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Muscle time recruitment patterns of upper, middle, lower trapezius and posterior deltoid.

An electromyographic research

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1.0 Introduction

It is well recognised that the shoulder and scapula together play a vital role in sports activities as well as in everyday life. The shoulder complex has the greatest mobility of all joints. This mobility is because of little bony congruity of its articulating surfaces. The joints of the shoulder complex have to rely on adjacent ligaments and muscles to provide stability. Whereas the shoulder girdle is a complex multi – articulated functional unit which is capable of achieving great mobility. This mobility arises through the coordinated activation of numerous muscles, which act simultaneously to produce limb segment motion and to maintain joint stability.
Shoulder dysfunctions are associated with abnormal scapula positioning and dynamic control. The failure of the scapula to perform this control causes inefficient physiology and biomechanics and, therefore, inefficient shoulder functions. This can cause poor performance, or exacerbate shoulder injury.

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The maintenance of smooth and coordinated motion requires intact joints and coordinated contractions among the muscles. Muscles are trying to correct their timing recruitment patterns. Synchronised activities between these muscles in the shoulder girdle ensure that motion acquired at the sternoclavicular, acromioclavicular, glenohumeral and scapulothoracic articulation is efficient and harmonious.

Especially the muscles Upper trapezius (UT), Middle trapezius (MT), and Lower trapezius (LT) play a very important role in the mobility of the scapula. Pd (posterior deltoid) is a muscle that doesn’t play an important role to the shoulder joint but has a reference activity in the shoulder. Moreover, when the demands for the shoulder mobility are high (in coordination of movements), then the quality of the movements depend on the interaction, between these three muscles (UT, MT, LT) and posterior deltoid (PD) and their timing relations.
Abnormal scapular kinematics and associated muscle function presumably contribute to shoulder pain and pathology. Thus, from the findings of other researches, we conclude that most patients had a variety of dysfunctions: anterior instability, multidirectional shoulder laxity, subacromial impingement, abnormal scapulothoracic rhythm, shoulder motion, scapular position and glenohumeral instability.

Except for these four muscles, whose latency time, we are going to examine their latency time in four different exercises the rotator cuff muscles act also co-ordinately, promoting glenohumeral stability. A stable scapula platform is being “created” in which muscles can operate easily. A possible instability in the shoulder is often “silent” and difficult to demonstrate by ordinary tests and therefore, it has been named Functional Instability. It is one of the causes of involving microtraumata and/or secondary impingement that may lead to chronic shoulder pain.

Overhead movements of the shoulder conclude to impingement syndrome. This syndrome is classified as primary or secondary impingement. It refers to mechanical encroachment into the subacromial space by the humerous head. The symptoms of the secondary impingement syndrome are a result of shoulder instability, posterior capsule tightness and scapulothoracic weakness. In a recent research, Cools A. et al., found that overhead athletes with impingement symptoms showed abnormally timed muscle recruitment pattern in the trapezius muscle.

The muscular control of the scapula has become a recent focus of therapeutic intervention. Most of the literature on this relationship between scapular positioning and shoulder function is based on personal observations and recently research data. Most authors agree that weakness in one or more scapular rotators may cause a relative muscular imbalance in the force couples around the scapula, thus leading to abnormal kinematics. However, recently the assumption has been made that not only the intensity of the muscle contraction is determing the scapulothoracic and shoulder function, but also timing of the muscle activity around the scapula is of major importance. Intensity of muscle activity in scapular muscles have been investigated by a number of researchers in healthy shoulders, and in shoulder with glenohumeral instability or impingement (Cools et al, 2002). Most authors suggest, based on their data, alterations in muscle activity in Upper, Middle, Lower Trapezius and Serratus anterior in patients with symptoms of impingement. No research existed until recently it has examined all these four muscle timing : Upper, Middle, Lower Trapezius and Posterior Deltoid muscles recruitment patterns and the electromyografic response of these 4 muscles in 4 different exercises.

Therefore a comparative study investigating timing of muscle activity of the previous muscles was obliged as a necessity. The purpose of our study was to evaluate muscle latency times of UT, MT, LT, and PD during 4 different exercises, following a protocol of Pr. Ann Cools which is being analysed in the second part of this paper, in healthy young subjects and compare the UT, MT, LT muscle reaction time with their of the PD. we measured EMG activity in the posterior deltoid in order to have a glenohumeral muscle to compare scapular muscle activity with, and since according to literature during these exercises this muscle is highly active. These exercises were: forward flexion in side lying position, horizontal abduction with external rotation, prone extension and side lying external rotation.

2.0 Literature

2.1 Healthy shoulder

Movements of the human shoulder represent a complex dynamic relationship of many muscle forces, ligament constrains, and bony articulations. Shoulder motion is the result of the complex interplay of static and dynamic stabilisers. Static and dynamic stabilisers allow the shoulder the greatest range of motion of any joint in the body. With regard to the glenohumeral joint, the capsuloligamentous complex provides static restraint, while the rotator cuff muscles, with their respective force-couple antagonist's guide, steer, and maintain the head dynamically in the glenoid fossa. The bony architecture of the glenohumeral joint, with its large articulating humeral head and relatively small glenoid surface, relies heavily on ligamentous and muscular stabilisers throughout its motion arc. (78) This composition allows the involved muscles to work in the most efficient part of their length-tension curve and the glenoid to be placed underneath the humeral head to bear some weight of the arm. (121) the bony anatomy provides the structural foundation from which the forces are generated and subsequently acted on. (131)

2.1.1 Anatomy

2.1.1.1 Anatomy of shoulder girdle

The shoulder or pectoral girdle consists of articulations between the clavicle, scapula and the proximal end of the humerus. The sternoclavicular articulation is the only bony link between the upper limb and the axial skeleton. Through the acromioclavicular articulation, the clavicle can act as a strut maintaining the upper limb away from the thorax permitting a greater range of upper limb motion. This joint also helps provide static stability to the upper limb reducing the need to use muscle energy to keep the upper limb in its proper alignment. The scapula is suspended on the thoracic wall by muscle forming a "functional joint" called the scapulothoracic joint. These muscles act to stabilize and / or to actively move the scapula. Active movements of the scapula help increase the range of motion of the shoulder joint (78,131)

2.1.1.1.1 Ligaments

Supporting structures of the acromion of the scapula, the distal clavicle, and the coracoid include the acromioclavicular ligament and the coracoacromial ligament, which extends from the coracoid process to the under surface of the acromion just distal to the acromioclavicular joint. The coracoclavicular ligament is divided into the coronoid and the trapezoid bands. These ligaments prevent upward displacement of the clavicle by the muscle forces of the trapezius and sternocleidomastoid muscles.

The capsule of the shoulder is supported by several fibrocapsular ligaments. The most consistent of these ligaments is the coracohumeral ligament, which is a strong band arising from the most lateral edge of the coracoid process and extending over the superior aspect of the shoulder to attach to the grater tuberosity. The inferior glenohumeral ligament extends from the middle anterior margin of the glenoid labrum to the lower medial aspect of the humeral neck. The middle glenohumeral ligament is attached somewhat superior to this, extending from both the labrum and the coracoid attaching to the anterior aspect of the lesser tuberosity. The superior glenohumeral ligament arises at the same level as the middle and extends in a parallel manner to the middle glenohumeral ligament. The transverse ligament extends across the greater lesser tuberosities, enclosing the synovial sheath and long head of the biceps tendon.

Acromioclavicular Joint

a. Acromioclavicular
b. Coracoclavicular
c. Conoid
d. Trapezoid

Sternoclavicular Joint

a. Sternoclavicular
b. Anterior and posterior
c. Interclavicular
d. Costoclavicular

Glenohumeral Joint

a. Coracoacromial
b. Coracohumeral

c. Transverse Humeral Ligament

d. Glenohumeral Ligaments - 3 parts all attach from upper margin of glenoid cavity and strengthen anterior portion of capsule

  i. Superior - over the humeral head to a depression above the lesser tuberosity
  ii. Middle - in front of humerus to lower lesser tuberosity
  iii. Inferior - to lower part of the anatomical neck

2.1.1.1.2 Muscles

Muscles of the shoulder girdle

(a) (CLASSIFIED INTO THREE GROUPS
ACCORDING TO LOCATION OF ATTACHMENTS)

I. FROM AXIAL SKELETON TO SHOULDER GIRDLE (SCAPULA AND CLAVICLE)

- Serratus anterior
- Upper trapezius
- Middle trapezius
- Lower trapezius
- Rhomboid major and minor
- Pectoralis minor
- Levator scapulae

II. FROM SCAPULA AND CLAVICLE TO HUMERUS

- Deltoid
- "Rotator cuff"
    - Supraspinatus
    - Infraspinatus
    - Teres minor
    - Subscapularis
- Teres major
- Coracobrachialis
- Biceps brachii (long head)
- Triceps brachii (long head)

III. FROM AXIAL SKELETON TO HUMERUS
  - Pectoralis major
  - Latissimus dorsi

2.1.1.2 Anatomy of the shoulder joint (glenohumeral articulation)

The shoulder is comprised of three bony structures – the clavicle, scapula, and humerus.

In strict anatomical terms, the shoulder joint consists of the glenohumeral articulation. However, from a practical clinical point of view, the function of the shoulder depends on a complex of four articulations: the glenohumeral joint, the acromioclavicular joint, the sternoclavicular joint, and the sliding "articulation" between the scapula and the thoracic wall, known as the scapulothoracic joint.

2.1.1.2.1 The glenohumeral surface

The articular surface of the shoulder's joint is described as glenohumeral articular surface. The bony radius of the curvature of the glenoid is slightly flattered with respect to the humeral head. However, the glenoid articular cartilage is thicker at the periphery. Thus, creating significant articular surface conformity and resultant stability. This resultant articular conformity additionally provides the foundation for the concavity- compression effect provided by the rotator cuff and the surrounding musculature. The normal glenohumeral joint is fully sealed by the capsule and normally contains less than 1ml of joint fluid under slightly negative intraarticular pressure, which provides a custom effect to resist humeral head translation, thereby increases the stability.

2.1.1.2.2 The glenoid labrum

The glenohumeral articulation is formed by the shallow glenoid cavity, which is surrounded by a cartilaginous labrum. The labrum is composed of fibrocartilage similar to the meniscus in the knee. The labrum is somewhat blunted or rounded posteriorly and generally more triangular and sharper-appearing anteriorly.

2.1.1.2.3 The glenoid capsule

The capsule of the shoulder is lined with synovial membrane that arises from the margin of the glenoid labrum and extends around the head of the humerus anteriorly and posteriorly, where it attaches at about the level of the physead line or anatomic neck.

2.1.2 Shoulder kinesiology

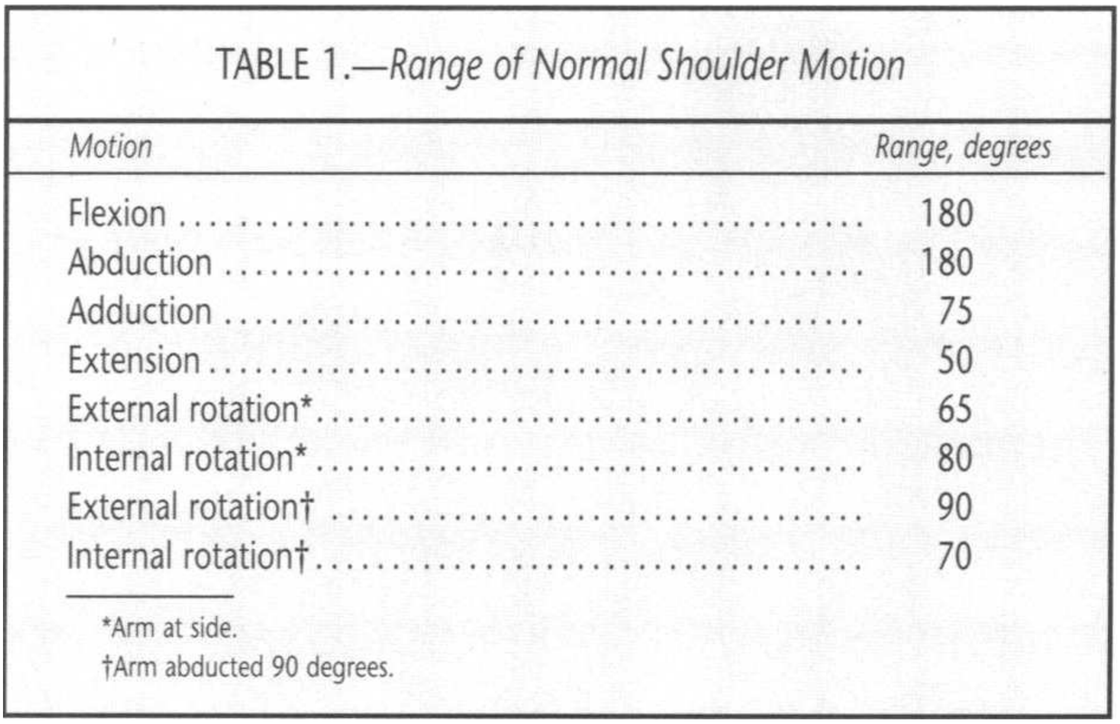


TABLE 1.—*Range of Normal Shoulder Motion*

Motion	*Range, degrees*
Flexion	180
Abduction	180
Adduction	75
Extension	50
External rotation*	65
Internal rotation*	80
External rotation†	90
Internal rotation†	70

*Arm at side.
†Arm abducted 90 degrees.

2.1.2.1 Motions of the glenohumeral articulation

As a ball-and-socket joint, the glenohumeral joint has three axes of motion that lie in the cardinal planes of the body. Therefore the motions available at the glenohumeral joint are

- Flexion/extension
- Abduction/adduction
- Medial/lateral rotation

Abduction and flexion sometimes are each referred to as elevation. Authors also distinguish between elevation of the glenohumeral joint in the plane of the scapula and that in the sagittal and frontal planes. Flexion and abduction in the sagittal and frontal planes of the body, respectively, occur with simultaneous rotation of the glenohumeral joint about its long axis, lateral rotation with abduction, and medial rotation with flexion. (16,142,153).

It has been theorized that this motion helps prevent contact between the greater tubercle and the acromion; however, Saha notes that there is never contact between these bony structures in any position of abduction(142).Movement of the greater tubercle toward the acromion narrows the subacromial space that contains the subacromial bursa, the muscle and tendon of the supraspinatus, the superior portion of the glenohumeral joint capsule, and the intraarticular tendon of the long head of the biceps brachii muscle. Thus, lateral rotation of the glenohumeral joint during abduction is important in preserving the subacromial space. Lateral rotation of the glenohumeral joint also is required to avoid impingement of the greater tubercle on the superior rim of the glenoid fossa. (78).Clearly, lateral rotation of the humerus is essential for full, pain-free abduction of the glenohumeral joint in the frontal plane. Rotation about the long axis of the humerus during abduction and flexion disappears by the time the shoulder reaches approximately 160° of flexion or abduction. Saha refers to this position as the "zero-position" and suggests that it results from an unwinding of the ligaments and muscles of the glenohumeral joint, which occurs as the scapula and humerus move through the range. (142)

Indeed, one of the characteristics of flexion and abduction in the plane of the scapula is that no glenohumeral rotation is required during the movement. Although flexion, abduction, and rotation of the glenohumeral joint imply pure rotational movements, the asymmetrical articular areas of the humeral head and glenoid fossa, the pull of the capsuloligamentous complex, and the forces from the surrounding muscles result in a complex combination of rotation and gliding motions at the glenohumeral joint. If the motion of the glenohumeral joint consisted entirely of pure rotation, the motion could be described as a rotation about a fixed axis. When rotation is accompanied by gliding, the rotation can be described as occurring about a moving axis. The degree of mobility of the axis of rotation in the two-dimensional case is described by the instant center of rotation (ICR). The ICR is the location of the axis of motion at a given joint position. The more stable the axis of motion, the more constant is the ICR. The ICR of the glenohumeral joint moves only slightly during flexion or abduction of the shoulder, indicating only minimal translation. (162)

The amount of humeral head translation during shoulder motion has received considerable attention among clinicians and researchers.

(63, 53, 87, 162) Glenohumeral translation is less during active shoulder motions when muscle contractions help to stabilize the humeral head than during passive motions. (53).

In active elevation of the glenohumeral joint in the plane of the scapula, the humeral head undergoes minimal superior glide (≤ 3 mm) and then remains fixed or glides inferiorly no more than 1 mm.

(23, 38, 53, 85, 133, 151)Individuals with muscle fatigue or glenohumeral instability, however, consistently exhibit excessive superior glide during active shoulder elevation. (17, 33, 38, 84)The humeral head glides posteriorly in shoulder extension and in lateral rotation; it translates anteriorly during abduction and medial rotation. (53, 115, 63, 123, 151)These data contradict the so-called concave–convex rule, which states that the convex humeral head glides on the concave glenoid fossa in directions opposite the humeral roll. For example, the concave– convex rule predicts that inferior glide of the humerus accompanies its superior roll in flexion or abduction, and lateral rotation occurs with anterior glide. (142, 153)Direct measurements reveal otherwise. Although slight, joint glides appear to accompany glenohumeral motions. This recognition supports the standard clinical practice of restoring translational movement to restore full ROM at the glenohumeral joint (63).

However, shoulder rotation comes solely from the glenohumeral joint. Although protraction of the sternoclavicular joint and abduction of the scapulothoracic joint cause the humerus to face medially, these are substitutions for medial rotation of the shoulder rather than contributions to true medial rotation. Similarly, retraction of the sternoclavicular joint and adduction of the scapulothoracic joint can substitute for lateral rotation of the shoulder. True shoulder rotation ROM values range from approximately 70 to 90˚ for both medial and lateral rotation.

2.1.2.2 Movement of the Scapula and Humerus during Arm–Trunk Elevation

During arm–trunk elevation the scapula rotates upward as the glenohumeral joint flexes or abducts. In addition, the scapula rotates posteriorly about a medial–lateral axis and laterally about a vertical axis during shoulder elevation.

(53,83,102).

It has long been recognized that the upward rotation of the scapula and the flexion or abduction of the humerus occur synchronously throughout arm–trunk elevation in healthy individuals (111)

The Glenohumeral joint contributes approximately 120˚ of flexion or abduction and the scapulothoracic joint contributes approximately 60˚ of upward rotation of the scapula, yielding a total of about 180˚ of arm–trunk elevation (9, 43, 53, 111, 133).

The healthy shoulder:

- The scapulothoracic and glenohumeral joints move simultaneously through most of the full range of shoulder elevation.

- Both the glenohumeral and scapulothoracic joints contribute significantly to the overall motion of flexion and abduction of the shoulder.
- The scapula and humerus move in a systematic and coordinated rhythm.
- The exact ratio of glenohumeral to scapulothoracic motion may vary according to the plane of motion and the location within the ROM.
- The exact ratio of glenohumeral to scapulothoracic motion during active ROM is likely to depend on muscle activity.
- There is likely to be significant variability among individuals.

2.1.2.3 Sternoclavicular and Acromioclavicular

Motion during Arm–Trunk Elevation

With the upward rotation of the scapula during arm–trunk elevation, there must be concomitant elevation of the clavicle to which the scapula is attached. The sternoclavicular joint elevates approximately 40˚ during arm–trunk elevation. Although the total scapular upward rotation is 60˚.(9, 74, 161)This motion generally is completed in the first two thirds of the shoulder motion (9, 74). Therefore, full shoulder flexion or abduction can still be augmented by additional sternoclavicular elevation in activities that require an extra-long reach, such as reaching to the very top shelf. This sequence of events, first proposed by Inman et al., demonstrates the significance of the crank shape of the clavicle and the mobility of the acromioclavicular joint to the overall motion of the shoulder complex. (134, 161).

The coordinated pattern of movement at the sternoclavicular and scapulothoracic joints during normal shoulder flexion and abduction also reveals the role of the conoid ligament in producing movement. This description of sternoclavicular and acromioclavicular motion reveals the remarkable synergy of movement among all four joints of the shoulder complex necessary to complete full arm–trunk flexion and abduction. The scapulothoracic joint must rotate upward to allow full glenohumeral flexion or abduction. The clavicle must elevate and upwardly rotate to allow scapular rotation.

2.1.3 Biomechanics

The ability to position and control movements of the scapula is essential for optimal limb function. The inability to achieve this stable base frequently accompanies the development of shoulder and upper limb pain and pathology. Unlike other joints the bony, capsular and ligamentous constraints are minimal at the scapulothoracic 'joint' so stability is dependant on active control. Shoulder dysfunctions are associated with abnormal scapula positioning and dynamic control

The humeral head and the glenoid articular surface show a high degree of conformity. The humeral head is believed to be more convex in the anterior-posterior direction than in the superior-inferior direction. The glenohumeral joint possesses six degrees of freedom, three rotations and three translations. With simulated cadaver or active in vivo glenohumeral abduction in the scapular plane (approximately 30–40° anterior to the frontal plane), the humerus concomitantly externally rotates. External rotation is important for clearance of the greater tuberosity and its associated tissues as it passes under the coracoacromial arch, as well as for relaxation of the capsular ligamentous constraints to allow maximum glenohumeral elevation Translation of the humeral head in the magnitude of 1–3 mm in the superior direction, occurs in the first 30–60° of active glenohumeral scapular plane elevation or during simulated elevation in the scapular plane. Conversely, one study demonstrated inferior translation of 0.7 mm during the 30–60° phase of glenohumeral abduction, which was performed with the subjects lying supine (on their back) and thus most likely, did not similarly recruit muscle activity. Superior humeral head translation that occurs during the initial phase of elevation may in part be due to the deltoid. With the arm at the side, the deltoid is line of pull is such that in addition to its rotational torque, it also produces a translatory force in the superior direction.

Conversely, the translatory force component of the supraspinatus is compressive in nature, which helps stabilize the joint. Therefore, the superior translation that occurs during the initial phase of elevation appears to be due in part to the cranially directed pull on the head of the humerus by the deltoid muscle.

The scapulothoracic articulation is assessing kinematically either two-dimensionally or three-dimensionally. The scapula demonstrates a pattern of upward rotation, external rotation, and posterior tilting during glenohumeral elevation.

The predominant motion of the scapula is upward rotation, and to a lesser degree scapular external rotation and posterior tilt. Less well examined are scapular translations, depicted as scapular positions. Scapular positions can be represented by clavicular rotations about the sternoclavicular joint in two different planes: clavicular elevation/ depression for superior/inferior translation and clavicular protraction / retraction for anterior/posterior translation. During glenohumeral elevation the clavicle retracts posteriorly and elevates, putting the scapula in essentially a more superior and posterior position. In the normal abduction mechanism, the scapula moves laterally in the first 30° to 50° of glenohumeral abduction. As further abduction occurs, the scapula then rotates about a fixed axis through an arc of approximately 65° as the shoulder reaches full elevation. Protraction is the combination of forward movement of the scapula away from the vertebral column, rotation of the scapula around the acromioclavicular joint (anterior tilt), and internal rotation. Retraction is the combination of opposite movements. Abduction of the scapula increases the range of humerothoracic motion, (3) it maintains muscle efficiency by enabling the muscles to work in the optimal portion of their length-tension curve, and (4) it allows the glenoid to be brought underneath the humerus to share some weight of the arm.

2.1.4 Mobility-Stability

2.1.4.1 Stability

The glenohumeral joint is a ball and socket joint. The humeral head is four times larger than the glenoid fossa of the scapula. This permits significant range of motion but also results in an increased susceptibility to instability. The clavicle and the sternoclavicular articulation provide important support in maintaining the muscular efficiency of the shoulder.

Midrange stability requires the precise activation and control of the rotator cuff muscles, more so than end range stability, which depends to a greater extent on passive ligament tension (15)

Stability muscles need to be recruited prior to movement. (96) Muscles primarily involved in movement of the scapula are the levator scapulae, rhomboid major and minor, pectoralis minor and lattisimus dorsi.

2.1.4.2 Mobility

Position and mobility of the thoracic spine can directly influence scapulothoracic and glenohumeral kinematics. A relatively small increase in thoracic spine flexion has resulted in a more elevated and anteriorly tilted scapula at rest, and less upward rotation and posterior tilt during glenohumeral elevation (123). An increase in thoracic spine flexion has also resulted in a decrease in the amount of elevation of the glenohumeral joint(123), and a decrease in the amount of force generated at 90 degrees of glenohumeral scapular plane abduction.

2.1.4.3 Trapezius muscle contribution in stability and mobility

Trapezius and serratus anterior are the most important stabilizers muscles acting upon the scapulothoracic joint. The middle fibres of trapezius run horizontally to attach to the inner border of the acromion and along the crest of the scapula. The upper fibres of the trapezius elevate the scapula but Johnson et all 1994 refute that traditional view as their fibre direction is predominantly transverse. During upward rotation of the scapula, these fibres do not significally change in length, hence they maintain the horizontal and vertical equilibrium, by stabilizing the scapula rather than producing movement. The inferior fibres ascend and converge to a tendon which attaches to the tubercle on the inferior edge at the medial end of the spine of the scapula. These fibres upwardly rotate the scapula and resist the lateral displacement of the scapula from the pull of anterior serratus. The scapula fibres of trapezius are especially active during the first 60 degrees of abduction (152) which indicates their role in maintaining good scapula position with initial humeral movement and at 90 degrees all fibres are active to counteract the pull of anterior serratus. Many texts agree that the upper and lower fibres of trapezius and serratus anterior work as a force couple to produce upward rotation of the scapula. In elevation, this force couple works to counteract the downward rotation force of deltoid on the scapula, and so maintains the optimal length tension ratio in deltoid.

2.1.4.4 Joint articulations

i. GLENOHUMERAL

The glenohumeral joint is suited for extreme mobility with its mismatched large humeral head and small glenoid articular surface. The precise constraint of the centre of rotation through a large arc of motion is the result of interplay of static and dynamic forces. The stabilizing effect of the articular surfaces and capsulolabral ligamentous complex is magnified by muscle forces which produce a concavity – compression effect directed towards the glenoid center.

ii. ACROMIOCLAVICULAR JOINT

The acromioclavicular joint is a diarthrodial joint between the lateral border of the clavicle and the medial edge of the acromion and is covered by a capsule. Stability of the acromioclavicular joint is provided mainly through the static stabilizers composed of the capsule, intraarticular disc, and ligaments. The joint is supported by a relatively weak capsule and stronger superior and inferior ligaments that are reinforced superiorly by aponeurotic fibers of the trapezius and deltoid muscles. The capsule is reinforced by the acromioclavicular ligaments superiorly, inferiorly, posteriorly, and anteriorly. The fibers of the superior acromioclavicular ligament are the strongest and bend with the fibers of the deltoid and trapezius muscles. Additional stability is derived through the coracoclavicular, trapezoid and conoid ligaments.

Upward rotatory forces applied to the scapula by the trapezius and serratus anterior muscles, therefore, produce the motion not at the AC joint but at the next available linkage in the chain—that is, at the SC joint(Sternoclavicular joint).

Coracoacromial arch.

The coracoacromial arch is an osteoligamentous vault consisting of the coracoid process, the coracoacromial ligament, and the acromion process. It serves the functions of preventing superior dislocation of the humeral head and protecting the humeral head from downwardly directed forces at the lateral shoulder.

When the rotator cuff and the deltoid are working in appropriate synergy, the humeral head remains relatively centred on the glenoid fossa, and little superior displacement occurs.

STERNOCLAVICULAR JOINT

The sternoclavicular joint represents the only true articulation between the upper extremity and the axial skeleton. Stability is provided by the surrounding ligamentous structures. These are the intra-articular disc-ligament, the costoclavicular, and the interclavicular ligament.

The SC joint is an incongruent, saddle-shaped joint with three degrees of freedom. Its congruence and stability are substantially enhanced by a fibrocartilaginous joint disk that diagonally transects the joint space (from the superior clavicular facet to the inferior manubrial facet).

When active elevation of the arm is initiated, activity in the upper trapezius muscle will pull the acromion and lateral end of the clavicle up while the other segments of the trapezius and the serratus anterior muscles exert an upward rotatory force on the scapula. The scapula cannot upwardly rotate at the AC joint, because the coracoclavicular ligament maintains a fixed scapuloclavicular angle. Rather, the upward rotatory forces of the trapezius and serratus anterior on the scapula are dissipated at the next available joint: the SC joint. The trapezius and serratus anterior muscles produce upward rotation of the scapula not by rotating the AC joint but by elevating the clavicle at the SC joint. As the trapezius and serratus anterior muscles continue to exert an upward rotatory force on the scapula, the coracoclavicular ligament still prevents upward rotation at the AC joint.

2.1.4.4.1 Static stabilisers

(a) GLENOID LABRUM

The glenoid labrum is a dense, fibrous structure, which is triangular on cross-section. Located at the glenoid margin, the labrum serves to extend the conforming articular surfaces, thereby increasing contact surface area and adding to stability. The labrum also enhances stability by deepening the concavity of the glenoid socket. The labrum also acts as an anchor point for the capsuloligamentous structures.

(b) JOINT CAPSULE

The surface area of the capsule is approximately twice than of the humeral head, allowing for extensive range of motion. The capsuloligamentous structures reciprocally tighten and loosen during rotation of the arm to limit translation. At the extremes of motion, the ligaments tighten and become functional; they are especially important in providing stabilization when all other stabilizing mechanisms are over helmed.

2.1.4.4.2 Dynamic stabilizers

- ROTATOR CUFF MUSCLES
- Deltoid
- Scapular stabilizers

The rotator cuff is a group of muscles consisting of the subscapularis, suprascapularis, supraspinatus, infraspinatus, and teres minor, which act as a dynamic steering mechanism for the humeral head. Three-dimensional movements or rotations of the humeral head are the result of the dynamic interplay between the muscles comprising the rotator cuff and the static stabilisers. Rotator cuff activation results in humeral head rotation and depression in positions of abduction. Contraction of the rotator cuff results in concavity-compression, and asymmetric contraction acts to cause humeral head rotation or “steering” during shoulder motion.

iii. SCAPULOTHORACIC ARTICULATION

The scapulothoracic articulation, not a true joint, is a “functional” joint and does not have the fibrous, cartilaginous, or capsular connections that characterize anatomic joints. The scapula is attached to the thorax anatomically by the articulation between the acromion of the scapula and the lateral end of the clavicle and by the articulation between the clavicle and the manubrium of the sternum. Consequently, the functional ST(scapulothoracic) joint forms a closed chain with the acromioclavicular (AC) and sternoclavicular joints (SC), and the motion of the scapula on the thorax depends on the other two articulations.(98)

Motion at this articulation is limited to slight gliding movements between the scapula and clavicle. Seventeen muscles attach to or originate from the scapula and the function to stabilize the scapula and provide.

SCAPULOTHORACIC MUSCLES

The trapezius has an extensive origin from the base of the skull to the upper lumbar vertebrae and inserts on the lateral aspect of the clavicle, acromion, and scapular spine. It functions mainly as a scapular retractor and elevator of the lateral angle of the scapula. Functionally, it is usually divided into three parts: upper, middle, and lower. The upper trapezius muscle originates from the occipital protuberance and the nuchal ligament of the upper cervical vertebra. The nuchal ligament attaches to the spinous processes of the cervical vertebra. The upper trapezius inserts on the lateral end of the clavicle and acromion process. Because its diagonal line of pull is more vertical (up) than horizontal (in), it is a prime mover in scapular elevation and upward rotation and only an assisting mover in scapular retraction.

The middle trapezius muscle originates from the nuchal ligament of the lower cervical vertebrae and spinous process of C7 and the upper thoracic vertebrae and inserts on the medial aspect of the acromion process and along the scapular spine. Its line of pull is horizontal, which makes it very effective at scapular retraction. Because the line of pull passes just above the axis for upward rotation, its role in scapular upward rotation is only assistive.

The lower trapezius muscle originates from the spinous processes of the middle and lower thoracic vertebrae and inserts on the base of the scapular spine. Its diagonal line of pull is more downward (vertical) than in (horizontal), making it effective in depression and upward rotation of the scapula and only assistive in retraction. All three parts of the trapezius muscle work together (synergists) to retract the scapula.

The deltoid muscle consists of 3 portions: an anterior portion originating from the lateral clavicle, a middle portion originated from the acromion, and a posterior portion originating from the spinous process of the scapula. Their common insertion is the deltoid tubercle on the humerus. The deltoid is the most important abductor of the glenohumeral joint. Although the acromial portion is the strongest one and starts the movement, the clavicular and spinal portions participate at higher degrees of abduction. Conversely, in low degrees of abduction, the medial fibers of the anterior and posterior portions can take part in adduction of the arm. Additionally the anterior portion affects flexion and the posterior portion extension. The posterior deltoid is a stronger transverse extensor (shoulder internally rotated) than transverse abductor (shoulder externally rotated). It is strongly involved in transverse extension particularly since the latissimus dorsi is very weak in strict transverse extension. The posterior deltoid is the primary shoulder hyperextensor, since the pectoralis major nor the latissimus dorsi does not extend the shoulder beyond anatomical position (hyperextension). The anterior and the middle portions allow for elevation in the scapular plane and assist in forward elevation with help from the pectoralis major and biceps.

(c) SHOULDER GIRDLE

The function of the shoulder girdle is to move the long lever of the upper extremity though a large frame of space for the placement of the hand. Concomitantly, the shoulder girdle must provide a stable base from which hand function can be performed. The structurally contradictory mobility and stability demands on the shoulder are met by distributing motion through a set of open- and closed-chain linkages that contribute in different ways to the dynamic stability requirements. Interference with the active or passive components of any one of the bony interfaces can, and commonly does, change the 3 dynamic at one or more of the other interfaces. (98)

The role of the scapula

The scapula performs several functions contributing to stability and mobility of the SC. As well as a base for the muscle attachments, appropriate orientation of the scapula optimizes the length tension relationship of muscles associated with the SC (40, 161). The scapula facilitates optimal contact with the humeral head thus increasing joint congruency and stability (142).

2.2 Shoulder dysfunction

2.2.1 The meaning of shoulder dysfunction

There are numerous clinical problems relating to the shoulder. Most patients with shoulder pathology present with pain / or pain with reduced range of motion. There are two primary shoulder complaints:

a) Pain
b) Instability.

Sometimes is hard to distinguish between the two. Secondary symptoms, such as stiffness, clicking, and weakness are also common when taking the history of the patient.

Most shoulder problems are due to overuse (tendinitis, bursitis) and trauma, and frequently there is an element of both these basic causes. Chronic dysfunction of any one component can result in failure of other components and potentially irreversible structural damage. Relatively increased motion at the glenohumeral joint may be caused by imbalance of the scapular movers, and decreased motion at the glenohumeral joint may be the result of restricted motion in the subacromial space to avoid pain.

2.2.2 Types and purposes of shoulder dysfunction

Types of Injuries

- Overuse

Overuse injuries of the shoulder include bursitis, tendonitis (rotator cuff, biceps tendon, or both), and degenerative or post-traumatic arthritis (21) The elements of overuse that are frequently implicated are repetitive overhead activities (swimming, throwing, installing drywalls) or unaccustomed repetitive strenuous activity (gardening, golfing, shovelling snow). The impingement syndrome-impingement of the periarticular soft tissues between the greater tuberosity of the humerus and the coracoacromial arch-also plays a common role in overuse injuries. Glenohumeral instability can be atraumatic, as is commonly seen in swimming and throwing athletes, or can be post-traumatic, as often seen after a shoulder dislocation. Glenohumeral instability leads to increased translation of the humeral head in the anterosuperior direction, narrowing the subacromial space. Imbalance between the rotator cuff muscles and the scapular stabilizing muscles (rhomboids, trapezius, levator scapulae) can result in excessive protraction and rotation of the scapula, resulting in inferior movement of the acromion and impingement.

- Trauma

Traumatic injuries of the shoulder can be classified as contusions, fractures, dislocations, subluxation, separation, or traumatic impingement (173). Fractures typically involve the proximal humerus, clavicle, or both. Shoulder dislocations are usually anterior (90%) and, less commonly, posterior (10%). Furthermore, shoulder subluxation is also an overlooked cause of symptoms in patients with pain or functional instability. Acromioclavicular separation is one of the most common injuries of the shoulder and of varying severity. Last, traumatic impingement often results in partial or complete rotator cuff tear, especially in persons older than 40 years.

2.2.2.1 Shoulder pain

Chronic dysfunction of any one component can result in failure of other components and potentially irreversible structural damage. The precise cause(s) of shoulder pain within the joint structure is unknown. However, it is presumed to result from degeneration, structural damage (torn rotator cuff and ligaments), inflammation or infectious processes (bursitis, tendinitis, arthritis), or anatomic abnormality (malalignment) of 1 or several periarticular or intra-articular (glenohumeral) structures .(71, 109, 156, 118, 154)

Presumed Causes of Shoulder Pain

Periarticular Disorders	*Intra-articular (Glenohumeral) Disorders*

Periarticular Disorders	*Intra-articular (Glenohumeral) Disorders*
Rotator cuff tendinitis/	Inflammatory arthritis
impingement syndrome	Osteoarthritis
Calcific tendinitis	Osteonecrosis
Rotator cuff tear	Cuff arthropathy
Bicipital tendinitis	Septic arthritis
Acromioclavicular arthritis	Adhesive capsulitis
Bursitis	(frozen shoulder)
	Glenohumeral instability

2.2.2.2 Muscular imbalances

I. INSTABILITY- POORLY COORDINATED MUSCLE ACTIVATION

The dynamic stabilization of the scapula is an essential part of the management of neuromuscuoloskeletal dysfunction of the shoulder girdle, the ability to position and control movements of the scapula is essential for normal upper limb function, inability to control the movement of the scapula during activities involving the upper limb accompanies the development of shoulder pain and pathology (40). The lack of ligamentous restraints at the scapulothoracic joint requires the muscles that attach the scapula to the thorax to have a major stabilizing role and hence these muscles need appropriate contractile and recruitment properties (40)

Multidirectional instability (MDI), which is characterized by symptomatic subluxation and/or dislocation of the glenohumeral joint in more than one direction. The pathology of MDI typically involves a loose and redundant joint capsule with episodes of recurrent pain and instability, particularly in the midrange positions of glenohumeral motion. Midrange stability requires the precise activation and control of the rotator cuff muscles, more so than end range stability, which depends to a greater extent on passive ligament tension (15). Not surprisingly, rotator cuff dysfunction has been implicated as a contributing factor to the development of MDI (102,103). Deficient rotator cuff activation compounds the lack of stability created by excessive capsuloligamentous laxity.

The relationship between glenohumeral instability and shoulder muscle function has been investigated in voluntary posterior instability, recurrent anterior instability (51, 95). In each of these studies, subjects with instability were found to have movement specific, abnormal levels of activation in several different shoulder muscles. For subjects with MDI, Morris et al. (2004) investigated six different shoulder muscles and found atypical levels of activation for all three sections of the deltoid, but found no differences in the activation of the rotator cuff. Electromyographic investigations of glenohumeral instability have quantified the level of muscle recruitment by comparing the amplitude of activation at different stages of the movement cycle. While recruitment level is an important characteristic of muscle function, an equally important factor is the timing of the activation.

Anterior glenohurneral instability is a common cause of morbidity in young patients, particularly athletes, and often requires surgical reconstruction to restore shoulder function. Soft-tissue structures are critical in maintaining passive anterior stability of the shoulder.

Past studies have associated glenohumeral instability GI with modifications in latency, recruitment order and/or EMG activity (135)

II. STRENTHENING IMBALANCES BETWEEN SHOULDER MUSCLES

A very common type of shoulder disorder is the intramuscular strengthening disorder. That name characterises the abnormal strengthening quantity of contraction between muscles or muscle groups performing an action at the same time. This refers to an isometric or isokinetic contraction of a muscle group where each muscle can work concentrically or eccentrically acting as stabilizing muscle or locomotive muscle.

The result of that kind of imbalance is an abnormal way of motion performance, through all the range of motion or a part of it. If there is the need of more than one muscle for the exact accomplishment of an action, a disorder of that type will not allow the performance of the exact action. Each, any or one muscle of them is/are contracting less or more forcibly than the demanding for the accurate action. That consequence is the delay, the discontinuation, or the acceleration of a part of the motion or the alteration of the movement's direction. If the motor muscle contracts with less power than the appropriate, the motion speed (in case of isotonic contraction) will be decreased, zero, or minus from the desired (opposite direction). If it contracts with more than the necessary power, the speed will be increased and the movement will not be normal anymore.

2.2.2.3 Dyskinesis

Scapular dyskinesis is an alteration in the normal position or motion of the scapula during coupled scapulohumeral movements. It occurs in a large number of injuries involving the shoulder joint and often is caused by injuries that result in the inhibition or disorganization of activation patterns in scapular stabilizing muscles. It may increase the functional deficit associated with shoulder injury by altering the normal scapular role during coupled scapulohumeral motions. Scapular dyskinesis appears to be a non specific response to shoulder dysfunction because no specific pattern of dyskinesis is associated with a specific shoulder diagnosis. It should be suspected in patients with shoulder injury and can be identified and classified by specific physical examination. Treatment of scapular dyskinesis is directed at managing underlying causes and restoring normal scapular muscle activation patterns by kinetic chain–based rehabilitation protocols.

2.2.2.4 Impingement

Subacromial impingement is defined as a painful contact between the rotator cuff, subacromial bursa and the under surface of the anterior acromion (NEER) (106)The potential etiology is multifactor and involves patient related factors (age, supraspinatus outlet anatomy, and prexisting rotator cuff pathology) and worker related factors (arm position, lifting requirements numbers of repetitions) (13, 126). Rotator cuff and subacromial impingement or in general impingement are the most common causes for shoulder pain. The vast majority of people with impingement syndrome who are younger than 60 years of age, relate their symptoms to occupational or athletic activities that involve frequent overhead use of the arm (13, 14, 58). Anatomically, the coracoacnromial arch, the supraspinatus tendon and the tendons of the subscapularis, infraspinatus and teres minor becomes confluent with the glenohumeral capsule near its humeral insertion.(106, 119, 120, 121)The trapezius, rhomboids, levator scapulae and serratus anterior stabilize the scapula against the thorax.(40, 43, 69, 79) Most authors noticed, based on their data, alterations in muscle activity in upper trapezius (UT), lower trapezius (LT) and serratus anterior in patients with symptoms of impingement(25, 26, 27, 28, 29, 30).

Motions that bring the greater tuberosity in closer contact with the coracoacromial arch are particularly problematic. These motions include excessive superior or anterior translations of the humeral head on the glenoid fossa, inadequate lateral (external) rotation of the humerus, and decreases in the normal scapular upward rotation and posterior tipping on the thorax, all occurring during humeral elevation (51, 102, 110, 130, 133).

In patients with impingement syndrome, even if their rotator cuff lacks a full thickness defect, there is increased superior translation with active elevation that may result in painful subacromial contact. Scapulothoracic slag from dys-rhythmic scapulothoracic motion also can contribute to subacromial impingemenhert because the acromion fails to rotate with the humerous thereby producing a relatively decrease of acromiohumeral interval (80, 106). Additionally, the hypothesized kinematic alterations in scapular motion have been linked to decreases in serratus anterior muscle activity, increases in upper trapezius muscle activity, or an imbalance of forces between the upper and lower parts of the trapezius muscle (80,125). Impingement is thought to be due to inadequate space for clearance of the rotator cuff tendons as the arm is elevated (80, 173). Evidence to support the existence of abnormal electromyographic (EMG) or kinematic patterns in people with shoulder pain is limited. Investigations of altered scapulothoracic EMG patterns in patient populations have been non-specific regarding subject diagnoses or restricted to testing of athletic activities (51, 130, 146).

2.3 Muscle evaluation tests

General Principles

Early warning symptoms of the diffuse muscle condition include:
_ fatigue _ muscle discomfort
_ burning _ stiffness
_ aches and pains _ soreness
_ weakness _

Clinical evaluation

Inspection and palpation

Examiners should inspect muscle tone, symmetry, and deformity, particularly at the acromioclavicular and sternoclavicular joints, shoulder, scapula, and clavicle.(152, 154, 167).

Because shoulder pain is most often unilateral, making anatomic comparisons to the contra lateral shoulder as a reference point is often useful. Palpation should then be performed to determine areas of tenderness, swelling, or anatomic abnormalities. It is useful in discerning acromioclavicular joint pathology from shoulder and referred neck pain (154). For example, neck pain and pain that radiates below the elbow are often signs of a cervical spine problem that is mistaken for a shoulder disorder (167). Obviously, a thorough neck and neurovascular examination should be part of the shoulder examination to rule out cervical spine pathology.

Range of motion

One of the next steps in diagnosing shoulder pain is to record active and passive range of motion (ROM) of the shoulder, including forward flexion, abduction, and internal and external rotation. (152, 154, 167)The progress of the patient can be followed over time, a goniometer can be used to record the ROM in degrees. A simple clinical evaluation of ROM can be particularly useful in differentiating tendinitis, impingement, adhesive capsulitis, and rotator cuff tears.

The various clinical diagnostic tests that have been reported in the literature can be differentiated by their sensitivity and specificity. One of the most sensitive tests for diagnosing impingement syndrome is Hawkins' test, which has a sensitivity of 87% to 92.1%. Neer's sign, also used for diagnosing impingement syndrome, has a reported sensitivity of 75% to 89%. However, the specificity of both these tests is low, with reported values of only 25% to 47.5%. In contrast, higher specificity is seen with the drop-arm test (97.2%), Yergason's test (86.1%), and the lift-off test (61%), although all 3 tests have low sensitivity (7.8%, 37%, and 0%, respectively). The crank test has high specificity (93%) and sensitivity (91%), whereas Speed's maneuver has relatively low sensitivity (68.5%) and specificity (55.5%).

Evaluation of impingement

A shoulder with symptoms of shoulder impingement was determined by history and confirmed by physical examination to check for signs of impingement (Neer, Hawkins, supraspinatus test, apprehension, and relocation test)

1. Positive Neer sign: reproduction of pain when the examiner passively flexes the humerus to end-range with overpressure.
2. Positive Hawkins' sign: reproduction of pain when the shoulder is passively placed in 90° forward flexion and internally rotated to end range.
3. Positive Jobe's sign: reproduction of pain and lack of force production with isometric elevation in the scapular plane in internal rotation (empty can).
4. Pain with apprehension: reproduction of pain when an anteriorly directed force is applied to the proximal humerus in the position of 90° of abduction and 90° of external rotation.
5. Positive relocation: reduction of pain after a positive apprehension test when a posteriorly directed force is applied to the proximal humerus in the position of 90°/90°.

For inclusion, at least one impingement sign needed to be positive, with, in addition, a second positive impingement test or painful apprehension/positive relocation test. It is thought that patients with minor instability and secondary impingement will experience pain, but not apprehension with these tests.(154)

2.4 Treatment -General exercises

Treatment of painful shoulder

Acute painful shoulder

Current therapy for acute painful shoulder includes rest and physical therapy, (34, 105) oral nonsteroidal anti-inflammatory drugs (NSAIDs), intra-articular corticosteroids, (34, 105) or intra-articular sodium hyal-uronates (44). Of note, a 2002 Cochrane report concludes that there is insufficient evidence to support or refute the benefit of corticosteroids in treating shoulder pain. (1, 44)

Chronic painful shoulder

Current non-operative treatment for chronic shoulder pain is initially conservative, using rest, ice, and exercise, as well as oral medications such as NSAIDs and acetaminophen (95, 109, 167)

Intra-articular corticosteroid injections may also be considered for flaring conditions. Exercise therapy is considered to be the mainstay of physiotherapy for chronic shoulder pain.

Non-pharmacologic interventions

Exercise is often combined with manipulation, mobilization, and physical therapies such as repetitive motion machines, ultrasound, laser, and transcutaneous electrotherapy (49) There is some evidence for the effectiveness of exercise therapy compared with no therapy (48) laser therapy, (144) and manipulation, compared with placebo. There is an apparent lack of effect of ultrasound (49, 125) and transcutaneous electrotherapy in chronic shoulder pain. (57) However, ultrasound is sometime used as an adjunctive modality in some hospitals in the management of tendonitis. The effects of physiotherapy on long-term clinical outcome remain to be determined. It is also unclear whether physiotherapy is more effective than analgesics, corticosteroid injections, or a wait-and-see approach. Randomized clinical trials comparing the effectiveness of corticosteroid injections with physical therapy for shoulder pain in primary care show inconsistent short-term results (34, 39, 65,163). Variation in the content of treatment and the selection and definition of outcome measures may explain these differences. Therefore, it is important to obtain consensus on a core set of outcome measures for shoulder pain.

Treating Injuries of the Shoulder

The following general treatment guidelines are for both overuse and traumatic shoulder injuries:

1. Decrease the inflammatory response with ice, nonsteroidal anti-inflammatory drugs (NSAIDs), or both;
2. Alleviate pain;
3. Properly immobilize the shoulder or use modified rest; and properly rehabilitate to maximize the functional outcome.

In general, shoulder rehabilitation begins with isometric exercises, progressing to passive then active range of motion, incorporating strengthening of the rotator cuff and scapular stabilizing muscles. The specifics of treatment depend on the diagnosis.

Traumatic Impingement

A fall onto an outstretched hand or onto the proximal humerus can cause traumatic impingement. Initial treatment consists of ice, NSAIDs, and modified rest with or without a sling, depending on the severity of a patient's symptoms. As the patient's symptoms resolve, and if further strength testing of the shoulder shows a rotator cuff tear, an adequate period of rehabilitation (2 to 3 months) will often lead to good functional results. (122) Referral to an orthopedist is appropriate for possible surgical intervention if the patient fails to improve or the patient is an athlete or heavy laborer. Early recognition of this injury improves the subsequent outcome.

Overuse Injuries

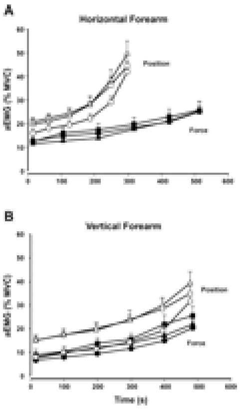
Rotator cuff tendinitis, subacromial bursitis, bicipital tendinitis, and degenerative or post-traumatic arthritis should be treated initially with ice, NSAIDs, and modified rest until pain-free, followed by active ROM exercises and strengthening. If the impingement syndrome is present, the underlying biomechanical abnormality glenohumeral instability, muscle imbalance, or poor throwing or swimming techniques-should be addressed. Also, specific rehabilitation should be directed toward rotator cuff strengthening and impingement protection, avoiding ranges that stress the shoulder. If these conditions fail to respond, administering a corticosteroid to the joint and physical therapy are often effective. Physical therapy modalities of ice, ultrasound, laser, and interferential therapy are useful adjuncts. In refractory cases, referral to an orthopedist is appropriate. In summary, in treating common shoulder injuries, proper diagnosis and an aggressive rehabilitative approach are keys to obtaining a good functional result and in preventing long-term disability.

2.5 Electromyography (EMG)

Electromyography or EMG is an experimental technique which is concerned with the development, recording and analysis of myoelectric signals (measures the electrical impulses of muscles at rest and during contraction) as with other electrophysiological signals, an EMG signal is small and needs to be amplified with an amplifier that is specifically designed to measure physiological signals. At any instant, the shape of the muscle signal, the motor unit action potential (**MUAP**), is constant unless there is movement of the position of the electrode or biochemical changes in the muscle due to changes in contraction level. The rate of neuron pulses, whose exact times of occurrence are random in nature, is related to the time duration and force of a muscle contraction.

The EMG signal can be modelled as the output signal of a filtered impulse process where the neuron firing pulses. It is assumed to be the input of a system whose transfer function is the motor unit action potential. Representing the neuron pulses as a point process with random times of occurrence, the higher order statistics based system reconstruction algorithm can be applied to the EMG signal to characterize the motor unit action potential. Myoelectric signals are formed by physiological variations in the state of muscle fiber membranes. When EMG is measured from electrodes, the electrical signal is composed of all the action potentials occurring in the muscles underlying the electrode. This signal could either be of positive, or negative voltage since it is generated before muscle force is produced and occurs at random intervals. Muscular movement involves the action of muscles and nerves and needs an electrical current (the membrane depolarization causes a quickly change from -80mV up to +30mV). That depolarization-repolarization cycle forms a depolarization wave or electrical dipole which travels along the surface of a muscle fiber. So, the EMG signal directly reflects the recruitment and firing the characteristic motor units within the measured muscle. A number of techniques have been developed to assess EMG signals (both wEMG and sEMG) in the frequency domain. The spectrum of the EMG signal is mainly composed of energy in frequencies ranging between 50 to 70 Hz K (127). The frequency of an EMG signal is between 0 to 500 Hz. However, the usable energy of EMG signal is dominant between 50-150 Hz .The frequency spectrum may change due to physiological processes, such as fatigue (11). The change in the frequency spectrum of the fatigued muscle EMG signal is a reduction in the power in the higher frequencies which suggests that a different type of MUAP may be generated due to the physiological processes in the muscle. A similar behaviour of frequency shifting and power reduction at high frequency was observed in the sEMG signal (127).The EMG signal power is located between 10 to 250 Hz and scientifically the amplifier is between 10 to 500 Hz.

EMG AND MUSCLE RESEARCH TESTS



The average rectified EMG [aEMG, normalized to the peak maximal voluntary contraction (MVC) value, means ± SE] for the three rotator cuff muscles during the four fatiguing contractions. *A*: aEMG for the force (solid symbols) and position (open symbols) tasks with the forearm horizontal. *B*: aEMG for the two tasks with the forearm in the vertical position. The aEMG was averaged over 30-s intervals for each task at 6 time points that correspond to the absolute times at start, 20, 40, 60, 80, and 100% of time to task failure. Circles, supraspinatus; squares, infraspinatus; triangles, teres minor.

Besides, physiological and biomechanical studies, kinesiological EMG is established as an evaluation tool for applied research (orthopaedic, surgery, gait and posture analysis), physiotherapy/rehabilitation (post surgery/accident, neurological rehabilitation, and active training therapy physical therapy, sports training and interactions of the human body to industrial products and work (ergonomics) conditions. Electromyography as a tool for the study of muscle function has been in use since the mid-1900s. Since then, both normal and pathological muscle functions have been examined by this method. Electromyography has been used to quantify muscle activity patterns during shoulder rehabilitation protocols as well as to analyze shoulder muscle activity and coordination during sports activity and all-day work (67). In some medical conditions the electrical activity of the muscles or nerves is not normal. Finding and describing these electrical properties in the muscle or nerve may help your doctor diagnose your condition. EMG is used to diagnose two general categories of disease: neuropathies and myopathies. EMG may aid with the diagnosis of nerve compression or injury (such as carpal tunnel syndrome), nerve root injury (such as sciatica), and with other problems of the muscles or nerves. Less common medical conditions include amyotrophic lateral sclerosis, myasthenia gravis, and muscular dystrophy.

2.5.1 Types

There are three types of EMG: intramuscular EMG ,surface EMG(SEMG) and vaginal and anal probes

Intramuscular EMG (the most commonly used type) involves inserting a needle electrode through the skin into the muscle whose electrical activity is to be measured. Needle EMG techniques can detect MUAPs in a small volume near the needle tip and provide localized information concerning either superficial or deep muscle structures.

Surface EMG (SEMG) involves placing the electrodes on (not into) the skin overlying the muscle to detect the electrical activity of the muscle. The only disadvantage is that the surface electrodes can only detect surface muscles. Surface techniques can detect MUAPs in a large volume and provide global information that is dominated by the most superficial motor units. Recent surface techniques based on linear electrode arrays or two dimensional electrode grids allow the implementation of spatial filters and the detailed observation of properties of individual superficial motor units.

Vaginal and anal probes

For pelvic floor muscle evaluation special anal and vaginal probes are established. The use of these electrodes may require special signal processing (highpass filtering).

2.5.2 Benefits

- EMG allows to directly "look" into the muscle
- It allows measurement of muscular performance
- Helps in decision making tests before /after surgery
- Documents treatment and training regimes
- Helps patients to "find" and train their muscles
- Allow analysis to improve sport activities
- Detects muscle report in ergonomic studies

2.5.3 Risks

(b) On its way from the muscle membrane up to the electrodes, the EMG signal influenced by several external factors altering its shape and characteristics. in that way, the results of a research or of a diagnosis can be misleading and fault.

- Tissue characteristics the human body is a good electrical conductor, the electrical conductivity varies with tissue type, thickness, physiological changes and temperature.
- Physiological cross talk neighbouring muscle may produce a significant amount of EMG. Especially when the EMG recording is performed on the upper trunk /shoulder muscles
- Changes in the geometry between muscle belly and electrode site
- External noise (incorrect grounding of the electrode)
- Electrode and amplifier. They must be put in the correct indicated position.

People usually have a small amount of discomfort during EMG testing because of pin insertion. Disposable needles are used so there is no risk of infection.

Recommendations to standardised test

- Load(use your body or body segments or static resistance)
- Angle ,ROM(use belts to arrange good fixation, goniometer ,mirror and training machines are useful)
- Velocity (use metronome)
- Duration(use fixed intervals, count repetitions, limit repetitions at high intensities)
- Preliminary status(room temperature, hygiene, non fatigue condition)
- General(time between the tests , orders, technique, multiple factors)

2.5.4 Muscle timing-EMG

The latency time is defined as the time in microseconds from a certain point to the beginning of muscle activation. There are three methods that measure the beginning of the muscle activation. The 1st method is the visual evaluation of the EMG trace. The 2nd possibility is defining by the muscle activity through an assumed measured EMG value. For each one, at random, the EMG value is expressed in the percentage of maximal measured value that can be used as a reference point. Hodges used a 3rd method. In this method, the muscle activity is measured from the time that EMG signal exceed the one or more standard deviation of the basic activity.

The timing characteristics of a muscle within a certain movement event or in comparison to other muscles can be calculated on a metric time scaling base. This analysis type does not require any amplitude normalization and is therefore a helpful analysis strategy in patient or subject measurements.

The temporal characteristics of Electromyographic (EMG) recordings are parameters of neuromuscular function commonly used in the evaluation of posture and movement (32, 96). The onset of EMG is one of the most common of these parameters evaluated. In order to allow comparisons between muscles, experimental conditions and subjects or subject groups, accuracy of onset determination is crucial. In studies where the EMG onset determination method is described this is usually performed by visual evaluation of the EMG trace (98, 172), generally without reporting the criteria on which this visually determined decision is made.

Several studies report criteria such as the earliest detectable rise in EMG activity above the steady state (6, 169) or the point where the signal first deviates more than 1 or 1.5 SD (Sub periods Define) from the level recorded during the steady state (59) without mention of how this is determined. Although it is acknowledged that visual determination of EMG onset is not optimal, it currently provides the only standard objectivity. Furthermore, to identify the appropriate combination of parameters is the most accurately determining EMG onset with a variety of trace types. Identification of a computer algorithm that accurately identifies the onset of EMG will provide a method to increase the objectivity of EMG onset determination that is independent of the experience or bias of the examiner.

Accordingly, comparisons between muscles with similar background EMG activity are reasonable with any method since the error is identical. In contrast, when relating the onset of EMG to a time or movement event or when muscles with differing levels of background EMG activity are to be compared the systematic error is critical and the combination of parameters should be considered. Low pass filtration is performed to remove the higher frequency components of the signal producing a smoother trace to assist the identification of the EMG onset (150). However, excessive smoothing of the data results in a loss of information and inaccurate identification of EMG onset (22, 32, 37, 59, 68, 96, 150)

2.6 Timing

2.6.1 Physiology

Contractile mechanism of muscle cells

Muscles have been classified according to their anatomy (striated versus smooth muscle or according to their innervation. So we have the skeletal muscle cells and the hollow organs muscle cells.

Muscles cells attached to the skeleton are striated and under voluntary control. They are often very long and bridge the attachments points of the muscle to the skeleton .This arrangement allow to the cells to function independently. The total force produced by a muscle reflects the sum of the forces generated by its active cells .the myosceletal system is arranged, so that most gravitational loads are borne by the skeleton and the ligaments. Skeletal muscle cells are normally relaxed and are usually recruitment to generate force and movements.

Skeletal muscle is a classic example of a biological structure-function relationship. At both macro- and micro-scopic levels, skeletal muscle is exquisitely tailored for force generation and movement. A skeletal muscle is composed by bundles of extremely large multinucleated cells. The properties of a whole muscle depend not only on the properties of the fibers, but also on the organization of those fibers: the muscle architecture. Fibers rarely run the whole length of the muscle, tending to be somewhat oblique to the muscle's line of action. Peak force production is related to the physiological cross sectional area (PCSA), which estimates the sum of the cross sectional area of all the fibers. Contraction velocity and excursion range are related to fiber length.

Control of Contraction

Although each fiber is innervated by a single axon, a motor neuron may have a hundred or more axons. A single motor neuron, with all the fibers it controls, is called a motor unit. As the brain's signal for contraction increases, it both recruits more motor units and increases the "firing frequency" of those units already recruited. Even during a "maximal voluntary contraction", it is unlikely that all the motor units (and hence muscle fibers) are activated.

Biomechanics of Strength

The above discussion focused on the muscle itself. All joints, however, are set up as lever systems: the fulcrum where two bones meet, one force produced by the muscle, and the other by a load. Strength is not just muscle force, but muscle force as modified by the mechanical advantage of the joint. To complicate matters further, this mechanical advantage usually varies with joint rotation (as does the muscle force). The net result is strength that varies with joint angle and may be somewhat decoupled from muscle force. Joint strength can (obviously) be increased with exercise.

From Depolarization to Contraction

Contraction is regulated by calcium ion concentration. In the resting state, a fiber keeps most of its intracellular calcium carefully sequestered in an extensive system of vessicles known as the sarcoplasmic reticuluum. There are at least two receptors in the chain between depolarization and calcium release. Once released, calcium binds to troponin, opening the myosin binding sites on filamentous actin, and force is produced.

Architecture

Skeletal muscle comprises the largest single organ of the body. It is highly compartmentalized, and we often think of each compartment as a separate entity. Skeletal muscle is not only highly organized to function at the microscopic level, the arrangement of the muscle fibers at the macroscopic level also demonstrates a striking degree of organization. Skeletal muscle architecture is defined as "the arrangement of muscle fibers relative to the axis of force generation." The functional properties of a whole muscle depend strongly on its architecture. The various types of arrangement are as numerous as the muscles themselves. Muscles with fibers that extend parallel to the muscle force-generating axis are termed parallel or longitudinally arranged muscles. While the fibers extend parallel to the force-generating axis, they never extend the entire muscle length. Muscles with fibers that are oriented at a single angle relative to the force generating axis are termed unipennate muscles. The angle between the fiber and the force-generating axis generally varies from 0° to 30°. Most muscles fall into the final and most general category, multipennate muscles composed of fibers that are oriented at several angles relative to the axis of force generation. As we will discuss, an understanding of muscle architecture is critical to understanding the functional properties of different sized muscles.

Effect of Muscle Architecture on Muscle Function:

The functional effect of muscle architecture can be simply stated as: muscle force is proportional to physiologic cross-sectional area (PCSA), and muscle velocity is proportional to muscle fiber length. PCSA is the sum of the areas of each fiber in the muscle. It may be apparent, based on the brief discussion of architecture presented above, that neither fiber length nor PCSA can easily be deduced based on gross muscle inspection. Detailed dissections of cadaveric muscles are required for architectural determination (141). However, after determining architectural properties, it is possible to understand how much force the muscle generates and how fast it contracts (or how far it contracts).

2.6.1.1 Fundamental Functional Properties of Skeletal Muscle

Length-tension Relationship

The isometric length-tension curve represents the force a muscle is capable of generating while held at a series of discrete lengths. When tension at each length is plotted against length, a relationship in its most basic form, the length-tension relationship states that isometric tension generation in skeletal muscle is a function of the magnitude of overlap between actin and myosin filaments.

Force-velocity Relationship

The force generated by a muscle is a function of its velocity. Historically, the force-velocity relationship has been used to define the dynamic properties of the cross-bridges which cycle during muscle contraction.

The force-velocity relationship, like the length-tension relationship, is a curve that actually represents the results of many experiments plotted on the same graph. Experimentally, a muscle is allowed to shorten against a constant load. The muscle velocity during shortening is measured and then plotted against the resistive force. The general form of this relationship is shown in Figure 2. On the horizontal axis is plotted muscle velocity relative to maximum velocity (V_{max}) while on the vertical axis is plotted muscle force relative to maximum isometric force (P_o)

The force generated by a muscle depends on the total number of cross-bridges attached. Because it takes a finite amount of time for cross-bridges to attach, as filaments slide past one another faster and faster (i.e., as the muscle shortens with increasing velocity), force decreases due to the lower number of cross-bridges attached. Conversely, as the relative filament velocity decreases (i.e., as muscle velocity decreases), more cross-bridges have time to attach and to generate force, and thus force increases (2,6,19,42,81,106,134,142, 141).

2.6.2 Latent Muscle Reaction Time (LMRT)

The neuromuscular reflexive arc consists of both afferent and efferent neural components and is greatly influenced by visual, auditory, and vestibular exteroception. Afferent components originate from musculotendinous, capsuloligamentous, and cutaneous mechanoreceptors and terminate in the dorsal spinal cord, while the efferent components originate from the ventral spinal cord and terminate at the myoneural junctions of numerous muscle fibers (80).

No previous studies to our knowledge have reported rotator cuff muscle latent muscle reaction timing (LMRT) for either normal untrained subjects or trained overhead throwing athletes. (107). During the acceleration phase of throwing, glenohumeral joint internal rotation can achieve velocities of $9000^0 \cdot s^{-1}$ (130). Following ball release, sudden shoulder deceleration occurs via eccentric rotator cuff and posterior deltoid muscle activation (130, 52).

Because of their slowly adapting nature, the contributions of capsuloligamentous mechanoreceptors to proprioception tends to be diminished during higher (functional) velocity movements, with this function being primarily provided by musculotendinous mechanoreceptors. (125)

Previous glenohumeral joint proprioception studies have relied on relatively low (non-functional) velocities to maximize capsuloligamentous proprioceptive contributions while minimizing musculotendinous contributions. (3,150) Muscle spindles and golgi tendon organs (GTO) are rapid response mechanoreceptors responsible for sensing musculotendinous length and tension changes, respectively. During the deceleration phase of throwing, peak shoulder external rotator muscle torque of 300 inch-lbs (or 33.88 Nm) may occur at terminal range of motion, thereby stimulating the GTO. (109)

Houck et al. reported that GTO activation was minimal until the end range of motion when the passive tension of muscular antagonists was greatest (70).

Brindle et al., 1998 compared differences in rotator cuff LMRT in response to a sudden internal rotation perturbation force between trained overhead throwers and untrained normal control subjects. The hypothesis of his study was that the specific training of the overhead throwing group would produce rotator cuff LMRT differences ($P <= 0.05$) compared with control group subjects. Differences detected between trained overhead throwers and untrained control subjects are attributed to the proprioceptive influences of repetitive overhead throwing. The ability to detect the instant at which the rotator cuff muscles decelerate the glenohumeral joint would provide critical data to clinicians who design and implement conditioning programs for injury prevention and who rehabilitate overhead throwers following injury or surgery. These data would provide evidence of neuromuscular adaptations that occur as a direct result of overhead throwing training which would prove useful in designing injury prevention conditioning programs for the glenohumeral joint or in the rehabilitation of injured throwers (20).

2.6.2.1 Relative muscle activity

Coordinated activity of all three divisions of the trapezius muscle is necessary during shoulder elevation and for control of scapular orientation at rest. When the arm is elevated, the upper trapezius indirectly contributes to scapula external rotation by elevating the outer clavicle and consequently the acromion via the acromioclavicular joint. (20, 28). The horizontal mid fibers of trapezius work to control the axis of rotation when elevation of the shoulder girdle increases, whilst lower trapezius muscle works at constant length to control the axis of rotation and assists to prevent unwanted protraction from contraction of the serratus anterior and scapula elevation from the contraction of the levator scapulae (20)

In addition to the relevance of the mid and lower divisions of the trapezius muscles from an anatomical and functional perspective in scapula control and upper limb movement, there is accumulating evidence of impairment in the lower division of the trapezius muscle in people with shoulder muscle dysfunction (26, 104).

The quality of neuromuscular control around the scapula depends on several parameters, determining the muscle balance of the scapular muscles. This muscular balance consists of balanced timing of muscle recruitment, balanced force production, and balanced muscle activity in the scapular muscles. (88,77, 168, 98)

Disturbances in scapulothoracic muscle balance have often been suggested in the literature (88, 77, 168, 146).

They result in scapular instability, potentially increase the list of shoulder problems, and would be present in timing properties as well as in force output and proportional electomyographic activity. These variables had not been studied before the research of Ann Cools, neither in healthy population, nor in a population of overhead athletes with shoulder problems.

2.6.3 Timing properties of the muscles in the presence of fatigue

It has been suggested in the literature that timing properties of a muscle may be altered by fatigue, thus increasing the risk of fatigue-related injuries. Scapular muscle fatigue during rigorous exercise or physical labour may decrease the potential of dynamic stabilisation (88, 147, 3, 20, 111, 172).

The results of Cools A et al. 2002, study showed that the scapular muscle responses ere considerable slower in the presence of fatigue, but the temporal sequence of muscle recruitment remained unchanged. Based on these results, they conclude that in healthy, non athletic shoulders, the three trapezius parts react as a unit in response to sudden perturbation, and that muscular fatigue affects the onset of muscle activity, without altering the temporal sequence. Although not statistical significant, a preferential recruitment order was observed, in which the upper trapezius was activated prior to the middle and the lower trapezius. This recruitment order suggests that, in response to unexpected sudden movement, the upper trapezius reacts to move the scapula into an upward rotation (since the perturbation itself indirectly causes a downward rotation movement of the scapula), whereas the lower trapezius stabilises the scapula and regulates its smooth motion. The results of this research revealed that fatigue of the scapulothoracic muscles did cause a delay in muscle reaction times, but the intermuscular order of activation was not altered (30).

2.6.4 Muscle timing reflex

The shoulder has been described as a joint with a high level of mobility necessary for placing the hand in a position of function. Because of this level of mobility, inherent stability is compromised. Specifically the shoulder relies on static and dynamic restraints. Static restraints include osseous geometry, negative intraarticular pressure, the glenoid labrum, and capsuloligamentous restraint. Dynamic restraints refer to the joint stability provided by muscles that cross the shoulder through mechanical and neuromuscular mechanisms. Although described as separate entities (static versus dynamic) the shoulder relies on the neurologic interaction between these two mechanisms for joint stability (4,116).

Previous research in relaxed muscles shows that muscle reflex latencies are too slow to protect the shoulder. Muscle reflex latencies were measured as the time from perturbation application to onset of muscle activity. Electromyography measured activity onset of the rotator cuff muscles and the primary humeral movers (118).

The research has shown that a reflexive arc exists between the capsuloligamentous structures and muscles about the shoulder. Several investigators showed that a spinal reflex exists between the joint capsule and musculature surrounding the feline glenohumeral joint using electrical stimulation of the joint capsule. Latimer et al measured muscle latencies of the shoulder resulting from an anterior translation force. Reflex latencies ranged from 110 to 220 ms (103).

Overall, anterior muscles fired first followed by the posterior muscles. Being that the shortest latency was approximately 110 ms, the authors concluded that the reflexive responses are too slow to protect the joint during a traumatic instability episode. It has been suggested that some level of underlying muscle contraction might increase the muscle spindles sensitivity to intramuscular length changes, quickening the reflexive response of the muscle (6,150).

2.6.5 Timing-dysfunction

An increased number of studies have correlated abnormalities in scapular position and motion (dyskinesis) with impingement syndrome, rotator cuff dysfunction and instability (61, 102, 104, 110, 159)

Various authors have suggested that shoulder abnormalities and abnormal scapular motions may be linked to global weakness of the scapulothoracic muscles (25, 26, 54, 132, 146)

Other authors attribute scapular dyskinesis to scapular muscular imbalance rather than absolute strength deficits (16, 17, 19, 61).

In particular,excess activation of the upper trapezius (UT)combined with decreased control of lower trapezius(LT)and serratus anterior , has been proposed as contributing to abnormal scapular motion(25, 26, 28, 29, 104, 130).

Altered muscle activity in the scapular muscles is commonly believed to be a factor contributing to shoulder impingement syndrome. However, further investigations about measure of the muscular coordination in the scapular muscles, the timing of the temporal recruitment pattern, is crucial. In one of the researches of Cools et al., 2003, muscle latency times were measured in all three parts of the trapezius muscle and in the middle deltoid muscle of 39 "overhead athletes" with shoulder impingement syndrome and compared with that of 30 overhand athletes with no impingement during a sudden downward falling movement of the arm. The results showed that there were significant differences in the relative muscle latency times between the impingement and the control group subjects. Those with impingement showed a delay in muscle activation of the middle and lower trapezius muscle. The results of this study indicate that overhand athletes with impingement symptoms show abnormal muscle recruitment timing in the trapezius muscle. The findings support the theory that impingement of the shoulder may be related to delayed onset of contraction in the middle and lower parts of the trapezius muscle (30).

3.0 Materials and methods

3.1 OBJECTIVE

To evaluate the muscle latency times of the trapezius and the posterior deltoid muscles to four different exercises.

Muscle latency times were investigated in 19 healthy shoulders with surface-EMG.

3.1.1Purpose of the research

In our study ,we examined the muscle time recruitment pattern of each part of trapezius muscle (UT,MT,LT) in comparison with the posterior deltoid (timing intermuscular differences), as well as their between relation (the intramuscular difference in timing) in four different exercises.

In our controlled laboratory research, we examined 21 subjects on a selection of four different exercises based on a protocol with the help of surface EMG (electromyography) in order to find out the latency time of each examined muscle.(2 subjects were excluded from the research)

3.2 METHODS

3.2.1 The subjects

Twenty-one healthy subjects (8 male, 13 female), volunteered students from 12 different countries, participated in our study.

Exclusion criteria were:

- Current or past history of shoulder pain,
- Shoulder instability or chronic cervicobrachial pain symptoms,
- History of cervical spine and shoulder injury or surgery,
- Participation in overhead sports in competitive level,
- Regular upper extremity strength training, for more than 5 hours per week.

Inclusion and exclusion criteria were assessed with a questionnaire.

All subjects completed a questionnaire about their history of shoulder pain and their training and athletic performance history.

The mean age of the group was 24.952 years (range 20-31year), the mean body mass was 67.76190476kg (range 53-82kg), and the mean body height was 172.5238095 cm (range 160-190 cm). The mean BMI was 0.226770952 (range 0.1868-0.26122). From the 21 subjects, 18 subjects were right-handed and 3 were left-handed. The dominant shoulder was tested in all subjects. Due to the selected criteria of our research, we excluded two of the twenty-one subjects. All volunteers signed an informed consent. The project has been approved by the Ethical Committee of the Ghent University.

3.2.2 Instrumentation

Prior to the electrode application, the skin was prepared with alcohol in order to reduce skin impedance (typically ≤ 10 kOhm) (also shaved if necessary). Bipolar surface electrodes (blue sensor – medicotest, Denmark) were placed with a 2cm inter-electrode distance over the upper, middle, lower portion of the trapezius and the posterior section of the deltoid muscle. Electrodes for the upper trapezius were placed midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of trapezius. The middle trapezius electrode was placed midway on a horizontal line between the root of the spine of the scapula and the third thoracic spine. The lower trapezius electrode was placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process. The posterior deltoid electrode was placed in the middle of the muscle belly on the midline between the tuberositas deltoideus and the posterior part of the acromion. A reference electrode was placed over the clavicle. Each set of bipolar recording electrodes from each of four muscles was connected to a Noraxon Myosystem 2000 electromyografic receiver (Noraxon USA, Inc., Scottsdale, AZ). The sampling rate was 1000Hz. All raw myo-electric signals were preamplified (overall gain=1000, common rate rejection ratio 115dB, Signal to Noise Ratio <1µV RMS baseline noise, filtered to produce a bandwidth of 10-1000Hz).

3.2.3 Testing Procedure

- Placement checking of the electrode and EMG signal

U.T: Shoulder shrug
M.T&L.T: Shoulder retraction
P.D: Isometric shoulder retroflexion

- Verification of EMG signal quality for each muscle by performing maximal isometric contractions in manual muscle test positions specific to each muscle of interest

Determination MVIC (maximum voluntary isometric contraction)

The first step of the testing was to record the resting level of electrical activity of each muscle. Verification of EMG signal quality was then completed for each muscle by having the subject performed maximal isometric contractions in manual muscle test positions specific to each muscle or muscle part of interest. (1,2)

Every subject had to follow the following steps in order to determine the MVIC (maximum voluntary isometric contraction) for each of the four muscles. The procedure was composed of three repetitions of a five second isometric contraction. A total relaxation should be succeeding during five seconds between the repetitions. The time and the rhythm were shown by the principal investigator with chrono and verbal feedback. Verbal stimulation had always been necessary.

For the upper trapezius muscle, resistance was applied to abduction of the arm (upper of the elbow joint) while the subject was in the sitting position. (3)

Schuldt and Harms-Ringdahl found this position superior to shoulder girdle elevation in activating the upper trapezius muscle.(145) The resistance application starts at the moment that the arm reaches the 90˚ of abduction and stays the same for the whole five second isometric contraction. The middle trapezius muscle was tested by applying resistance to horizontal abduction (90˚) in (maximal) external glenohumeral rotation. In this test, the subject stays in prone position. The resistance is also applied proximal to the elbow joint. The shoulder has to be fixated passively heterolateral. For lower trapezius muscle testing, the arm was placed diagonally overhead in line with the lower fibers of the trapezius muscle. Resistance was applied against further elevation of 145°(the shoulder has to be fixated passively heterolateral). Manual testing of the posterior deltoid muscle was performed in seating position with resistance applied against glenohumeral retroflection. Subjects performed three 5-second maximal voluntary isometric muscle contractions against manual resistance by the principal investigator (AMC), with a 5-second pause between muscle contractions. A metronome was used to control duration of contraction. (4, 5)

As a normalization reference, EMG data were collected during maximal voluntary contraction for each muscle. After signal filtering with a low-pass filter (single pass, Butterworth, 6-Hz low-pass filter of the sixth order) and visual inspection for artifacts, the baseline activity was subtracted from the maximal voluntary contraction signal. The peak average EMG value over a window of 50 msec was selected as a normalization value (100%).The subjects received standardized information about the purpose of the test Each subject performed a series of 4 exercises, which were randomized to avoid systematic influences of fatigue and learning effects. The exercises were selected based on literature review. (6, 7, 8, 9, 10, 11, 12, 13, 14)

The subjects were well informed by the principal investigator on the way of performing the four exercises. Each exercise was performed in three phases, a concentric, isometric, and eccentric phase, each during three seconds (sec). Metronome was a useful instrument to control the duration of phases of the exercises. Each subject performed five trials of each exercise and between there was a resting period of five seconds. The exercises had to be started from a relaxed position. There was provided to the subject a resting period of two minutes between the exercises. The investigator was giving an oral feedback, so that the subject knew when and how to begin the exercise. A verbal encouragement was also necessary; corrections had to be made by the examiner to the subject. Furthermore, the exercises are performed without resistance, before recording in the EMG for familiarization purposes. The amount of weight resistance used by subjects was determined based on the gender and body weight (Table 1).

Table 1: Weights used for each exercise depended on the gender and the weight bearing.

EXERCISE	GENDER	50 - 59 Kg	60 - 69 Kg	70 - 85 Kg
FORWARD FLEXION IN SIDE LYING POSITION	FEMALE	1,5Kg	1,5Kg	1,5Kg
HORIZONTAL ABDUCTION WITH EXTERNAL ROTATION	FEMALE	1Kg	1,5Kg	1,5Kg
PRONE EXTENSION	FEMALE	2Kg	2,5Kg	3Kg
SIDE LYING EXTERNAL ROTATION	FEMALE	2,5Kg	3Kg	3Kg
FORWARD FLEXION IN SIDE LYING POSITION	MALE	1,5Kg	2Kg	3Kg
HORIZONTAL ABDUCTION WITH EXTERNAL ROTATION	MALE	1,5Kg	2Kg	3Kg
PRONE EXTENSION	MALE	2,5Kg	3Kg	3,5Kg
SIDE LYING EXTERNAL ROTATION	MALE	2,5Kg	3Kg	3,5Kg

Exercise 1: Forward flexion in side lying position

In this exercise the subject takes a side lying position with the shoulder in a neutral position. In that position the subject performs forward flexion in a sagittal plane. The forward flexion of the arm is until 135°. The exercise has been performed by one hand.

Exercise 2: Horizontal abduction with external rotation

The subject is lying in a prone position on a suitable for the experiments table. The neutral position for this exercise is 90° of forward flexion. For this purpose, a smaller table was used to support the resistant weight that the subject should hold during all trials. The subject performs horizontal abduction to horizontal position, with an additional external rotation of the shoulder at the end of the movement. The exercise has been performed bilateral.

Exercise 3: Prone extension
The position of the subject that the experiment requires for this exercise is prone. The shoulders have to be in a resting 90˚ forward flexion position. The subject performs extension in neutral position with the shoulder in neutral rotational position. The elbow should always be stretched.

Exercise 4: Side lying external rotation
The position of the subject requires him or her to have a side- lying position in the table with the shoulder in a neutral position and the elbow flexed at 90˚.The subject performs external rotation of the shoulder. A towel is necessary to be placed between the trunk and the elbow in order to avoid compensatory movements.

3.2.4 Signal processing and data analysis

All raw EMG signals were analog/digital converted (12-bit resolution) at 1000 Hz. Signals were then digitally full-wave rectified and low-pass filtered (single pass, Butterworth, 6 Hz low-pass filter of sixth order).

The results were normalized to the maximum activity observed during the maximal voluntary trials. Moreover, the procedure of determining the value for MVIC, is to select the MVIC for each the four muscles. Then, with the choice of signal processing, we could rectify, reduce ECG and smooth the EMG signal. Marker had to be placed on the 2nd second of each repetition(3 marker in total).Thus, from the average of the three repetitions, we could take the value for MVIC for UT(Upper Trapezius),MT(Middle Trapezius),LT(Lower Trapezius)and PD(Posterior deltoid) doing the same procedure separately for each one.

Furthermore in order to determine the base activity for the UT, MT, LT and PD in the four exercises, some rectifications, normalizations and signal processing are necessary. To continue with, the marker has to be placed in the area with the least activity between trials.

Further analysis was performed with interval of 2 sec before the marker and the value of the base activity for the four muscles was found. This procedure had to be repeated four times because of the four different exercises.

The determination of the activation of the muscle activity is complicated. First of all, some calculations for each muscle are needed

For UT: base activityUT+10%MVIC UT,

For MT: Base activity MT+ 10% MVIC MT,

For LT: base activity LT+10%MVIC LT,

For PD: base activity PD + 10%MVIC PD.

Secondly, the marker has to be placed before each muscle activity at the same value for the activation of the muscle activity as been previously calculated. The position at which the marker is been placed is necessary to be written down for the second, the third and the forth trial of each 4 muscles and also for each 4 exercises for the results of our tests.

Determining the activation of the muscle activity in relation to the activation of the PD is crucial for the tests. So, the calculations between UT-PD, MT-PD, LT-PD for the 2nd, 3rd, 4th trial for each the 4 exercises were necessary.

3.2.5 Statistical analysis

Means, standard deviations, and ranges of each exercise were calculated for each subject and for all variables: the muscle latency times of the four muscle parts of interest (upper, middle and lower trapezius and posterior deltoid). In addition, relative muscle latency times were calculated for the three trapezius muscle parts in relation to that of the posterior deltoid muscle. Because all data were normally distributed with equal variances, parametric tests were used for statistical analysis.

First, a One sample T test was used to determine which mean relative latency times were significantly different than zero. This was done in order to know which muscle parts were activated significantly earlier or later than the posterior deltoid muscle. This presents the intermuscular differences in timing.

Secondly, variance analysis with repeated measures (ANOVA) was used to determine which mean relative latency times of the different trapezius muscle parts were mutually different, so representing intramuscular differences in timing. The “within-subjects” factors were the three parts of the trapezius muscle. Post hoc analysis were performed by using a Bonferroni procedure when a significant difference was found with analysis of variance (p=0,05).

All statistical analyses were performed with the Statistical Package for the Social Sciences, version 10.0 (SPSS Inc., Chicago, Illinois).

4.0 Results

For each intramuscular trapezius ratio (UT/LT, UT/MT), four exercises were selected for testing the intramuscular difference in timing between UT, MT, LT and PD. The exercises prone extension , side-lying forward flexion ,side-lying external rotation, prone horizontal abduction with external rotation were found to be the most appropriate for intramuscular trapezius muscle balance rehabilitation. As the major topic of interest of this study, were intramuscular ratios during shoulder exercises in the trapezius muscle and the posterior deltoid. For purposes of this study, we calculated the result of subtraction of the latency time of the muscle of interest minus the latency time of the posterior deltoid muscle. The general linear model one-way analysis of variance revealed significant differences among the muscles (P <0,05).

In the first exercise of the T-test**,** we can observe that UT (upper trapezius) is activated after PD (posterior deltoid) while MD (middle trapezius) and LT (lower trapezius) are activated before the PD. In the second exercise, UT, MT, LT were activated before PD. In the third exercise UT, LT were activated after the activation of the PD while MT was activated before PD. In the forth exercise, UT, MT, LT were activated before PD.

In the General Linear Model, in the prone extension (exercise 1) the UT-MT relation was statistically significant while the UT-LT and the MT-LT relation wasn't see the table 6. In the second exercise all the three relations weren't statistically significant. On the other hand, in the third exercise the analyses of the tests have shown that the UT-MT and UT-LT relations were statistically significant but in the contrary the MT-LT relation was not, see table 6. In the forth exercise there were no significant differences between the relations.

T-Tests

Table 2: exercise 1: Prone extension (retroflexion)

	Significant Difference	Mean Difference
RUT	0,779	29,28053
RMT	**0,000**	**-346,45684**
RLT	0,060	-213,63158

Table 3: exercise 2: Forward flexion in side lying position (anteflexion)

	Significant Difference	Mean Difference
AUT	0,180	-76,38632
AMT	**0,041**	**-60,98263**
ALT	0,807	-9,17526

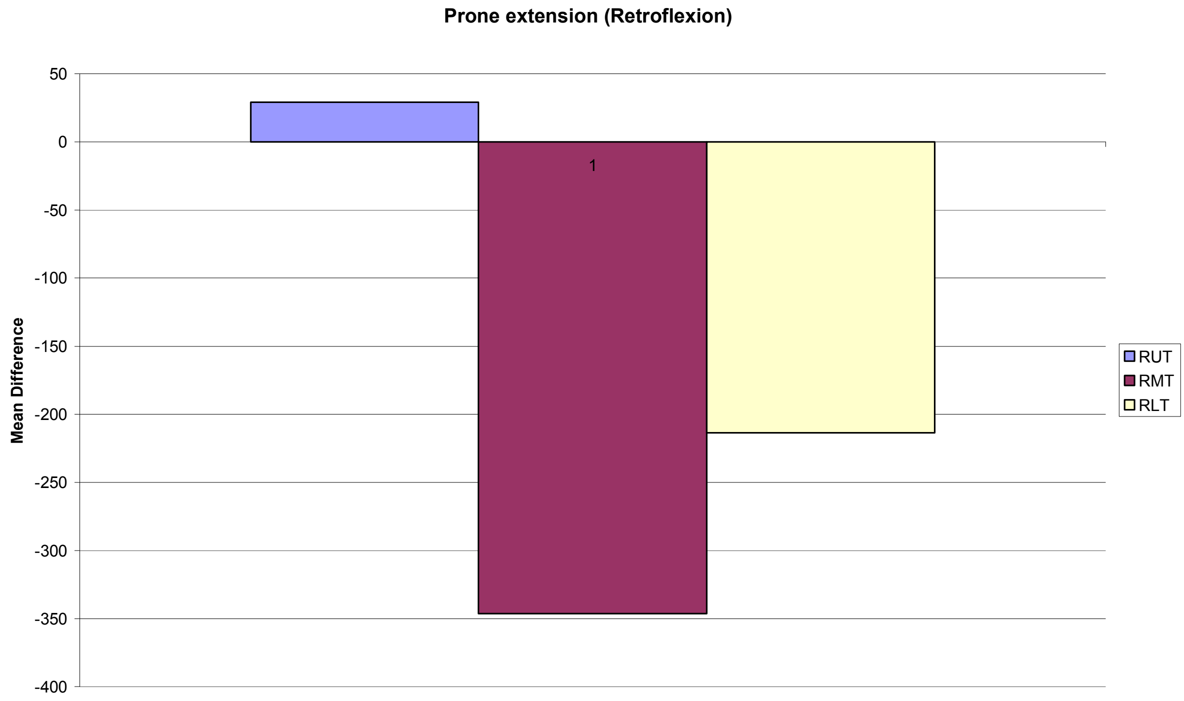
Table 4:exercise 3: Side lying external rotation

	Significant Difference	Mean Difference
EUT	**0,001**	**337,29789**
EMT	0,817	-6,35158
ELT	0,418	28,57842

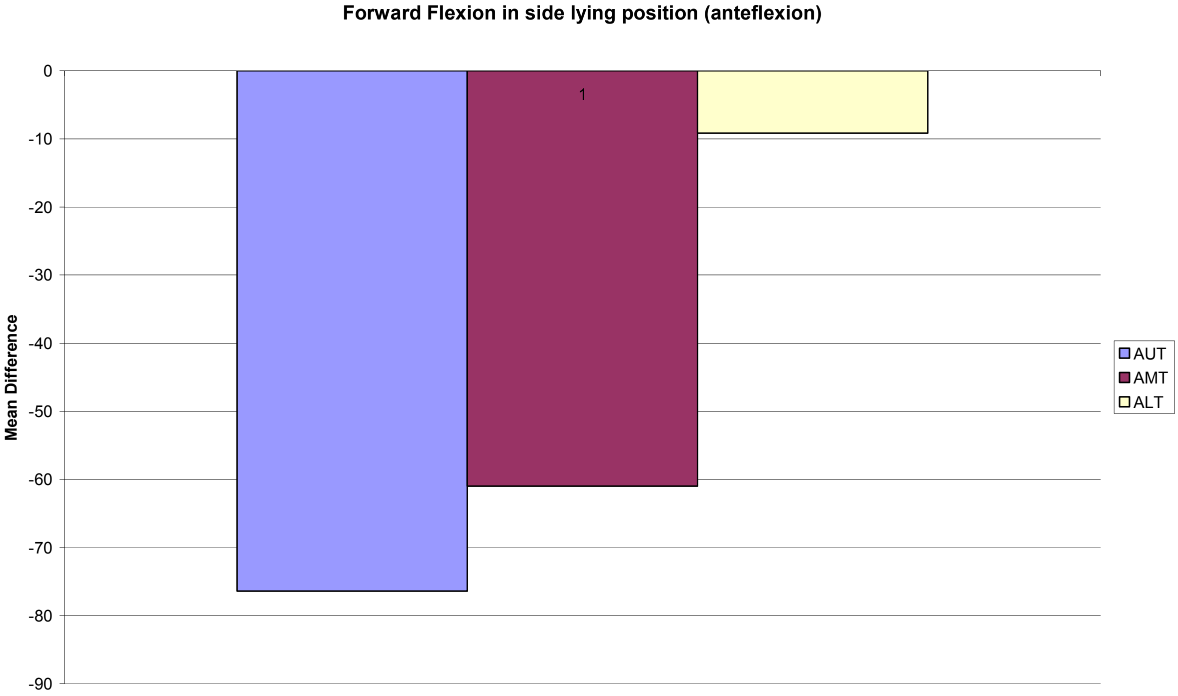
Table 5: exercise 4: Horizontal abduction with external rotation in prone position

	Significant Difference	Mean Difference
ABUT	0,172	-122,84211
ABMT	**0,000**	**-252,51000**
ABLT	0,028	-492,12263

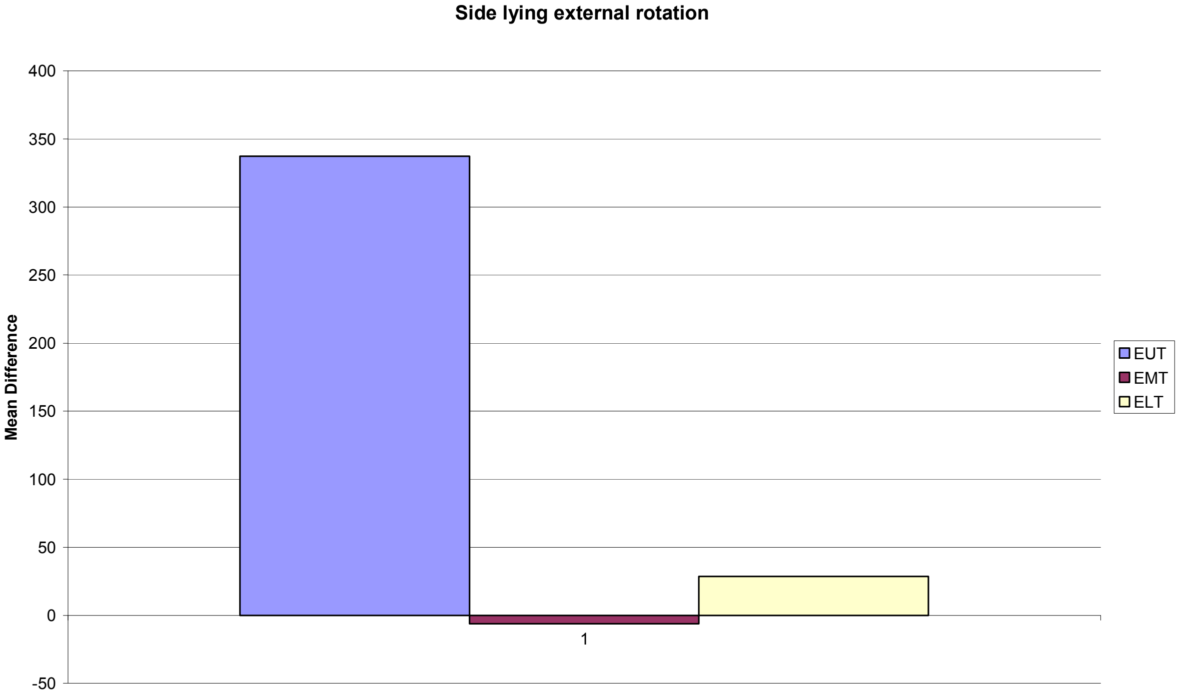
<u>Graph 1</u>: T-test 1



<u>Graph 2</u>: T-test 2



<u>Graph 3</u>: T-test 3



Graph 4: T-test 4

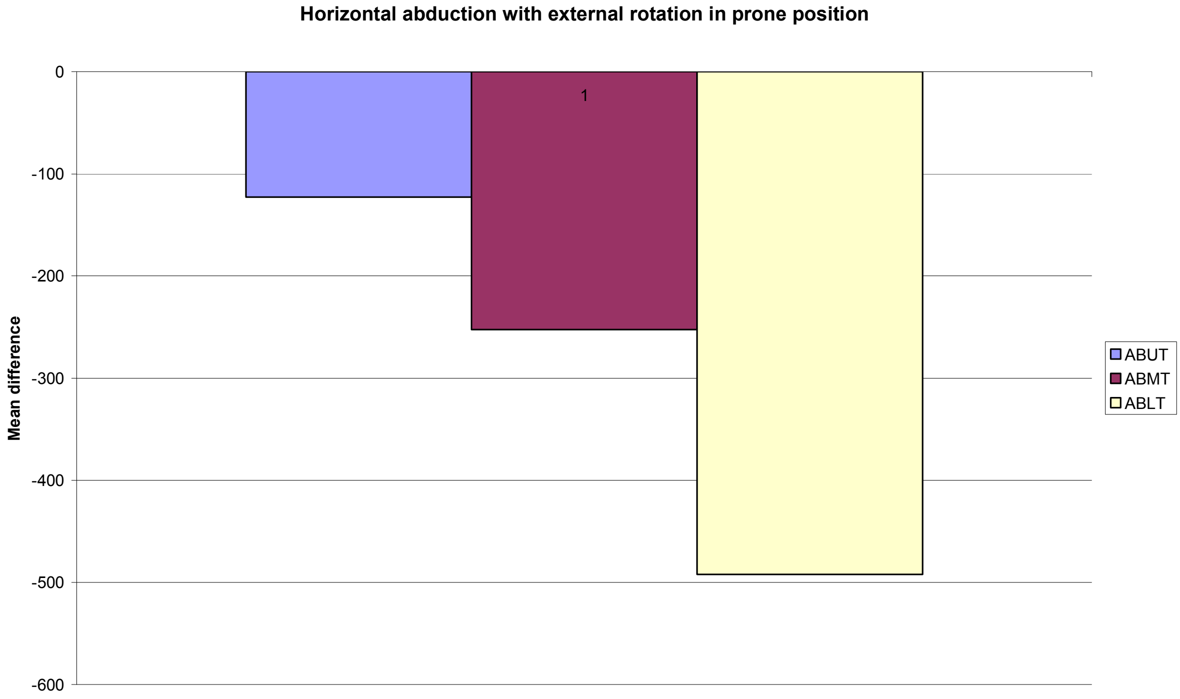
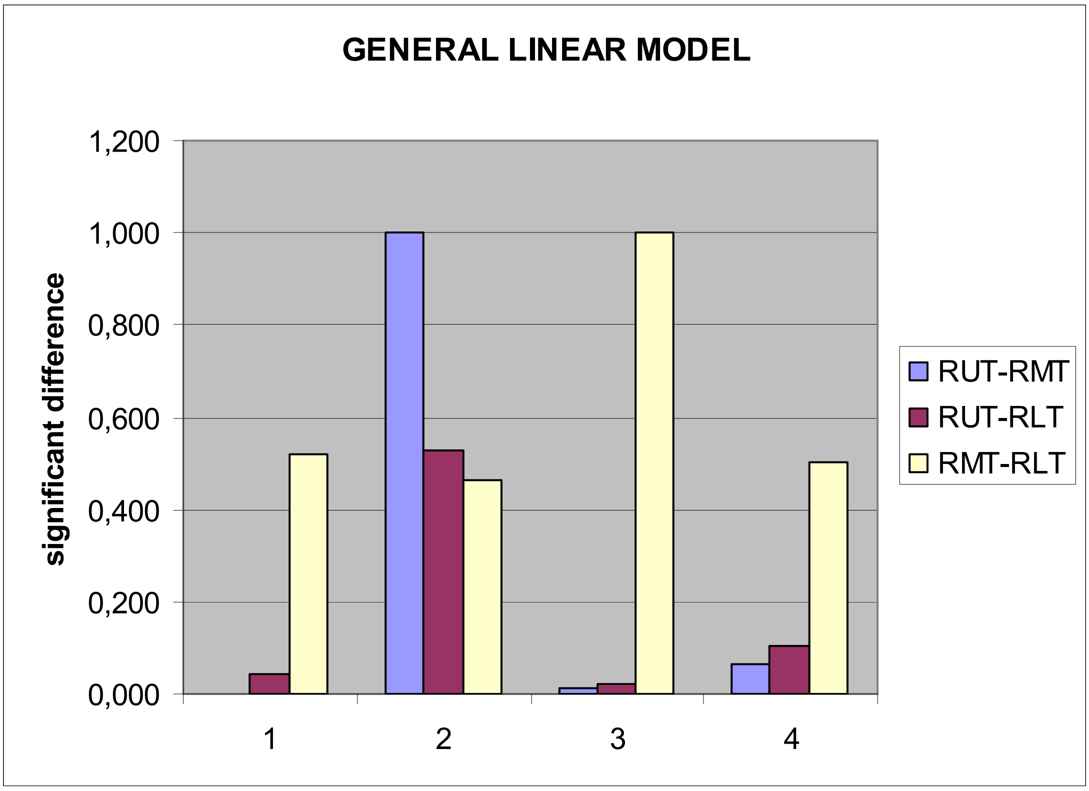


Table 6: General linear model of the four exercises

Relationship with the PD	Significant Difference			
	Exercise 1	Exercise 2	Exercise 3	Exercise 4
RUT-RMT	**0,001**	1,000	**0,011**	0,063
RUT-RLT	0,043	0,529	0,021	0,104
RMT-RLT	0,518	0,465	1,000	0,501

Graph 5: General Linear model .$RUT - RMT$ (Relation of (UT with MT) in relationship with PD , $RUT - RLT$ Relation of (UT- LT) in relationship with PD, $RMT - RLT$ relation of (MT- LT)in relationship with PD .



5.0 Discussion

What we have studied is not the result of a training program in upper, middle, lower trapezius and posterior deltoid muscles but merely an investigation. In that investigation, we examined which of these muscles are activated before or after the activation of PD, their relative timing as also the comparison of their relation. Furthermore, we examined this in four different exercises. Trapezius muscles (middle and lower) were the stabilizers muscles. Posterior deltoid is a prime mover and a glenohumeral muscle to compare scapular muscle activity with scapular muscles and since according to literature during these exercises this muscle is highly active. In our investigation, we wanted to examine if the stabilizers muscles were activated before or after activation of the posterior deltoid. Other shoulder muscles should be also compared with the Trapezius muscles (timing intermuscular differences), as well as the relative relation among them (the intramuscular difference in timing).

Exercises with optimal muscle balance ratios might be selected based on EMG analysis. We used side lying external rotation, side-lying forward flexion, prone horizontal abduction with external rotation, and prone extension exercises based on the results of another research which investigated the activation of the 3 trapezius muscle parts and the Serratus Anterior muscle. The investigation in these specific exercises was in order to promote LT and MT activity with minimal activation of the UT part. (28) Previous investigations have shown that the side-lying external rotation exercise enhances activity in the posterior deltoid (157). Ballantyne et al (12) also demonstrated high levels of EMG activity in the LT muscle when the shoulder was externally rotated ,with the patient in a prone position. Performing the exercise in a side-lying position possibly minimizes UT activity by eliminating gravity and thus minimizing the postural role of that muscle. Probably for the same reason, side-lying forward flexion gives minimal UT activity (30). In side-lying external rotation and side-lying forward flexion during the isometric phase which should revealed the lowest UT/LT ratio. This emphasizes the importance of a controlled contraction throughout the required range of motion, with a "hold" phase at maximal external rotation or 135° of forward flexion. An exercise with low (optimal) UT/MT ratio is prone extension. Moseley et al (115) found the MT to be highly activated during the prone extension movement. Ann Cool's research results confirm the accuracy of this movement for training this muscle part, with minimal UT activation (30).

In our research, we used the statistical analysis t-Test with the` ANOVA statistic analysis system. The purpose of the t-Test was to find out if the null hypothesis was either correct or false. When the null hypothesis was correct the muscles had almost the same muscle recruitment pattern. In the T-tests, when $p<0.05$ the null hypothesis was rejected and the alternative hypothesis was correct (significantly different muscle latency time). If the magnitudes of the differences are small, the contractions of the muscles compared occur almost simultaneously.

Observing the significant difference from the table 2 (prone extension) we notice that for the relation Upper Trapezius with Posterior Deltoid muscle, ($p>0.05$ so the null hypothesis is correct) the muscles contraction happens almost at the same time. The contraction of the UT is later than the contraction of the PD but that difference is not statistically important. In the same table we can see the significant difference of the MT-PD relation $p<0.05$ and conclude that our hypothesis was rejected and the examined muscles differ in timing activation. Moreover, the mean difference in this table is a negative number and this is the result of the timing priority of the second in the calculations compared muscle(MT). Thus, the Posterior Deltoid muscle (PD) is activated after the Middle Trapezius muscle. In the same exercise the Lower Trapezius is activated almost at the same time with Posterior Deltoid muscle but the PD activation is later in that trial.

In the forward flexion in side lying position (table 3) the movement starts with the contraction of the MT and after that, we have the contraction of the UT, LT and PD with the PD having the latest reaction. .In the side lying external rotation (table 4) MT and LT muscles are activated almost at the same time with PD but UT is activated later than PD.

In the last exercise (table 5) , (horizontal abduction with external rotation in prone position) UT and LT have exactly the same latency time as PD. MT is activated before PD and is the first muscle which contracts also in this exercise.

In these tests, we observed that in the second and forth exercises (table 3, 5), the UT, MT and LT were activated before PD. This fact indicates that using side lying forward flexion and horizontal abduction with external rotation, the subjects lifting the weight of the experimental protocol activates first by the stabilizers(trapezius muscle) and then the prime mover (PD).This happens owing to the facts that in these positions (side lying forward flexion and prone horizontal abduction with external rotation) there is a necessity to stabilise first the shoulder and then move the shoulder with the arm(95 formal part of literature)

In the second part of the statistical analyses(General Linear Model) we compared the relations among the UT-PD (RUT), the MT-PD (RMT) and the LT-PD (RLT).(table 6 ,graph 5) The results of this comparison have shown that only the relation RUT-RMT in the first exercise and RUT-RMT in the third exercise were statistically significant. Correspondingly, there were noticed intramuscular differences in timing in the prone extension and side lying external rotation as a result of mutually different relative latency time of the upper and middle trapezius.

In our judgement, our testing procedure may be considered a reliable method of determing the sequence of muscle recruitment. The stimulus for the onset of the muscle activity in the trials was our oral command and the visual feedback from the EMG program screen, so the subjects in our research did not fired simultaneously the muscles but under our commands and always under the directions of the protocol.

It has been suggested that correct timing of muscle activity is imperative for joint stabilisation, smooth coordinated movement and injury protection.(170) Consequently delay on the muscle onset of the lower trapezius may influence the quality of scapulohumeral rhythm, thus causing scapular instability and jeopardize the functional glenohumeral joint and its stability.(154)

Some limitations of our investigation should be noted.

1. The use of surface electromyography during dynamic movements has been a topic of discussion in literature, regarding skin displacement, movement artifacts, influences of contraction modalities on the EMG signals, and normalization methods. In general, systematic control of all interfering factors during the test is recommended to obtain reliable EMG data in a non-invasive manner. On the basis of these recommendations, our investigation was executed with maximal standardization and accuracy

2. Differences in muscle fiber type might create different functional demands on the trapezius muscle parts in various movements. Lindman et al found that the largest part of the trapezius muscle is formed with type I fibers arising from the spicous processes and interspinous ligaments of approximately T_4 through T_{12} vertebra and attaching in the region of the tubercle at the medial end of the spine of the scapula, whereas the most superior part of the trapezius (from the lateral third part of the

clavicle) has higher frequency of type II fibers. Also, anatomical difference in orientation and shape of the fibers of the lower trapezius, maintains horizontal and vertical equilibrium. (100, 101)

3. Differences in methods and determination of testing weight may account for the differences in the EMG values. Therefore, as the purpose of our study was not to evaluate muscle activity but muscle timing recruitment patterns. We should note that some of our subjects used different weight from the appropriate (the kilos that were suggested in the protocol, table 1) in the tests. This happened because a number of subjects couldn't execute the exercises with the weight of the protocol. Instead they used less, in some cases 0,5 kg or 1kg.mostly in the last exercise. This would be a good subject for initiative a research, to question if they would be an effect from a change on the preferred weight of the protocol. On the basis of our research question and our results, we believe further examinations should be performed, a new testing protocol (the same protocol with different weight) has to be developed and its reliability has to be tested.. In addition, it may be interesting to obtain data from other muscle time recruitment beyond the PD (that it was already investigated in other researches) and the trapezius.

6.0 Conclusion

We investigated the muscle recruitment patterns of the three trapezius muscle parts and the PD muscle in the four commonly used shoulder girdle rehabilitation exercises. What we examined is not the effect of Prone Extension, Forward Flexion, External Rotation, and Horizontal Abduction with external rotation on the referred muscles but only an investigation of which muscles are activated before or after and their timing relation, as also the comparison of their relation. This is the first study comparing the muscle reaction time of Trapezius activity with the reaction time of Posterior Deltoid during these exercises in healthy young people. The results do confirm that there are differences on the latency time of these 3 trapezius muscle part that we examined and revealed also differences in the relation with PD but we cannot draw any further conclusions.

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