of muscles are to be made, surface electrodes may be used (Komi and Buskirk, 1970). Basmajian states that "surface electrodes can be used where a broad or global pick up of a number of muscles or a large area of muscle is desired". Grossman and Weiner (1966) in a discussion of the factors influencing the reliability of surface electromyography stated "surface electromyography provides a measure of electrical activity which is doubtless related to muscle contraction". Komi and Buskirk (1970) reported on the reproducibility of electromyographic measurements with inserted wire electrodes and surface electrodes. They stated that the relatively high reliability coefficients obtained with the surface electrodes are encouraging and suggest that this technique is acceptable for use in long-term studies.

Surface electrodes have been used in the examination of shoulder muscle activity. Sigerseth and McCloy (1956) investigated the activity of biceps, deltoid, latissimus dorsi, pectoralis major, serratus anterior, sternomastoid, teres major, trapezius and triceps using bipolar surface electrodes placed four cm apart along the length of the fibres of the muscles. Slaughter (1959) used surface electrodes to study the activity of biceps, triceps and pronator teres. Scheving and Pauly (1959) used a surface electrode technique to study deltoid, serratus anterior and latissimus dorsi. Yamshom and Bierman (1948 and 1949) used surface electrodes in their studies of trapezius and deltoid. Wiendebauer and Mortensen (1952) also used surface electrode techniques in a study of the action of trapezius.

Surface electrodes are usually made of silver, platinum, gold or a combination of a metal and one of its salts, such as silver and silver chloride (Quanbury, 1972). Surface electrodes can be used singly or in pairs. The bipolar arrangement is preferred because it greatly reduces any common noise signal picked up by both active electrodes. In the bipolar arrangement two active electrodes are placed over the belly of the muscle (O'Connell et al, 1963).

Surface electrodes are applied with a contact paste or jelly, to provide adequate electrical contact, and attached to the required area by an adhesive collar. The surface electrode may be applied dry but is usually used with a saline paste or jelly to improve electrical contact. In addition the skin on which the electrode is placed is shaved, cleaned with an alcohol acetate mixture and rubbed with a slightly abrasive material. The objective is to reduce the electrical surface impedance to practical levels of around 3000 ohms by removing body oils and layers of dry skin (Quanbury, 1972; Basmajian, 1974). The method of electrode attachment has a substantial effect on its electrical stability. Any movement or change in contact area can result in a movement artifact. An artifact is a spurious artificial signal not generated by the process under evaluation (McLeod, 1973). The electrode can be attached to the skin by adhesive tape. The double-sided adhesive collar is one of the most satisfactory methods in that it restricts movement between electrode and skin and forms a seal which prevents the saline paste from drying out under the electrode (Quanbury, 1972). Properly applied the surface electrode is electrically stable, free from movement artifact and maintains these properties for several hours. The electromyographic signal which it delivers is an integration of the electrical activity over a fairly large volume of muscle tissue so that it gives a good indication of that muscle's activity. Kramer, Frauendorf and Kuchler (1972) demonstrated that electrode pressure and interelectrode distance are important factors in surface electromyography. They suggest an optimum distance is six to 10 cms.

The major advantage of surface electrodes is convenience. They are readily available and can be applied easily with no discomfort to the subject. Minimum discomfort to the patient is of considerable importance in clinical studies. The attachment of surface electrodes rather than the insertion of indwelling electrodes is probably more acceptable to both patient and physician. The limitations of surface electrodes to the study of large muscle areas or groups of muscles must however be appreciated. For most kinesiological work the preferred technique utilises the fine wire bipolar electrodes as developed by Basmajian and Stecko (1962). The fine wire electrodes have a number of advantages. They are extremely fine, easily implanted and withdrawn and painless. They produce clear, precise signals and are broad in their pick up (Basmajian, 1974).

CHAPTER III

MATERIALS AND METHODS

INTRODUCTION

The purpose of this investigation was to examine the activity of three muscles acting on the shoulder complex. Normal subjects and subjects with limitation of shoulder mobility due to hemiplegia or lesions of a glenohumeral joint structure, were included in the experiment. The muscles examined were the upper fibres of trapezius, serratus anterior and the anterior, middle and posterior fibres of deltoid. Trapezius and serratus anterior were representative of muscles acting on the scapula and contributing towards its control during arm movements. Deltoid is a major abductor of the glenohumeral joint.

Surface electrodes were placed on trapezius over the central area of the bulk of the upper fibres. Electrodes were placed on deltoid in the centre of the anterior, middle and posterior sections of the muscle. Electrodes were placed on serratus anterior in the mid-axillary line at the level of the seventh rib.

The investigation was concerned with the phasic activity of the muscles in the normal, and in the two abnormal groups during attempted voluntary elevation of the upper extremity in the scapular plane of abduction. Phasic activity refers to the phases or periods of changing activity seen in the electromyographic record of muscle activity.

More specifically, the objective was to evaluate quantitatively abnormal muscle activity, to gain an increased understanding of muscle contribution to attempted movement of the arm in a neurological or soft tissue lesion affecting shoulder function. This study was also directed towards the development of a system which would assist in the clinical assessment of the patient by the evaluation of electromyographic and limb position data.

The investigation included a study of a control group of 30 normal subjects. The age range from 10 to 88 years was wide in order to determine whether there was any difference in muscle activity within the control group according to age. The mean age of the normal group was 46.2 years. Normals were selected on the basis that they had no current medical history or history of any previous lesion which might alter scapulohumeral mobility, e.g., upper extremity fracture or joint pathology.

The 21 hemiplegic and 18 soft tissue lesion subjects were selected from the Health Sciences Centre and St. Boniface Hospital, Winnipeg. The requirements were that the patient should have a primary diagnosis of hemiplegia, or a diagnosis indicating a lesion in a glenohumeral joint soft tissue structure, excluding bone pathology, fractures or dislocations. The age range of the hemiplegic group was 28 to 73 years. The mean age was 58.4 years. The age range of the group with lesions of a glenohumeral soft structure was from 39 to 70 years. The mean age of the latter group was 53.1 years. It was necessary for all subjects to be able to perform limited elevation of the arm. Three attempts at elevation were necessary during the test, as the muscle activity was assessed on an average of three attempts.

No information is available as to whether the fact that a lesion is right-sided or left-sided influences the pattern of impairment of movement and function of the shoulder complex.

Subjects were selected only on the basis of their availability at the time the study was being done. No attempt was made to select only hemiplegics with one category of clinical history. Subjects with a lesion of a soft tissue structure of the glenohumeral joint were also accepted according to availability. The variety of diagnoses seen in the latter group is indicative of the general lack of agreement on a classification of lesions of this type. The diagnoses of the group of 18 subjects with lesions of a glenohumeral joint structure were:

Frozen Shoulder	- 3
Adhesive Capsulitis	- 8
Bursitis	- 5
Rotator Cuff Lesion	- 2
TOTAL	18

However, although the terminology of classification varies, the lesions were all of soft tissue structures of a glenohumeral joint structure.

All subjects in the abnormal groups exhibited limitation of movement of the shoulder,with difficulty in elevating the arm in the scapular plane of abduction. Elevation is essential in functional movement which bring the hand towards the face. All abnormal subjects exhibited some limitation in the performance of activities of daily living which required free shoulder mobility. Activities of daily living which were affected included dressing, eating and routine toilet activities.

LABORATORY FACILITIES

The electromyography laboratory at the Department of Anatomy, Faculty of Medicine, University of Manitoba was developed to provide the technology used in this study.

Equipment used in the laboratory included:

1. Pre-amplifier
2. Ink recorder
3. Electrogoniometer
4. Oscilloscope

The electromyographic data from the subjects was fed to a pre-amplifier. From the pre-amplifier the signals were relayed to an ink recorder, with an attenuator to regulate the degree of pen deflection or gain, most suitable for the input signal amplitude. Data was collected for subsequent analysis on the revolving paper scroll of the ink recorder. Electrogoniometric signals were fed directly from the goniometer to the ink recorder. Amplification of this signal by the pre-amplifier was not necessary. A diagram of the apparatus layout is shown in Fig. 3.1 and 3.3.

Pre-amplifier

The pre-amplifier for this experiment was developed, designed and constructed in the Electronics Shop of the Biomedical Engineering Research Department, Shriners Hospital, Winnipeg. The circuit design is shown in Fig. 3.2.

The pre-amplifier was designed so as to provide output of either raw or processed electromyographic signals. Each of the eight channels of the pre-amplifier was provided with two pairs of output terminals, one for raw, the other for processed signals. Although data analysis was based on the processed signal the raw signal was periodically sampled and compared with the processed information. A processed signal results in

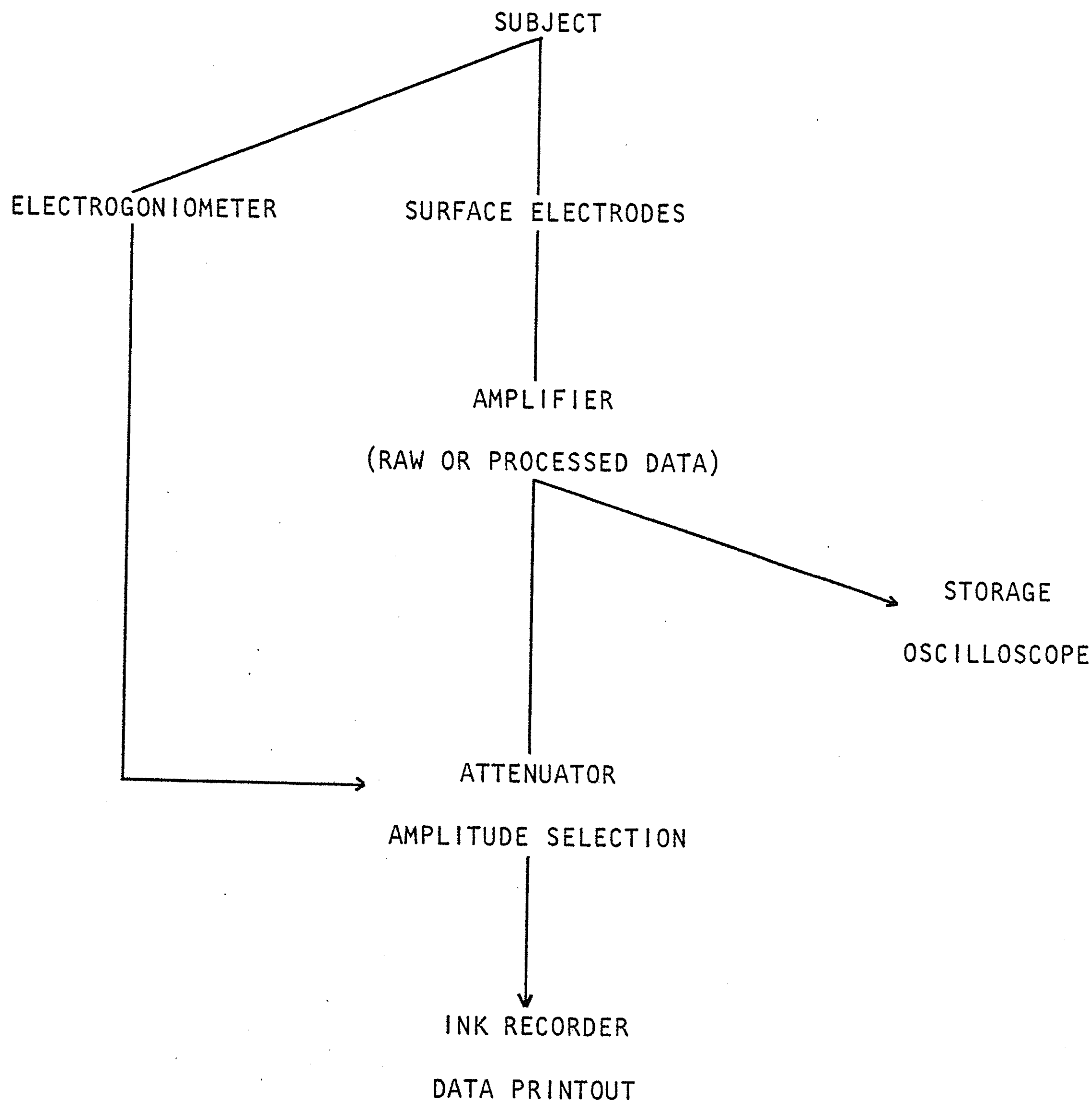


FIGURE 3.1. ELECTROMYOGRAPHIC LABORATORY DESIGN.

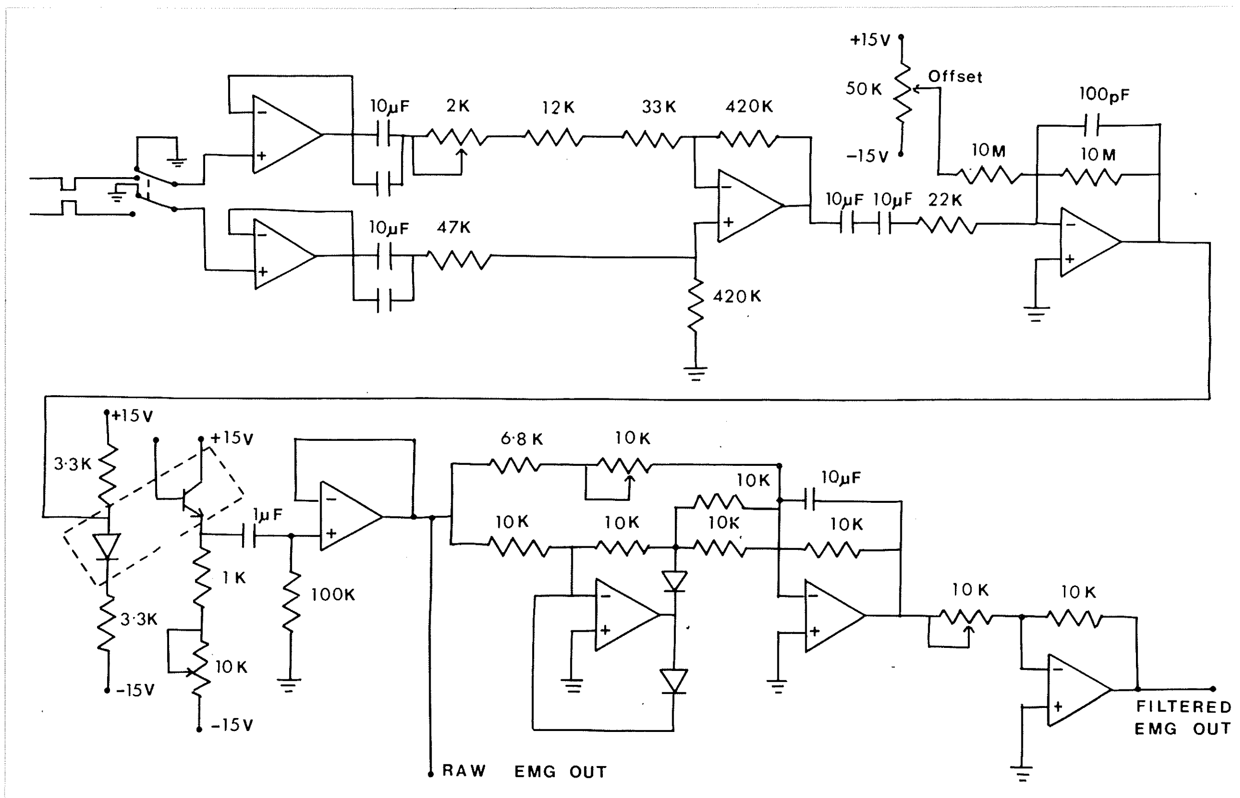


FIGURE 3.2. AMPLIFIER CIRCUIT.

an envelope wave form, the magnitude of which is proportional to the 'spikes' of the raw EMG signal (Quanbury, 1975). Processed date has been used in previous studies (Letts, Winter and Quanbury, 1975; Peat et al, 1976).

Electrical features of the pre-amplifier:

A. Input stage

B. Electrical characteristics

C. Band width

D. Common Mode Rejection Ratio

E. Voltage gain

F. Processing

A. The input stage is that part of the apparatus which is connected to the electrodes. This is electrically isolated from the casing of the unit so that should an electrical fault arise, the patient is protected from electrical hazard.

B. The electrical characteristics of the input impedance is 20 Megohms and the common mode impedance is 10 Megohms. The input impedance is measured at the terminals to which the surface electrodes are attached. The common mode impedance is measured between ground and electrode terminal. The level of input and common mode impedance is substantially higher than the impedance of the electrodes themselves so that there is minimal attenuation of the signal picked up from the electrodes.

C. Band width ranges from 20 Hertz (Hz) to in excess of five Kilohertz (KHz). This band width prevents the transmission of artefacts due to cable motion or electrode movement. An artefact is a spurious artificial signal not generated by the process under evaluation (McLeod, 1973).

D. The Common Mode Rejection Ratio (CMRR) extends from 80 to 100 decibels (dB) at 60 Hz. This eliminates the 60 Hz noise that may be picked up by the electrodes.

Noise refers to power line frequency electrical interfence (McLeod, 1973). If this interference is not eliminated there can be severe distortion of the EMG signal so as to make the latter unusable.

E. The overall voltage gain of the pre-amplifier is 4700. This gives sufficient signal amplitude to cause full scale deflection of the ink recorder.

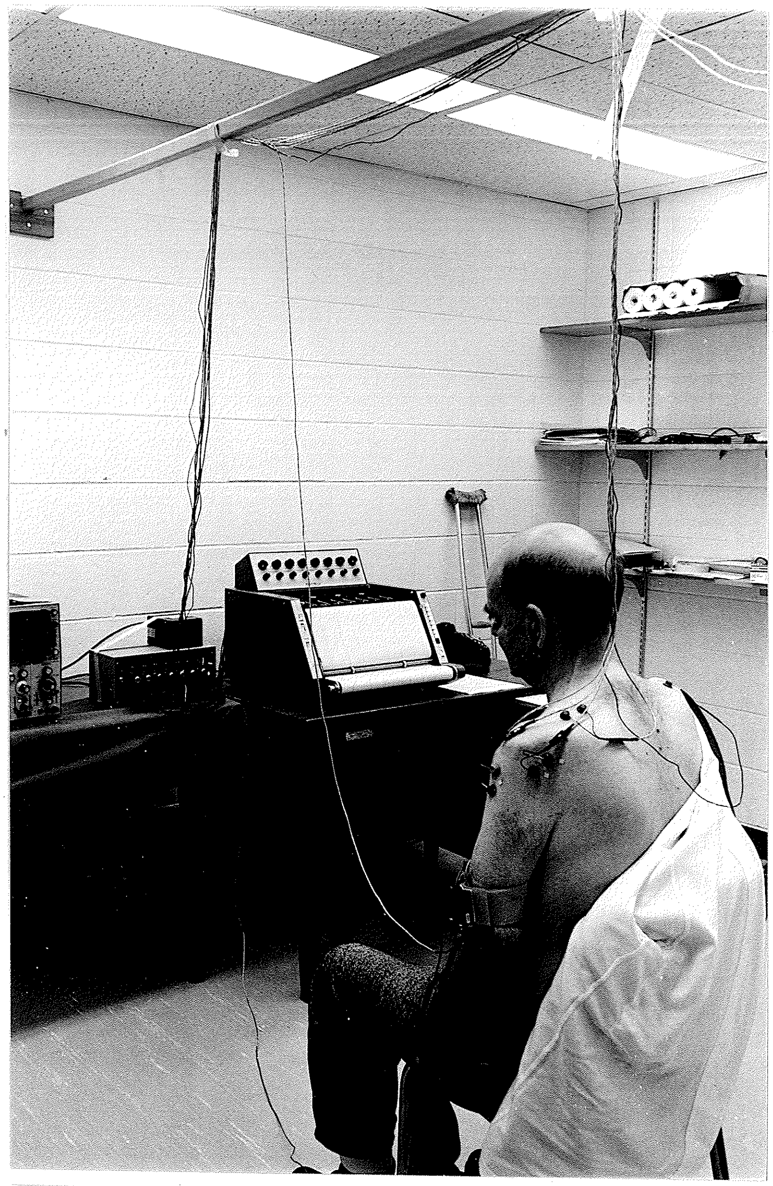
F. Processing consists of full wave rectification of the raw EMG signal followed by low pass filtering with a time constant of 100 milliseconds.

Ink Recorder

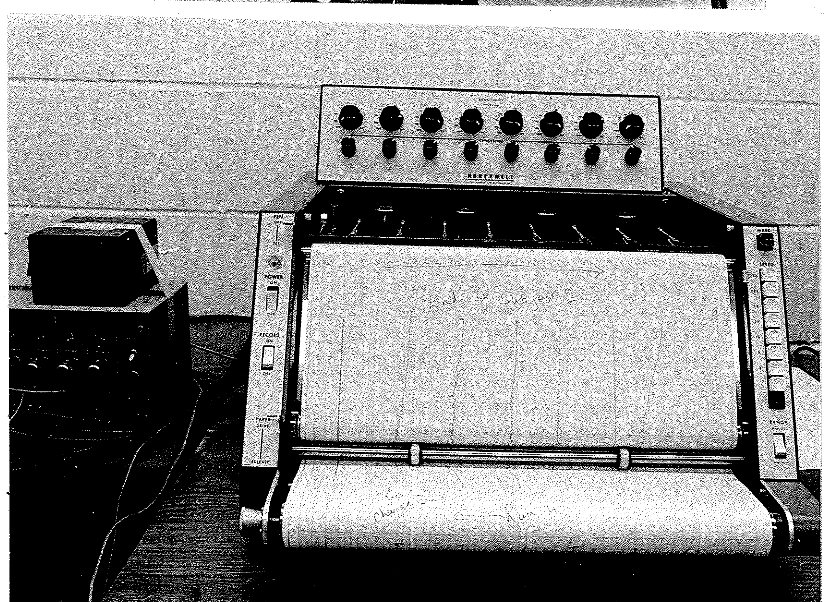
A series 2508 eight channel Honeywell Pen Recorder was used for all data recording. The unit is shown in Fig. 3.3.

This ink recorder is a rectilinear ink writing oscillograph that simultaneously records up to eight channels of analog data at frequencies varying from direct current (DC) to beyond 50 Hz.

All signals were fed to the pen recorder via a Honeywell attenuator. The attenuator range included settings of 0.5, 1, 2, 5, 10, 20, 50, 100 and 200 volt/cm. The deflection of the pen recorder for data recording was set in the attenuator at 2, 1 or 0.5 volt/cm. This range of sensitivity was satisfactory for EMG signal recording. A sample of data recorded is shown in Fig. 3.4.



SUBJECT CONNECTED TO AMPLIFIER.



HONEYWELL PEN RECORDER.

FIGURE 3.3.

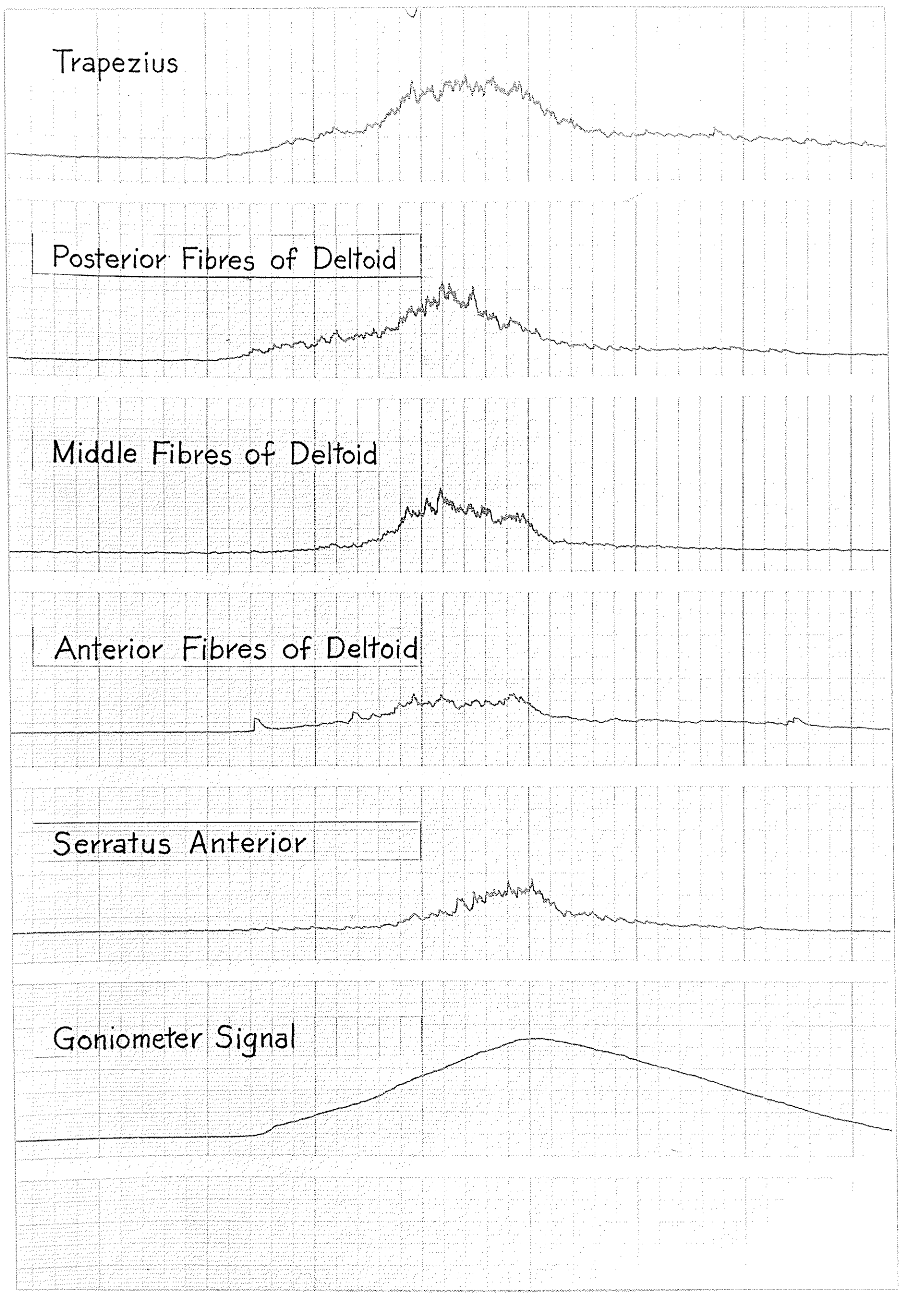


FIGURE 3.4.

SAMPLE OF EMG DATA AND GONIOMETER SIGNAL.

PHOTOGRAPH OF DATA FROM (NORMAL SUBJECT)

THE INK RECORDER.

Electrogoniometer

Mechanical Construction

The basic design of the electrogoniometer followed the gravity reference principle of Jones (1970). The electrogoniometer consisted of a potentiometer with a pendulum weight attached to its shaft and mounted in a special bracket with two small bearings (Peat et al, 1976)(Fig. 3.5). The potentiometer was free to rotate in its mounting bracket about an axis at right angles to its shaft. This ensured that the plane of the pendulum weight was always vertical even though the subject's arm might rotate about its long axis, during the movement. It was necessary to apply a counter-weight to the rear of the potentiometer to balance the weight of the pendulum and the position of this weight was adjusted so that the potentiometer shaft was always horizontal. The potentiometer was a low torque (0.7×10^{-3} N-m) 360° rotation type (Linear Beckman Potentiometer; TSP-5K) with a maximum resistance of five Kohms. The pendulum weight, which always hangs vertically, caused the shaft to turn as the body of the potentiometer was rotated about the axis of the shaft. Connected to the mounting bracket through a simple adjustable joint was a curved metal arm plate which was held in position over the upper arm with a 2" wide velcro strap. A 360° protractor mounted concentrically with the potentiometer shaft permitted comparison of angle readings with electrical output for calibration purposes. The weight of the electrogoniometer is 285 gms.

Electrical Circuitry

The electrical circuit of the electrogoniometer is shown in Fig. 3.6. The batteries and other components were mounted directly on the

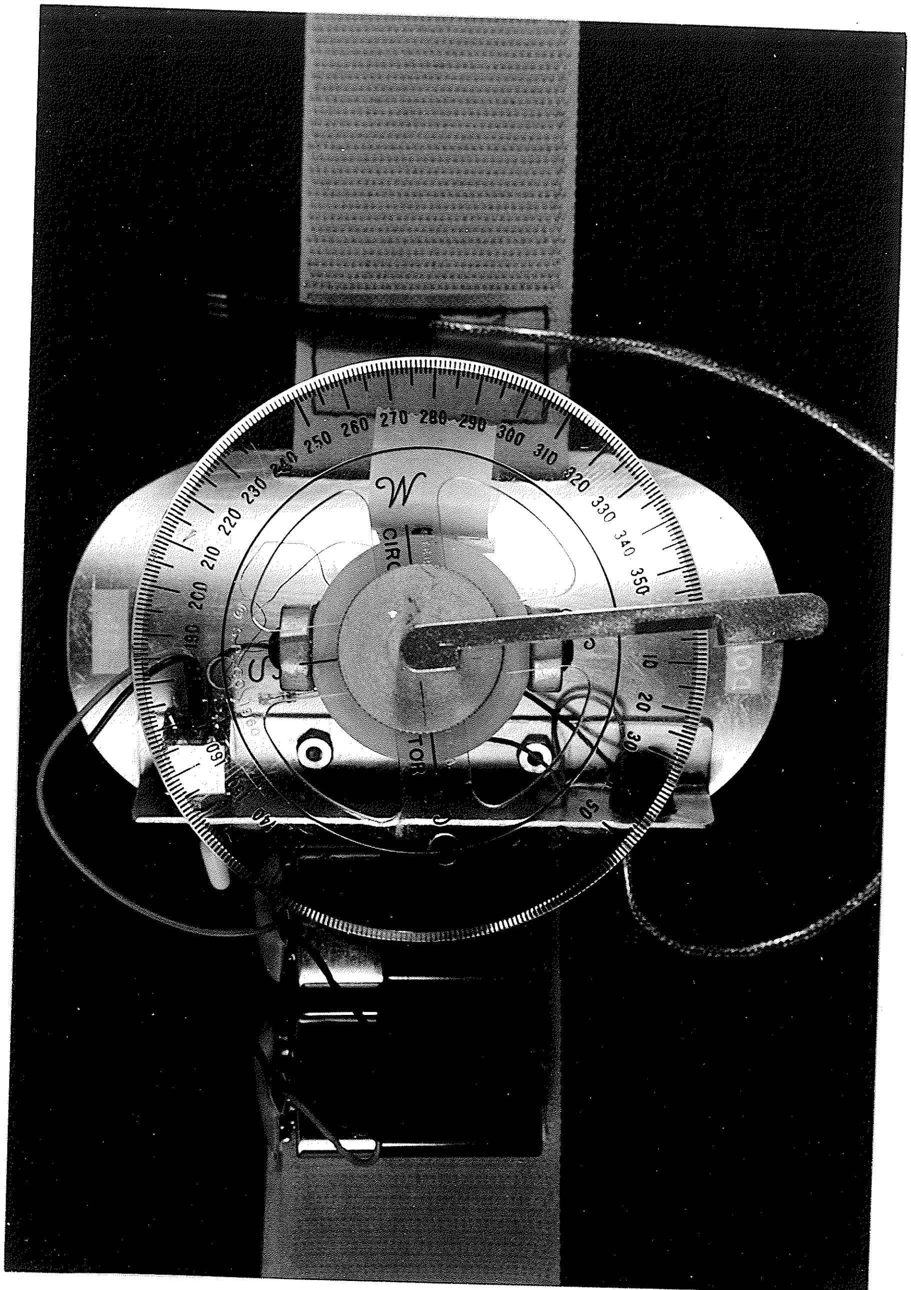


FIGURE 3.5. ELECTROGONIOMETER.

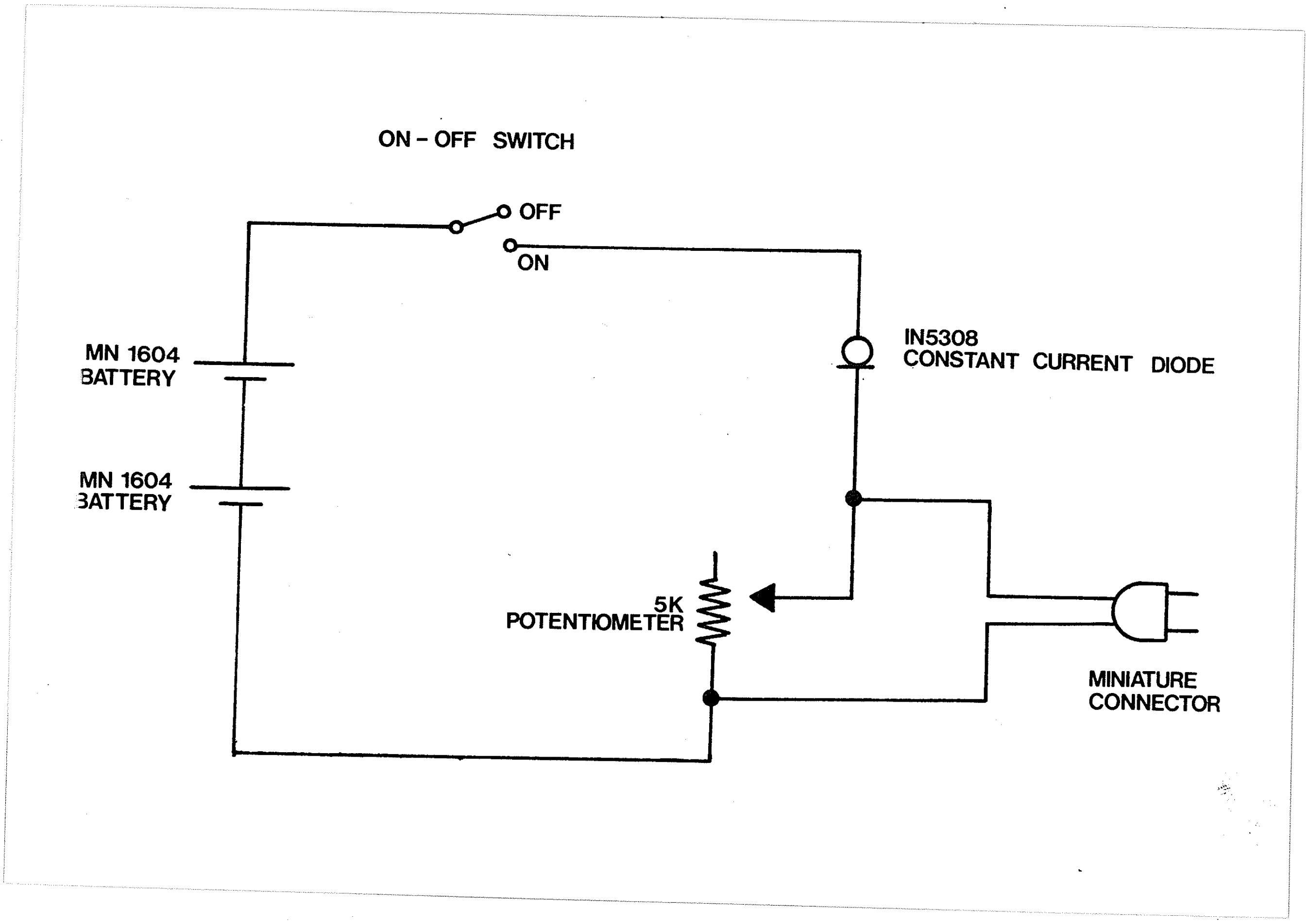


FIGURE 3.6.

ELECTRICAL CIRCUIT OF THE ELECTROGONIOMETER.

goniometer and its strap, leaving only a single pair of flexible leads to connect to the chart recorder. The IN5308 constant current diode ensured linearity between voltage output and angular rotation for this circuit configuration. The transfer characteristic shown in Fig. 3.7 illustrates the relationship between voltage output and angle for this design.

Oscilloscope

The oscilloscope used was a Hewlett-Packard Model 1201A Dual Trace Oscilloscope. This unit permitted viewing slow speed signals. A storage feature was used to store single short phenomena for later viewing or photographing. Comparison of wave forms could be accomplished by storing several separate signals and later viewing them simultaneously. The oscilloscope was used to check the position of electrodes, a procedure used particularly in the early part of the investigation when the technique of electrode placement was being established. The oscilloscope was also used periodically to assess the general form of the raw and processed EMG wave form.

MEASUREMENT SYSTEM

In this experiment the data was collected while the patient was in the sitting position with the arm initially in the dependent resting position.

Bipolar surface electrodes were used to obtain the phasic activity of the muscle groups under study in normal subjects and in hemiplegic and soft tissue lesion subjects. The electrodes were placed over the following muscles:

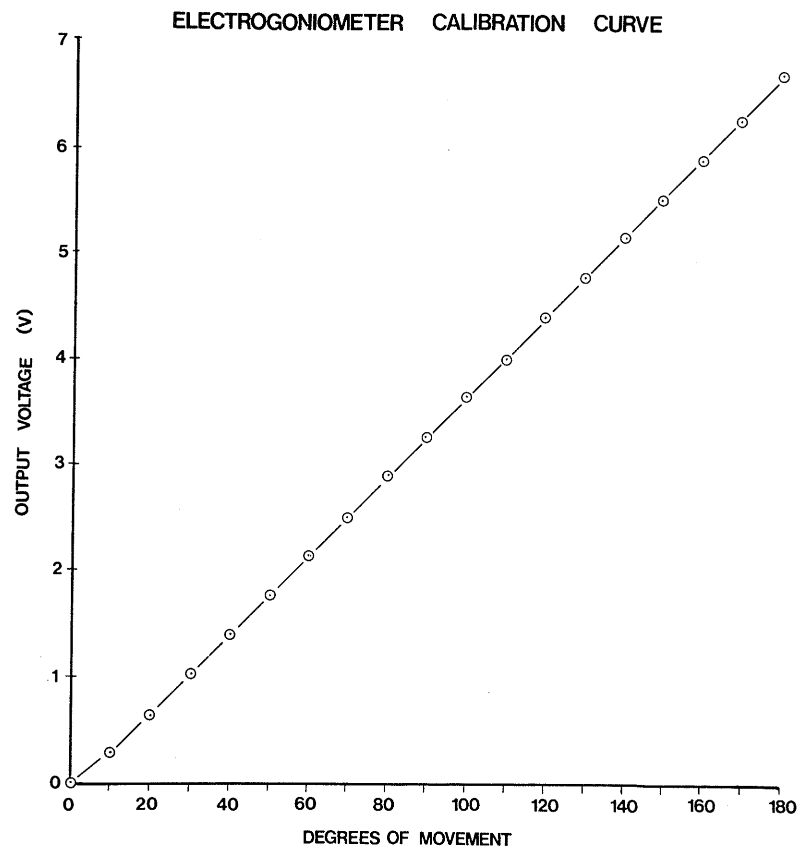


FIGURE 3.7.

RELATIONSHIP BETWEEN VOLTAGE OUTPUT AND DEGREES OF MOVEMENT OF THE ELECTROGONIOMETER.

A. Upper fibres of trapezius

B. Anterior fibres of deltoid

C. Middle fibres of deltoid

D. Posterior fibres of deltoid

E. Serratus anterior in the mid-axillary line at the level of the 7th rib.

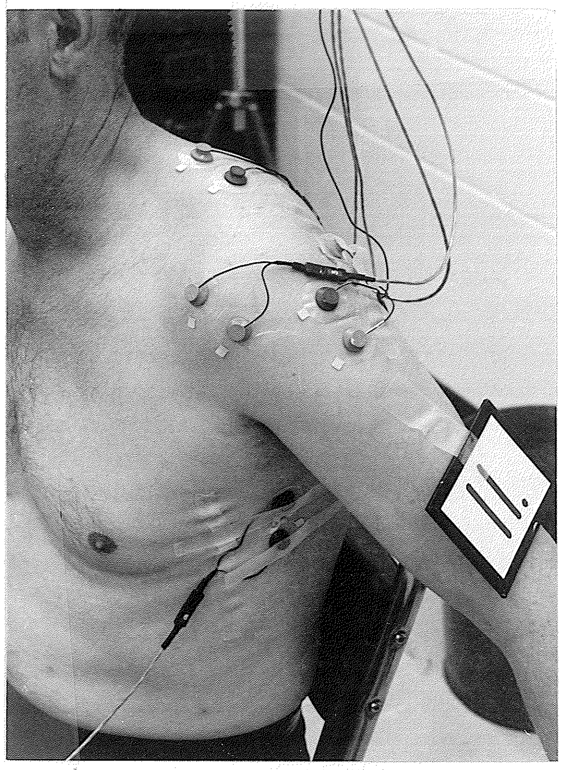
Where necessary the skin was shaved with an electric razor over the areas on which the electrodes were to be applied and the area was thoroughly cleaned and rubbed with gauze soaked in alcohol. The alcohol removed the dead surface layer of the skin with its protective oils, in order to lower the electrical resistance to practical levels.

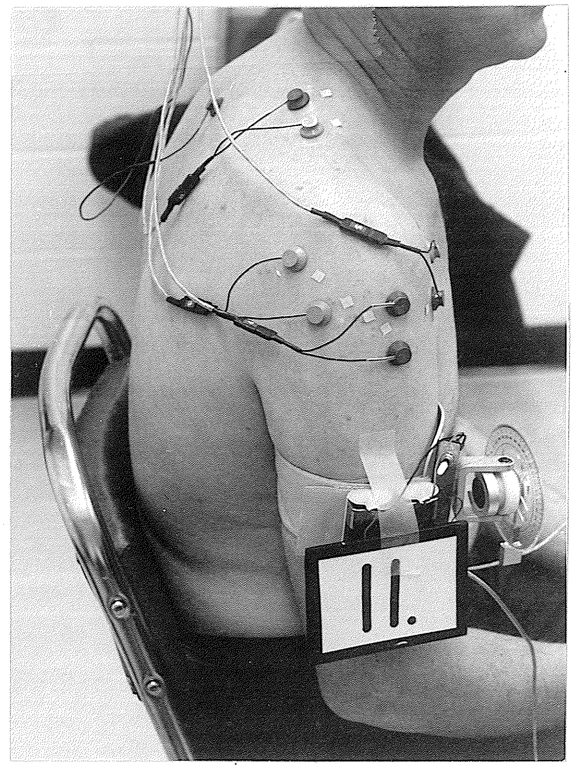
The electrodes were placed in pairs over the muscles and a ground electrode placed on the upper fibres of trapezius on the opposite side as a reference electrode.

All surface electrodes in the study were placed by the same investigator and every effort was made to locate the electrodes over the same area of the muscle belly in each subject. Photographic records of the electrode position in each subject were made. The position of the electrodes is illustrated in Fig. 3.8.

The electrodes were applied to the subjects by means of circular adhesive collars. Electrical contact between the electrode and the skin was made by EKG sol manufactured by Burton, Parsons and Co. This paste was retained between skin and electrode by the concave shape of the electrode where it is applied to the skin.

The silver, silver chloride surface electrodes used were manufactured by Beckman Laboratories.





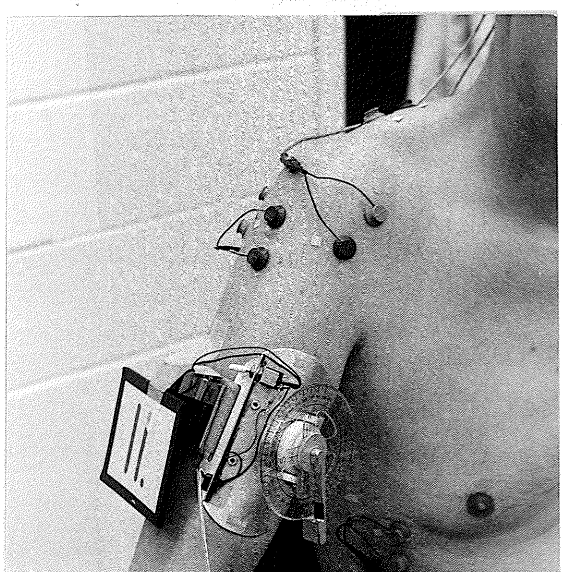


FIGURE 3.8.

POSITION OF ELECTRODES AND

ELECTROGONIOMETER.

ELECTROGONIOMETRIC MEASUREMENT

Simultaneously with the EMG data recording, limb position data was recorded using the electrogoniometer devised by Peat et al (1976). The electrogoniometer provided a varying amplitude signal which was correlated to degrees of movement. As a check of the reliability of the goniometer output, the investigator periodically manually operated the free limb of the electrogoniometer. The limb was moved from 0° to 10° and back to 0°. This was repeated with 0° to 20°, 0° to 30° and so on up to 180°. The signal levels produced on the ink recorder, by the movement of the limb of the electrogoniometer, was checked against previous signal levels. The height of the signal produced by movement of the limb of the goniometer was correlated with the degrees of movement shown on the protractor which was incorporated in the electrogoniometer design.

In the process of recording the phasic activity and data from the electrogoniometer it was important to devise a system that would not, in its application, interfere with the normal limb movement of the subject. Cables attached to the surface electrodes were suspended from a rod placed directly over the subject. This eliminated the possibility of the weight of the cables influencing the degree of movement of the arm. The weight of the electrogoniometer was also kept to a minimum, so as to eliminate the effect of a weight attached to the limb, inhibiting movement.

Before recording data, an explanation was given to the subject on the movements required. All subjects were allowed to practise the movement three times. Subjects with soft tissue lesions and hemiplegic subjects received the same explanation. A passive movement performed by the investigator on the unaffected limb was part of the explanation. Both raising and lowering the arm were continuous movements, with a slight pause only at the point of full abduction. All subjects were instructed to keep the elbow extended during abduction. Some hemiplegic subjects however, exhibited slight elbow flexion due to the flexor synergy.

In the clinical situation, assessment must not expose the disabled individual to the possibility of further trauma. In the assessment of joint movement, the insertion of metal pins into bony structures, the use of radiography or the application of apparatus which require time consuming adjustment have obvious serious limitations.

In assessing arm function it would be preferable to have an accurate evaluation of the contribution of glenohumeral, clavicular and scapular movement to total arm movement, while at the same time being able to correlate that information with EMG activity. The few systems which have been, or are being developed to assess the contribution of the individual joints of the shoulder complex have serious limitations. The scapulohumeral goniometer developed by Doody et al (1970) had to be held against the subject while a visual reading was taken from two goniometers. This could not easily be correlated with EMG activity. The electrogoniometer developed by Lewentoff (1970 and 1971) had major limitations in the time taken to attach and align the instrument to the subject. The system developed in the present investigation, while being limited to a measurement of total arm movement, has a number of advantages, particularily in the clinical setting. The electrogoniometer is easy to apply, light, and causes no discomfort. Time consuming adjustments are not required; limb position can be correlated with EMG activity by passing all signals simultaneously to an ink recorder. The data collected, together with other clinical findings, would be of value in the initial and ongoing assessment of the subject.

CONSENT FORM

All subjects were required to sign a consent form. In the case of the musculoskeletal and hemiplegic subjects their physician's written consent was also required. The consent form is shown in Fig. 3.9.

Before the normal subject's phasic activity was recorded each was required to perform a maximum contraction of each of the muscle components under investigation.

Trapezius - elevation of the shoulder girdle

Anterior deltoid - flexion of the shoulder

Middle deltoid - abduction of the shoulder

Posterior deltoid - extension of the shoulder

Serratus anterior - external rotation of the scapula

Each contraction was made against the manual resistance of the investigator. For trapezius the subject was asked to elevate the shoulder girdle. The operator applied resistance by exerting a downwards force on the point of the shoulder. For the anterior fibres of deltoid the subject was instructed to flex the arm. For the middle fibres the subject abducted, and for the posterior fibres, extended the shoulder. For serratus anterior the subject pushed the arm forward, as in a pushing or thrusting movement.

In each case maximum resistance was applied with the limb in 45° of flexion, abduction or extension.

Subjects in the abnormal groups could not perform a maximum isometric contraction of the muscles under investigation. This is discussed in detail in the following chapter.

Department of Anatomy
University of Manitoba
Electromyography Laboratory

I hereby consent to act as a subject in the Research Program on Muscle Activity in the Electromyography Laboratory of the Department of Anatomy. The procedure, which may include the insertion of fine wire electrodes into muscles, and photographic recording, has been explained to me fully, together with potential complications which may arise during the course of the study.

The photographic records will be used for analytical purposes and may also serve as documentation in research papers and medical lectures.

My participation is on a voluntary basis, and I reserve the right to withdraw immediately from the procedure whenever I wish.

SIGNATURE OF SUBJECT OF
RESPONSIBLE RELATIVE: ______________________________

SIGNATURE OF MEDICAL
SUPERVISOR: ______________________________

SIGNATURE OF WITNESS: ______________________________

SUBJECT ______________________________

NUMBER ______________ DATE ______________

PATIENT HISTORY ______________________________

____

____

RUN OBJECTIVE ______________________________

____

FIGURE 3.9. CONSENT FORM.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

A review of the literature indicated that there are a great variety of methods used to score and analyze the wave form in kinesiological electromyography. The method chosen will in part depend on whether a raw or processed signal is used. In the analysis of raw data, Bergström (1959, 1962), claimed that a simple counting of spikes is a quantitative reflection of the amount of muscular activity. Close et al (1960) described a technique based on an electronic counting of spikes. Another method is the visual inspection of the wave form, and the measurement of the amount of activity, assigning a series of symbols (+,++,+++ or .1, .2, .3, etc.) indicating relative magnitudes (Kelly, 1971). EMG activity can also be expressed as a percentage of the EMG obtained in a maximum isometric contraction (McLeod, 1973; Peat, 1974).

Many different methods have been devised using a variety of techniques such as computer analysis (Basmajian et al., 1974), power spectra analysis (Herberts et al, 1969) and integration of EMG potentials (Bigland and Lippold, 1954). Basmajian (1974), in evaluating various techniques states "experience has shown that the easiest and, in most cases,

> most reliable evaluation is by the trained observer's visual evaluation of results, colored by his knowledge of the technique involved".

Electromyography determines if, and when, muscles act. Also inferences may be drawn as to how and why muscles respond with varying magnitudes of activity. The electrical activity monitored from active muscles is related to the number of muscle fibres being stimulated. Provided that the muscle fibre contracts when it is stimulated, then it would follow that a greater number of fibres would produce a greater amount of force. While there is general agreement as to the relationship between EMG activity and muscular force in isometric contractions, there is some disagreement regarding the relationship during isotonic contractions (Kelly, 1971). Research into the change seen in the frequency, and the amplitude of the action potentials during increased work load, indicates that these two factors do not respond identically. Frequency tends to increase linearly with force of contraction until some limiting point is reached, where it then stabilises. Amplitude however, seems to continue to increase throughout an increasingly heavy action (Kelly, 1971). The amplitude of EMG seen on the recording device is influenced by a number of variables, e.g., where the electrodes are placed, and the condition of the skin and its resistance. Also the position of the amplification setting on the amplification and recording device is important. If amplification is set too high, the muscle would appear more active than its actual state, if too low, significant activity would be missed (Long, 1970). In order to control the variables as much as possible in this investigation, a careful routine of electrode placement and skin preparation was followed with each subject. In addition, all applications were made by the same investigator. The technique of application is described in detail in the previous chapter.

In the analysis of the EMG wave form in kinesiological study the investigator can examine the pattern of excitation of various muscles. The amount of electrical activity is important as an indication of the degree of activity rather than as an indication of the force produced by the muscle. Studying electrical activity of groups of muscles, as in shoulder movements, will show the duration and variation in the strength of activity of each muscle, and whether or not the muscles are active in repetitive phases of motion.

It is important to note that the changing levels of activity shown by a muscle are of the most value in assessing muscle function. Varying amplitude levels shown by one muscle can indicate the changing role of the muscle. In effect the muscle is being graded against itself.

MEASUREMENT OF ACTIVITY IN NORMAL SUBJECTS

In this investigation the analysis of the activity in normal subjects was calculated in two ways.

(a) Each normal subject was required to perform a maximum isometric contraction of the five muscles under investigation before the abduction activity was recorded. This maximum EMG wave was recorded.

(b) The printout of the EMG activity from the ink recorder was examined and a measurement taken in mm of the amplitude of the wave form at every 10° interval during raising and lowering the arm in the scapular plane of abduction. Measurements were taken for each muscle for three consecutive attempts at abduction. These readings were then averaged.

As the measurements of the phasic and maximum activity are available, the phasic activity of the five muscles in each subject could be calculated and expressed as a percentage of the maximum activity. Expressed in this way the activity of the muscles and the performance of the subjects could be more adequately compared with each other. The evaluation of maximum levels of EMG activity and levels consistent with activity present in unloaded raising of the arm, assisted in determining the most appropriate setting for amplification of the EMG signal on the attenuator. It was found that a setting of 1 volt/cm produced a recording level suitable for evaluation of the EMG signal when unresisted movements and most resisted movements were attempted. In some subjects the maximum contraction had to be recorded at 2 volts/cm. With a more sensitive setting (.5 volt/cm) the signal was too large to be accomodated by the movement of the pen of the ink recorder. However when, as with some of the hemiplegic subjects, no activity was seen on one or more channels of the ink recorder the sensitivity was increased to 0.5 volts/cm just in case some discernible signal might be located at that level.

For the statistical analysis of the data, a measurement of 1 millimeter on the EMG wave form was assigned a value of 100, 1 centimeter as 1000. A subject could, for example, show an amplitude of 10 mm, 12 mm and 9 mm as the level recorded during three consecutive movements. This would give a mean value 10.3 mm which was recorded as 1030 'units'. This number will be referred to as EMG 'units' of activity. The signal level indicated by the pen recorder is the product of the EMG signal from the subject, amplified by the amplifier circuit and adjusted again by the gain control of the attenuator which is placed between the amplifier and the recorder.

The calculations used to determine the mean and standard deviation show figures to three or more decimal places. It would be unrealistic to suggest that the amplitude of the EMG recordings could be measured with this degree of accuracy. The percentages and the mean of the direct movements of maximum activity, should be taken to indicate a value relative to the other measurements for that muscle.

In the analysis of the hemiplegic subjects and subjects with soft tissue lesions it was not possible to state the phasic action as a percentage of the maximum activity. The motor deficit in hemiplegia makes the performance of isolated maximum isometric contraction difficult, if not impossible. An attempt to isolate a single muscle in this way often stimulates a synergy or abnormal group action response. Patients with soft tissue lesions of glenohumeral joint structures were also omitted from attempts at maximum contraction, as the performance of such a movement could elicit pain and could, in some instances, exacerbate the condition. In a case of bursitis, for example, an attempt at a strong resisted movement may further traumatise an already abnormal joint structure. In both abnormal groups the phasic muscle activity was measured directly and compared with the similar measurement of the normal group.

All tests used in the analysis of data in the present investigation utilized the 'Statistics On-Line' system of the Computer Department for Health Sciences, Faculty of Medicine, University of Manitoba.

ELECTROGONIOMETER RECORDING

As discussed in Chapter 2, the four joint system in the shoulder complex does not permit direct measurement of all the components of the shoulder complex during shoulder movement. In order to obtain a general indicator of the behaviour of the shoulder complex during abduction it was decided to measure the position of the humerus in relation to the gravity field. The electrogoniometer provided automatic measurement of the angle between the humerus and the vertical line, determined by a weight hanging by a rigid bar from the potentiometer rotor. The potentiometer registered zero until movement commenced, then as it progressed, the potentiometer responded with a varying voltage output signal.

While the electrogoniometer responded to movement of the arm as it was abducted, it did not indicate the relationship of the stationary arm to the rest of the body at the beginning of the movement. When the electrogoniometer was attached to the arm, at rest by the side, no signal was produced. The potentiometer of the electrogoniometer was activated only on the initiation of movement.

The position of the arm at the beginning of the movement of abduction was that of a position of rest at the side of the body, with the subject in the sitting position. To standardise the subjects' posture, and at the same time provide adequate sitting support for all subjects, a chair with a backrest was used. It was noted that in a relaxed sitting position the arm did not hang vertically but assumed a position of slight abduction. This arm position was due partly to the seat width and partly to the position assumed by the subject when instructed to adopt a relaxed posture. Assessment of the resting arm position in relation to the vertical was made by evaluating the angle between the long axis of the upper arm and the vertically hanging central moveable bar of the electrogoniometer. The evaluation indicated a resting arm position of slight abduction. A value of 15^{o} from the vertical was assigned to the resting arm position. On performing the movement of abduction the subjects were instructed to raise the arm to a position they felt represented a comfortable completion of the movement. After pausing briefly in that position the subjects lowered the arm to the resting position. A demonstration and practise of the movement familiarized the subject with the movement required. No attempt was made to add to the range of movement if the investigator determined that a subject had not obtained a fully vertical arm position. One object of the investigation was to evaluate a range of motion, in normal subjects, representing a free and functionally satisfactory elevation through abduction.

The range of 180° abduction motion classically attributed to the shoulder complex is from a vertically dependent to a vertically elevated position. This investigation was however, related to a study of muscle activity in the shoulder complex during a range of movement from a position of rest at the side of the body to a position the subjects felt represented a completion of their normal voluntary effort. It was noted that not all subjects completed 160° of abduction. All 30 normals completed 130°, 27 normals completed 140°, 14 normals completed 150° and only two normals completed 160°. This applies to the data acquired for all five muscles studied in this investigation in normal subjects. The ranges of movement in normal and abnormal groups is shown in Table 4.1.

ANALYSIS OF ACTIVITY

This investigation was concerned with an evaluation of the role of five major shoulder girdle muscles during raising and lowering the arm. The investigation included: (a) normal subjects

(b) subjects with hemiplegia

(c) subjects with a soft tissue lesion affecting a glenohumeral joint structure

TABLE 4.1. RANGES OF MOVEMENT FOR NORMAL AND ABNORMAL GROUPS.

	MEAN
NORMAL (N = 30)	
140 140 150 160 150 140 130 140 150 140 150 150 140 140 160 140 140 140 140 140 150 130 140 150 150 130 130 140 150 150	143.3°
RIGHT HEMIPLEGIA (N = 11)	
50 70 50 120 130 40 50 80 100 60 40	71.8°
LEFT HEMIPLEGIA (N = 10)	
60 40 140 120 70 60 50 50 110 70	77.0°
UNAFFECTED SIDE IN HEMIPLEGIA (N = 10)	
110 120 120 120 130 150 140 120 140 140	129.0°
SOFT TISSUE LESIONS, RIGHT SHOULDER (N = 10)	
70 80 110 50 60 80 40 60 50 100	70.0°
SOFT TISSUE LESIONS, LEFT SHOULDER (N = 8)	
100 60 110 60 100 70 70 100	83.7°
UNAFFECTED SIDE IN SOFT TISSUE LESIONS (N = 10)	
130 140 140 140 120 130 140 120 140 140	134.0°

The data from all five muscles was measured at each 10° interval of movement and subjected to statistical analysis.

The first part of the investigation was concerned with an evaluation of the data obtained from normal subjects. This data included an analysis of:

(a) the muscles of the right shoulder in 30 normal subjects.

(b) the muscles of the left shoulder in 16 of the 30 subjects in whom right shoulder analysis had been completed.

(c) the muscle activity in 15 subjects with a mean age of 28.2 years.

(d) the muscle activity in 15 subjects with a mean age of 64.1 years.

(e) the muscle activity of 20 normal subjects when the activity was expressed as a percentage of a maximum isometric contraction.

The objective of the analyses listed above, was to determine the phasic activity characteristic of normal subjects. This would be a baseline for comparison with the activity pattern of groups exhibiting a lesion of shoulder girdle motor function. It would also determine the validity of the technique of recording. The hypothesis tested in the analyses of data from normal subjects was that the phasic activity or muscle contribution to movement would be the same, and not differ from right to left limb, or differ in age groups in normal subjects.

A calculation was made of the activity of each muscle at every 10° of motion. The activity was recorded in both raising and lowering the arm. The calculations included the establishment of the mean and standard deviation.

Trapezius (Upper Fibres)(Fig. 4.1 and 4.2)

Trapezius showed a gradual increase in activity from 0^{o} to 110^{o}, with a slightly greater rate of increase from 0^{o} up to 30^{o}. Following this there was a slightly more pronounced increase to 130^{o}. The level of activity decreased after this to 150^{o}. Termination of activity at 160^{o} was represented by a slight increase in activity. When activity was calculated as a percentage of a maximum contraction, there was a gradual increase from 4.4% at 10^{o}, to 16% at 110^{o}. This increased to 19.1% at 120^{o}, 20.1% at 130^{o} and then a decrease to 15.7% at 150^{o}, finally an increase to 21.7% at 160^{o} (Table 4.2 and 4.3).

Decrease in activity in lowering the arm from 160^{o} to 0^{o} was gradual, showing consistently lower levels of activity than that seen during raising the arm.

When the means of the direct measurement of EMG amplitude and the percentage of maximum activity were compared, the variation was similar, producing a similar type of graphic representation (Fig. 4.3).

The findings of this investigation showed an increasing amplitude of EMG activity as the arm was raised. The curve rose rapidly in the first 30^{o} thereafter there was a gradual rise. In this activity the upper fibres of trapezius functioned to elevate the shoulder as well as forming the upper component of the force couple necessary for scapular rotation. The pattern of activity seen in trapezius in this investigation was similar to that obtained by Inman et al (1944), Long (1970) and Jones (1970). In

TRAPEZIUS

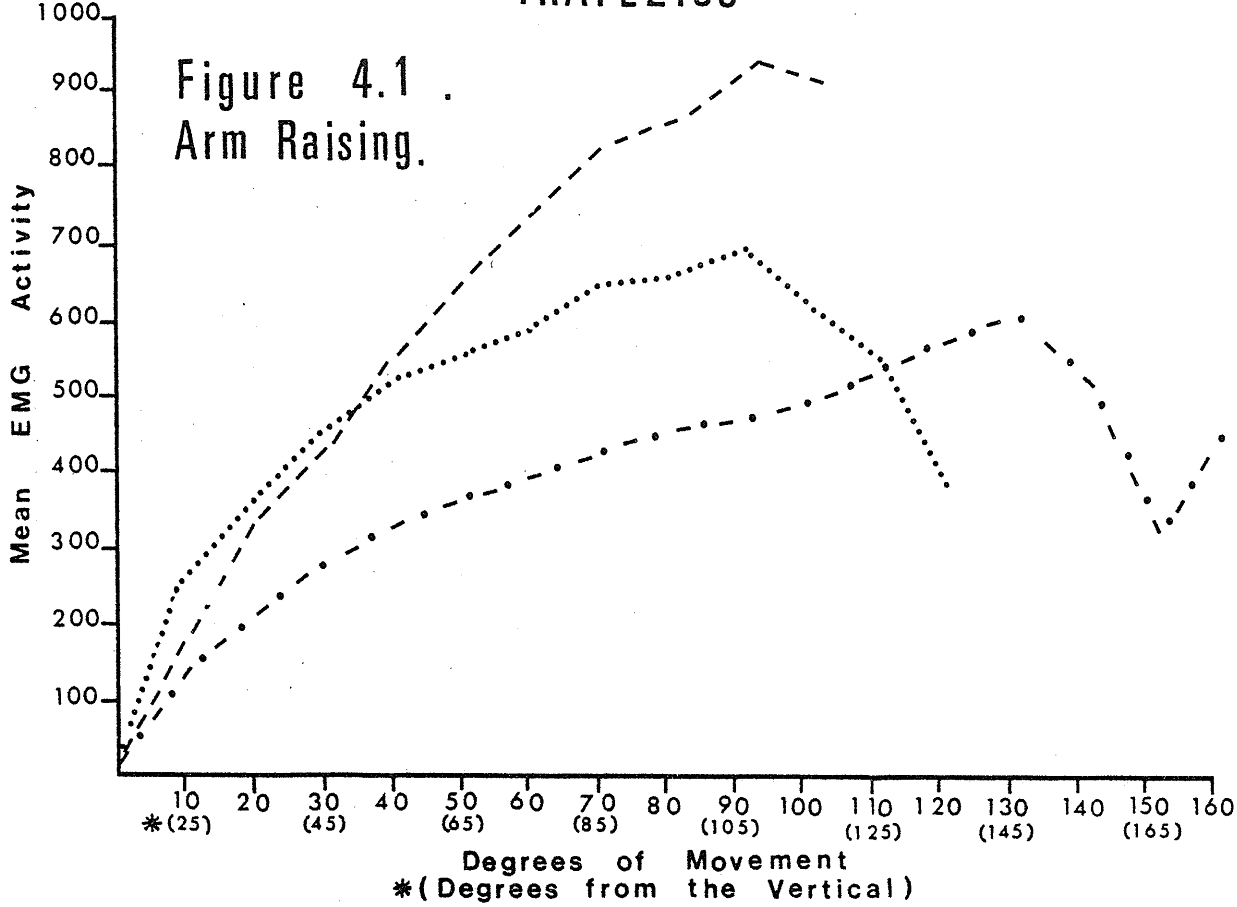


Figure 4.1 . Arm Raising.

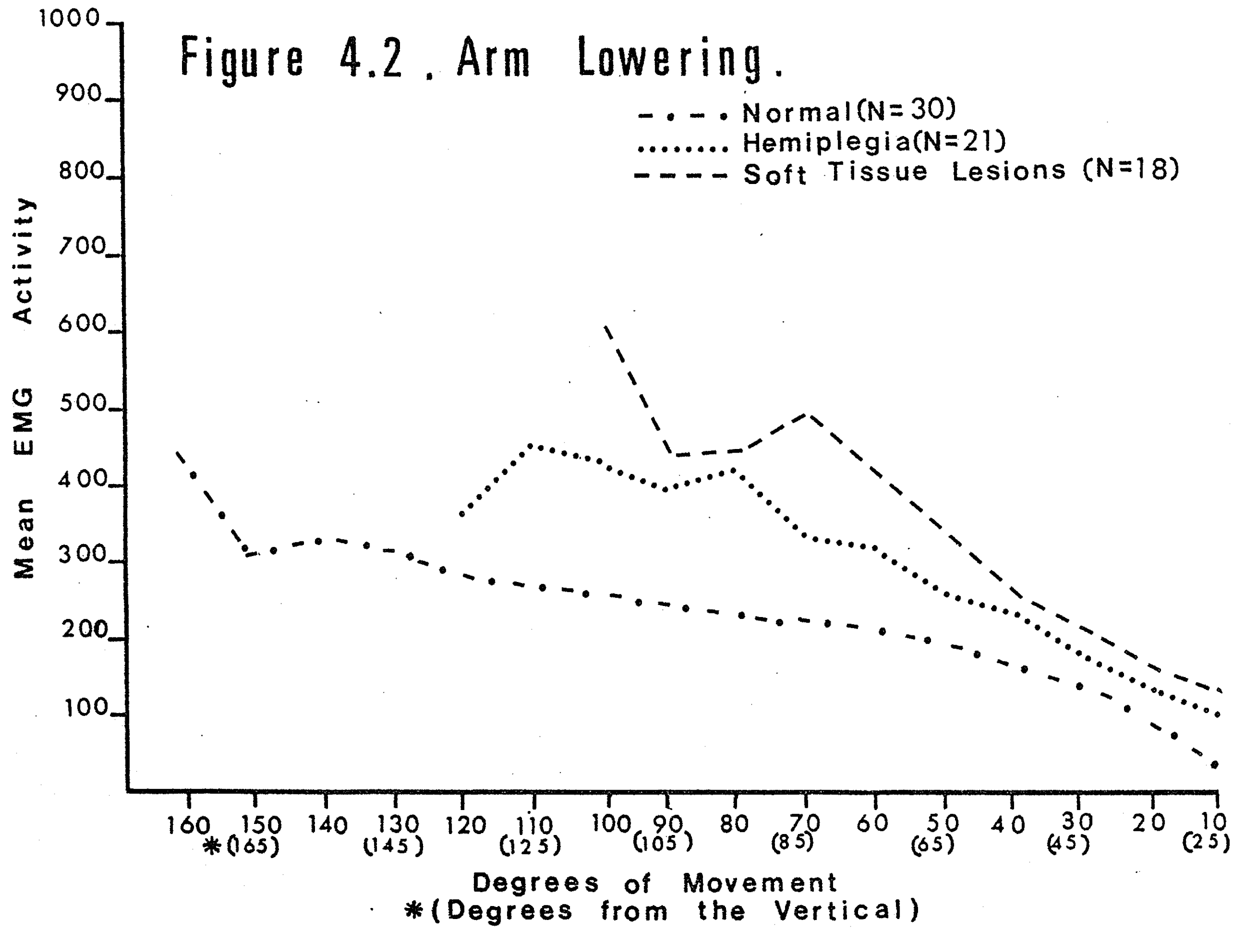


Figure 4.2 . Arm Lowering.

TRAPEZIUS

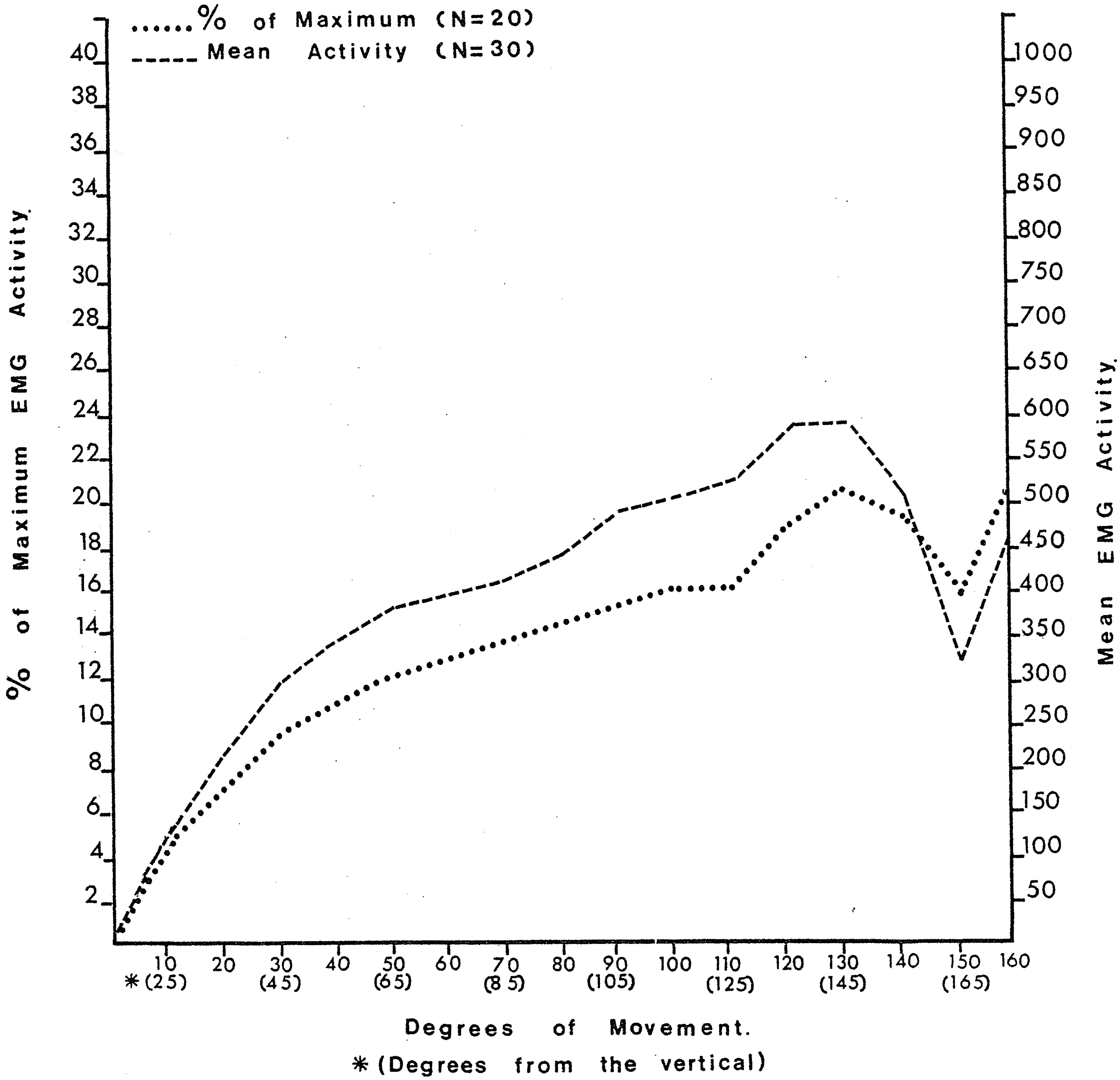


Figure 4.3 . Comparison between Mean EMG Activity and % of Maximum Activity.

TABLE 4.2. ACTIVITY OF TRAPEZIUS IN NORMAL SUBJECTS IN RAISING THE ARM IN ABDUCTION.

Degrees of Abduction	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
10	139.9	111.1	4.4	3.7
20	212.5	148.8	6.9	4.0
30	281.0	178.5	9.2	4.8
40	331.8	202.6	10.8	5.3
50	364.8	220.9	12.0	6.2
60	381.1	230.0	12.5	6.4
70	412.5	243.9	13.1	6.1
80	440.2	256.1	14.0	6.3
90	463.4	276.8	15.0	8.2
100	496.6	317.1	16.0	8.8
110	493.4	313.2	16.0	8.4
120	576.9	438.6	19.1	10.1
130	589.4	417.1	20.1	10.0
140	504.0	371.6	19.2	10.1
150	317.0	144.6	15.7	6.6
160	455.0	289.9	21.7	2.4

$\bar{X}$ = mean

SD = standard deviation

TABLE 4.3. ACTIVITY OF TRAPEZIUS IN NORMAL SUBJECTS IN LOWERING THE ARM THROUGH THE PLANE OF ABDUCTION.

Degrees	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
160	455.0	289.9	21.7	2.4
150	315.5	165.3	15.2	8.8
140	343.3	204.8	12.6	6.2
130	320.6	183.3	11.9	6.2
120	294.0	162.7	11.3	5.9
110	284.2	173.3	10.5	4.9
100	273.4	153.7	10.3	4.6
90	266.5	150.2	10.4	4.8
80	246.0	138.1	9.2	4.0
70	228.3	135.9	8.5	3.7
60	211.0	126.4	7.8	3.6
50	192.0	124.5	6.7	3.4
40	158.9	113.9	5.1	3.5
30	132.3	93.8	4.1	3.3
20	97.0	72.9	3.4	2.8
10	67.8	53.6	2.0	1.9

$\bar{X}$ = mean

SD = standard deviation

the study by Inman, the curve of activity progressively increased to the region of 90° and thereafter "undulates slightly". The studies by Long (1970) and Jones (1970) showed a pattern in which there was a rapid rise to 20° to 30° followed by a slower rise to the region of 130°, this was then followed by a sharper increase to the region of 160° followed by a fall in activity. The pattern of activity seen in the present investigation correlated very closely with those found by Long (1970) and Jones (1970). The similarity continued throughout the activity seen in lowering the arm. Here the activity gradually decreased with activity levels lower than that seen during elevation.

Raising the arm constitutes a concentric contraction of the muscle during which the muscle activity is producing the movement. Lowering the arm, an eccentric contraction, is concerned with control of the movement under extrinsic motivation (Assmussen, 1960; Kelly, 1971). Assmussen (1960) has indicated that only about one-third as many fibres are required to perform a task eccentrically as are needed to perform a task concentrically. It must be assumed that the eccentric operation, because of its lower active fibre demands, would result in a lower electrical activity output even though the force exerted might be the same (Kelly, 1971). The results of the present investigation show lower levels of EMG amplitude during lowering the arm from the abducted position than that seen during raising the arm through concentric contraction. This coincides with the previous analysis of EMG activity in concentric and eccentric muscle work (Jones, 1970; Kelly, 1971).

In lowering the arm, activity decreased from 21.7% of maximum at 160° to 15.2% at 150°. From here to 90° the activity level remained somewhat constant. From 80° the EMG amplitude decreased gradually and consistently to 2% at 10°.

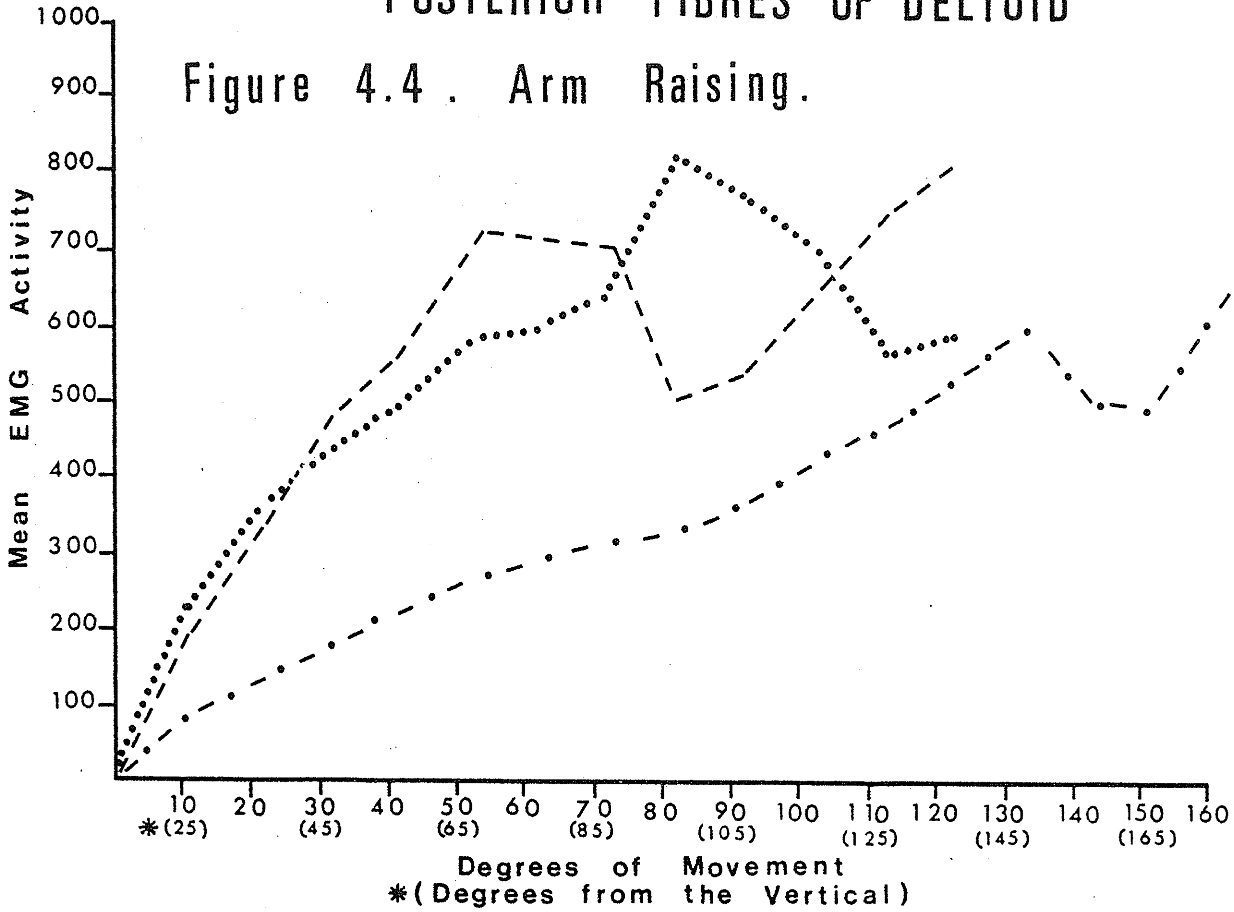
Posterior Fibres of Deltoid (Fig. 4.4 and 4.5)

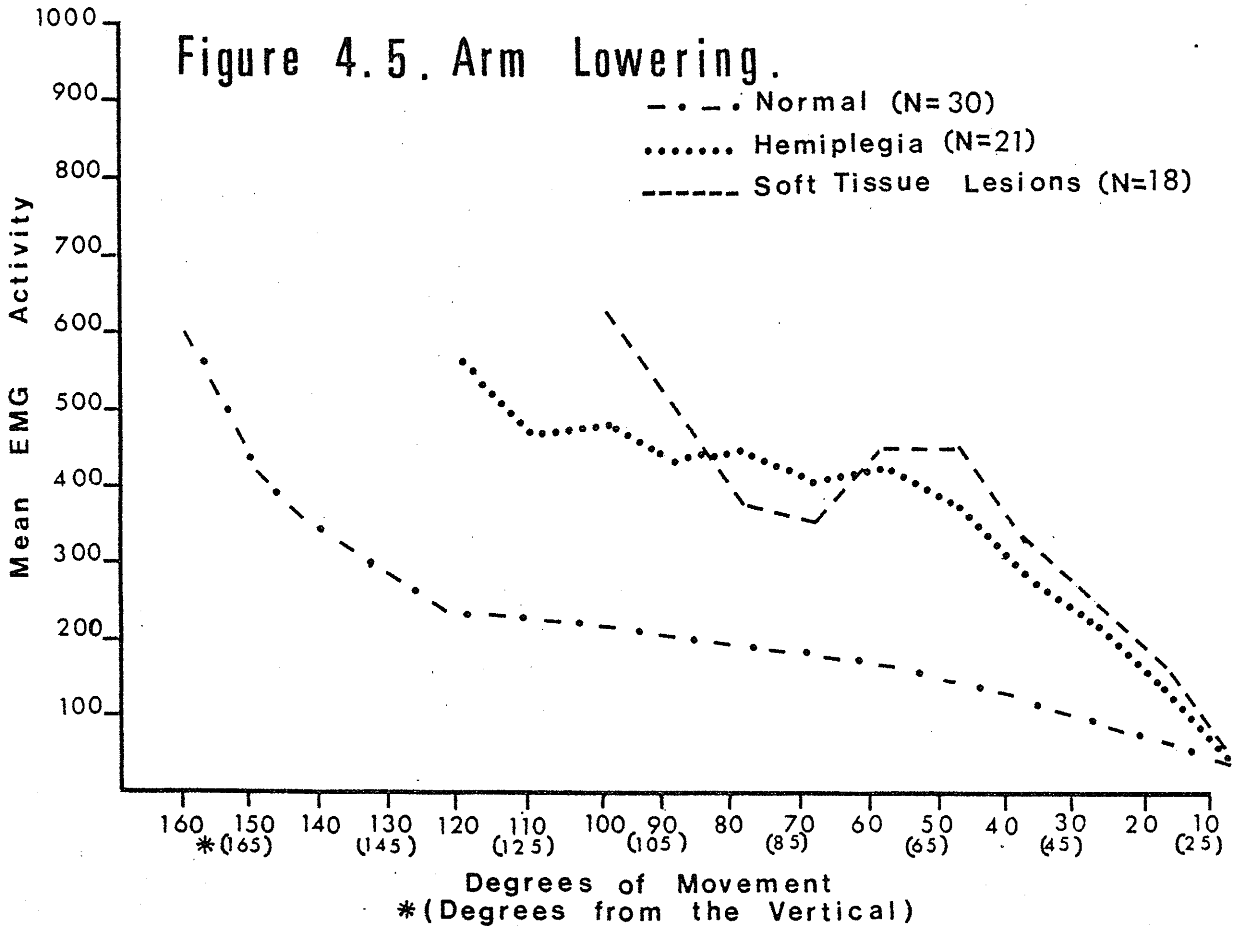
The posterior fibres of deltoid showed a gradual increase from 0° to 130° abduction. This was followed by a slight decrease in activity at 140° and 150°, before activity was completed by a slight rise in activity at 160° (Tables 4.4 and 4.5). The percentage activity showed a gradual increase from 1.6% at 10° to 10.2% at 120°. Thereafter the activity remained at the same level apart from a slight decrease to 9.2% at 140°. When the means for the direct measurement of EMG amplitude and the percentage of maximum were compared, the variation was similar, producing a corresponding type of graphic representation (Fig. 4.6).

Scheving and Pauly (1959) found that the three parts of deltoid are active in all movements of the arm. They suggested that, although one part may act as a prime mover, the other parts contract to stabilise the joint in the glenoid cavity. Wertheimer and Ferrez (1958) and Shevin et al (1969) found that the posterior part of deltoid had its principal action in extension, but that the action was "inconstant" and slight in abduction and elevation of the arm. Brunnstrom (1966) considered the posterior part of deltoid an accessory muscle in elevation of the humerus in abduction. Long (1970), in the extensive Ampersand report, showed the posterior fibres of deltoid progressively active throughout abduction.

The results of the present investigation show consistent activity throughout the range of motion. The pattern corresponded with that demonstrated by Long (1970), in which the activity increased throughout

POSTERIOR FIBRES OF DELTOID





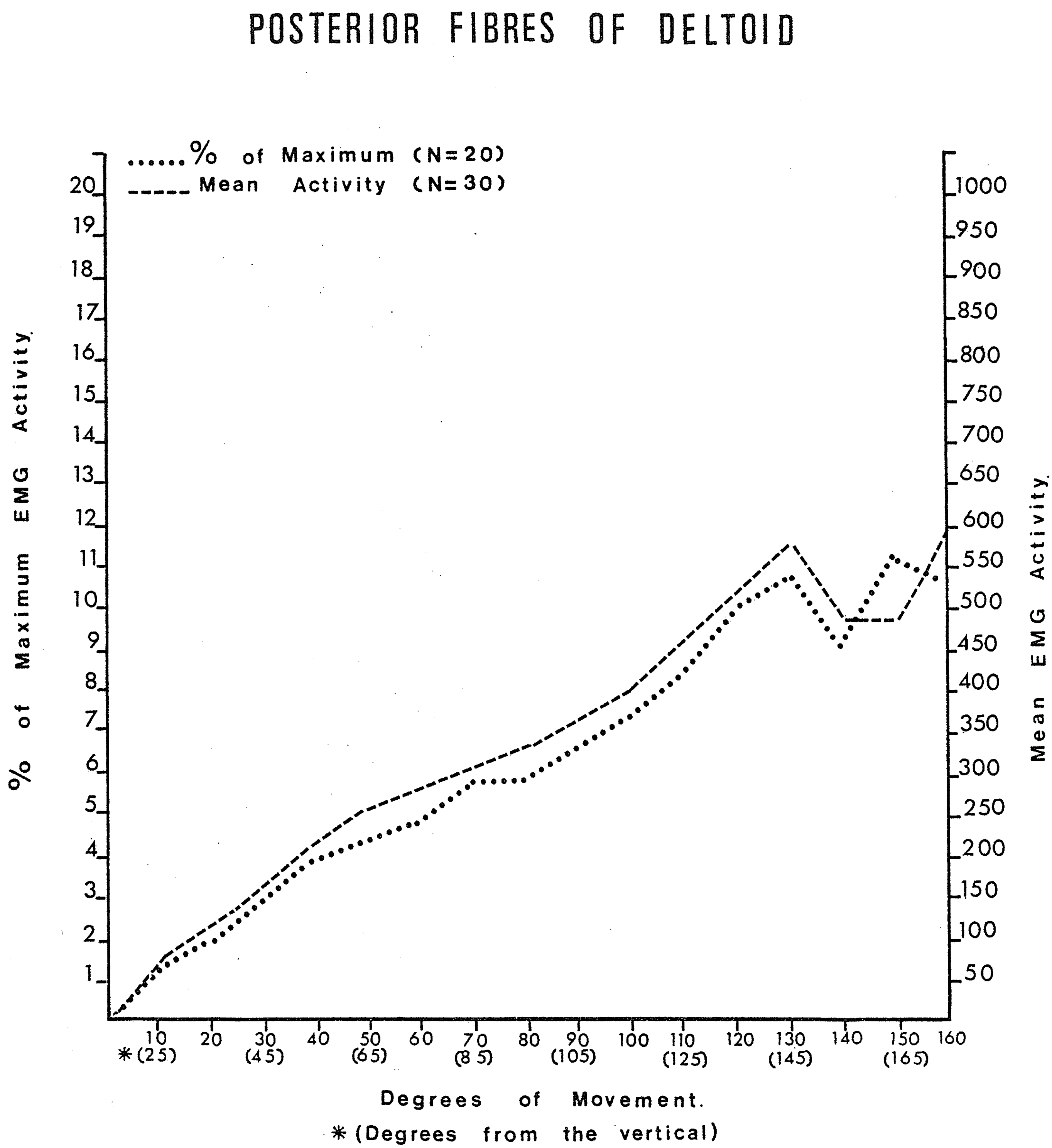


Figure 4.6 . Comparison between Mean EMG Activity and % of Maximum Activity.

abduction, with a leveling off of activity after 130° to 140° of abduction. The activity of the posterior part of deltoid appears to function throughout the movement of abduction primarily as a stabilising component. However, in the present investigation, this part of deltoid showed the lowest level of activity of the three parts when activity was expressed as a percentage of a maximum contraction.

The posterior part of deltoid showed a gradual reduction in activity during lowering from the elevated position (Fig. 4.5). The greatest reduction occurred between 160° to 110°, thereafter the reduction in activity level was consistently gradual. When the means of the amplitude of the EMG signal were compared with the means of the percentage of maximum activity the pattern of activity was similar. The level of activity during descent of the arm was 9.6% at 160° and this decreased to 6.8% at 140° and 5.7% at 130°. The reduction to 1.3% at 10° was a continuous lowering in activity levels. The activity during the period of eccentric muscle activity was less than that during abduction. Previous studies on shoulder muscle activity were largely limited to the analysis of activity during raising the arm. However, the results of the present investigation were consistent with the fact that generally lower levels of muscle electrical activity are seen in eccentric movements. The findings were similar to those of Long (1970) who did show activity levels in shoulder muscles during controlled descent of the arm through the plane of abduction.

TABLE 4.4. ACTIVITY OF POSTERIOR PART OF DELTOID IN NORMAL SUBJECTS IN RAISING THE ARM IN ABDUCTION.

Degrees of Abduction	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
10	89.2	71.8	1.6	1.4
20	133.7	101.3	2.3	1.7
30	179.2	123.9	3.2	2.5
40	223.3	157.4	4.1	3.4
50	254.6	183.8	4.5	3.6
60	293.8	191.9	4.8	2.8
70	319.9	206.1	5.9	4.4
80	327.6	208.8	5.8	4.4
90	364.5	221.2	6.6	4.6
100	404.1	251.9	7.5	5.5
110	452.5	315.8	8.5	6.2
120	536.6	397.4	10.2	7.3
130	585.8	460.8	10.8	8.0
140	484.0	351.1	9.2	6.9
150	480.5	305.5	11.1	9.2
160	635.0	516.5	10.4	5.3

$\bar{X}$ = mean

SD = standard deviation

TABLE 4.5. ACTIVITY OF THE POSTERIOR FIBRES OF DELTOID IN NORMAL SUBJECTS IN LOWERING THE ARM THROUGH THE PLANE OF ABDUCTION.

Degrees	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
160	600.0	565.6	9.6	6.5
150	429.6	247.4	9.9	9.1
140	348.0	207.1	6.8	5.6
130	283.8	155.5	5.7	4.7
120	246.8	143.1	5.1	3.9
110	225.4	131.8	4.5	3.7
100	204.6	123.1	4.0	3.4
90	188.3	114.1	3.6	2.9
80	182.4	112.5	3.5	2.8
70	173.9	109.6	3.2	2.5
60	156.7	102.4	3.1	2.6
50	138.4	96.8	2.7	2.2
40	120.1	82.6	2.5	2.0
30	96.1	64.7	2.0	1.5
20	72.3	48.3	1.6	1.3
10	58.0	40.7	1.3	1.3

$\bar{X}$ = mean

SD = standard deviation

Middle Fibres of Deltoid

The activity in the middle section of deltoid progressed throughout the range from 0^{o} to 120^{o} and thereafter the activity remained at about the same level with some slight variations (Fig. 4.7)(Table 4.6).

When the activity was expressed as a percentage of maximum activity the level rose from 3% at 10^{o} to 32% at 120^{o}. Following this the level was 32% at 130^{o}, 28.2% at 140^{o}, 37.7% at 150^{o}, decreasing to 23.3% at 160^{o}. When the means for the direct measurement of EMG amplitude and the percentage of maximum contraction were compared, the variation in activity pattern was similar (Fig. 4.9).

Previous investigators demonstrated that deltoid exhibited its greatest activity between 90^{o} and 180^{o} of elevation, the curve plateauing between these points (Inman et al, 1944; Long, 1970; Basmajian, 1974). The activity of the middle fibres of deltoid seen in the present investigation was similar to the findings previously reported. The activity levels shown by the middle fibres, when expressed as a percentage of maximum, exceeded the percentage levels of the anterior and posterior fibres. This would be consistent with the prime-mover activity of the middle fibres during elevation in abduction (Scheving and Pauly, 1959).

During arm lowering, the middle fibres of deltoid showed a gradual decline in activity (Fig. 4.8)(Table 4.7). The most rapid decrease occurred between 160^{o} and 130^{o} and thereafter the decrease was gradual to 0^{o}. The activity showed 19.9% at 160^{o}, 26.6% at 150^{o} and 17.7% at 130^{o}. Following this, the decline in activity was gradual to 1.4% at 10^{o}. The middle fibres showed lower levels of activity during lowering the arm. This is consistent with the lower EMG amplitude expected of eccentric

MIDDLE FIBRES OF DELTOID

Figure 4.7. Arm Raising.

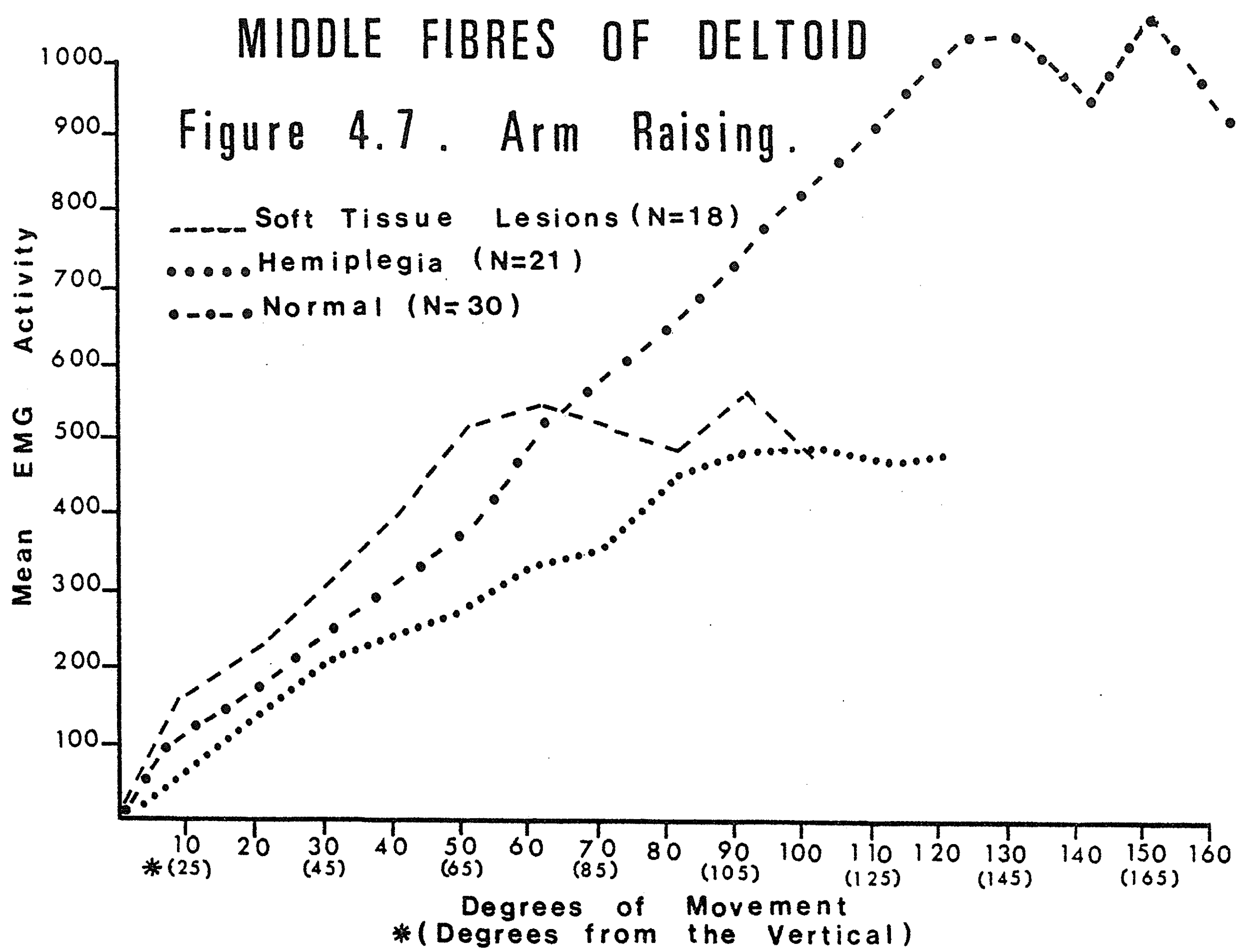
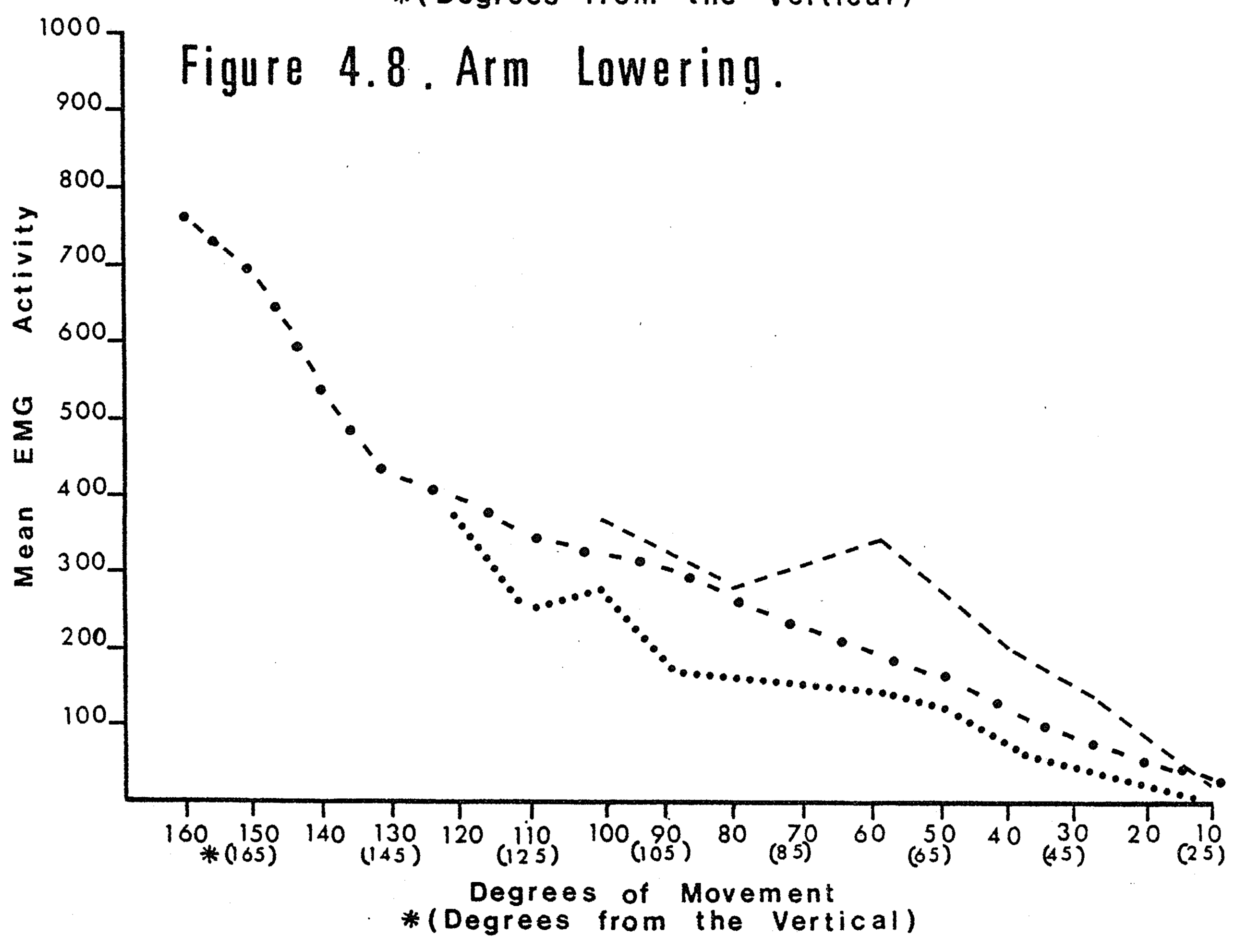


Figure 4.8. Arm Lowering.



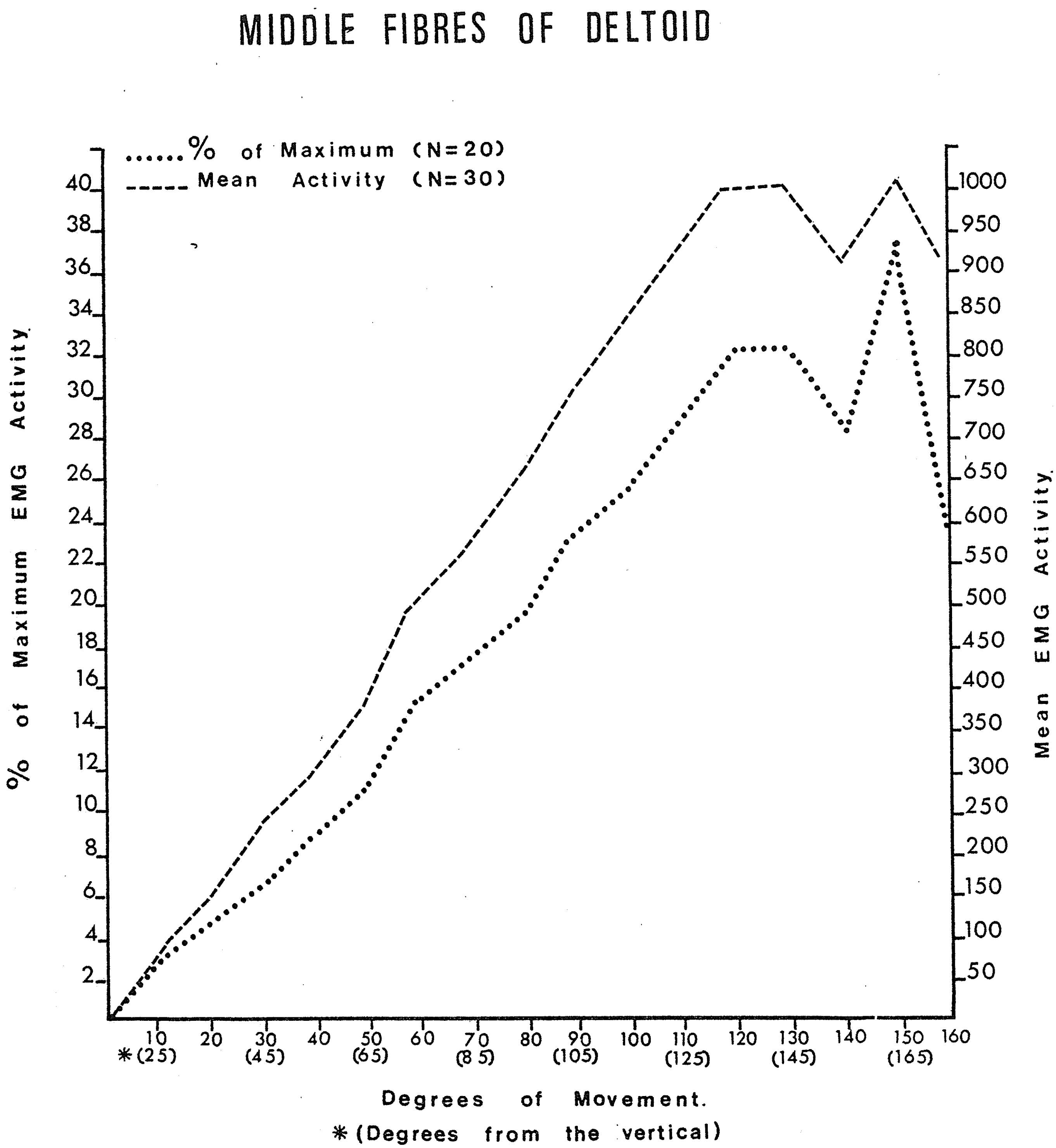


Figure 4.9 . Comparison between Mean EMG Activity and % of Maximum Activity.

TABLE 4.6. ACTIVITY OF THE MIDDLE FIBRES OF DELTOID IN NORMAL SUBJECTS IN RAISING THE ARM IN ABDUCTION.

Degrees of Abduction	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
10	113.4	84.6	3.0	1.6
20	172.9	117.7	4.5	2.6
30	253.6	183.7	6.6	4.3
40	318.4	205.9	8.9	6.8
50	393.4	259.5	11.3	9.2
60	508.6	333.7	14.9	11.5
70	497.4	370.1	17.5	13.5
80	659.3	346.7	19.1	13.4
90	777.1	483.7	22.7	17.1
100	836.2	454.8	25.4	18.2
110	923.5	443.1	28.8	18.7
120	1000.5	502.0	32.0	20.8
130	1005.2	532.4	32.0	20.0
140	924.4	507.8	28.2	20.1
150	1042.6	603.8	37.7	29.4
160	900.0	360.5	23.3	13.4

$\bar{X}$ = mean

SD = standard deviation

TABLE 4.7. ACTIVITY OF THE MIDDLE FIBRES OF DELTOID IN NORMAL SUBJECTS IN LOWERING THE ARM THROUGH THE PLANE OF ABDUCTION.

Degrees	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
160	783.3	246.6	19.9	14.0
150	724.9	428.3	26.6	25.9
140	550.6	301.1	17.7	15.2
130	438.9	246.3	14.4	11.2
120	408.8	208.1	12.7	10.0
110	362.6	206.1	11.1	10.0
100	340.5	202.1	10.2	8.8
90	318.6	203.5	9.4	7.9
80	266.6	183.8	7.9	7.7
70	233.5	183.3	6.8	6.8
60	192.4	149.4	5.7	6.4
50	160.2	124.0	4.9	5.0
40	122.0	99.3	3.8	3.8
30	95.0	76.6	2.8	3.1
20	71.7	52.4	2.1	1.9
10	48.8	40.0	1.4	1.3

$\bar{X}$ = mean

SD = standard deviation

movement. During lowering, this section of the muscle was concerned with the controlled descent of the arm and was acting in the capacity of prime mover.

Anterior Fibres of Deltoid

As was found in the posterior and middle fibres of deltoid, the activity level rose throughout elevation (Fig. 4.10)(Table 4.8). Activity showed a tendency to level off after 130^{o} with some slight fluctuations at 140^{o}, 150^{o} and 160^{o}. When activity was expressed as a percentage of maximum, activity increased from 3.3% at 10^{o} to 24.7% at 130^{o}. Thereafter activity was 25% at 140^{o}, 28.6% at 150^{o} and 34% at 160^{o} (Fig. 4.12). The activity of the anterior fibres of deltoid showed activity similar to that found by Long (1970) where activity levels tended to stabilize after 130^{o} abduction. Scheving and Pauly (1959), and Shevin et al (1969) also reported activity of the anterior fibres in abduction. The function of the anterior fibres was related to stabilisation of the glenohumeral joint while abduction was taking place.

The findings of this investigation were similar to those of other observers. Shevin et al (1969) however, suggested that the anterior fibres only functioned "slightly" in abduction. The present investigation showed percentage of maximum activity levels greater than that seen in the posterior fibres and at levels which indicated a contribution of up to 25% and 34% of maximum. In an unloaded free movement this could be regarded as more than "slight" activity.

The anterior fibres of deltoid showed a gradual decrease in activity during lowering of the arm (Fig. 4.11)(Table 4.9). The activity levels

ANTERIOR FIBRES OF DELTOID

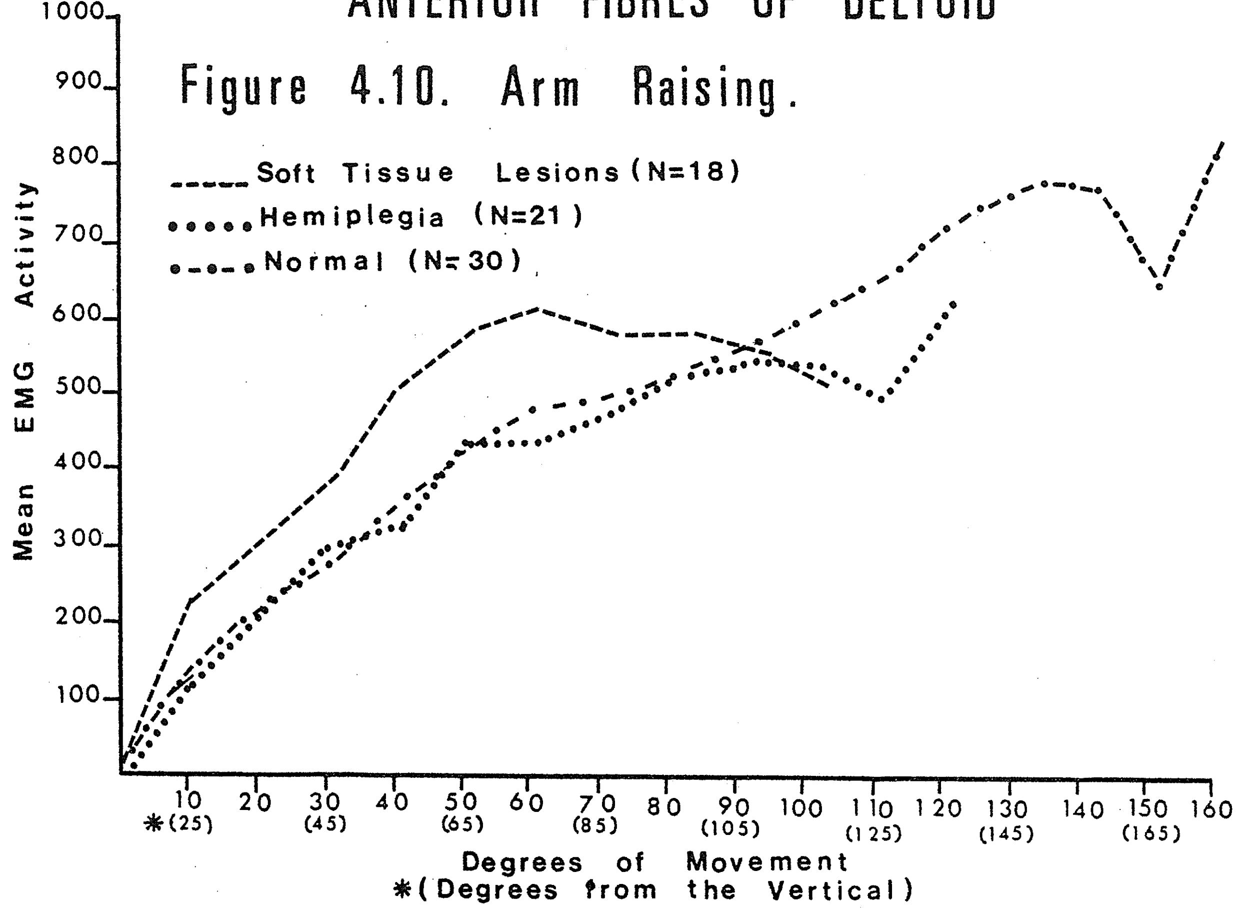


Figure 4.10. Arm Raising.

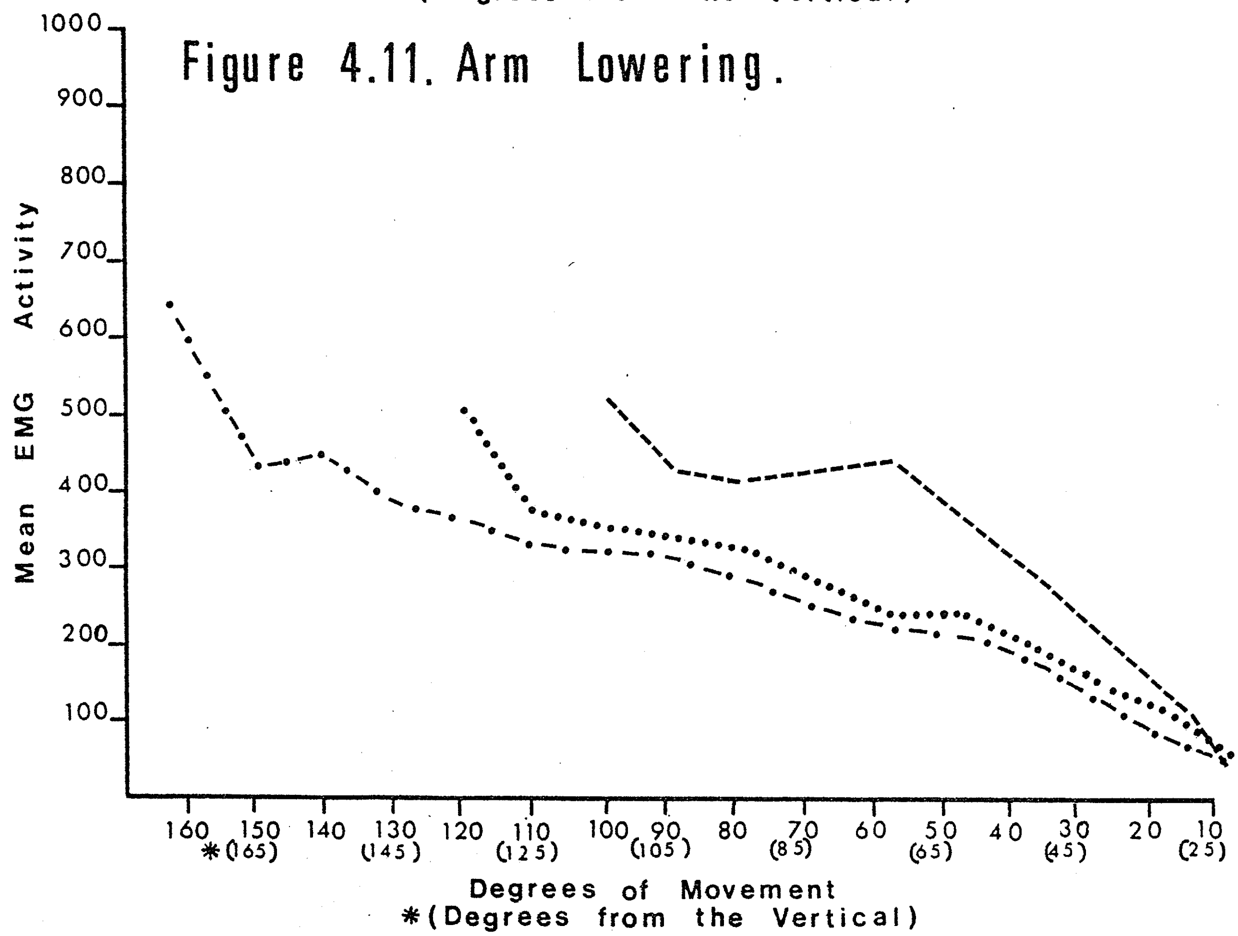


Figure 4.11. Arm Lowering.

ANTERIOR FIBRES OF DELTOID

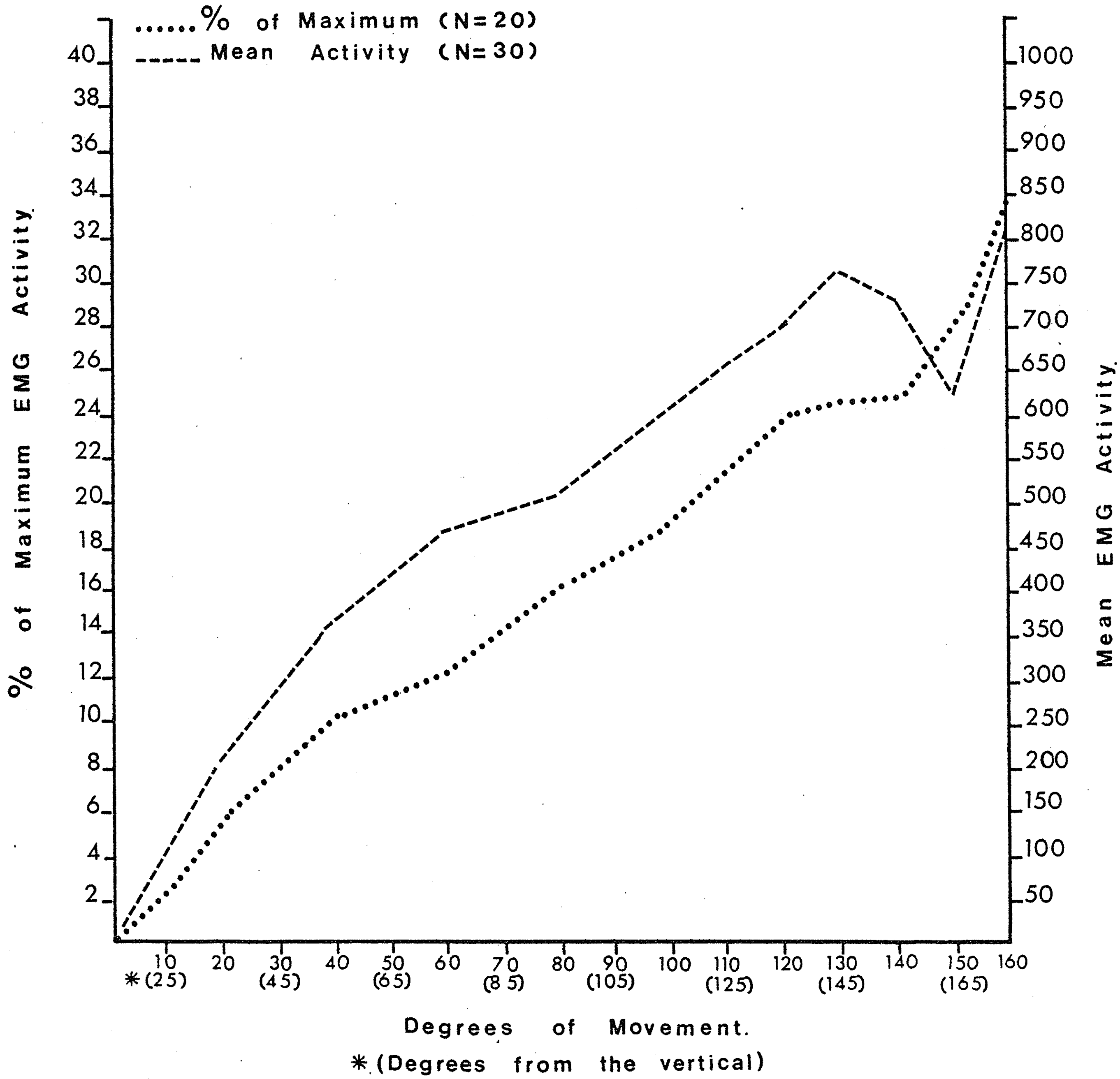


Figure 4.12. Comparison between Mean EMG Activity and % of Maximum Activity.

TABLE 4.8. ACTIVITY OF THE ANTERIOR FIBRES OF DELTOID IN NORMAL SUBJECTS IN RAISING THE ARM IN ABDUCTION.

Degrees of Abduction	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
10	135.1	129.9	3.3	2.5
20	216.4	168.6	6.1	4.2
30	291.2	205.8	8.4	4.9
40	358.6	246.7	10.1	6.0
50	406.3	276.1	11.3	7.0
60	474.8	345.6	12.5	8.2
70	498.2	291.6	14.2	9.3
80	509.1	294.9	16.0	11.5
90	587.9	335.6	17.8	14.2
100	615.1	340.1	19.4	15.0
110	653.4	326.7	21.4	15.7
120	710.6	344.2	24.6	17.3
130	757.3	443.8	24.7	17.7
140	743.8	446.0	25.0	19.7
150	631.3	392.9	28.6	23.3
160	825.0	106.0	34.0	22.6

$\bar{X}$ = mean

SD = standard deviation

TABLE 4.9. ACTIVITY OF THE ANTERIOR FIBRES OF DELTOID IN NORMAL SUBJECTS IN LOWERING THE ARM THROUGH THE PLANE OF ABDUCTION.

Degrees	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
160	621.9	359.5	23.5	18.4
150	443.0	253.0	14.3	12.7
140	458.2	266.0	13.5	11.6
130	394.4	230.8	11.1	9.5
120	367.0	221.1	10.5	9.2
110	343.3	209.9	9.7	8.3
100	325.2	201.2	9.3	8.3
90	308.9	179.2	8.9	7.6
80	288.0	162.1	8.3	5.9
70	257.2	148.1	7.3	5.3
60	236.0	146.5	6.7	4.4
50	202.8	127.2	5.9	3.9
40	170.4	127.4	4.5	2.5
30	134.7	122.5	3.6	3.0
20	96.3	111.5	2.6	2.4
10	65.3	56.4	2.6	2.8

$\bar{X}$ = mean

SD = standard deviation

were lower than seen during raising the arm. The findings were consistent with the lower levels expected of eccentric muscular contraction. The muscle functioned as an important influence in controlled descent of the arm.

Serratus Anterior (Lower Fibres)

The activity of serratus anterior showed a continuous increase throughout elevation. There was a slight decrease in activity between 120° and 130°. Except for this, the activity was continuously progressive throughout the movement of raising the arm (Fig. 4.13)(Table 4.10).

The lower part of the serratus anterior, together with the inferior portion of trapezius, constitutes the lower component of the scapular rotary force couple (Inman et al, 1944; Basmajian, 1974). Inman et al (1944) described a curve of activity starting at zero and continuously progressive to the point of maximum elevation. Long (1970) showed an activity pattern which reached a maximum level soon after 90° and remained constant to full elevation. The results of the present investigation were similar to those of Inman et al (1944) and Basmajian (1974).

When activity was expressed as a percentage of maximum activity, the muscle activity increased from 2.9% at 10° to 51.1% at 130°. This then went to 48.3% at 140°, 49.9% at 150° and 62.5% at 160°. Serratus anterior showed higher percentage levels than the other muscles evaluated in this investigation (Fig. 4.15).

The activity of serratus anterior during descent of the arm from the elevated position showed a steady decline from 55% at 160° to 2.1% at 10° (Fig. 4.14.)(Table 4.11). The activity levels were lower than

SERRATUS ANTERIOR

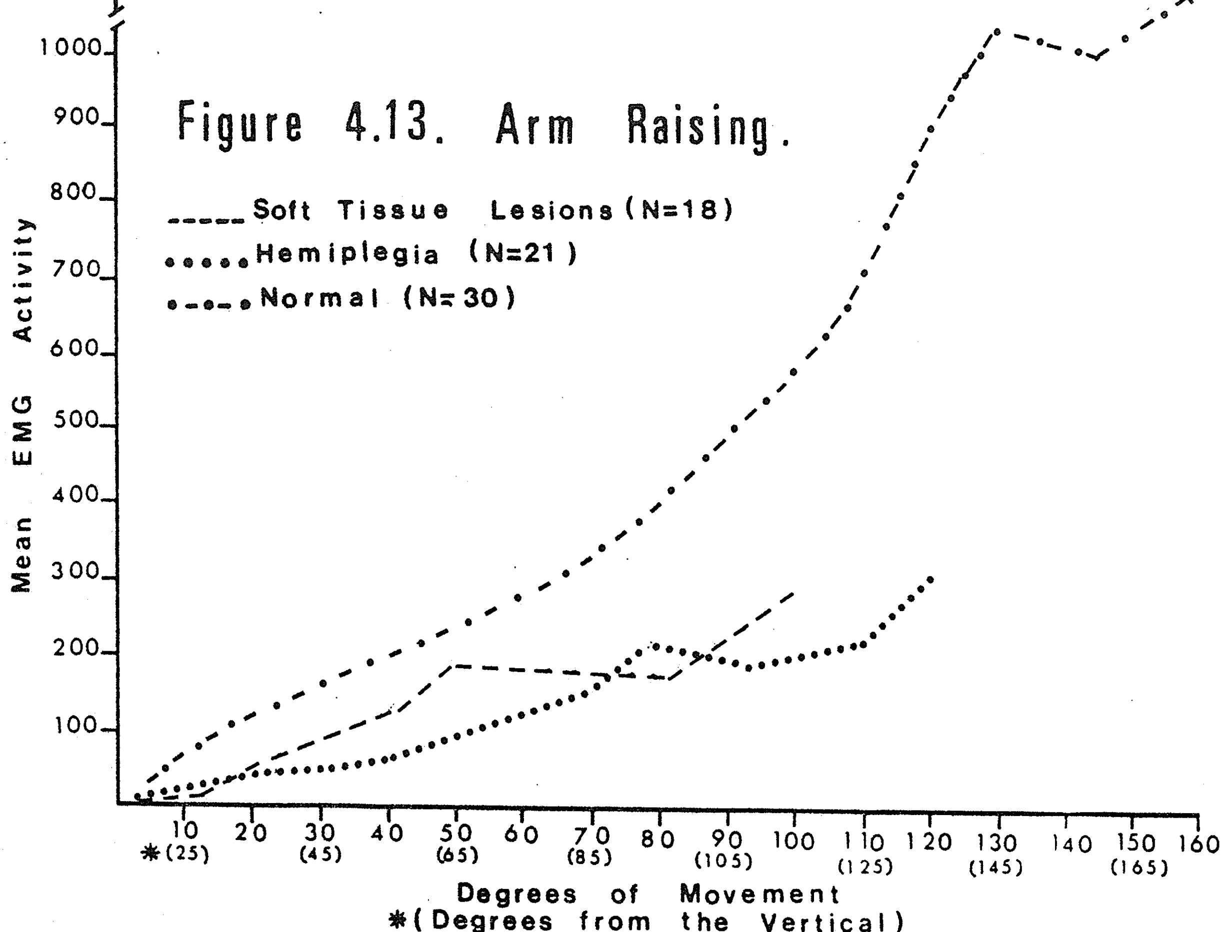
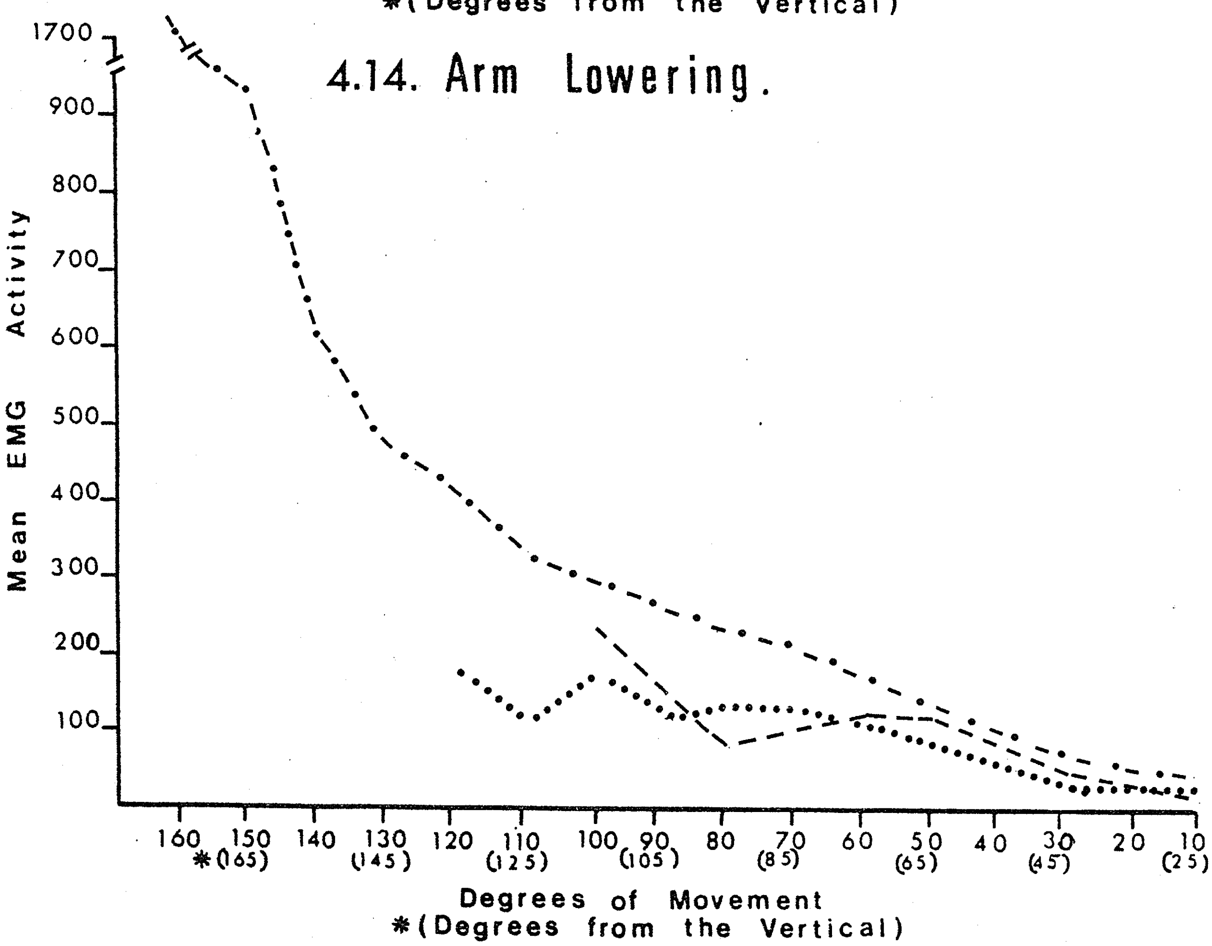


Figure 4.13. Arm Raising.



4.14. Arm Lowering.

SERRATUS ANTERIOR

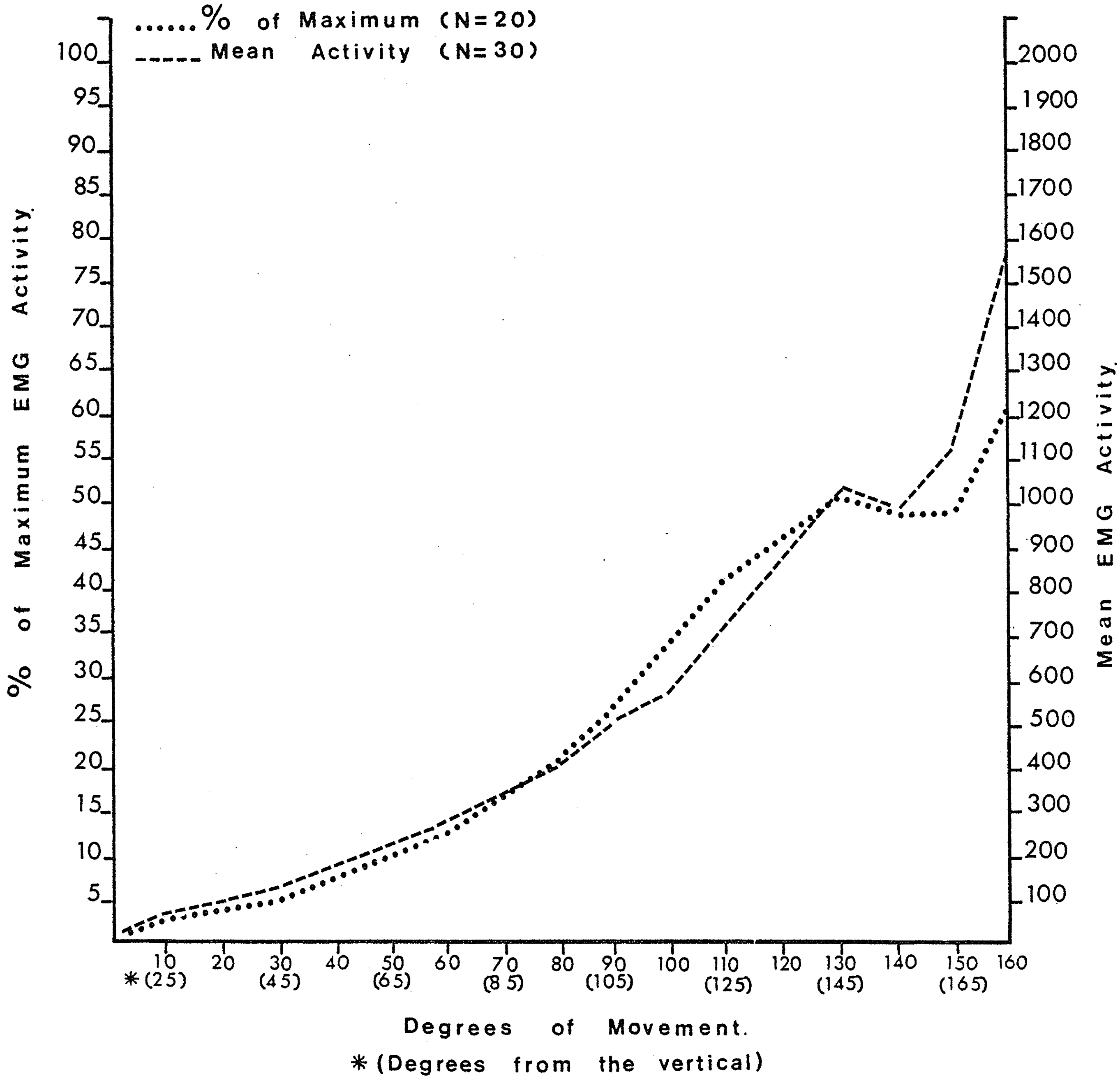


Figure 4.15. Comparison between Mean EMG Activity and % of Maximum Activity.

TABLE 4.10. ACTIVITY OF THE LOWER FIBRES OF SERRATUS ANTERIOR IN NORMAL SUBJECTS IN RAISING THE ARM IN ABDUCTION.

Degrees of Abduction	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
10	76.6	74.7	2.9	2.6
20	117.8	100.6	4.9	3.0
30	152.7	126.6	6.3	3.9
40	193.0	141.9	8.2	6.3
50	231.9	168.0	10.2	7.3
60	286.7	212.7	12.5	8.0
70	351.1	251.4	16.4	10.3
80	418.9	290.7	21.7	15.1
90	503.5	316.4	27.6	19.3
100	588.7	359.3	34.2	25.7
110	733.6	465.7	42.3	29.5
120	900.2	604.1	47.6	29.9
130	1029.7	744.6	51.1	29.6
140	976.9	654.0	48.3	29.1
150	1199.6	841.6	49.9	26.5
160	1575.0	388.9	62.5	42.4

$\bar{X}$ = mean

SD = standard deviation

TABLE 4.11. ACTIVITY OF THE LOWER FIBRES OF SERRATUS ANTERIOR IN NORMAL SUBJECTS IN LOWERING THE ARM THROUGH THE PLANE OF ABDUCTION.

Degrees	$\bar{X}$ Activity (Units of Amplitude) (N = 30)	SD	$\bar{X}$ % Activity (N = 20)	SD
160	1675.5	247.4	55.0	32.5
150	964.9	703.4	36.7	14.0
140	613.5	418.1	32.2	26.3
130	456.4	321.3	26.9	22.9
120	403.7	335.9	23.8	21.7
110	311.5	207.9	20.8	20.9
100	286.7	249.2	13.0	8.9
90	242.9	219.2	10.8	7.4
80	215.6	182.7	9.7	6.7
70	190.5	161.5	8.8	5.7
60	154.2	130.0	7.4	5.0
50	115.0	106.6	5.3	3.1
40	88.9	85.0	4.7	3.3
30	60.4	61.9	3.3	2.6
20	47.2	51.7	2.5	2.8
10	37.3	45.1	2.1	2.5

$\bar{X}$ = mean

SD = standard deviation

that recorded during raising the arm. The findings were consistent with the lower levels expected of eccentric muscular contraction. Long (1970) showed serratus anterior with two levels of activity, one extending from full elevation to the region of 60°, the other from 60° to 0°. This plateauing of activity was not recorded in the present investigation as the decline noted was continuous.

During descent of the arm serratus anterior functioned as a controlling influence on scapula position (Kelly, 1971).

COMPARISON OF ACTIVITY IN MUSCLES OF THE RIGHT AND LEFT SHOULDER

The muscle activity recorded during movements of the right arm was compared with activity seen in the same muscles of the opposite side during the performance of an identical movement of the left shoulder complex. This evaluation was completed to test the reliability of the technique and system being used (Tables 4.12 and 4.13).

It was assumed that there would be no difference in the muscle activity produced by identical movements of the right and left sides.

Sixteen subjects were tested and the data from the recordings of the movements of both limbs evaluated in the same manner. The sixteen subjects represented the last sixteen normals recruited for the investigation. The ages in this group ranged from 10 years to 88 years with a mean age of 56.5 years.

The statistical test used was a two-sample paired t test. The null hypothesis was that there would be no differences between the two samples. In this test the activity measurements for each muscle was compared with the measurement of the same muscle, at the same degree of abduction on the opposite limb.

The tests were completed using the ST15 program of the "Statistics On-Line" system of the Computer Department for Health Sciences, Faculty of Medicine, University of Manitoba.

Trapezius

The t test did not reveal any significant differences between the activity levels exhibited by the right and left trapezius. Trapezius was compared at every 10° interval from 10° to 140° during raising and lowering the arm. As this was the first muscle to be evaluated it was decided to examine the activity at each 10° of the range of motion. The activity at 150° and 160° was not compared as the number of normals completing this range decreased substantially. As no differences were noted in the activity levels of trapezius, comparisons on activity levels in the other muscles were completed at intervals of 20° and 30°. If any differences had been noted at these levels, an examination at every 10° would have been completed.

Posterior Fibres of Deltoid

The activity of this section of deltoid was examined at 10°, 40°, 70°, 100°, 130° and 140° during raising the arm. The examination was made at 110°, 80°, 50°, 30° and 10° during arm lowering. No significant differences were found between the right and left limb activity.

Middle Fibres of Deltoid

The activity of the middle section of deltoid was examined at 10°, 40°, 70°, 100°, 130° and 140° during abduction. During lowering of the arm the activity was compared at 140°, 100°, 70°, 40° and 10°. No significant differences were found between the activity levels assessed.

Anterior Fibres of Deltoid

The activity of the anterior fibres of deltoid was examined at 10°, 40°, 70°, 100° and 140° during abduction. During lowering of the arm activity was assessed at 140°, 110°, 70°, 30° and 10°. No significant differences were found between the activity levels assessed.

Serratus Anterior

The activity of this muscle was examined at 10°, 40°, 70°, 100° and 140° during abduction and at 140°, 110°, 70°, 40° and 10° during lowering of the arm. No significant differences were found.

Results of Comparison Between Right and Left Shoulder Muscles

The t test was used in 70 comparisons between right and left limb activity. None of these comparisons showed any significant difference in activity levels. The establishment of similar patterns of activity in the shoulder complex muscles tested, was used primarily to confirm the techniques being used. An evaluation of activity in both limbs of normal subjects was also necessary as both right and left limbs were to be evaluated in subjects with hemiplegia or a soft tissue lesion affecting a glenohumeral joint structure.

TABLE 4.12. t TEST FOR COMPARISON OF EMG ACTIVITY LEVELS IN RIGHT AND LEFT SHOULDER COMPLEX MUSCLES DURING ABDUCTION (N = 16).

	TRAPEZIUS			POSTERIOR DELTOID			MIDDLE DELTOID			ANTERIOR DELTOID			SERRATUS ANTERIOR		
Degrees	t	p	df	t	p	df	t	p	df	t	p	df	t	p	df
10	-0.577	>.05	15	0.114	>.05	15	-0.81	>.05	15	-0.155	>.05	15	-1.885	>.05	15
20	-0.049	>.05	15												
30	-0.031	>.05	15												
40	-0.282	>.05	15	0.229	>.05	15	-0.407	>.05	15	-0.069	>.05	15	-2.210	<.05*	15
50	-0.15	>.05	15												
60	0.217	>.05	15												
70	-0.038	>.05	15	0.817	>.05	15	-1.495	>.05	15	0.57	>.05	15	-2.236	<.05*	15
80	-0.061	>.05	15												
90	-0.055	>.05	15												
100	0.133	>.05	15	1.581	>.05	15	-0.59	>.05	15	1.028	>.05	15	-1.385	>.05	15
110	0.245	>.05	15												
120	0.053	>.05	15												
130	0.055	>.05	15	0.785	>.05	15	-0.188	>.05	15						
140	0.224	>.05	12	-0.444	>.05	15	-0.838	>.05	15	0.242	>.05	15	-1.408	>.05	15

t = t value p = probability value df = degrees of freedom

*Other than a difference ($p < .05$) noted in serratus anterior at 40° and 70° the tests did not indicate any significant difference between the activity of the right and left limb muscles. All other tests show a probability value greater than .05.

TABLE 4.13. t TESTS FOR COMPARISON OF THE EMG ACTIVITY LEVELS IN RIGHT AND LEFT SHOULDER COMPLEX MUSCLES DURING ARM LOWERING THROUGH THE PLANE OF ABDUCTION (N = 16).

	TRAPEZIUS			POSTERIOR DELTOID			MIDDLE DELTOID			ANTERIOR DELTOID			SERRATUS ANTERIOR		
Degrees	t	p	df	t	p	df	t	p	df	t	p	df	t	p	df
10	1.946	>.05	15	-0.835	>.05	15	-0.528	>.05	15	-0.12	>.05	15	-0.86	>.05	15
20	1.273	>.05	15												
30	0.375	>.05	15	0.308	>.05	15				-0.721	>.05	15			
40	-0.200	>.05	15				-0.578	>.05	15				-1.582	>.05	15
50	-0.183	>.05	15	0.053	>.05	15									
60	0.148	>.05	15												
70	-0.107	>.05	15				-1.478	>.05	15	0.415	>.05	15	-1.215	>.05	15
80	-0.005	>.05	15	0.573	>.05	15									
90	0.012	>.05	15												
100	-0.216	>.05	15				-1.042	>.05	15						
110	0.517	>.05	15	-0.126	>.05	15				0.911	>.05	15	-0.502	>.05	15
120	0.673	>.05	15												
130	0.769	>.05	14												
140	0.740	>.05	11	-0.444	>.05	15	-0.804	>.05	15	0.826	>.05	15	-0.925	>.05	15

t - t value p = probability value df = degrees of freedom

All tests of the muscle activity during lowering the arm have a probability value greater than .05. No significant differences in activity were obtained.

AGE GROUP COMPARISON IN NORMAL SUBJECTS

The mean age of the group of 30 normal subjects was 46.2 years. The ages ranged from 10 years to 88 years. To determine if the older subjects in the total group exhibited any variation in activity from those of a younger age, a comparison was made between 15 normal subjects with a $\bar{X}$ age of 28.2 years and 15 normals subjects with a $\bar{X}$ age of 64.1 years. The examination of this data from normal subjects would also be of value, since the age group of the other subjects, with whom comparisons are made is near that of the older group.

The comparison between age groups was made by using a one-way analysis of variance to find out if there was any significant difference between the means. In this analysis the measurements of activity for the younger group were compared with measurements of the older group for each muscle at various points in the range of motion.

This analysis was completed using the ST41 "Statistics On-Line" program of the Computer Department for Health Sciences, Faculty of Medicine, University of Manitoba.

Results of Age Group Comparison

The activity of the younger group was compared with the older group at eight different points, for each of the five muscles, during raising the arm in abduction. The analysis demonstrated similar patterns of activity. When activity levels were compared no significant differences were found (Table 4.14).

TABLE 4.14. COMPARISON OF MUSCLE ACTIVITY BETWEEN AGE GROUPS OF NORMAL SUBJECTS DURING RAISING THE ARM IN ABDUCTION. (FIFTEEN SUBJECTS IN EACH GROUP)

Degrees Moved	Trapezius F Value	Posterior Deltoid F Value	Middle Deltoid F Value	Anterior Deltoid F Value	Serratus Anterior F Value
10	3.206	0.194	0.000	1.409	0.072
20					
30	1.588	0.240	0.060	0.816	0.590
40					
50	1.325	0.278	0.081	1.782	1.142
60					
70	1.844	0.098	0.000	1.621	1.761
80					
90	1.451	0.027	0.025	1.109	1.365
100					
110	1.958	1.141	0.347	0.720	0.420
120					
130	0.111	1.358	1.796	0.710	0.084
140					
150	0.212	0.021	1.486	0.007	1.017

All tests of the muscle activity have a probability value greater than .05. No significant differences in activity were obtained.

MEASUREMENT OF MUSCLE ACTIVITY IN ABNORMAL GROUPS

This analysis was based upon the measurement of muscle activity in millimeters (mm). The data from the hemiplegic group and from those with soft tissue lesions, were compared with the phasic activity shown by the similar group of muscles in normal subjects. Abnormal limb position at the beginning and during movement could influence muscle activity patterns. Abduction of the arm could be accompanied by postural and limb position variations such as altered scapulo-humeral rhythm and abduction of the arm with a flexed elbow. Pain could also influence muscle contribution. It was, however, not possible in this investigation to identify and record each variation in limb position during attempted abduction.

The group of abnormal subjects was made up as follows: 21 hemiplegic (11 right side hemiplegic and 10 left side hemiplegic) and 18 soft tissue lesions (10 affecting the right glenohumeral joint and 8 affecting the left glenohumeral joint).

In the analysis of data, five groups were compared with each other: (1) normal, (2) right hemiplegic, (3) left hemiplegic, (4) right soft tissue lesion, and (5) left soft tissue lesion.

An evaluation was made of these five groups in addition to the comparison between the total hemiplegic and soft tissue groups with normal. The statistical tests used included a one-way analysis of variance for all five muscles, to find out if there was any significant difference between the activity of each subject group at every 10° moved in raising and lowering the arm. In addition, a least significant difference multiple comparison test was completed, to determine where particular pairs or groups were different.

Because of the large number of tests completed in this analysis there is a high degree of probability that a difference might exist by chance. On this basis the traditional .05 and .01 level of significance, although reported on in this investigation, may not indicate a real difference.

MEASUREMENT OF MUSCLE ACTIVITY IN HEMIPLEGIA

Introduction

This group was made up of 21 subjects, all of whom had a primary diagnosis of hemiplegia. The age of the group ranged from 28 years to 73 years, with a mean age of 58.4 years.

Trapezius in Hemiplegia

The hemiplegic subjects showed greater activity levels than normals in the first 70° of abduction (Fig. 4.16). The graphic representation shows both right and left hemiplegic subjects following a similar pattern up to 80°. Following this, the right hemiplegic subjects showed a gradual decline in activity until the completion of activity at 120°. The left hemiplegic group showed a somewhat similar pattern with a lowering of activity levels to 120°. Although graphically the activity levels appeared higher than that of normal subjects there was no statistically significant difference (Table 4.15).

The hemiplegic subjects, within the limitation of movement, showed a somewhat similar pattern of phasic activity when compared with that of normals. There is an increase in muscle activity, followed by a decrease towards the termination of movement.

Figure 4.16.

Trapezius

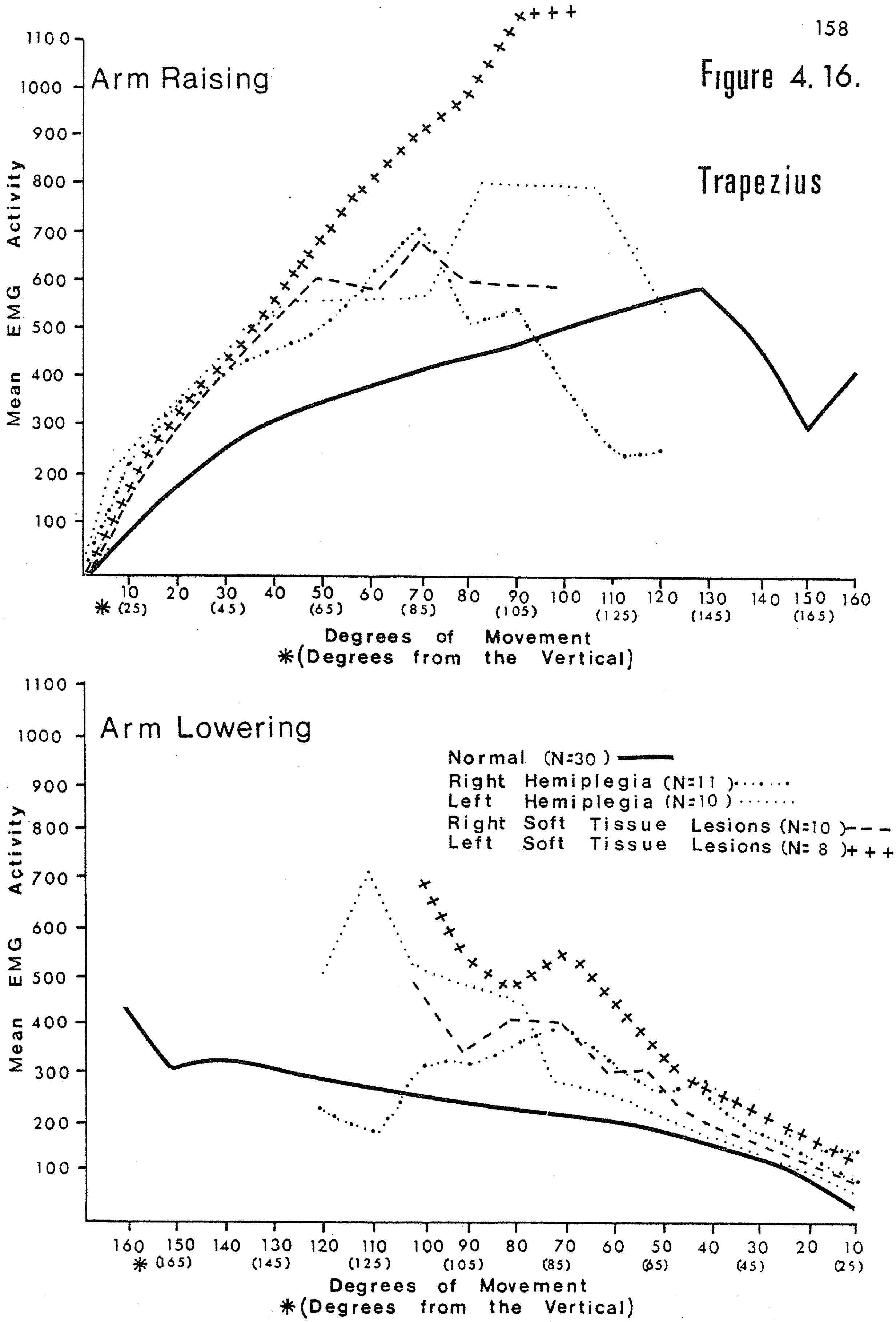


TABLE 4.15. THE ACTIVITY OF TRAPEZIUS DURING ARM RAISING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	1.523	4/64	239.8	186.1	1.786	NS	251.7	192.2	1.929	NS
20	1.601	4/64	356.8	222.1	1.724	NS	382.1	211.5	1.959	NS
30	1.604	4/64	426.9	251.8	1.481	NS	489.5	240.8	2.043	<.05
40	1.794	4/64	453.6	234.1	1.090	NS	559.5	270.8	1.966	NS
50	2.221	4/61	504.2	258.7	1.059	NS	571.6	275.8	1.571	NS
60	2.394	4/54	631.5	331.5	1.359	NS	561.2	276.0	1.042	NS
70	3.001	4/46	736.0	439.0	1.785	NS	596.0	287.8	1.012	NS
80	3.231	4/40	531.5	279.3	0.494	NS	803.3	601.6	1.729	NS
90	3.858	4/37	561.0	479.2	0.442	NS	820.0	628.6	1.614	NS
100	3.593	4/37	383.0	209.0	0.505	NS	833.3	611.0	1.496	NS
110	1.518	2/32	250.0	70.7	1.019	NS	826.6	604.6	1.332	NS
120	0.544	2/31	258.0	59.3	1.024	NS	500.0	141.4	0.248	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.16. THE ACTIVITY OF TRAPEZIUS DURING ARM LOWERING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
120	2.136	2/31	213.0	66.4	0.696	NS	515.0	120.2	1.899	NS
110	5.097	2/32	198.0	45.2	0.502	NS	726.6	669.8	3.106	<.01
100	4.291	4/37	332.0	234.2	0.436	NS	543.3	404.5	2.009	NS
90	2.475	4/37	332.0	234.2	0.552	NS	491.6	421.5	1.899	NS
80	1.995	4/40	379.0	268.0	1.129	NS	471.0	488.3	1.680	NS
70	2.719	4/46	405.8	218.6	1.372	NS	295.8	221.2	0.522	NS
60	3.316	4/54	351.6	147.1	1.562	NS	284.2	141.2	0.866	NS
50	1.810	4/61	287.7	117.3	1.592	NS	245.1	139.7	0.883	NS
40	2.702	4/64	296.8	155.6	2.786	<.01	185.3	127.1	0.494	NS
30	1.705	4/64	209.2	100.5	2.014	<.05	155.8	95.8	0.594	NS
20	1.460	4/64	151.3	79.2	1.771	NS	118.8	70.3	0.685	NS
10	1.798	4/64	113.3	43.9	2.188	<.05	92.3	62.0	1.136	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

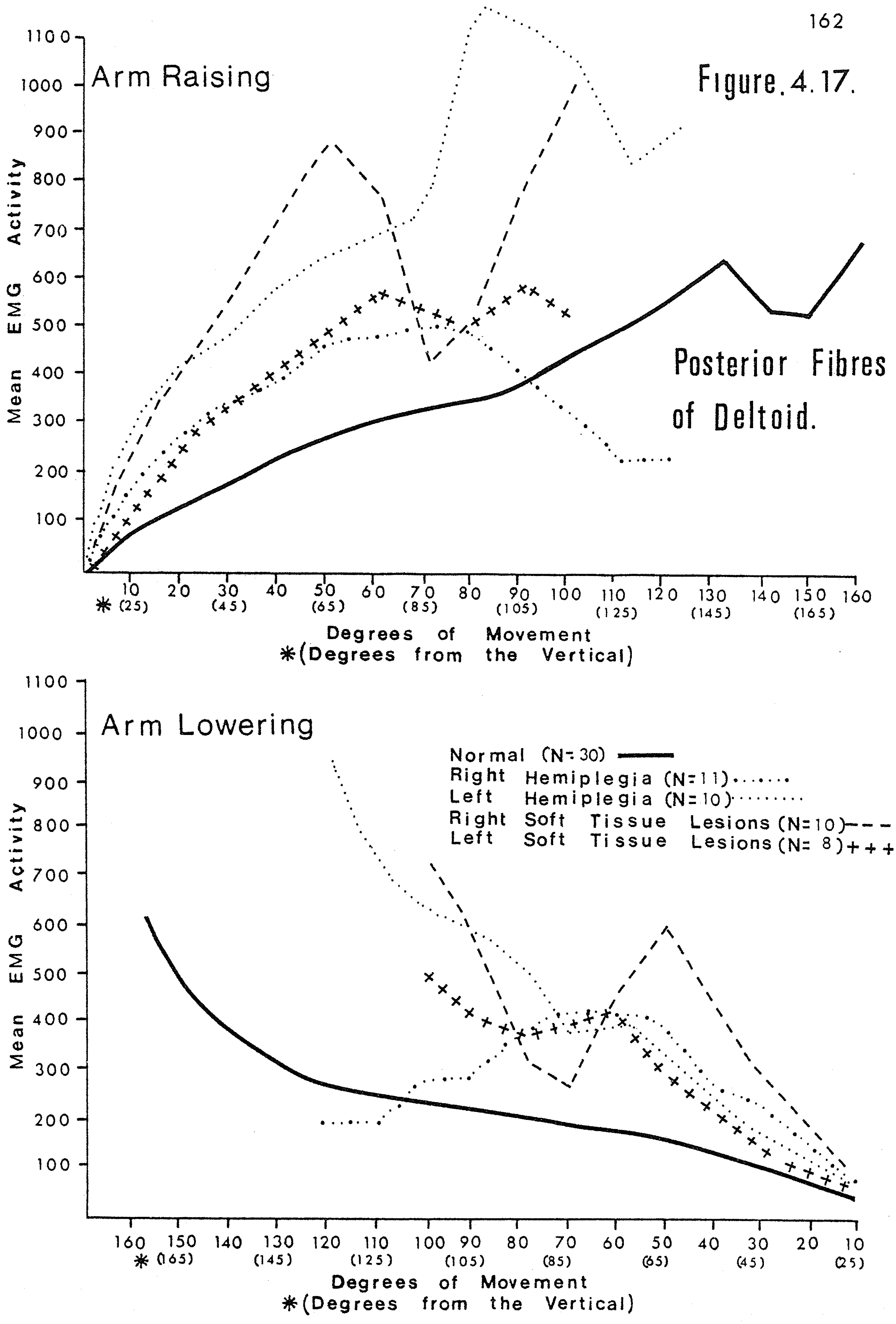
$\bar{X}$ = mean activity

The muscle activity pattern in lowering the arm was again similar to that of normals (Table 4.16). However the group of right hemiplegic subjects showed an increased level of activity at 40° ($p<.01$), 30° ($p<.05$) and 10° ($p<.05$). The left hemiplegic group showed a higher level at 110° ($p<.01$). As in arm raising, the graphic representation (Fig. 4.16) showed the hemiplegic groups exhibiting a slightly higher level of activity.

It appeared that on arm raising and lowering the activity pattern was similar to that of normal subjects with a statistical difference found in some points on arm lowering.

Posterior Fibres of Deltoid in Hemiplegia

Both right and left hemiplegic subjects showed an increase in activity during abduction, up to the region of 70° and 80°. Following this, activity levels decreased to the termination of the movement. When compared with normal subjects, the left hemiplegic group showed statistically the greatest increased level of activity from 10° to 100° (Fig. 4.17) (Table 4.17). In the latter group, differences at the $p<.001$ level were recorded at all points of the movement other than at 50° and 60°. The right hemiplegic subjects, although graphically showing an increased level of activity, only showed a statistical difference at 20° ($p<.05$). The increased level of activity seen in the posterior fibres of deltoid was consistent with the flexor synergy pattern seen in the upper limb in hemiplegia (Brunnstrom, 1970; Kottke, 1975). In this, when attempting to abduct, the subject may show extension of the shoulder with retraction of the scapula.



Arm Raising
Figure. 4.17.
Posterior Fibres of Deltoid.
Mean EMG Activity
1100
1000
900
800
700
600
500
400
300
200
100
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
* (25) (45) (65) (85) (105) (125) (145) (165)
Degrees of Movement
*(Degrees from the Vertical)
Arm Lowering
Normal (N=30)
Right Hemiplegia (N=11)
Left Hemiplegia (N=10)
Right Soft Tissue Lesions (N=10)
Left Soft Tissue Lesions (N= 8)
160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
* (165) (145) (125) (105) (85) (65) (45) (25)
Degrees of Movement
*(Degrees from the Vertical)

TABLE 4.17. THE ACTIVITY OF POSTERIOR DELTOID DURING ARM RAISING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	4.445	4/64	160.0	169.5	1.448	NS	281.8	249.6	3.799	<.001
20	6.048	4/64	293.5	249.3	2.235	<.05	421.1	349.2	3.878	<.001
30	6.705	4/64	348.0	264.4	1.943	NS	495.0	370.4	3.508	<.001
40	6.909	4/64	378.3	260.8	1.517	NS	598.8	401.2	3.546	<.001
50	6.914	4/61	490.5	217.5	1.779	NS	660.5	407.7	3.061	<.01
60	4.437	4/54	483.1	198.7	1.220	NS	680.5	419.5	2.656	<.02
70	3.919	4/46	506.4	237.5	1.558	NS	749.8	508.2	3.591	<.001
80	7.639	4/40	481.5	191.9	1.180	NS	1122.0	616.6	5.355	<.001
90	7.306	4/37	410.0	285.1	0.299	NS	1094.0	498.7	4.787	<.001
100	6.316	4/37	333.3	208.1	0.430	NS	1060.6	524.2	3.992	<.001
110	2.376	2/32	250.0	212.1	0.824	NS	850.8	589.4	1.950	NS
120	1.479	2/31	250.0	212.1	0.977	NS	933.0	612.3	1.352	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.18. THE ACTIVITY OF POSTERIOR DELTOID DURING ARM LOWERING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
120	14.330	2/31	200.0	141.4	0.354	NS	950.0	636.3	5.309	<.001
110	7.730	2/32	200.0	141.4	0.155	NS	755.0	734.8	3.906	<.001
100	8.780	4/37	300.0	200.0	0.825	NS	666.3	491.0	3.993	<.001
90	7.934	4/37	286.6	201.3	0.980	NS	605.3	405.9	4.155	<.001
80	4.801	4/40	390.0	279.4	2.232	<.05	538.6	346.4	3.367	<.01
70	5.139	4/46	428.0	265.0	3.096	<.01	383.2	264.1	2.550	<.02
60	5.346	4/54	413.6	220.6	2.426	<.02	409.4	277.5	2.542	<.02
50	7.744	4/61	414.3	229.2	2.928	<.01	330.4	208.0	2.038	<.05
40	6.414	4/64	282.4	245.6	2.446	<.02	267.2	163.9	2.139	<.05
30	5.494	4/64	239.1	202.6	2.922	<.01	192.6	110.7	1.902	NS
20	4.193	4/64	156.0	127.8	2.486	<.02	129.2	73.0	1.632	NS
10	1.888	4/64	90.4	67.0	1.677	NS	89.4	56.3	1.567	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

In lowering the arm from the abducted position, both right and left hemiplegic subjects showed increased levels of activity. In the early part of descent of the arm the activity of the right and left groups showed some variation. However, as the arm descended to the region of 80° the groups showed a similar pattern. From 80° throughout the rest of arm descent both groups showed a similar pattern of increased activity. Statistical levels on the right limb ranged from $p<.05$ to $p<.01$ while on the left the levels were greater, ranging from $p<.05$ to $p<.001$ (Table 4.18).

Both groups showed activity levels consistent with spasticity and synergy.

Middle Fibres of Deltoid in Hemiplegia

The middle fibres of deltoid show a marked similarity to normal subjects in both raising and lowering the arm. The graphic representation shows activity levels slightly lower than that of normal subjects. The slight difference is more noticable as movement approaches the limits of abduction. Statistical tests however indicate a statistical difference between normals and right hemiplegic only at 80° ($p<.05$). At all other points at which activity between right and left hemiplegics were compared with normal, no statistical differences were identified (Fig. 4.18)(Table 4.19 and 4.20).

Anterior Fibres of Deltoid in Hemiplegia

The pattern of activity seen in the anterior fibres of deltoid resembled that of the normal group. The muscle increased in activity

Figure 4.18. Middle Fibres of Deltoid.

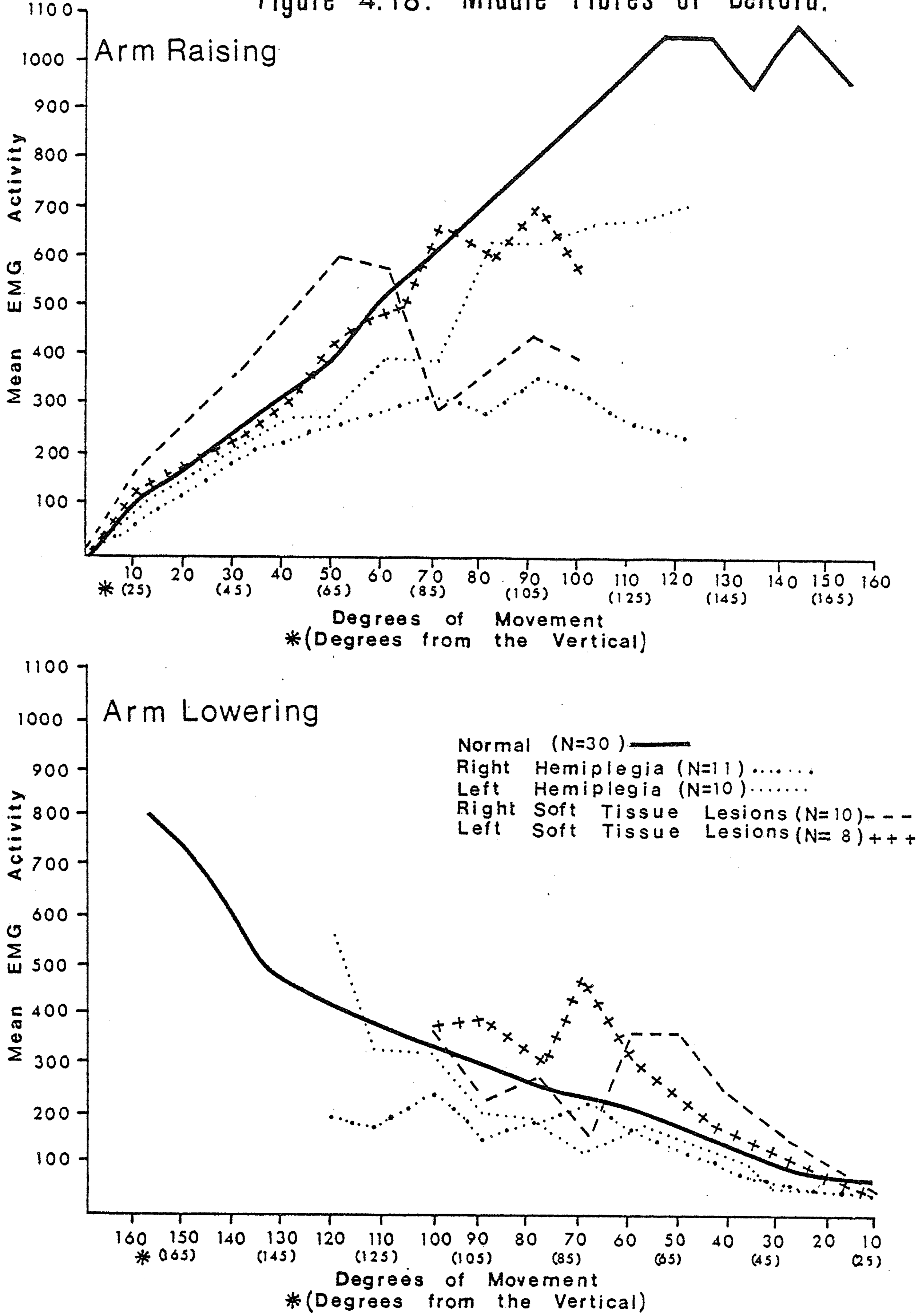


TABLE 4.19. THE ACTIVITY OF MIDDLE DELTOID DURING ARM RAISING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	1.648	4/64	67.2	54.1	1.357	NS	69.5	83.5	1.247	NS
20	1.165	4/64	116.5	72.8	1.185	NS	143.2	157.3	0.604	NS
30	0.953	4/64	193.8	137.8	0.821	NS	220.6	255.1	0.438	NS
40	1.566	4/64	228.9	119.3	1.085	NS	273.0	278.1	0.531	NS
50	1.776	4/61	261.7	149.7	1.091	NS	294.2	294.5	0.822	NS
60	0.715	4/54	285.0	123.5	1.367	NS	406.8	361.9	0.663	NS
70	1.656	4/46	316.0	89.6	1.609	NS	396.4	454.6	1.150	NS
80	1.657	4/40	286.5	49.0	2.120	<.05	622.0	515.0	0.187	NS
90	0.786	4/37	365.3	135.0	1.499	NS	625.0	378.3	0.554	NS
100	0.572	4/37	332.0	89.9	1.976	NS	672.0	297.9	0.644	NS
110	2.373	2/32	283.0	117.3	2.041	NS	686.0	315.8	0.913	NS
120	2.340	2/31	266.0	141.4	2.064	<.05	725.0	176.7	0.774	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.20. THE ACTIVITY OF MIDDLE DELTOID DURING ARM LOWERING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

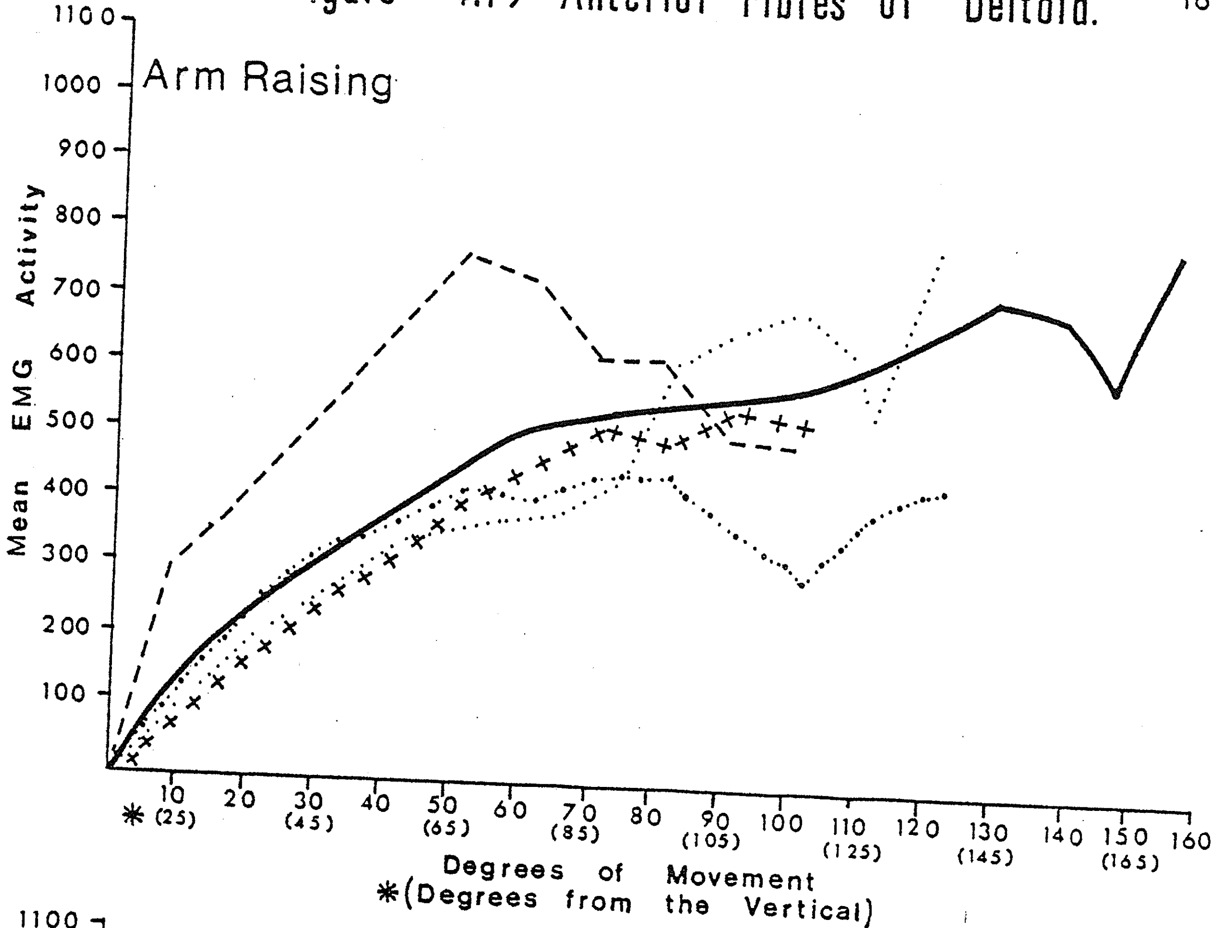
			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
120	1.547	2/31	198.0	45.2	1.393	NS	558.0	271.5	0.985	NS
110	0.809	2/32	180.0	70.7	1.266	NS	336.6	70.9	0.307	NS
100	0.207	4/37	238.6	145.8	0.824	NS	333.0	159.9	0.061	NS
90	0.828	4/37	160.6	42.2	1.328	NS	222.0	144.0	0.812	NS
80	0.504	4/40	169.7	93.2	1.053	NS	199.6	164.3	0.640	NS
70	2.031	4/46	209.8	136.3	0.213	NS	120.0	130.3	1.015	NS
60	1.765	4/54	151.5	68.3	0.385	NS	169.8	187.5	0.226	NS
50	2.636	4/61	120.2	65.7	0.531	NS	151.4	164.3	0.116	NS
40	2.211	4/64	93.1	68.7	0.647	NS	93.2	112.0	0.624	NS
30	2.882	4/64	57.0	44.3	1.134	NS	51.0	83.6	1.267	NS
20	1.739	4/64	28.5	34.9	2.007	<.05	40.6	81.5	1.397	NS
10	1.062	4/64	22.5	36.5	1.695	NS	24.9	52.6	1.489	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

Figure 4.19 Anterior Fibres of Deltoid.



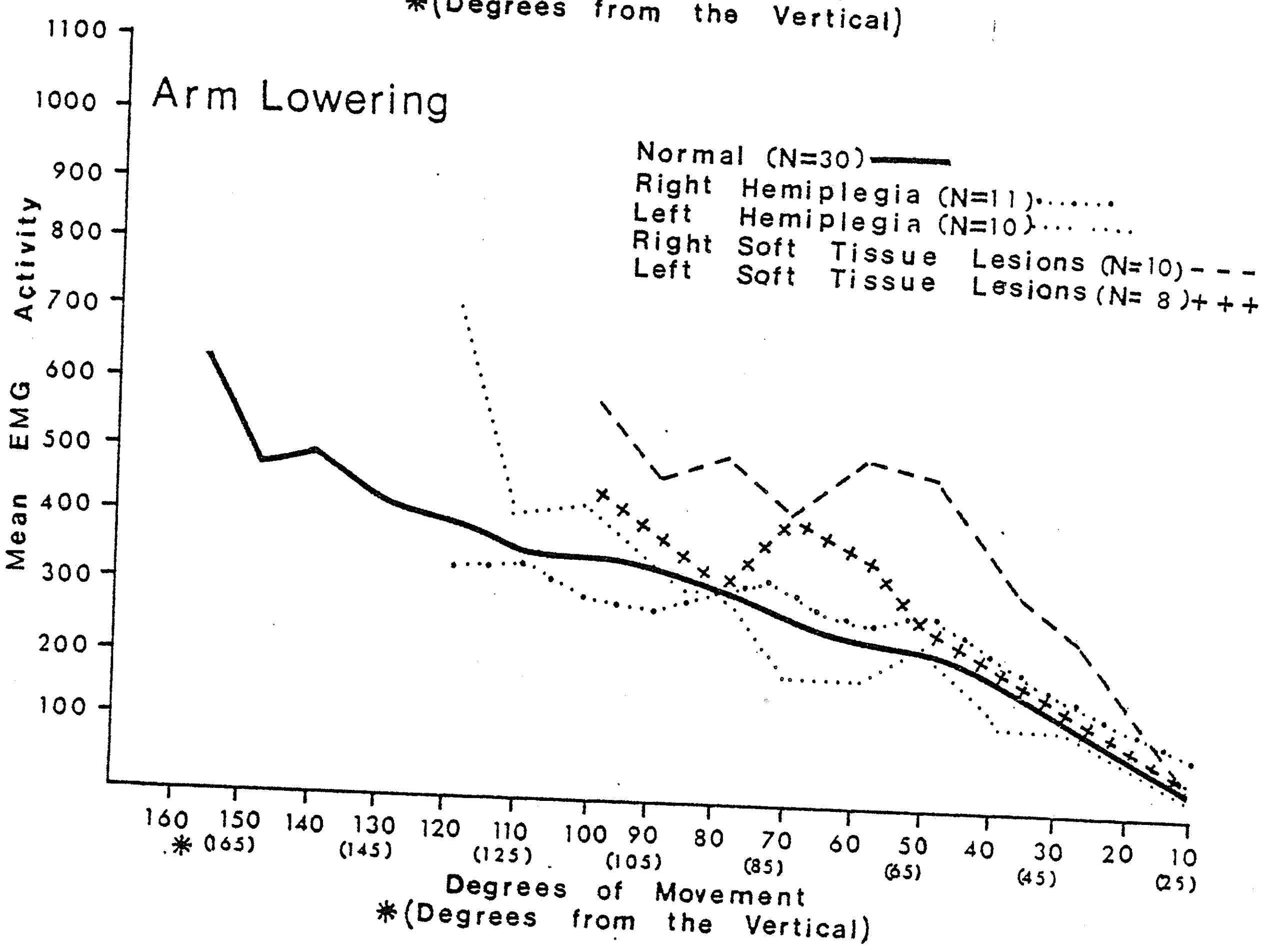


TABLE 4.21. THE ACTIVITY OF ANTERIOR DELTOID DURING ARM RAISING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	3.502	4/64	126.2	80.3	0.157	NS	123.8	103.2	0.194	NS
20	3.715	4/64	226.1	161.7	0.159	NS	187.6	123.8	0.452	NS
30	3.192	4/64	317.4	211.9	0.355	NS	282.7	174.9	0.108	NS
40	4.128	4/64	371.6	263.2	0.154	NS	335.5	188.4	0.256	NS
50	3.946	4/61	421.0	238.1	0.150	NS	395.0	221.4	0.115	NS
60	1.652	4/54	418.3	363.3	0.408	NS	398.7	228.4	0.585	NS
70	0.329	4/46	478.6	203.9	0.144	NS	445.8	333.7	0.384	NS
80	0.283	4/40	454.0	161.6	0.360	NS	605.3	321.2	0.552	NS
90	0.372	4/37	388.6	153.3	1.008	NS	694.0	358.8	0.537	NS
100	0.634	4/37	344.3	249.9	1.349	NS	716.6	325.3	0.506	NS
110	0.547	2/32	433.0	329.5	0.938	NS	550.0	229.1	0.331	NS
120	0.674	2/31	450.0	353.5	1.051	NS	816.5	118.0	0.427	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.22. THE ACTIVITY OF ANTERIOR DELTOID DURING ARM LOWERING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
120	2.333	2/31	350.0	212.1	0.107	NS	708.0	59.3	2.146	<.05
110	0.231	2/32	350.0	212.1	0.044	NS	427.6	94.5	0.680	NS
100	1.319	4/37	300.0	173.2	0.208	NS	431.3	71.4	0.873	NS
90	0.685	4/37	286.6	150.1	0.211	NS	322.0	62.8	0.124	NS
80	1.480	4/40	344.0	200.9	0.606	NS	294.3	41.7	0.060	NS
70	2.813	4/46	348.4	186.0	1.124	NS	200.0	206.4	0.705	NS
60	5.981	4/54	284.3	128.7	0.660	NS	198.5	129.5	0.544	NS
50	7.446	4/61	292.5	126.8	1.642	NS	215.7	138.9	0.237	NS
40	5.231	4/64	221.7	132.0	1.136	NS	161.2	117.8	0.197	NS
30	4.288	4/64	160.2	90.1	0.680	NS	112.6	80.8	0.567	NS
20	0.771	4/64	115.6	62.5	0.590	NS	112.6	80.8	0.480	NS
10	0.805	4/64	86.1	65.4	1.075	NS	44.8	50.1	1.025	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

throughout the movement with a slight leveling off after 80°. Right and left hemiplegic groups followed a very similar pattern up to 80°. After this there was a reduction in activity in the right hemiplegic group. The left hemiplegic group after 80° continued to follow the pattern of the muscle activity in normal subjects (Table 4.21).

During lowering the arm from the abducted position, both right and left hemiplegic groups followed a very similar course of gradually declining activity. Statistical tests (Table 4.22) showed no significant difference between the hemiplegic and normal pattern of activity, other than at 120° during lowering the arm in the left hemiplegic group ($p<.05$). Other than there being a limitation of movement, the activity of this part of deltoid shows a gradual increase and decrease in activity during movement of the arm. This activity was consistent with normal phasic patterns (Fig. 4.19).

Serratus Anterior in Hemiplegia

Serratus anterior showed substantially lower levels of activity, when compared with normal. The lower levels were recorded in both arm raising and lowering. Not only were low levels recorded but of the 11 right hemiplegics, five showed no activity either in raising or lowering the arm. In the group of 10 left hemiplegics, four showed no activity.

When the activity levels of the right hemiplegic groups are compared with normal, statistical differences were recorded. As the arm was raised the level of differences extended from $p<.02$ at 10° and 20° to $p<.01$ at 30°, 40° and 50°. Following 50° the differences decreased to $p<.02$ at 100° to 110° and to no significant difference at 120° when the

Figure 4.20. Serratus Anterior

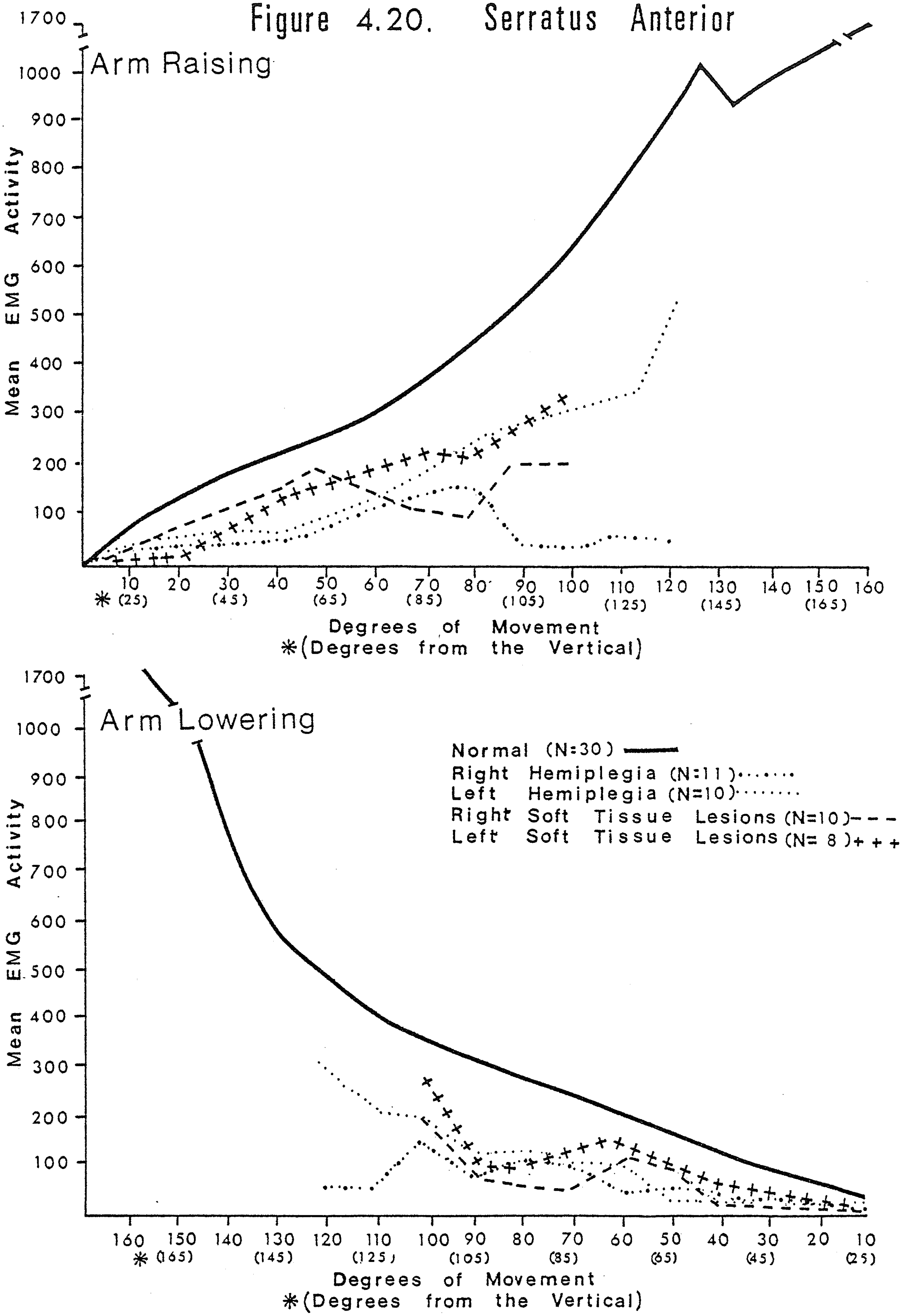


TABLE 4.23. THE ACTIVITY OF SERRATUS ANTERIOR DURING ARM RAISING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	2.990	4/64	21.1	60.1	2.486	<.02	36.4	63.6	1.741	NS
20	2.765	4/64	43.6	86.2	2.407	<.02	50.8	71.3	2.099	<.05
30	3.045	4/64	34.5	68.0	3.016	<.01	61.0	81.0	2.259	<.05
40	4.008	4/64	46.6	74.7	3.408	<.01	67.9	89.3	2.812	<.01
50	2.420	4/61	62.5	92.7	2.709	<.01	100.7	108.5	2.098	<.05
60	2.318	4/54	104.8	156.2	2.210	<.05	139.8	97.5	1.901	NS
70	2.509	4/46	130.0	156.5	2.141	<.05	196.4	78.3	1.498	NS
80	2.229	4/40	166.5	226.1	1.813	NS	226.6	175.5	0.961	NS
90	2.420	4/37	44.3	50.9	2.578	<.02	286.3	267.4	1.219	NS
100	2.510	4/37	49.6	59.7	2.628	<.02	338.6	326.7	1.219	NS
110	2.856	2/32	58.0	82.0	2.052	<.05	358.0	321.0	1.376	NS
120	2.189	2/31	58.0	82.0	1.973	NS	550.0	70.7	0.820	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.24. THE ACTIVITY OF SERRATUS ANTERIOR DURING ARM LOWERING IN RIGHT AND LEFT HEMIPLEGIC SUBJECTS.

			RIGHT (N = 11)				LEFT (N = 10)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
120	1.160	2/31	50.0	70.7	1.489	NS	305.0	63.6	0.416	NS
110	1.726	2/32	50.0	70.7	1.763	NS	222.6	174.0	0.722	NS
100	0.401	4/37	133.3	152.7	1.090	NS	209.6	167.4	0.548	NS
90	1.012	4/37	66.6	57.7	1.475	NS	149.6	109.4	0.781	NS
80	1.208	4/40	116.5	172.8	1.131	NS	132.0	67.0	0.839	NS
70	1.044	4/46	113.2	149.9	1.097	NS	118.8	68.9	1.017	NS
60	1.000	4/54	58.1	69.4	1.701	NS	100.7	79.9	1.010	NS
50	1.083	4/61	66.2	72.2	1.297	NS	49.8	75.4	1.731	NS
40	1.783	4/64	42.3	51.2	1.781	NS	38.1	69.1	1.877	NS
30	1.971	4/64	21.0	33.1	2.052	NS	28.3	65.7	1.614	NS
20	1.598	4/64	18.0	34.4	1.772	NS	24.0	63.1	1.364	NS
10	1.232	4/64	18.0	34.4	1.272	NS	24.0	63.1	0.850	NS

t and p values related to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

movement terminated. In this attempt at abduction the greatest disparity between right hemiplegic and normal activity was recorded at 30^{o}, 40^{o} and 50^{o} (Fig. 4.20)(Table 4.23).

The group of left hemiplegic subjects also showed decreased activity throughout arm raising. The differences were recorded at 20^{o} ($p<.05$), 30^{o} ($p<.05$), 40^{o} ($p<.01$) and 50^{o} ($p<.05$). After this the left hemiplegic group continued to show a decreased level (Fig. 4.20), but no significant differences were located (Table 4.24). In both right and left hemiplegic groups the interval between 20^{o} and 50^{o} in arm raising showed the greatest differences when compared with normal activity. The low levels of activity recorded in both right and left hemiplegic groups would contribute substantially to a diminished range of abduction. During arm lowering activity levels were also lower than that seen in normal subjects.

Summary of Activity in Hemiplegic Subjects

It was noted in the tables showing the mean activity levels and standard deviations, that the latter measurements were often quite large. This was due, in part, to the variation in activity levels between subjects, for example, some subjects exhibited no activity, as in serratus anterior, whereas other subjects showed substantial activity.

During the attempt to raise the arm in the plane of abduction, the anterior and middle fibres of deltoid exhibited few differences from the phasic activity pattern seen in normal subjects. Posterior fibres of deltoid exhibited increased activity. Trapezius showed phasic activity somewhat similar to normal although graphically the levels of activity were greater than normal. Serratus anterior showed a considerable reduction in activity, and nine of the 21 hemiplegic subjects showed no activity in this muscle.

In the patient with hemiplegia, this investigation has indicated a pattern of limited abduction with overactivity of the posterior fibres of deltoid and considerably reduced activity in serratus anterior. The inability of the latter muscle to function adequately would be a major contribution to the limitation of abduction. The activity patterns of right and left sided hemiplegic subjects showed occasional variations. Overall activity however, in lesions of the right and left were similar.

MUSCLE ACTIVITY IN SUBJECTS WITH SOFT TISSUE LESIONS

Introduction

This group was made up of 18 subjects. All subjects exhibited pain and limitation of movement associated with a lesion of a glenohumeral joint structure. The diagnoses of this group are shown on page 93. The age of the group ranged from 39 to 70 years. The mean age was 53.1 years.

Trapezius in Soft Tissue Lesions

Trapezius of both right and left-sided lesions showed increased levels of activity (Fig. 4.16). The soft tissue groups followed the pattern of normal subjects in the first 10^{o}-20^{o} of abduction. After this the activity of the normal group increased gradually whereas the soft tissue groups had a more rapid rate of increase. Statistically, the difference was greatest in the group with lesions on the left side. From 40^{o} ($p<.05$) the levels of significance increased throughout the movement to $p<.01$ and ultimately $p<.001$ at 100^{o} (Table 4.25). The activity during arm lowering followed a similar pattern with the soft tissue groups showing greater activity than normals. Again statistically the group with

Figure 4.16.

Trapezius

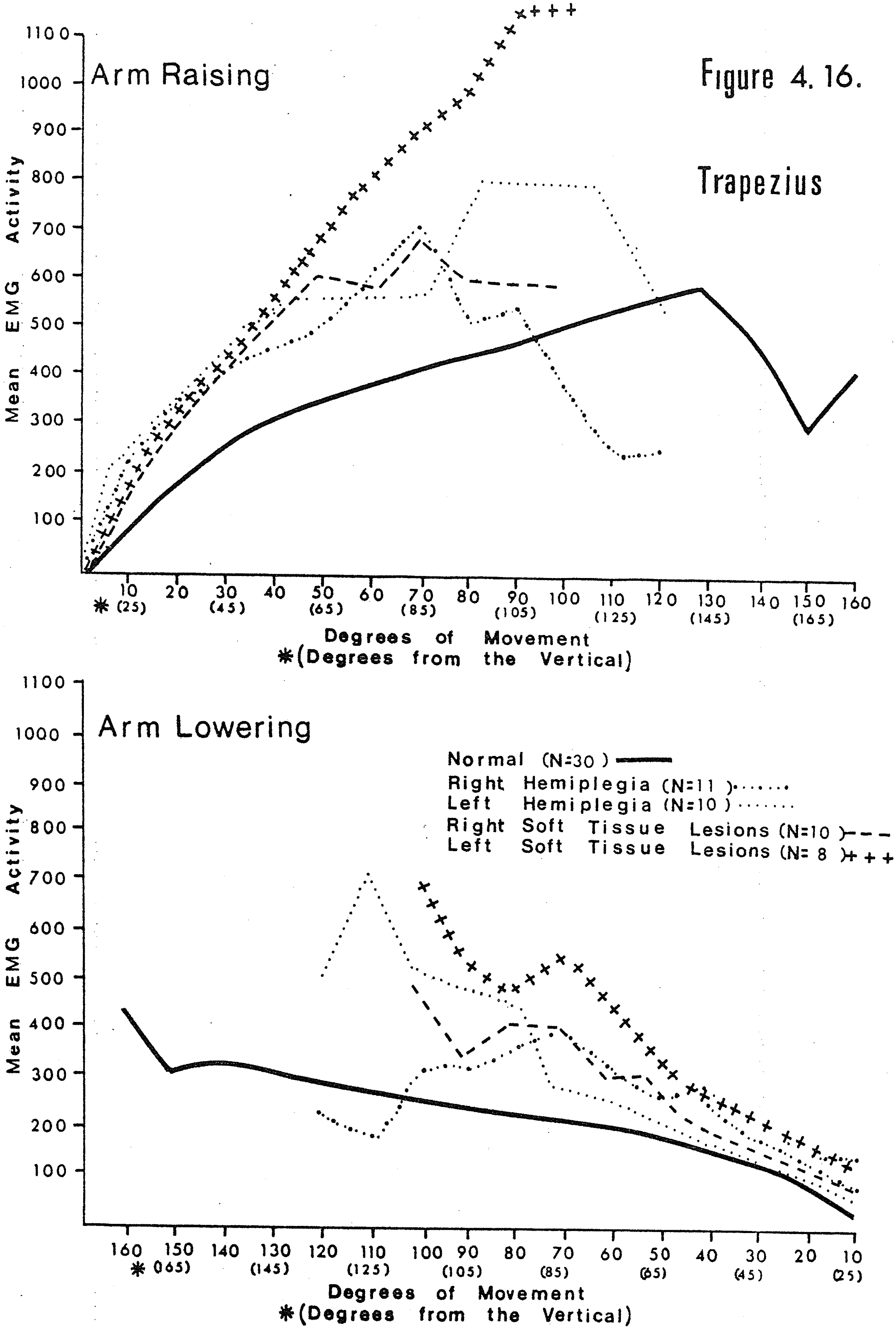


TABLE 4.25. THE ACTIVITY OF TRAPEZIUS DURING ARM RAISING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	1.523	4/64	147.7	212.6	0.135	NS	202.3	154.5	0.989	NS
20	1.601	4/64	322.7	439.4	1.272	NS	357.0	213.6	1.531	NS
30	1.604	4/64	423.9	513.8	1.400	NS	455.1	277.0	1.566	NS
40	1.794	4/64	514.1	541.6	1.574	NS	586.2	447.0	2.016	<.05
50	2.221	4/61	617.8	546.4	1.999	NS	705.5	544.4	2.471	<.02
60	2.394	4/54	586.1	396.9	1.251	NS	859.8	887.4	2.921	<.01
70	3.001	4/46	721.8	488.8	1.706	NS	913.3	733.9	2.984	<.01
80	3.231	4/40	624.7	474.6	0.999	NS	1044.7	651.8	3.275	<.01
90	3.858	4/37	615.0	403.0	0.569	NS	1187.0	656.4	3.725	<.001
100	3.593	4/37	600.0	282.8	0.405	NS	1162.7	654.0	3.577	<.001

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.26. THE ACTIVITY OF TRAPEZIUS DURING ARM LOWERING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
100	4.291	4/37	515.0	403.0	1.491	NS	704.0	422.8	3.646	<.001
90	2.475	4/37	350.8	212.1	0.584	NS	545.5	290.8	2.676	<.02
80	1.995	4/40	429.0	402.8	1.554	NS	479.0	273.9	1.979	NS
70	2.719	4/46	429.2	281.9	1.553	NS	587.6	641.3	3.001	<.01
60	3.316	4/54	337.0	141.2	1.572	NS	406.8	440.3	3.443	<.01
50	1.810	4/61	304.0	239.2	1.938	NS	320.6	205.1	2.043	<.05
40	2.702	4/64	226.6	151.5	1.320	NS	283.8	202.1	2.236	<.05
30	1.705	4/64	187.6	116.1	1.397	NS	215.7	165.6	1.934	NS
20	1.460	4/64	140.0	79.4	1.352	NS	161.8	154.0	1.873	NS
10	1.798	4/64	105.9	62.7	1.766	NS	105.3	84.9	1.598	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

lesions on the left showed the greatest differences (Table 4.26). The levels however, were not as great as those seen during arm raising. From 100° ($p<.001$) the activity decreased to $p<.02$ at 90°, $p<.01$ at 70° and 60°, $p<.05$ at 50° and 40°. At 30°, 20° and 10° no significant differences were recorded.

Posterior Fibres of Deltoid in Soft Tissue Lesions

The activity of the posterior fibres of deltoid increased up to 50° and 60°. Following this, activity decreased slightly to 70°, before a final rise to the termination of the movement. The graphic representation (Fig. 4.17) shows activity increasing more rapidly than the activity levels of normal subjects. The slight drop in activity towards the end of the movement, seen in subjects with soft tissue lesions, was absent in normals. During arm raising the activity exhibited by the group of subjects with lesions on the right side was statistically different from the normals. The greatest differences were located between 20° to 60° ($p<.001$). After 60° the differences were less at 70° and 80°, as the activity level dropped slightly. The end of the movement to 90° and 100° again produced a difference when compared with the normal group ($p<.02$ and $p<.01$)(Table 4.27).

During lowering the arm, the group of subjects with soft tissue lesions again exhibited higher levels of activity (Fig. 4.17). The descent of the arm did not produce a smooth decrease in muscle activity. There was a rapid drop to 100° to $70^{\circ}/80^{\circ}$ then a rise in activity to $50^{\circ}/60^{\circ}$ before the final, relatively rapid reduction in activity to 0°.

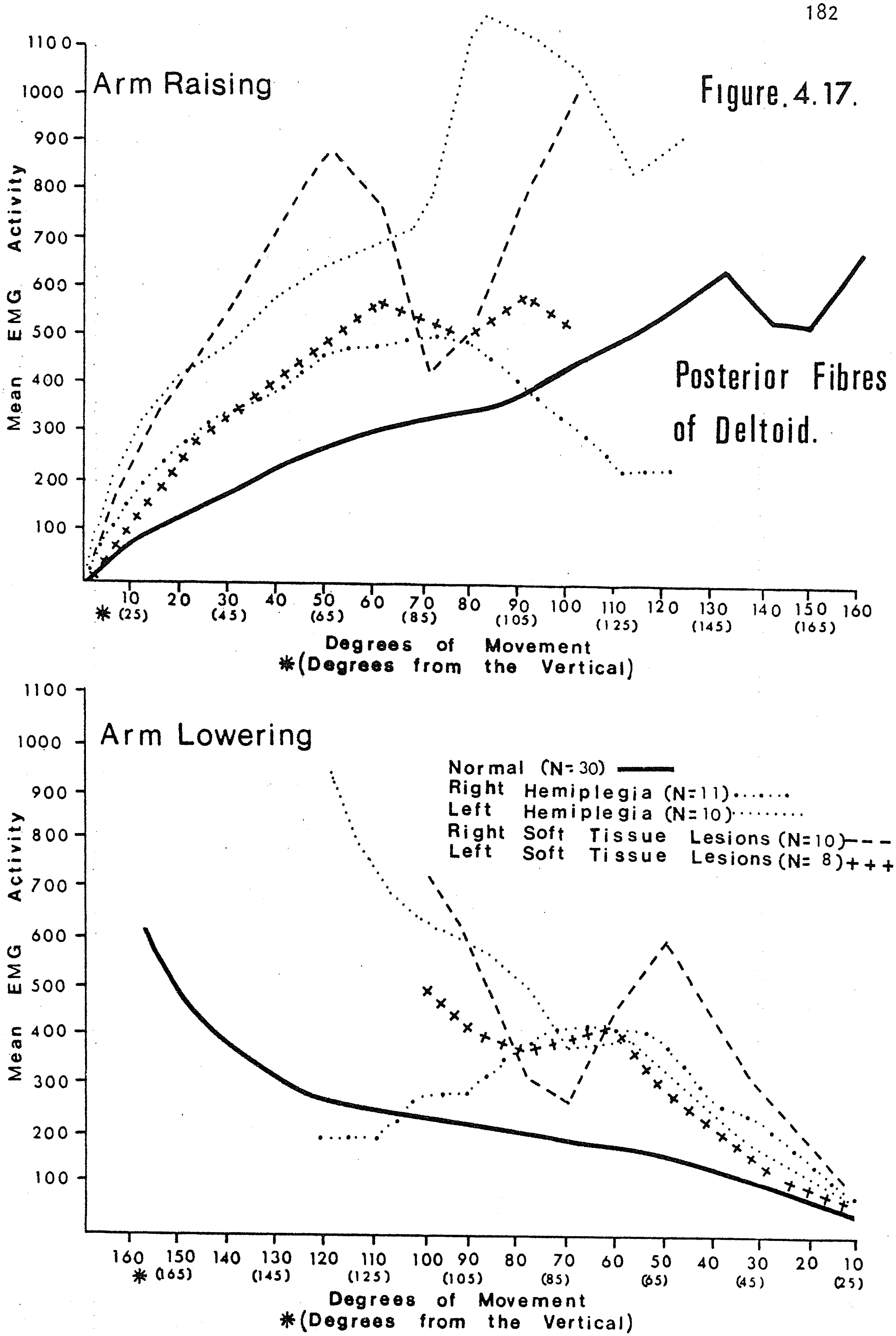


Figure. 4.17.

Posterior Fibres of Deltoid.

TABLE 4.27. THE ACTIVITY OF POSTERIOR DELTOID DURING ARM RAISING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	4.445	4/64	224.6	153.5	2.670	<.01	133.7	57.3	0.805	NS
20	6.048	4/64	416.4	242.0	3.815	<.001	238.1	112.6	1.293	NS
30	6.705	4/64	588.9	376.1	4.551	<.001	344.7	183.4	1.687	NS
40	6.909	4/64	714.4	488.2	4.638	<.001	404.2	235.3	1.568	NS
50	6.914	4/61	872.1	640.7	4.846	<.001	529.7	386.4	1.981	NS
60	4.437	4/54	786.3	665.3	3.568	<.001	578.8	392.4	2.065	<.05
70	3.919	4/46	434.2	212.8	0.954	NS	535.8	174.1	1.948	NS
80	7.639	4/40	506.5	193.9	1.372	NS	540.5	224.6	1.632	NS
90	7.306	4/37	833.0	282.8	2.549	<.02	607.2	248.1	1.812	NS
100	6.316	4/37	1033.0	329.5	3.170	<.01	516.5	218.5	0.777	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.28. THE ACTIVITY OF POSTERIOR DELTOID DURING ARM LOWERING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
100	8.780	4/37	766.5	47.3	4.029	<.001	506.2	339.3	2.967	<.01
90	7.934	4/37	599.5	47.3	3.397	<.001	440.7	274.3	2.861	<.01
80	4.801	4/40	355.0	219.9	1.856	NS	391.5	279.5	2.248	<.05
70	5.139	4/46	299.6	168.1	1.531	NS	416.0	247.1	3.187	<.01
60	5.346	4/54	486.2	468.4	3.496	<.001	435.2	263.3	2.955	<.01
50	7.744	4/61	615.5	530.6	5.270	<.001	310.2	158.4	1.741	NS
40	6.414	4/64	454.4	345.0	4.862	<.001	225.5	148.1	1.406	NS
30	5.494	4/64	312.2	223.1	4.260	<.001	161.8	143.7	1.190	NS
20	4.193	4/64	203.4	146.7	3.759	<.001	124.3	125.8	1.370	NS
10	1.888	4/64	105.7	59.0	2.381	<.05	72.3	74.5	0.656	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

Statistically the greatest differences were recorded at 100°, 90°, 70° and 60°. However it was noted that throughout descent of the arm the group of subjects with lesions on the right side exhibited substantially elevated levels of activity ($p<.001$). The differences noted at 70° and 60° corresponded with a peak of activity at this level. This differed from normal activity which showed as a gradual, even decline of activity.

Middle Fibres of Deltoid in Soft Tissue Lesions

During arm raising the activity of this section of deltoid closely resembled the phasic activity of normal subjects. Towards termination of the movement there was a slight decline or leveling in activity (Fig. 4.18).

Statistical tests did not reveal any differences when normal activity patterns were compared with those of subjects with soft tissue lesions. The similarity of activity was seen again during arm lowering. A slight difference was noted at the $p<.05$ level on the right side at 60° to 30°. This difference was relatively slight at the levels reported (Tables 4.29 and 4.30).

Anterior Fibres of Deltoid in Soft Tissue Lesions

During raising the arm the levels and pattern of activity resemble that shown by normals. However, it was noted that at 40° and 50° the group of right side soft tissue lesions exhibited higher levels of activity than that shown by normal ($p<.001$). This group also exhibited a slightly elevated level at 10°, 20° and 30° ($p<.01$)(Table 4.31).

Figure 4.18. Middle Fibres of Deltoid.

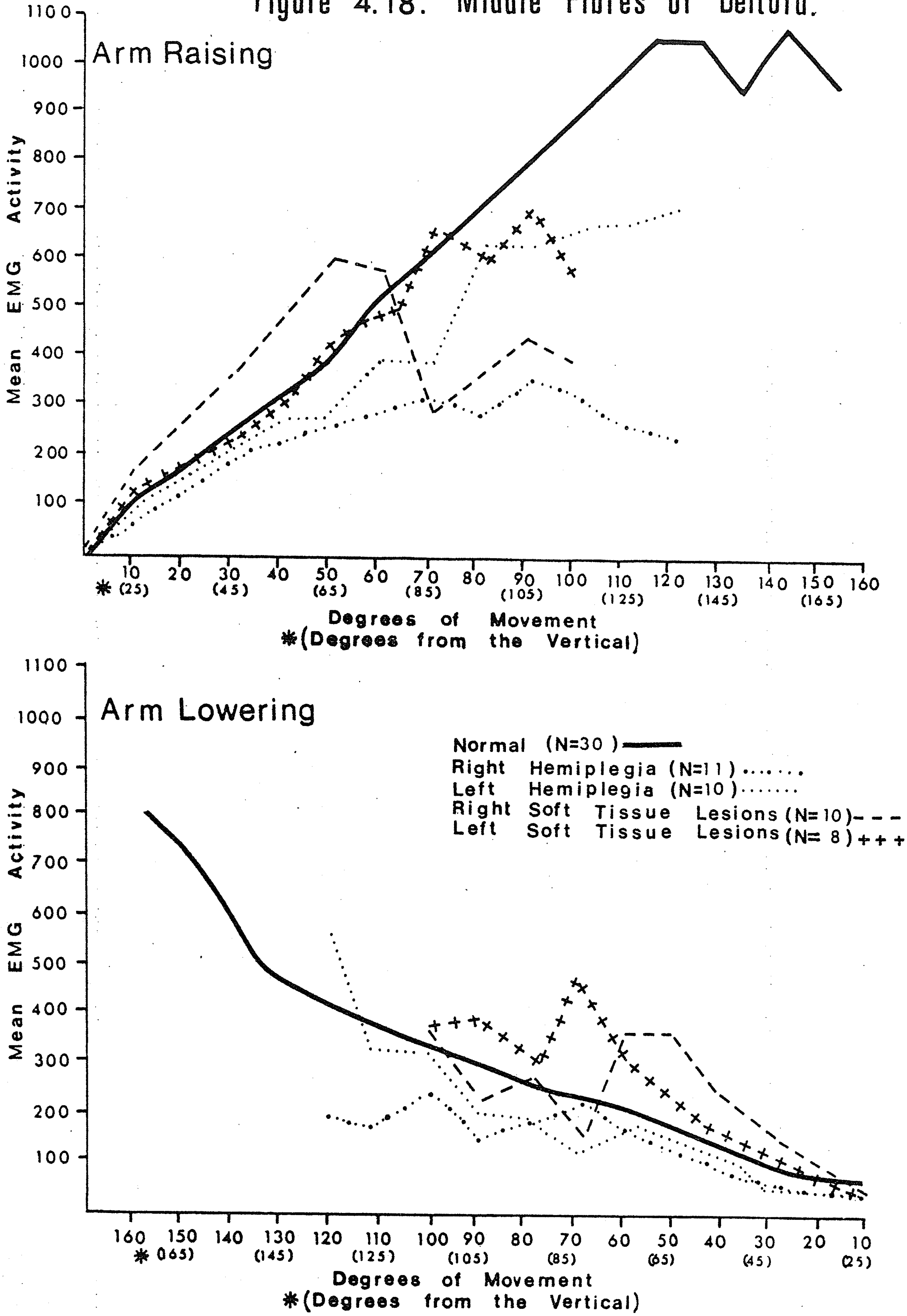


TABLE 4.29. THE ACTIVITY OF MIDDLE DELTOID DURING ARM RAISING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	1.648	4/64	158.0	161.1	1.272	NS	124.3	91.7	0.289	NS
20	1.165	4/64	237.5	216.0	1.309	NS	178.6	99.3	1.105	NS
30	0.953	4/64	359.5	312.7	1.404	NS	247.7	115.1	0.071	NS
40	1.566	4/64	471.2	379.3	1.788	NS	306.5	142.5	0.128	NS
50	1.776	4/61	609.5	564.5	1.864	NS	421.3	254.4	0.221	NS
60	0.715	4/54	586.1	583.4	0.532	NS	497.7	326.9	0.075	NS
70	1.656	4/46	310.4	137.2	1.641	NS	699.8	473.7	0.632	NS
80	1.657	4/40	362.5	97.4	1.688	NS	604.0	322.0	0.315	NS
90	0.786	4/37	450.0	212.1	0.987	NS	704.0	392.9	0.303	NS
100	0.572	4/37	415.0	261.6	1.369	NS	570.7	321.4	1.184	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.30. THE ACTIVITY OF MIDDLE DELTOID DURING ARM LOWERING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
100	0.207	4/37	365.0	332.3	0.164	NS	366.5	225.6	0.239	NS
90	0.828	4/37	223.0	151.3	0.667	NS	385.5	229.9	0.639	NS
80	0.504	4/40	279.0	118.4	0.134	NS	319.0	174.5	0.569	NS
70	2.031	4/46	183.8	76.2	0.445	NS	479.3	515.6	2.370	<.05
60	1.765	4/54	387.0	442.7	2.058	<.05	340.2	337.1	1.563	NS
50	2.636	4/61	368.3	403.3	2.878	<.01	229.3	181.4	0.878	NS
40	2.211	4/64	230.9	229.0	2.359	<.05	166.0	122.1	0.876	NS
30	2.882	4/64	177.2	176.4	2.367	<.05	108.7	80.3	0.363	NS
20	1.739	4/64	85.8	79.1	0.629	NS	70.3	66.4	0.057	NS
10	1.062	4/64	41.1	40.1	0.481	NS	45.6	59.4	0.183	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

Figure 4.19 Anterior Fibres of Deltoid.

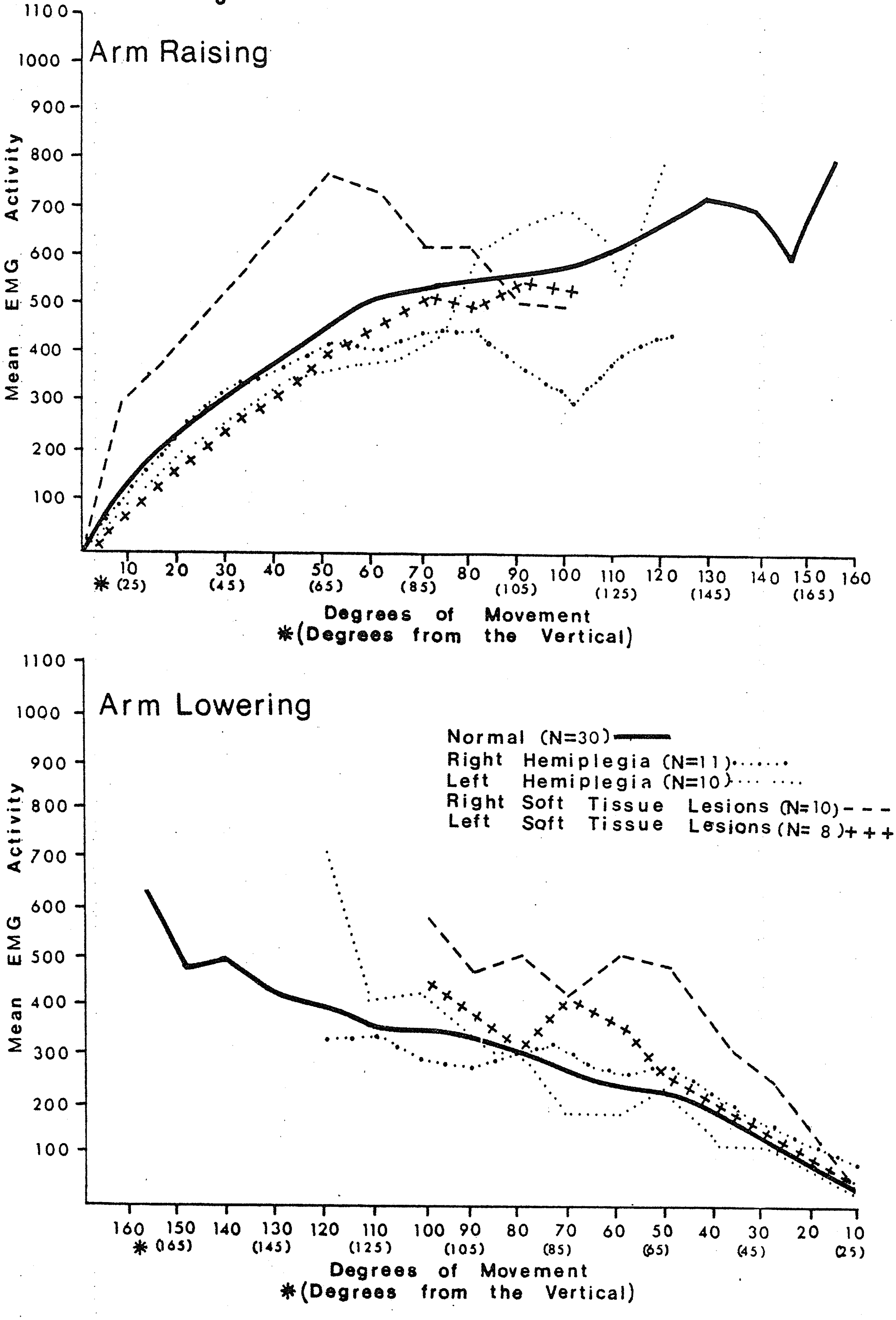


TABLE 4.31. THE ACTIVITY OF ANTERIOR DELTOID DURING ARM RAISING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	3.502	4/64	333.4	329.5	3.382	<.01	114.8	55.7	0.318	NS
20	3.715	4/64	431.5	279.6	3.374	<.01	169.2	56.5	0.679	NS
30	3.192	4/64	543.4	302.1	3.273	<.01	254.7	106.5	0.431	NS
40	4.128	4/64	687.8	317.8	3.689	<.001	316.0	140.2	0.436	NS
50	3.946	4/61	759.1	282.0	3.745	<.001	413.0	202.0	0.065	NS
60	1.652	4/54	784.7	249.6	2.222	<.05	465.3	269.6	0.076	NS
70	0.329	4/46	630.2	256.3	0.966	NS	534.3	260.4	0.285	NS
80	0.283	4/40	633.2	235.5	0.811	NS	522.5	333.9	0.087	NS
90	0.372	4/37	516.5	164.7	0.300	NS	571.5	338.1	0.095	NS
100	0.634	4/37	516.5	164.7	0.407	NS	520.0	339.5	0.539	NS

t and p values relate to comparison with normal subjects

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.32. THE ACTIVITY OF ANTERIOR DELTOID DURING ARM LOWERING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degree	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
100	1.319	4/37	600.0	282.8	1.875	NS	454.0	234.3	1.206	NS
90	0.685	4/37	483.0	117.3	1.368	NS	397.5	203.6	0.955	NS
80	1.480	4/40	508.0	239.2	2.383	<.05	342.2	218.6	0.587	NS
70	2.813	4/46	445.2	206.4	2.318	<.05	426.0	241.3	2.248	<.05
60	5.981	4/54	523.8	250.7	4.415	<.001	376.5	170.5	2.155	<.05
50	7.446	4/61	482.1	207.7	5.318	<.001	273.3	131.2	1.233	NS
40	5.231	4/64	374.6	159.4	4.365	<.001	205.0	85.0	0.678	NS
30	4.288	4/64	283.9	123.8	3.827	<.001	153.3	47.9	0.440	NS
20	0.771	4/64	115.4	91.3	1.746	NS	107.5	45.9	0.302	NS
10	0.805	4/64	56.4	41.9	0.447	NS	64.2	52.8	0.051	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

The graphic representation shows the muscle in both right and left sided groups increasing in activity as the arm is raised in abduction. Towards the end of the movement, the activity of the right side group gradually decreases. Other than the exceptions noted above this muscle followed the phasic pattern shown by normal subjects (Fig. 4.19).

During lowering the arm, the anterior fibres of deltoid showed elevated levels of activity, particularly on the right side at 60°-30° ($p<.001$). The differences between the soft tissue lesion subjects and normals were greatest on the right at 60° to 30°, on the left at 70° to 60°.

Serratus Anterior in Soft Tissue Lesions

During abduction the two groups with soft tissue lesions showed a substantially similar level and pattern of activity when compared with that shown by normals. At 70°, 80° and 90° serratus anterior on the right side exhibited slightly lower levels ($p<.05$). This corresponded to a continuation of the same level of activity at these points while normal levels continued to increase throughout the range (Table 4.33). Unlike the hemiplegic group, where several subjects showed no activity in serratus anterior, only one of the total of 18 soft tissue lesion subjects showed no activity during arm raising.

During lowering the arm from the elevated position the group with soft tissue lesions showed a pattern and level of activity similar to that of normal subjects. The muscle activity did however, show a fall in activity from 100° to 90° and 80° in both right and left groups. This is followed by a slight rise to 70° and 60°, thereafter the decline follows closely that of normal subjects (Fig. 4.20).

Figure 4.20. Serratus Anterior

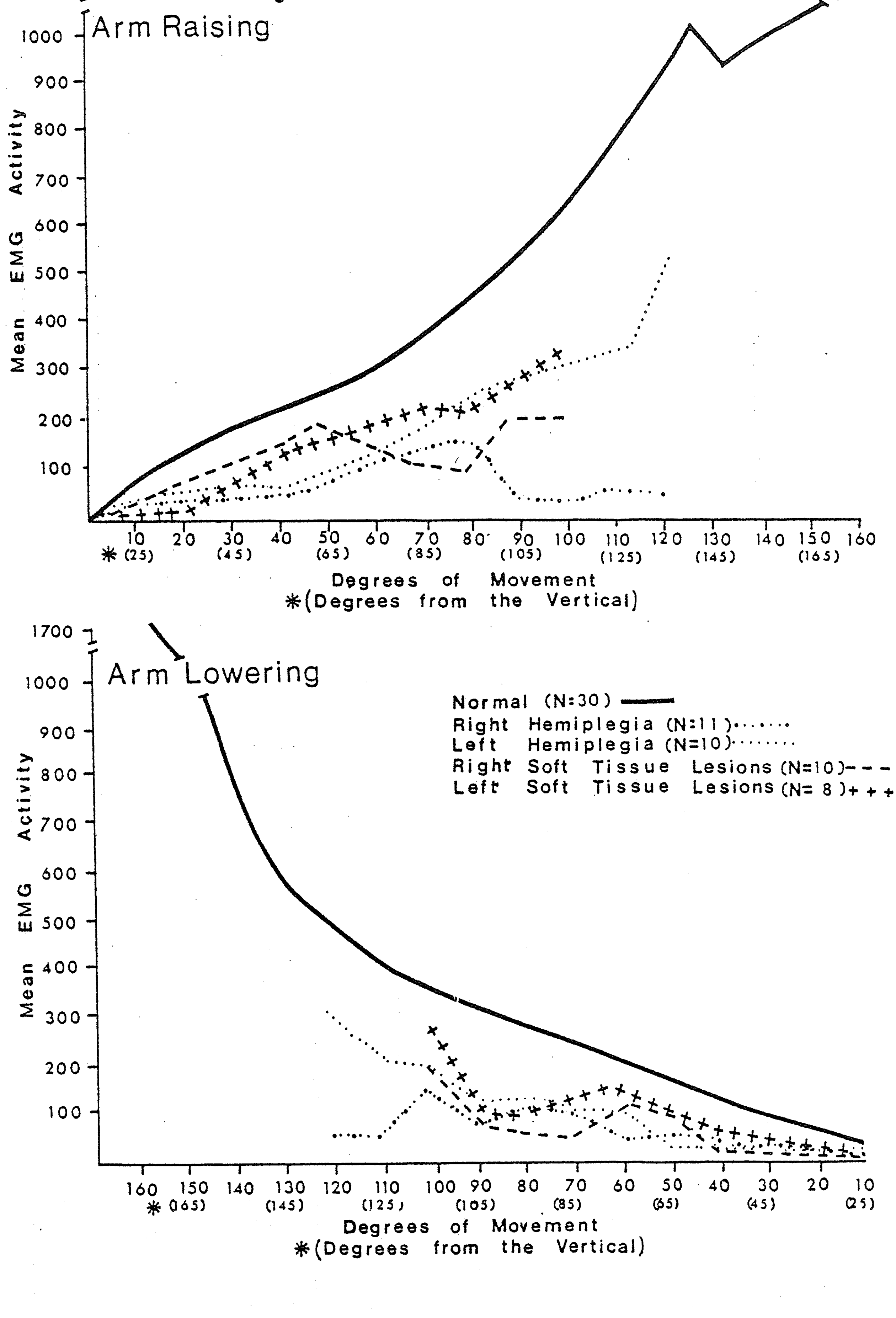


TABLE 4.33. THE ACTIVITY OF SERRATUS ANTERIOR DURING ARM RAISING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
10	2.990	4/64	23.2	37.7	2.312	<.05	16.5	34.5	2.338	<.05
20	2.765	4/64	54.2	80.9	1.992	NS	41.0	47.8	2.208	<.05
30	3.045	4/64	87.4	137.9	1.609	NS	78.5	84.0	1.678	NS
40	4.008	4/64	117.5	128.5	1.698	NS	112.3	113.8	1.664	NS
50	2.420	4/61	188.2	218.0	0.728	NS	174.7	185.4	0.873	NS
60	2.318	4/54	139.5	120.2	2.011	<.05	197.3	183.6	1.221	NS
70	2.509	4/46	116.0	74.3	2.277	<.05	213.8	157.5	1.436	NS
80	2.229	4/40	103.2	76.9	2.267	<.05	215.0	132.7	1.465	NS
90	2.420	4/37	215.0	21.2	1.343	NS	290.0	223.1	1.363	NS
100	2.510	4/37	225.0	35.3	1.470	NS	358.2	305.8	1.278	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

TABLE 4.34. THE ACTIVITY OF SERRATUS ANTERIOR DURING ARM LOWERING IN RIGHT AND LEFT SOFT TISSUE LESION SUBJECTS.

			RIGHT (N = 10)				LEFT (N = 8)			
Degrees	F	df	$\bar{X}$	SD	t	p	$\bar{X}$	SD	t	p
100	0.401	4/37	200.0	0	0.511	NS	291.4	177.0	0.038	NS
90	1.012	4/37	83.0	24.0	1.110	NS	137.5	75.0	1.004	NS
80	1.207	4/40	66.5	47.1	1.701	NS	112.2	54.9	1.179	NS
70	1.044	4/46	69.8	58.2	1.712	NS	147.1	142.7	0.665	NS
60	1.000	4/54	102.0	127.4	1.040	NS	149.2	166.9	0.100	NS
50	1.083	4/61	92.9	98.3	0.611	NS	119.5	115.3	0.114	NS
40	1.783	4/64	36.5	44.9	1.936	NS	76.5	88.1	0.420	NS
30	1.971	4/64	16.6	35.9	2.202	NS	45.2	49.3	0.699	NS
20	1.598	4/64	13.3	32.1	1.993	NS	22.6	24.9	1.326	NS
10	1.232	4/64	10.0	31.6	1.744	NS	10.2	17.6	1.585	NS

t and p values relate to comparison with normal subjects.

SD = standard deviation

$\bar{X}$ = mean activity

Summary of Activity in Soft Tissue Lesions

It was noted in the tables showing the mean activity levels and standard deviations, that the latter measurements were often quite large. This was due, in part, to the variations in activity levels between subjects, for example, in posterior deltoid some subjects showed substantially high levels while others demonstrated levels nearer normal values.

The middle fibres of deltoid and serratus anterior showed activity similar to that seen in normal subjects. Trapezius showed a slight increase in lesions affecting the left side but only at the end of the range of movement. Significant differences were located in the posterior and anterior fibres of deltoid. In both muscles the increased levels were seen particularly during arm lowering and more on the right than on the left.

COMPARISON BETWEEN NORMAL SUBJECTS AND THE UNAFFECTED LIMB OF ABNORMAL SUBJECTS

It was noted in the analysis of the ranges of motion, that the mean range of abduction of the unaffected side of both abnormal groups was less than that of the normal group. A comparison was made to determine if the phasic muscle activity also exhibited any differences.

In the evaluation of the data, the activity of the normal group and the unaffected side of the two abnormal groups was compared. In the comparison, the activity levels of the 30 normal subjects was compared with that of the unaffected side in 10 subjects from the hemiplegic group and 10 subjects from the group with soft tissue lesions. This comparison was made using a one-way analysis of variance to find out if there was any significant difference between the activity of each subject group at various points in raising and lowering the arm. In addition to the above, a least significant difference multiple comparison test was completed to determine specifically where and to what level the abnormal groups differed from normal.

The following tables exhibit the t value and probability value between the abnormal and normal groups.

Trapezius (Tables 4.35 and 4.36)

In the activity of trapezius, the three groups are similar in that they show a gradual increase in abduction and decrease in arm lowering. In abduction in the first 20° the hemiplegic group show greater activity ($p<.05$). In arm lowering at 10° again the hemiplegic group show increased activity ($p<.001$).

Posterior Fibres of Deltoid (Tables 4.37 and 4.38)

Throughout arm raising and lowering the posterior fibres of deltoid in the hemiplegic and normal group show similar patterns of activity. When the means are compared, the group of subjects with soft tissue lesions show slightly elevated activity levels. This is most obvious in arm raising where the soft tissue lesion group show a significantly higher level throughout abduction (Table 4.37). During lowering, the soft tissue lesion group corresponded more to the other groups and exhibited lower significance levels in only three of the areas sampled (Table 4.38).

Middle Fibres of Deltoid (Tables 4.39 and 4.40)

When the activity of the middle fibres of deltoid in abnormal and normal groups was compared the pattern of activity was similar. A slightly higher activity level of the soft tissue lesion group at 140° during arm raising has a statistical value of $p<.05$. The hemiplegic group also showed differences at 110° ($p<.05$) and 120° ($p<.05$). In arm lowering, the groups showed no significant differences. The differences which were identified, and mentioned above have a relatively low statistical value. On the basis of this data it could be assumed that all three groups investigated showed similar activity patterns.

Anterior Fibres of Deltoid (Tables 4.41 and 4.42)

During raising the arm in abduction the hemiplegic group showed no differences from the normal. The group with soft tissue lesions showed elevated levels during the final stages of abduction from 110° to 140°.

During lowering the arm the activity levels of the three groups were similar. The group of soft tissue lesions showed a slightly higher level of activity at 140° ($p<.05$), 130° ($p<.01$) and 120° ($p<.05$). The hemiplegic group at 110° ($p<.05$) and 100° ($p<.05$) also exhibited slightly higher levels.

The investigation indicated a similar pattern of activity in normals and abnormals in the anterior fibres of deltoid.

Serratus Anterior (Tables, 4.43 and 4.44)

The activity in serratus anterior during abduction showed a lower level of activity in the group of subjects with soft tissue lesions. The lower level of activity was seen throughout the complete range of movement (Table 4.43). There was a significant difference which was greater in the early part of the movement. The least differences were at the termination of the movement. Hemiplegic subjects showed no differences when compared with normals.

During arm lowering, serratus anterior, in the soft tissue lesion group, showed lower levels of activity when compared with normals (Table 4.44). The levels of significance extended from $p<.05$ at 140°, $p<.02$ at 130°, $p<.02$ at 120° and then a continuous level of $p<.01$ throughout the rest of the arm descent. Hemiplegic subjects showed no significant differences when compared with normals.

Summary of Comparison Between Normal and the Unaffected Limb of Abnormal Groups

The hemiplegic group showed activity levels similar to that of normal in all muscles investigated. Occasional dissimilarities that were recorded were slight in the overall pattern of activity.

Subjects with soft tissue lesions showed significant differences from normal in the activity of the posterior fibres of deltoid. In this section of deltoid the group with soft tissue lesions showed activity levels higher than that seen in normals. This difference was more obvious in raising than lowering the arm. The group with soft tissue lesions also exhibited differences in the activity levels seen in serratus anterior where the soft tissue group showed significantly lower levels of activity during both raising and lowering the arm. It was interesting to note that subjects with soft tissue lesions exhibited differences of muscle activity in the unaffected shoulder. This is a finding which requires further investigation. It would also be of value to institute a long term follow-up of these subjects to determine if any further diminishing range of activity and altered muscle function occurs.

TABLE 4.35. COMPARISON OF THE ACTIVITY OF TRAPEZIUS DURING ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	Soft Tissue Lesions p	Hemiplegia t value	Hemiplegia p
10	2/47	3.626	0.559	NS	2.411	p<.05
20	2/47	2.476	0.353	NS	2.039	p<.05
30	2/47	1.738	0.446	NS	1.641	NS
40	2/47	1.413	0.245	NS	1.549	NS
50						
60	2/47	1.478	0.646	NS	1.704	NS
70						
80	2/47	0.983	0.842	NS	1.296	NS
90						
100	2/47	0.891	1.090	NS	1.019	NS
110						
120	2/46	0.647	0.003	NS	0.483	NS
130	2/42	0.177	0.541	NS	0.134	NS
140	2/33	1.999	1.236	NS	0.727	NS

TABLE 4.36. COMPARISON OF THE ACTIVITY OF TRAPEZIUS DURING LOWERING THE ARM IN THE PLANE OF ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	p	Hemiplegia t value	p
140	2/33	1.645	1.583	NS	0.632	NS
130						
120	2/46	0.521	0.700	NS	0.553	NS
110						
100	2/47	0.449	0.161	NS	0.944	NS
90						
80	2/47	0.455	0.663	NS	0.830	NS
70						
60	2/47	1.005	0.447	NS	1.402	NS
50						
40	2/47	1.413	0.832	NS	1.623	NS
30						
20	2/47	1.815	0.282	NS	1.895	NS
10	2/47	7.752	0.654	NS	3.596	p<.001

TABLE 4.37. COMPARISON OF THE ACTIVITY OF POSTERIOR FIBRES OF DELTOID DURING ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	Soft Tissue Lesions p	Hemiplegia t value	Hemiplegia p
10	2/47	3.403	2.596	p<.02	0.895	NS
20	2/47	7.754	3.920	p<.001	1.342	NS
30						
40	2/47	5.227	3.208	p<.01	1.193	NS
50	2/47	4.651	3.006	p<.01	1.250	NS
60	2/47	4.265	2.899	p<.01	1.071	NS
70	2/47	3.726	2.694	p<.02	1.101	NS
80	2/47	5.200	3.214	p<.01	1.055	NS
90	2/47	8.512	4.118	p<.001	0.776	NS
100	2/47	3.435	2.600	p<.02	0.331	NS
110	2/47	3.675	2.671	p<.02	0.219	NS
120	2/46	0.985	1.268	NS	0.279	NS
130						
140	2/33	3.637	2.551	p<.02	1.229	NS

TABLE 4.38. COMPARISON OF THE ACTIVITY OF THE POSTERIOR FIBRES OF DELTOID DURING LOWERING THE ARM IN THE PLANE OF ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	Soft Tissue Lesions p	Hemiplegia t value	Hemiplegia p
140	2/33	1.440	1.642	NS	0.674	NS
130						
120	2/46	0.820	1.126	NS	0.863	NS
110						
100	2/47	1.435	1.643	NS	0.810	NS
90						
80	2/47	2.352	2.091	p<.05	1.081	NS
70						
60	2/47	3.584	2.455	p<.02	1.649	NS
50						
40	2/47	1.812	1.874	NS	1.007	NS
30						
20	2/47	4.242	2.795	p<.01	1.493	NS
10	2/47	0.481	0.233	NS	0.864	NS

TABLE 4.39. COMPARISON OF THE ACTIVITY OF THE MIDDLE FIBRES OF DELTOID DURING ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	p	Hemiplegia t value	p
10	2/47	1.863	1.858	NS	0.971	NS
20						
30	2/47	1.005	0.522	NS	1.407	NS
40						
50	2/47	1.493	0.134	NS	1.635	NS
60						
70	2/47	1.408	1.641	NS	0.069	NS
80						
90	2/47	1.940	0.250	NS	1.829	NS
100						
110	2/46	4.096	0.894	NS	2.407	p<.05
120	2/46	3.551	0.833	NS	2.457	p<.05
130	2/42	2.617	1.394	NS	1.483	NS
140	2/33	3.899	2.381	p<.05	1.089	NS

TABLE 4.40. COMPARISON OF THE ACTIVITY IN THE MIDDLE FIBRES OF DELTOID DURING LOWERING THE ARM IN THE PLANE OF ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesion t value	p	Hemiplegia t value	p
140	2/33	1.486	1.042	NS	1.185	NS
130						
120	2/46	0.795	0.453	NS	1.251	NS
110						
100	2/47	1.096	0.205	NS	1.471	NS
90						
80	2/47	0.823	0.566	NS	1.256	NS
70						
60	2/47	1.264	1.131	NS	1.365	NS
50						
40	2/47	1.755	1.722	NS	1.146	NS
30						
20	2/47	3.649	2.697	$p<.02$	0.522	NS
10	2/47	2.965	2.346	$p<.05$	0.046	NS

TABLE 4.41. COMPARISON OF THE ACTIVITY OF THE ANTERIOR FIBRES OF DELTOID DURING ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	p	Hemiplegia t value	p
10	2/47	0.962	0.584	NS	1.073	NS
20						
30	2/47	1.800	0.872	NS	1.850	NS
40						
50	2/47	1.050	1.168	NS	1.122	NS
60						
70	2/47	1.442	1.253	NS	1.423	NS
80						
90	2/47	1.775	1.738	NS	1.399	NS
100						
110	2/47	4.817	3.065	<.01	0.290	NS
120	2/46	6.340	3.180	<.01	0.791	NS
130	2/42	7.502	3.444	<.01	1.050	NS
140	2/33	4.073	2.676	<.02	0.615	NS

TABLE 4.42. COMPARISON OF THE ACTIVITY IN THE ANTERIOR FIBRES OF DELTOID DURING LOWERING THE ARM IN THE PLANE OF ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects

Degrees	df	F	Soft Tissue Lesions t value	Soft Tissue Lesions p	Hemiplegia t value	Hemiplegia p
140	2/33	2.208	2.098	p<.05	0.170	NS
130	2/42	3.806	2.759	p<.01	0.590	NS
120	2/46	2.707	2.180	p<.05	1.312	NS
110	2/47	3.263	1.953	NS	2.083	p<.05
100	2/47	2.699	1.521	NS	2.081	p<.05
90	2/47	2.489	1.667	NS	1.853	NS
80						
70	2/47	2.252	1.318	NS	1.940	NS
60						
50	2/47	1.949	1.088	NS	1.867	NS
40						
30	2/47	0.780	0.857	NS	1.094	NS
20						
10	2/47	0.099	0.388	NS	0.113	NS

TABLE 4.43. COMPARISON OF THE ACTIVITY IN SERRATUS ANTERIOR DURING ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normals; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesion t value	p	Hemiplegia t value	p
10	2/47	5.254	3.327	p<.01	0.634	NS
20	2/47	7.333	3.812	p<.001	1.306	NS
30	2/47	6.891	3.712	p<.001	0.980	NS
40	2/47	7.841	3.960	p<.001	1.052	NS
50	2/47	7.099	3.762	p<.001	0.744	NS
60	2/47	6.285	3.545	p<.01	0.820	NS
70	2/47	5.900	3.429	p<.01	0.655	NS
80	2/47	4.397	2.911	p<.01	0.182	NS
90	2/47	7.016	3.610	p<.001	0.105	NS
100	2/46	6.336	3.402	p<.01	0.199	NS
110	2/46	5.460	3.305	p<.01	0.790	NS
120	2/46	4.888	3.112	p<.01	0.972	NS
130	2/42	3.544	2.491	p<.02	1.418	NS
140	2/33	2.798	2.338	p<.05	0.660	NS

TABLE 4.44. COMPARISON OF THE ACTIVITY IN SERRATUS ANTERIOR DURING LOWERING THE ARM IN THE PLANE OF ABDUCTION IN NORMAL SUBJECTS WITH THE UNAFFECTED LIMB IN ABNORMAL SUBJECTS. (N = 30 Normal; 10 Hemiplegic; 10 Soft Tissue Lesion Subjects)

Degrees	df	F	Soft Tissue Lesions t value	p	Hemiplegia t value	p
140	2/33	2.794	2.338	p<.05	0.028	NS
130	2/42	3.772	2.662	p<.02	0.277	NS
120						
110	2/46	3.979	2.587	p<.02	0.471	NS
100						
90	2/47	3.863	2.779	p<.01	0.638	NS
80	2/47	4.420	2.955	p<.01	0.447	NS
70						
60	2/47	6.077	3.486	p<.01	0.857	NS
50						
40	2/47	5.610	3.253	p<.01	0.042	NS
30						
20	2/47	4.177	2.890	p<.01	0.655	NS
10	2/47	3.691	2.716	p<.01	0.613	NS

FUTURE CLINICAL APPLICATION

A major purpose of this investigation was to develop and evaluate a technique which could be used in the clnical assessment of lesions affecting shoulder complex function. It was initially proposed that detailed information on range of movement, correlated with muscle action, would assist in evaluating the current status as well as the ongoing response of a patient to therapeutic programs. In addition a better understanding of the action of muscles in the performance of abnormal movement patterns would improve the understanding of the mechanism of disability.

The results of this investigation have indicated that information on range of movement and muscle activity can be obtained using the electrogoniometric and electromyographic techniques developed and described in detail in Chapter III. The data obtained in the analysis of both the abnormal groups in this study produced clinically relevant information which could be of value in determining appropriate treatment program emphasis. In addition, the assessment could be repeated at intervals to determine the changing status of the patient. Repeated assessment of the patient would also be of value in examining the effect and appropriateness of various therapeutic modalities.

The system described here is not limited to the assessment of the muscles examined in this study. Various groups of muscles acting on the shoulder complex could be evaluated.

Basmajian (1975) states "Electromyography and biomechanics offer broad avenues of research in rehabilitation. Electromyography provides a powerful tool for studying both normal and abnormal patterns of movement. Only with the knowledge of such patterns can we design appropriate therapies".

CHAPTER V

SUMMARY

The purpose of the study was to examine the activity of muscles acting on the shoulder complex during elevation of the arm, in the plane of abduction. The activity pattern was assessed in normal subjects, and compared with the activity in subjects with hemiplegia and in subjects with a lesion of a glenohumeral joint structure.

Thirty normal subjects were assessed. The electromyographic record of muscle activity was recorded on an ink-writing oscillograph during raising and lowering the right arm in the scapular plane of abduction. These records were measured at every 10^{o} of movement during raising and lowering the arm. The pattern of activity was obtained from a statistical analysis of the data.

Information on arm position was obtained from an electrogoniometer, specifically designed for this investigation. The electrogoniometer produced a varying voltage signal during movement of the arm. This signal was correlated, at every 10^{o}, with the electromyographic data, to indicate the varying muscle contribution during raising and lowering the arm.

Twenty of the normal subjects were required to perform a maximum isometric contraction of each muscle under investigation. The measurements of the phasic muscle activity was then expressed as a percentage of this maximum activity. The results of direct measurement of the electromyographic data and the activity, expressed as a percentage, were compared. The results of the analysis of each muscle's activity in arm raising and lowering were also compared with the results of previous studies and found to be consistent with the findings of other researchers.

The activity patterns of the muscles of the left shoulder complex in 16 of the 30 normal subjects were compared with the data obtained from measurements of the electromyographic activity of the right shoulder muscles. This comparison was made to identify any variation that might occur between right and left shoulder muscle groups. Examination of the data demonstrated similar patterns of activity in the muscles of both sides.

A comparison of muscle activity seen in the 15 younger subjects of the normal group of 30 subjects was made with the 15 older subjects. This comparison was made to identify any differences in activity patterns which might be attributed to age. The activity of the two groups was similar; no differences in muscle contribution to movement was recorded.

The shoulder complex muscles in 21 hemiplegic subjects were examined, 11 exhibiting lesions of the right side, and 10 exhibiting lesions of the left side. The activity of these two groups was compared with the activity patterns of normal subjects. The hemiplegic subjects exhibited a reduction in movement when attempting elevation of the arm. When the activity of the muscle groups of subjects with hemiplegia was compared with normal it was seen that the anterior and middle fibres of deltoid exhibited patterns of activity similar to normal. The posterior fibres of deltoid showed increased activity. Trapezius showed phasic activity somewhat similar to normal, although graphically the levels were greater than normal. Serratus anterior showed a considerable reduction in activity, nine of the 21 subjects exhibited no activity in serratus anterior.

In the subjects with hemiplegia, the investigation has indicated a pattern of limited abduction with overactivity of the posterior fibres of deltoid and considerably reduced activity in serratus anterior. This is characteristic of flexor synergy activity.

Eighteen subjects with soft tissue lesions of a glenohumeral joint structure were examined. Ten subjects exhibited lesions of the right side and eight showed lesions of the left side. In these subjects, the middle fibres of deltoid and serratus anterior showed activity similar to that seen in normal subjects. Trapezius, however, showed a slight increase in lesions affecting the left side, but only at the end of the range of movement. Significant differences were located in the posterior and anterior fibres of deltoid. In these the increased levels were seen particularly during arm lowering, and more on the right than on the left.

The final part of this investigation involved the comparison between the activity levels of the normal subjects and the unaffected limb of 10 subjects from each of the abnormal groups. The hemiplegic group showed activity levels similar to that of normal subjects in all muscles investigated. Subjects with soft tissue lesions showed significant differences from normal in the posterior fibres of deltoid. Higher activity levels were recorded in this part of deltoid particularly during arm raising. Serratus anterior showed levels lower than normal in both raising and lowering the arm. The middle and anterior fibres of deltoid and trapezius in subjects with soft tissue lesions showed patterns similar to normal.

It was also noted that the range of abduction in the unaffected limb of abnormal groups was less than that of normals.

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