EFFECTS OF DIFFERENT JOINT POSITIONS, ROTATOR CUFF MUSCLE FATIGUE AND EXPERIENCE ON SHOULDER PROPRIOCEPTIVE SENSE AMONG MALE VOLLEYBALL PLAYERS

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ABSTRACT

EFFECTS OF DIFFERENT JOINT POSITIONS, ROTATOR CUFF MUSCLE FATIGUE AND EXPERIENCE ON SHOULDER PROPRIOCEPTIVE SENSE AMONG MALE VOLLEYBALL PLAYERS

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The aim of this study was to evaluate the effect of different joint positions, rotator cuff muscle fatigue and experience on shoulder proprioceptive sense among male volleyball players. The participants of the study were 20 experienced (M_{age}= 20.7 ± 2.8) and 20 inexperienced (M_{age}= 17.1 ± 1.0) male volleyball players being members of first league volleyball teams. Measurements were made by Biodex System 3 pro (Biodex Medical Systems, Inc., New York, USA) and only dominant extremities were assessed. Shoulder proprioceptive sense was determined by measuring participant’s perception of joint position sense with the joint at 90° abduction, external rotation and 90° abduction, neutral rotation. Participants were tested at a speed of 2 deg/s before and after exercising on an isokinetic testing machine until fatigued. Fatigue protocol was practiced at 60 deg/s and it was terminated when the internal rotation maximal peak torque decreased by 50%. There was significant difference between proprioceptive sense of inexperienced volleyball players at 10°-20° ($p< .01$) and 15°-20° ($p< .05$) in external rotation before fatigue. The difference between before and after fatigue proprioceptive sense of experienced volleyball players at 20° ($p< .05$) was found statistically significant, whereas the significant difference was observed between before and after fatigue proprioceptive sense of inexperienced players at 10° ($p< .01$) and 15° ($p< .05$) in internal rotation. It was concluded that the effect of fatigue on proprioceptive sense is related with experience, but experience itself had no effect on proprioceptive sense.

Keywords: Proprioceptive Sense, Shoulder Joint, Fatigue, Isokinetic Measurements, Volleyball.

ÖZ

ERKEK VOLEYBOL OYUNCULARINDA DEĞİŞİK EKLEM POZİSYONLARININ, ROTATOR MANŞET YORGUNLUĞUNUN VE DENEYİMİN OMUZ PROPRİOSEPSİYON DUYUSU ÜZERİNE ETKİSİ

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Bu çalışmanın amacı erkek voleybol oyuncularında değişik eklem pozisyonlarının, rotator manşet kas grubu yorgunluğunun ve deneyiminin omuz propriosepsiyon duyusu üzerine etkisini incelemektir. Çalışmaya birinci voleybol liginde mücadele eden deneyimli (n= 20; $X_{\text{yaş}}= 20.7 \pm 2.8$) ve deneyimsiz oyuncular (n= 20; $X_{\text{yaş}}= 17.1 \pm 1.0$) katılmıştır. Ölçümler biodex isokinetic sistem 3 pro (Biodex Medical Systems, Inc., New York, USA) ile yapılmış olup sadece dominant omuz değerlendirilmiştir. Omuz propriosepsiyon duyusu eklem pozisyon hissi ölçülerek belirlenmiştir. Ölçüm, omuz eklemi 90° abduksiyon, dış rotasyon ve 90° abduksiyon, nötral rotasyonda olmak üzere iki pozisyonda gerçekleştirilmiştir. Olgular yogunluk öncesi ve sonrasında 2 derece/s hızda değerlendirilmiştir. Yorgunluk protokolü 60 derece/s hızda uygulanmış ve olgunun internal rotasyon yönünde elde edilmiş maksimum tepe tork kuvveti değeri %50 oranında azaldığında sonlandırılmıştır. Deneyimsiz oyuncularda yorgunluk öncesi dış rotasyon yönünde belirlenen propriosepsiyon duyusu 10°-20° ($p< .01$) ve 15°-20° ($p< .05$) anlamlı derecede farklıdır. Yorgunluk öncesi ve sonrası propriosepsiyon duyusu arasındaki fark internal rotasyon yönünde deneyimli oyuncularda 20° ($p< .05$), deneyimsiz oyuncularda ise 10° ($p< .01$) ve 15° ($p< .05$) anlamlı bulunmuştur. Sonuç olarak, yorgunluğun propriosepsiyon duyusu üzerine etkisi deneyim ile ilişkilidir. Ancak deneyim ile propriosepsiyon duyusu arasında bir bağlantı bulunmamaktadır.

Anahtar Kelimeler: Propriosepsiyon Duyusu, Omuz Eklemi, Yorgunluk, İzokinetik Ölçümler, Voleybol.

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I hereby declare that all information in this document has been obtained and presented in accordance with academics rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Date: 27-1-2004 Signature:

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LIST OF SYMBOLS AND ABBREVIATIONS

A-C: Acromioclavicular
S-C: Sternoclavicular
S-T: Scapulothoracic
G-H: Glenohumeral
SGL: Superior glenohumeral ligament
MGL: Middle glenohumeral ligament
IGL: Inferior glenohumeral ligament
SHR: Scapulohumeral rhythm
CNS: Central nervous system
GTO: Golgi tendon organ
ATP: Adenosine tri-phosphate
PC: Phosphocreatine
pH: Power of the hydrogen ion
Pi: Inorganic phosphate
ACh: Acetylcholine
kg: Kilogram
m: Meter
hr: Hour

BMI: Body mass index

deg/s: Degree per second

º: Degree

s: Second

ROM: Range of motion

CHAPTER I

INTRODUCTION

Volleyball consists of five basic skills as (a) serve, a skill in which players have total control during the execution of movement, (b) pass (serve reception), the act of hitting the ball to another teammate, (c) set, an overhead pass (d) spike (hit or attack), a skill that the player drives the ball into the opponent's court with great force and (e) block, a defense against the spike (Bahr, Karlsen, Lian, & ∅vrebo, 1994; Neville, 1990; Viera & Ferguson, 1989). Volleyball mostly involves repeated forceful and quick overhead arm actions with extended forearms and fingers. These overhead ballistic movements generate a great deal of eccentric load on the shoulder joint (Solgard et al, 1995; Wang, Macfarlane, & Cochrane, 2000). For example, forces at the glenohumeral joint exceed body weight of the player during throwing (Buschbacher & Braddom, 1994). Thus, the ability to elevate the hand over the head and execute many forceful functional tasks requires muscular coordination on shoulder joint (Schafle, Requa, Patton, & Garrick, 1990).

It is evident that the optimal control of muscle actions and timing requires accurate proprioceptive information (Carpenter, Blaiser, & Pellizzon, 1998; Janwantanakul, Magarey, Jones, & Dansie, 2001). Proprioceptive sense is generally defined as the ability to detect the sensation of joint motion (kinesthesia) and the position of body parts with respect to each other (position sense) (Aydın, Yıldız, Yanmış, Yıldız, & Kalyon, 2000; Safran, Borsa, Lephart, Fu, & Warner, 2001) and it varies at different points in the range of motion (ROM) (Janwantanakul et al., 2001). It has been shown that proprioceptors existing within the capsulotendonous junction and in muscle itself act through reflex arcs to supply cortical feedback on shoulder position (Myers & Lephart, 2002). They also contribute to the motor programming for neuromuscular control required for precision movements and muscle reflex. In this way, proprioceptive sense plays an important role in providing and maintaining the dynamic stability of shoulder joint as well as muscular coordination especially in volleyball (Hammer, 1999; Myers & Lephart, 2002).

Muscle fatigue is considered to have negative effects on muscle proprioceptive sense (Carpenter et al., 1998; Pedersen, Lönn, Hellström, Djupsjöbacka, & Johansson, 1999). It may be defined as the decline in maximal force generating capacity (Fitts, 1996; Fitts & Balog, 1996; Foss & Keteyian, 1998; Jensen, Laursen, & Sjogaard, 2000; Pincivero, Gear, & Sterner, 2001) and results from following factors; (a) accumulation of lactic acid (Foss & Keteyian, 1998; Frontera, Dawson, & Slovik, 1999), (b) depletion of muscle glycogen stores (Foss & Keteyian, 1998), (c) depletion of ATP and PC stores (Fitts, 1994; Foss & Keteyian, 1998; Garcia, Serratos, Morgan, Perreault, & Rozycka, 1991) and (d) lack of oxygen through inadequate blood flow (Bompa, 1990; Foss & Keteyian, 1998). It has also been shown that receptors were affected negatively by increased intramuscular concentrations of metabolites and inflammatory substances released during muscle contractions (Pedersen et al., 1999). There are few studies (Carpenter et al., 1998; Voight, Hardin, Blackburn, Tippett, & Canner, 1996) showing the decrease in proprioceptive sense and performance with muscle fatigue. Thus, it is not exactly known whether muscle fatigue affects shoulder joint proprioceptive sense and what kind of effects it has on upper extremity performance.

Rotator cuff muscles are prime rotator muscles of the shoulder joint. They consist of the supraspinatus, the infraspinatus and the teres minor that rotate the shoulder outwards (external rotation) and the subscapularis one of the muscles which rotate the shoulder inwards (internal rotation) (Ihashi, Matsushita, Yagi, & Handa, 1998; Nordin, Frankel, & Forssen, 1989; Prentice, 1999). Besides, rotator cuff muscles are one of the sources of proprioceptive signals in the shoulder joint and play a significant role in shoulder joint stability. Shoulder joint stability is accomplished by compression of the humeral head into the glenoid cavity by the rotator cuff muscles or by the tendons of the muscles which also provide an additional mechanical block to excessive translation (Carpenter et al., 1998). Players place their arms in an extremely stressful position when they are executing maximal effort on spiking and serving. The infraspinatus and the teres minor muscles act eccentrically to control the movement of the humerus and provide a stabilizing posterior restraint to anterior subluxation in the acceleration phase while the player is spiking and performing a serve (Wang & Cochrane, 2001). Proprioceptive deficit caused by fatigue in this muscle group may lead to failure of rotator cuff muscles to prevent excessive movement of the shoulder complex, resulting in functional instability and this may cause a decrease in performance (Janwantanakul et al., 2001; Lephart, Pincivero, Giraldo, & Fu, 1997; Wülker, Mansat, & Fu, 2001).

Perceptual learning appears to have a positive effect on proprioceptive sense (Janwantanakul et al., 2001). It refers to the improvement of sensory discriminative capacity and improves dramatically with practice (Ahissar & Hoschstein, 1993; Gold, Bennett, & Sekuler, 1999; Janwantanakul et al., 2001). One may assume that experienced players, being the members of a 1st league team, with extensive competitive and training experience have more advantages than those of inexperienced players, being the members of youth team, in proprioceptive sense.

Although proprioceptive sense is likely to play an important role in muscle coordination and timing, it has not been widely studied in the shoulder joint (Carpenter et al., 1998). There is a lack of evidence regarding the effect of different positions on shoulder position sense in the literature (Janwantanakul et al., 2001). Proprioceptive sense measurements were generally made at positions where the contribution of capsuloligamentous structures was excessive (Jantanakul et al., 2001; Lee, Liau, Cheng, Tan, & Shih, 2003; Pedersen et al., 1999; Safran et al., 2001). It is believed that muscle fatigue has negative effects on muscle proprioceptive sense. However, the effect of shoulder muscle fatigue on shoulder joint is still unclear (Lee et al., 2003). Studies (Carpenter et al., 1998; Lee et al., 2003; Pedersen et al., 1999; Voight et al., 1996) investigating the effect of fatigue on shoulder proprioceptive sense revealed contradictory results. They have mostly evaluated the effect of fatigue on proprioceptive sense in sedentary participants and there are few studies (Safran et al., 2001) on trained athletes. Besides, the relationship between experience and proprioceptive sense is not well documented. Effect of different factors on shoulder joint proprioceptive sense among volleyball players was open for investigation. A better understanding of the shoulder joint proprioceptive sense will help scientists to reach a common conclusion and give information on how performance and shoulder joint stability can be increased. Furthermore, proprioceptive exercise patterns in training programs can be addressed to coaches and volleyball players.

1.1. Aim of the Study

The aim of this study was to evaluate the effect of different joint positions, rotator cuff muscle fatigue and experience on shoulder proprioceptive sense among male volleyball players.

1.2. Hypotheses

1. There will be an increase in proprioceptive sense as the shoulder movement angle increases.
2. There will be a negative relationship between rotator cuff muscle fatigue and shoulder proprioceptive sense.
3. The effect of muscle fatigue on proprioceptive sense will be excessive among inexperienced than that of experienced volleyball players.

1.3. Limitation of the Study

1. The current study included only male volleyball players.
2. Only dominant extremities were assessed.
3. Measurements were made in laboratory conditions.

CHAPTER II

REVIEW OF LITERATURE

2.1. Volleyball

Volleyball is one of the most popular sports. Two teams, each having six players on a court divided into two equal parts by a net, play the game. Standard court dimensions are 9 m x 18 m and the net height is 2.24 m for female players and 2.43 m for male players (Fröhner, 1998; Viera & Ferguson, 1989). There are six players on each side and players who place in the front row are called forwards and players who place in the back row are called backs. The three players in the front are called left forward (LF), centre forward (CF) and right forward (RF). The three players in the back row are called left back (LB), centre back (CB) and right back (RB). Players need to be in their correct rotational positions until the serve is executed. That is, players cannot overlap positions from front to back or from side to side. After the serve, players are allowed to play in any position on or off court, with one restriction: back row players cannot move to the front to hit the ball while the team is at the attack line. A side out occurs when a team that is not serving wins the rally. When a team earns a side out, they rotate clockwise position. Thus, each player must master the intricacies of every one of the positions. This interesting aspect of volleyball differentiates it from other team sports. Players are finding it increasingly difficult to learn the in-depth characteristics of all six positions, as volleyball becomes more competitive. Specialisation of players is therefore commonly observed. When players specialise, they switch to the same area of court (left, centre or right) as soon as the serve is executed. These positions are referred to as their playing positions (Viera & Ferguson, 1989).

Volleyball is usually considered to consist of five basic skills as (a) serve, (b) pass (serve reception), (c) set, (d) spike (hit or attack) and (e) block (Bahr et al., 1994; Neville, 1990; Viera & Ferguson, 1989). Each skill has its own unique movement.

The Serve. The serve begins the game. It is the only skill in volleyball in which players have total control during the execution of the movement (Neville, 1990; Viera & Ferguson, 1989). Accurate placement, unpredictable movement and high velocity of the ball are crucial elements for an effective serve (Scates, 1976). Successful serves can force opponents into a difficult attack position, reducing their attack options and enabling the serving team to react more efficiently in setting up the defense (Neville, 1990). It is also important because a server can score a point by serving the ball in such a way that the opponent is unable to return it. Although there are many kinds of serves, the underhand and the overhand serves are generally executed during matches (Fröhner, 1998; Neville, 1990; Viera & Ferguson, 1989). The underhand serve is the easiest one to perform and usually easy for opponent to receive. The overhead serve may be executed with spin and without spin (Neville, 1990). The overhead serve with spin is similar to the spike (Fröhner, 1998), whereas the overhead serve without spin is defined floating ball (Neville, 1990).

The Pass. The pass simply refers to the act of hiting the ball to another temmate (Scates, 1976). There are two kinds of passing; the forearm pass and the overhead pass. The forearm pass is the first basic volleyball skill the player must learn and it is usually the first skill team, which does not serve, must execute. The ball contacted on the forearms and is passed to a designated target (Neville, 1990). The forepass is used to receive serves, receive spikes, play any ball at waist height or lower and any ball that has gone into the net. Making the transition from defense to offense, a good forearm pass is essential. The overhead pass is generally team's second contact of the ball in the three-step offensive effort. It is used to move the ball to a teammate and, rarely, to return the ball to the opponent (Viera & Ferguson, 1989). However, if the overhead pass is executed by the setter in order to deliver the ball to the attacker, it is called the set (Neville, 1990).

The Set. The set is an overhead pass that the player executes to place the ball in a position for the attack (Scates, 1976; Viera & Ferguson, 1989). The set is performed with open hands and with direction, height and speed controlled by the fingers and thumbs (Schafle et al., 1990). It determines where and how well attack develops. Generally, one or two players are designated to perform setting duties. Because a well-placed set enhances the attacking team's ability to gain an advantage over the opponent, it is extremely important that these players have outstanding ability in setting ball efficiently (Viera & Ferguson, 1989). Thus, the setter should have superior reaction, mobility and anticipation to move quickly after the pass (Scates, 1976).

The Spike. The spike is the predominat skill used in a team's attack. The aim of this skill is that the player drives the ball into the opponent's court with a great force (Neville, 1990; Scates, 1976; Viera & Ferguson). It is performed with the player at maximum vertical leap, moving the ball quickly downward by flexing the torso, rotating the shoulder and arm downward. The player snaps quickly the wrist at final contact for direction and speed (Schafle et al., 1990). This skill requires coordinating the jump and arm swing in order to contact the moving ball properly (Scates, 1976). Nowadays, players with high-level skills average leap 1 m height approximately 150 times per match and hit the ball enough to create velocities of 80 mph (Schafle et al., 1990).

The Block. The block is the first line of defense against attack and it is needed only when an opposing player can hit the ball harder than the other team's players can control in the back row. It involves one to three players leaping slightly later than the hitter so that they are positioned at the time of contact to block the ball's passage into their court. The hands are held up with the fingers spread and the arms extended and pushing forward and down on the ball to direct it back into the opponent's court (Neville, 1990; Scates, 1976). It is the most diffucult volleyball skill to teach and learn and success is limited by several factors including a blocker player's height, jumping ability and decision-making process. Blocking movements are also very precise. It requires discipline and compact control, so it is the least developed skill inexperienced players. In contrast, at higher levels of players, where the attack comes with frequency and force, blocking becomes extremely important (Neville, 1990).

In volleyball, the primary objective of each team is to try to hit the ball to the opponent's side in such a manner as to prevent the opponent from returning the ball. The ball may be played a maximum of three times on each team before it must be played into the opponents' court. This is usually accomplished using a three-hit combination of a forearm pass to a setter, followed by a set to an attacker, who spikes the ball into the opponent's court (Fröhner, 1989; Viera & Ferguson, 1989). Seen from the outside, specific game phases (passing serve, setting, attacking or blocking) occur repeatedly at regular intervals. Players must identify a particular game condition and the various possibilities for action quickly during the match. So, the major characteristic of volleyball is the integration of a quick succession of different and rapidly changing game situations. This requires high quality of decision-making processes (Fröhner, 1989). An important performance measure indicating the speed and effectiveness of decision-making is reaction time. The number of stimulus-response alternatives, amount of practice and amount of anticipation may affect this measure. It has been shown that as the number of possible alternative movement increase, the time required responding to any of them gradually increases. This slows down the speed of decision-making process. On the other hand, as the amount of practice and the amount of anticipation increases the effectiveness of decision-making improves (Schmidt, 1991). If players can recall the appropriate responses from memory, they can plan their motor skill response from the different possibilities available and select the most appropriate one (Fröhner, 1998; Schmidt, 1991). Moreover, players predict what is going to happen, when it will occur and then perform various information-processing activities in advance. This process is very important to organize the movement and react quickly in unanticipated events (Schmidt, 1991). The effectiveness of the decision-making process also depends on the ability of checking information received through the sensory organs during motor performance. The comparison between required or intended versus actual results during and following motor activity determine the accuracy of the performance. The fact that the player can transfer what they have practiced mentally into actual motor performance again and again results in that skill will be stored in memory for future decision-making (Fröhner, 1998). It is thought that this process causes preceptual learning. Perceptual learning can be defined as improvement of sensory discriminative capacity (Ahissar & Hoschstein, 1993; Gold et al., 1999; Janwantanakul et al., 2001) and it improves with practice (Janwantanakul et al., 2001). But, this improved performance has been found to be specific to the practiced directions and does not transfer to new motion directions (Ahissar & Hoschstein, 1993; Gold et al., 1999). It is believed that experienced players with extensive competitive and training experience have more advantages than those inexperienced players have in decision-making.

2.2. Shoulder Region

Both clinicans and investigators agree that the the function of human shoulder is complex as well as its anatomy which allows the arm to move in a number of directions to position the hand for both daily and sporting activities. However, it is an undeniable fact that because of the high degree of mobility, the shoulder is a very unstable joint. This may lead to decrease in performance, so it is vital to provide both static and dynamic stability to enhance sports performance during excessive movements. The overhead athletes, such as the thrower athlete, the racquet sport athlete, the volleyball or the basketball player must deal with lots of factors during sporting activity. During overhead movements, the athlete places tremendous stress on the shoulder and elbow complex (Buschbacher & Braddom, 1994). Thus, the ability to elevate the hand over the head and execute many functional tasks requires great flexibility while maintaning integrity for the multiple joints operative during normal function. This movement organization is necessary to produce both gross and fine movements. The following section will discuss the anotomy and biomechanics of the shoulder region.

2.2.1. Anotomy of the Shoulder Joint

Musculature. Today, there are several classifications of the shoulder joint muscles. Most of these classifications are made considering the muscles' origo and insertion. Nordin, Frankel and Forssen (1989) and Soderberg (1997) classified the musculature as scapulohumeral, claviculohumeral, scapuloradial, scapuloulnar, thoracohumeral, thoracoscapular and thoracoclavicular. In another classification made according to biogenetical structure, shoulder musculature is divided into three groups as brachial muscles, thoracal muscles and cranial muscles. Richardson and Iglarsh (1994) formed another categorization related to the origin and insertion of tendons; scapulohumeral, axioscapular and axiohumeral scapuloradial.

Although seventeen muscles are involved in shoulder motion, the major muscles of the shoulder complex are the trapezius, the serratus anterior, the pectoralis major, the deltoid and the rotator cuff muscles.

Of these muscles, the trapezius, composed of upper, middle and lower parts, plays a primary role in supporting the upper limb upon the axial skeleton (Arıncı & Elhan, 1993; Sobotta, 1989). The middle and the upper trapezius take part in abduction movements in the frontal plane and the lower part depresses the scapula

(Sobotta, 1989). The other important function of this muscle is to cause and maintain upward rotation of the scapula on the thorax (Soderberg, 1997).

The serratus anterior muscle is responsible for the motion of the scapula on the thorax. Its primary function is the anterior gliding of the scapula on the wall of the thorax (the motion of protraction). So, it is called the boxer's muscle. Another important function of the serratus anterior muscle is to assist the elevation of the scapula and enable the arm to be elevated over the head with the trapezius upper and lower fibers (Soderberg, 1997).

The pectoralis major muscle is important for powerful movements of the arm across the trunk (Soderberg, 1997). It is a strong adductor and internal rotator (Hutson, 1990) and assists the anteversion of the arm (Wülker et al., 2001). In addition to these functions, the pectoralis major is active throughout elevation of shoulder in frontal and saggital plane (Nordin et al., 1989).

The deltoid muscle is composed of three parts; the pars spinalis, the pars clavicularis and the pars acromialis (Wülker et al., 2001). Each part of the muscle has different functions according to the position of the arm. However, as a whole, the deltoid can be described as an essential mover of the glenohumeral joint by taking important roles in abduction, flexion and extension (Halder, Halder et al., 2001). The spinal part supports external rotation and extension. The clavicular part is involved in internal rotation and anteversion. The acromial part with the supraspinatus muscle causes abduction in the shoulder joint (Wülker et al., 2001). However, the line of action of the acromial deltoid fibers is parellel to the long axis of the humerus. Thus, when the arm is at the side, contraction of the fibers of the acroimal part does not produce the motion of elevation. At this stage, oblique rotator cuff muscles are involved in motion and they help the deltoid elevate the arm out to side providing a fixed fulcrum (Nordin et al., 1989).

The rotator cuff is composed of four muscles, each of which has different functions; the supraspinatus, the infraspinatus, the teres minor and the subscapularis (Ihashi et al., 1998; Prentice, 1999). In spite of relatively small individual muscle masses and their own responsibility, the collective functions of the rotator cuff musculature play a very important role in normal motion. It has been demonstrated that the rotator cuff, as a whole, has two principle funtions; (a) generation of torque necessary for rotation of the humerus on the glenoid concavity and (b) compression of the humeral head into glenoid concavity. In other words, the rotator cuff retains the humeral head in the glenoid concavity and maintains the instant center of rotation in a fixed position while the deltoid abducts the shoulder (Parsons, Apreleva, Fu, & Woo, 2002). The rotator cuff also can directly affect amount of the loads on the glenohumeral joint as a result of its distribution (Reider, 1996). When individual tendons of the rotator cuff were followed, it was observed that they are intersect and blend with fibers from adjacent tendons rather than inserting as individual tendons. Clark, Harryman and Washington (1992) made several important observations on the structure of the rotator cuff tendons insertions. They have found by gross examination that the tendons of the rotator cuff fuse into one continuous band at or near their insertions into tuberositas of the humerus. The scapularis and supraspinatus tendons fuse to form a sheath to surround the biceps tendon. The tendon of the supraspinatus forms the roof of this sheath. On the other hand, fibers from both tendons join together and form the floor of the sheath. This region is additionaly reinforced by the coracohumeral ligament. With this arrengement of blended fibers, loads from contraction of one muscle are not isolated to only one muscle's attachment to the humerus but affect the attachment of neighboring tendons. This interconnected arrangement may have importance in the pathogenesis of rotator cuff tears. Figure 2.2.1.1 represents the rotator cuff muscles (Hammer, 1999).

The teres minor and the infraspinatus muscles are not mainly responsible for any arm movement. But, they are involved in many shoulder joint movements. The lower part of the infraspinatus contributes to adduction, whereas, the cranial part of it can support the abduction when the arm is already placed in abducted position (Wülker et al., 2001). The teres minor is involved in shoulder abduction and flexion (Nordin et al., 1989). Besides, it showed that the teres minor and the infraspinatus make conrtibution to external rotation.

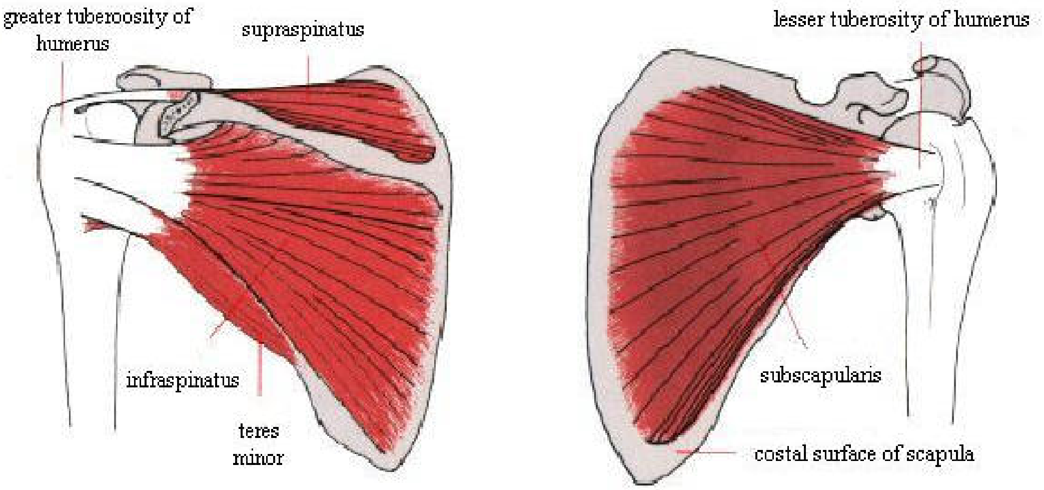

Figure 2.2.1.1 The Rotator Cuff Muscles

The subscapularis is a strong internal rotator. Its upper fibers support abduction when the arm is already abducted. On the other hand, the subscapularis plays a part in adduction of the elevated arm (Sobotta, 1989; Wülker et al., 2001). It has been shown that the subscapularis contributes to 53% of the rotator cuff movement. This may make the subscapularis one of the most important muscles in humeral head stabilization (Brotzman, 1999).

The supraspinatus has abduction and stabilization effects on the shoulder joint (Ihashi et al., 1998; Wülker et al., 2001). Moreover, the study carried out by Ihashi, Matsushita, Yagi and Handa (1998) on rotational action of the supraspinatus muscle on the shoulder joint has shown that the supraspinatus plays a role in both internal and external rotational movement according to the shoulder joint position. They indicated that when the humerus is relatively in internal rotation, stimulation of the supraspinatus results in the more internal rotation. On the other hand, stimulation of the supraspinatus when the humerus is external rotated or at neutral position, causes external rotation. According to Ihashi et al. (1998) the function of the supraspinatus also depends on the abduction angle level of shoulder. The stimulation of supraspinatus in smaller abduction angle causes internal rotation whereas an increase in abduction results in external rotation. Howell, Imobersteg, Seger and Marone (1986) researched the torque output of the shoulder in the functional planes of forward flexion and elevation in the plane of the scapula when the suprascapular and axillary nerves were sequentially paralysed. Howell et al. (1986) have found that the supraspinatus with the infraspinatus are responsible for producing torque for the shoulder joint in both planes as well as the deltoid. In another study (Nordin et al., 1989), the strength of various shoulder motions was investigated in different positions before and after administration of suprascapular nerve blocks. Suprascapular nerve block, out of the active contribution of the supraspinatus and infraspinatus muscle, reduced the force of elevation in the scapular plane by 35% at 0° of elevation and by 60% at 60°. Above 60° the loss of force became less; only a 30% reduction was observed at 150°. Furthermore, the force at external rotation was reduced by 50%.

Capsule. The glenohumeral (G-H) joint capsule arises in the anterior, posterior and inferior directions around the anatomic neck of the humerus. It inserts the glenoid labrum in circumferential fashion (Reider, 1996). Although the capsular redundancy demonstrates great individual variation, its weakest part is the inferior part (Reider, 1996; Wülker et al., 2001). The capsule is thin and loose, so it allows a wide range of movement (William, Doukas, & Speer, 2001; Wülker et al., 2001). Since the capsule is not enough to provide stability, ligaments, tendons and muscles reinforce it (Bigliani, Kelkar, Flatow, Pollock & Mow, 1996; Buschbacher & Braddom, 1994; Tsai et al., 1991; Wülker et al., 2001). The rotator cuff muscles mainly reinforce the capsule (Cain, Mutschler, Fu, & Lee, 1987; Halder, Halder et al., 2001; Halder, Zhao, O'Driscoll, Morrey & An, 2001; Soderberg, 1997). The deltoid, the triceps, the pectoralis major, the teres major and the long head of the biceps play an important role in reinforcing the capsule of the shoulder joint (Soderberg, 1997; Wülker et al., 2001). Likewise, ligaments achieve strengthening of the capsule and each of these ligaments contributes to stabilize the G-H joint in various directions and proportions (Bigliani et al., 1996; Ferrari 1990; O'Brien et al., 1990; Richardson & Iglarsh, 1994; Soderberg, 1997). These are the superior glenohumeral ligament (SGL), the middle glenohumeral ligament (MGL), the inferior glenohumeral ligament (IGL), the coracoacromial ligament and the coracohumeral ligament. The stability effects of the ligaments will be discussed in the next section.

Joints. There are four different joints in the shoulder region, each of which contributes to arm movement: the acromioclvicular (A-C) joint, the sternoclavicular (S-C) joint, the scapulothoracic (S-T) joint and the G-H joint (Buschbacher & Braddom, 1994; Kulund, 1988; Norris, 1993).

The A-C joint is a synovial articulation formed between the lateral end of the clavicula and medial margin of the acromion of the scapula. An articular disc is located between the two articular surfaces. It is surronded by a fibrous capsule, but the A-C joint capsule is fairly loose and reinforced by the tendons of the deltoid, the trapezius muscles and also the superior and inferior A-C ligaments (Andrews, Harrelson, & Wilk, 1999; Prentice, 1999; Sodenberg, 1997; Wülker et al., 2001). The ligamentous support of the A-C joint is relatively lax and weak, so the acromion and clavicula can glide and slide on one another in the anterior-posterior and superior-inferior directions. The stability of the joint depends mostly on the coracohumeral ligament than the A-C ligaments (Andrews et al., 1999; Hutson, 1990). The coracohumeral ligament is composed of two parts as the trapezoid part and the conoid part. The trapezoid ligament prevents overriding of the clavicula on the acromion. The conoid ligament limits upward movement of clavicula on the acromion (Prentice, 1999; Wülker et al., 2001). Together with the sternoclavicular joint, the A-C joint permits transverse rotation movement between the scapula and clavicula. This rotation is required to allow the scapula its 60° to 70° rotation on the chest wall during a full range of arm movement (Hutson, 1990). Posterior rotation of the clavicula on its long axis is observed as the arm moves in an elevated position. This rotation allows the scapula to continue rotating and it also allows full elevation. During elevation, the clavicula must rotate approximately 50° for full elevation to occur; otherwise elevation would be limited to approximately 110° (Prentice, 1999). In the literature, different ranges of clavicular rotation were also stated; 20°-40° by Norris (1993) and 40° by Nordin et al. (1989). According to Richardson and Iglars (1994) and Wülker, Mansat and Fu (2001) the total of rotation of the clavicula occurs in a range of 30° around its long axis and this rotation occurs after the shoulder has been elevated 90°.

The S-C joint is formed between the medial end of the clavicula and sternum. It is the only direct bone-to-bone attachment of the upper limb to trunk (Andrews et al., 1999; Prentice, 1999; Richardson & Iglarsh, 1994). The S-C joint lies outside the region of the shoulder but it makes an important contrubution to movements of the shoulder girdle. If the S-C joint is injured, limitation will take place in shoulder movements (Norris, 1993). The joint is strengthened by a capsule and four ligaments; the anterior and posterior S-C ligaments, the interclavicular ligaments and the costaclavicular ligaments (Richardson & Iglarsh, 1994). Because the S-C joint does not have inherent mechanical stability, the joint stability depends on these ligaments. Of these structures, the main stabilizing ligaments are the costaclavicular ligaments (Andrews et al., 1999; Hutson, 1990). The sternocleidomastoid, the sternohyoid and the sternothyroid muscles form additional stabilizing forces. The S-C joint is divided into medial and lateral compartment by an intra-articular meniscus. This meniscus, as well as shock absorber (Andrews et al., 1999; Prentice, 1999), acts as a stabilizing ligament. It prevents the medial end of clavicula from moving upwards and medially against sternum when pushing actions are performed (Andrews et al., 1999; Hutson, 1990). Functionally, the sternoclavicular joint operates as a ball and socket mechanism and it allows movements of the clavicula in the horizontal and frontal planes (Soderberg, 1997). Three types of movements take place in the joint; elevation-depression, primarly between the disc and the clavicula, protraction-retraction, primarily between the disc and the sternum and axial rotation (Buschbacher & Braddom, 1994; Nordin et al., 1989; Soderberg, 1997). Motions in the sternoclavicular joint occur mostly during the first 90° of elevation (Wülker et al., 2001). Moreover, there have been various opinions about the range of sternoclavicular joint motions. It is noted that there are 4° of calavicular elevation for each 10° of arm elevation throughout the first 90° (Hammer, 1999; Nordin et al., 1989; Wülker et al., 2001) and beyond 90° clavicular motion in this joint is almost negligible (Nordin et al., 1989). Norris (1993) noted that a total of about 60° elevation-depression and a total range of about 35° protraction-retraction of clavicula were avaliable.

It should be stated that, motions in the sternoclavicular joint are reciprocal with motions in the acromioclavicular joint during clavicular protraction-retraction and elevation-depression. This is a very important motion to prevent the clavicula from dislocating. However, the rotation of clavicula takes place in the same direction at both ends (Nordin et al., 1989; Norris, 1993).

The S-T joint is a bone-muscle-bone articulation formed by the ventral surface of the scapula and the thoracic wall (Andrews et al., 1999; Nordin et al., 1989; Prentice, 1999). Due to the fact that it lacks the general joint characteristics, it cannot be considered as a true anotomic joint (Richardson & Iglarsh, 1994; Prentice, 1999). However, the movement of the scapula on the wall of the thoracic cage is critical for shoulder joint function. The primary force holding the scapula on the thorax is atmospheric pressure (Andrews et al., 1999). Besides, contractions of scapular muscles are essential in stabilizing the scapula as well as its motion (Prentice, 1999). In the S-T joint, six motions are defined; elevation-depression, abduction-adduction and upward-downward rotation. The motions of the S-C joint are interrelated with the motions of the A-C joint and the S-T joint (Nordin et al., 1989; Richardson & Iglarsh, 1994). The combined motion in the S-C joint and in the A-C joint are equal to the displacement of the scapula on the thorax (Wülker et al., 2001). Investigators state that the 60° of scapular motion at the S-T joint is possible only when 20° motion in the acromioclavicular joint and 40° motion in the sternoclavicular joint occurs. Furthermore, clavicular rotation of about 40° is essential for the motion at the S-T and the G-H joints. Scapular rotation occurs in harmony with G-H joint motion (Buschbacher & Braddom, 1994; Nordin et al., 1989). The relationship between the S-T and the G-H joints will be discussed in the next section.

The G-H joint is a ball-and-socket synovial joint formed by the round head of the humerus and shallow glenoid fossa of the scapula (Kelkar et al., 2001; Veeger, Helm, Woude, Pronk, & Rozendal, 1991). Articular surfaces are deepened by the glenoid labrum, which is a fibrocartilaginous rim of about 4mm deep surronding, the fossa (Andrews et al., 1999). Since the head of the humerus is really larger than the glenoid fossa (the glenoid fossa is only one third of the size of the humeral head) and the glenoid fossa is shallow (Nordin et al., 1989; Richardson & Iglarsh, 1994; Wülker et al., 2001), only from 25 to 30 percent of the humeral head is in contact with the glenoid at any point during elevation (Prentice, 1999). A loose capsule surrounds the G-H joint. Its volume is twice as large as the humeral head (Richardson & Iglarsh, 1994). These characteristics allow the G-H joint a significant freedom of movements. These movements are flexion-extension, abduction-adduction, internal-external rotation and horizontal flexion-extension. In addition to these, there is circumduction movement, which is the combination of flexion, external rotation, abduction, extension, adduction and internal rotation (Nordin et al., 1989; Richardson & Iglarsh, 1994). Stability of the joint is provided by dynamic and static structures (Nordin et al., 1989; Prentice, 1999; Howell & Galiant, 1989). Shoulder joint stability will be discussed in the folowing section.

2.2.2. Biomechanics of the Shoulder Joint

The shoulder joint is the first link in a mechanical chain of levers that extends from the shoulder to the fingers. It is obvious that the shoulder joint is the most intricate joint complex in the body. A stable shoulder joint is the insurance of proper and skilful work of the hand. It meets unusual functional demands; (a) the wide range of motion of the shoulder joint, (b) positioning hand in the center of vision in front of the body, (c) producing high muscle joint forces during daily and sports activities and (d) providing sufficent stability despite the large motion and the highly variable direction and magnitude of forces acting on the shoulder joint. When all of these are taken into consideration, it should be stated that the shoulder joint must maintain the balance between mobility and stability of joints and efficent use of muscle resources to produce movements properly. This section will examine the kinematics and the kinetics of the shoulder joint complex. Kinematics can be defined as motion regardless of the forces causing the movement. Kinetics is the actions of muscles and the resultant forces on the joints (Wülker et al., 2001).

2.2.2.1. Kinematics

Ranges of Motions of the Shoulder Joint. There have been several movements in the shoulder joint; abduction-adduction, flexion-extansion, internal-external rotation, horizantal flexion-extension and protraction-retraction.

Shoulder elevation is defined as the movement of the humerus away from the side of the thorax in any plane (Nordin et al., 1989; Richardson & Iglarsh, 1994). Depending on the plane of motion, different types of shoulder elevation are possible; forward flexion in the sagittal plane and abduction in the frontal plane (Nordin et al., 1989; Richardson & Iglarsh, 1994; Wülker et al., 2001). Both have a range of about 180°. Besides, a more functional elevation is described; forward flexion in the plane of scapula (An, Browne, Korinek, Tanaka, & Morrey, 1991). Because the scapula is oriented at an angle approximately 30° to 45° anterior to the frontal plane, elevation in the plane of scapula is midway between forward flexion and abduction (Nordin et al., 1989; Richardson & Iglarsh, 1994). During motion in this plane, the inferior portion of the glenohumeral joint capsule is not twisted and the deltoid and the supraspinatus are optimally aligned for elevation of the arm. Therefore, probability of impingement of the subacromial tissues is lesser in the scapular plane. In most cases, maximum elevation in this plane is measured as 180°. Studies have shown that 28% of females and 4% of males exceeded elevation of 180° in the scapular plane. Besides, backward elevation (extension) (approximately 60°) in the sagittal plane and adduction (the action of bringing the humerus closer to the side of the body) are possible in the G-H joint (Nordin et al., 1989).

The other functionally important shoulder motions are internal and external rotations along the long axis of the humerus. They can be performed in varying degrees of elevation. When the humerus is abducted 90° and elbow is flexed 90°, internal rotation moves the hand downward while external rotation moves it upward. If the humerus is at the side of the thorax and the elbow is flexed 90°, internal rotation moves the forearm closer to the body and external rotation move it further away. Both ranges vary according to the degree of arm elevation; in general, each of them may reach 90° (Nodin et al., 1989).

Horizontal or transverse plane motion is performed at the position of 90° of humeral abduction (starting position). Two kinds of motions are available at this position; horizontal flexion (adduction) as the arm is drawn across the body and horizontal extension (abduction) as the arm crossed over the body is brought out to the side (Nordin et al., 1989; Richardson & Iglarsh, 1994; Wülker et al., 2001). The normal range of horizontal flexion is approximately 135°, whereas, horizontal extension is approximately 45°. Thus, the shoulder is capable of about 180 degrees of motion in the horizontal plane (Nodin et al., 1989).

Motions at the Four Shoulder Articulations. The four major articulations of the shoulder complex must act harmoniously providing shoulder joint movements with various degrees in different planes. This is required for full function during many daily and sports activities. For example, the clavicula must rotate so that both shoulder abduction and flexion can be performed at full range (Nordin et al., 1989;

Norris, 1993; Prentice, 1999). Motions at the four shoulder articulations and their relatioship with each other are discussed in the previous section.

The glenohumeral joint displays three types of surface motions (arthrokinematic rotation); rotation, rolling and gliding (translation). They may take place at the glenohumeral joint in any given plane. Rotation occurs when the contact point at the glenoid remains constant while the contact point at the head of the humerus moves. This corresponds to the wheel of a car spinning in the snow without moving forward. Rolling takes place when the contact points at the glenoid and at the humeral head displace equal amounts in opposite directions. The normal rolling of a wheel on the road surface is a good example for this motion. Gliding happens when the contact point at the humeral head remains constant while the contact point at the glenoid moves. This corresponds to the wheel of a car sliding while braking on slippery ground (Nordin et al., 1989; Richardson & Iglarsh, 1994; Wülker et al., 2001). Surface motions at the G-H joint are primarily rotational but some combination of gliding and rolling take place (Richardson & Iglarsh, 1994). The degrees of surface motions are important to provide normal shoulder motion (Nordin et al., 1989). For example, superior translation of the humeral head may lead to impingement against the acromion or translation in other directions may result in subluxation or dislocation of the G-H joint (Wülker et al., 2001).

The other important mechanism to cause and maintain normal G-H joint motions is the scapulohumeral rhythm. Interaction of the joints that permit elevation of the hand overhead is vital for producing movements during daily and sports activities. The movement of the scapula relative to the humerus is called the scapulohumeral rhythm (SHR) (Högfors, Peterson, Sigholm, & Herberts, 1991;

Högfors, Sigholm, & Herberts, 1987; Kulund, 1988; Veeger et al., 1991). Several investigators conducted studies on the relationship between the G-H and the S-T joints during arm elevation in various planes. Originally, it was assumed that during initial elevation of the arm, the scapula moved only, whereas G-H joint was involved in motion at higher degrees of elevation (Wülker et al., 2001). Later studies, however, have shown that G-H joint and the scapula move simultaneously (Hammer, 1999). It has been shown that about two thirds of the motion (approximately 120°) takes place in the G-H joint and one third (approximately 60°) at the S-T joint (Högfors et al., 1987; Nordin et al., 1989). During the first 30° to 60° of arm elevation, scapular motion is highly irregular and appears to depend on the position of the scapula at rest. After these degrees, there is a 2:1 ratio of the G-H and the S-T joint movements during arm flexion-extension and abduction-adduction. According to more recent investigations, the SHR varies significantly from one individual to another in particular during the first 30° of arm elevation. Above 30° the SHR becomes more constant (Wülker et al., 2001). However, it has been shown that there is no scapular movement as the humerus elevates to 30°. This stage is called the setting phase and the scapula seeks a stable position on the thorax wall (Prentice, 1999). One study indicated that the scapula was in a setting phase but moves laterally during the first 30° to 50° of humeral abduction or flexion (Hammer, 1999). From 30° to 90°, the scapula moves laterally and rotates upward 1° for every 2° of humeral elevation. From 90° to full elevation, the scapula moves latarally and upward rotates 1° for each 1° of humeral elevation (Nordin et al., 1989, Prentice, 1999; William et al., 2001). These differences in rations may be due to variation in measurement technique, plane of arm elevation measured and anatomic variations among individuals (Richardson & Iglarsh, 1994; Soderberg, 1997).

2.2.2.2. Kinetics

The study of kinetics deals with forces exerted by gravity, muscles, friction and external resistance on body. These forces lead to joint compression and distraction as well as pressure on soft tissues. To understand how and to what degree these forces act on the shoulder is vital to restore the function of the shoulder joint (Richardson & Iglarsh, 1994).

When we take a look at the shoulder joint, we should state that the analysis of forces at the shoulder joint is diffucult for three reasons; (a) muscles acting on the humerus must act simultaneously with other muscles to avoid producing dislocation at the joint as the shoulder joint is inherently instabile and (b) a single muscle may span several joints and exert an effect on each. Thus, the different positions of each joint may cause different and even opposing actions by the same muscle. (Nordin et al., 1989; Richardson & Iglarsh, 1994). In this section, the actions of the various muscles affecting on the shoulder joint will be described and the loads on the G-H joint will be discussed.

The deltoid and supraspinatus are the prime movers at the shoulder joint when the arm is abducted. This abduction is accompanied by an upward rotation of the glenoid cavity brought by the combined action of the serratus anterior and the upper and lower trapezius. If unopposed, the translatory component of the deltoid and supraspinatus forces will move the humeral head into the coracoacromial arch and impinge on the subacromial structure. The rotator cuff muscles act during abduction to compress the humeral head into the glenoid fossa. In addition, to acomplish full abduction, the humerus must be rotated externally by the infraspinatus and teres minor (Hammer, 1999; Richardson & Iglarsh, 1994).

The upper part of the trapezius muscle is the primary elevator during elevation of the arm. The levator scapula and the rhomboids help to produce elevation. However, depression of the shoulder girdle occurs as the tension in the elevators is released. If additional shoulder girdle depression is necessary, the lower part of trapezius, pectoralis major and the latissumus dorsi act together to accomplish this task (Richardson & Iglarsh, 1994).

Retreaction occurs as a result of the combined action of the trapezius and the rhomboids. On the other hand, protraction occurs as the serratus anterior and the pectoralis major contract. The upward and downward rotations counteract one another. When the trapezius and the rhomboids are elevating the scapula, the lower part of trapezius and the weight of the arm depress it. In this way, they control each other (Richardson & Iglarsh, 1994).

During the first 90° of arm flexion, the anterior and middle deltoid muscles, the supraspinatus, the pectoralis major, the chorabrachialis and both heads of the biceps act (Bassett et al., 1990; Buschbacher & Braddom, 1994; Richardson & Iglarsh, 1994). After 90° flexion, only the deltoid muscle acts to elevate the arm. During this motion, the rotator cuff muscles serve a similar synergistic force couple action (Richardson & Iglarsh, 1994).

The latisimus dorsi, the pectoralis major, the teres major, the posterior part of the deltoid muscle and the long head of triceps are involved in adduction and extension of the shoulder (Hammer, 1999; Richardson & Iglarsh, 1994). When extension continues past midline into hyperextension, the action of the pectoralis declines and that of the posterior deltoid increases (Richardson & Iglarsh, 1994).

Isolated external rotation of the humerus occurs as a result of contraction of the infraspinatus, the supraspinatus and the teres minor (Buschbacher & Braddom, 1994; Hammer, 1999; Richardson & Iglarsh, 1994). On the other hand, the subscapularis, the teres major, the latissimus dorsi and the pectoralis major form isolated internal rotation (Buschbacher & Braddom, 1994; Hammer, 1999).

The G-H joint is the most important component of the shoulder complex and makes the greatest contribution to total shoulder motion. When the shoulder complex is loaded, each articulation is subjected to increased stress. However, the G-H joint receives the largest portion of the load because its size is bigger than those of the other joints (Nordin et al., 1989). It has been shown that the maximum force of each muscle generally depends on the direction of its fibers, the initial length, the level of training and the type of contraction (Wülker et al., 2001). It was found that the force of isometric muscle activity (tension without shortening) is 10-15% higher than it is with concentric activity (tension with shortening) and 5-40% lowers than with eccentric muscle activity (tension against passive lengthening). Apreleva, Parsons, Warner, Fu and Woo (2000) searched the reaction forces at the G-H joint during active abduction. They have found that joint reaction force increase throughout abduction and it peaked at approximately at 90 and the supraspinatus contractions play very important role in increasing reaction forces on the shoulder joint. It was also shown that paralysis of the supraspinatus result in significant decrease in joint compression. In another study (Soderberg, 1997), it has also been shown that maximum shear force across the glenohumeral joint occurs at 60° of abduction. Similar calculations have been made for the arm at 90° of abduction with the elbow extended and a 2kg-weight hold in the hand. In this situation, the addition of a relatively light-weight to the outstretched arm doubles the glenohumeral joint reaction force, which is equal to body weight. When the same calculation has been made with the elbow maximally flexed and without weight, the reaction force on the G-H joint is found to be equal to 25% of body weight as flexion in the elbow shortens the lever arm for the gravitational force 30 to 15 cm. In other words, compared with keeping the arm straight, flexing the elbow maximally during shoulder abduction reduces the glenohumeral joint reaction force by about 50% (Nordin et al., 1989). Parsons, Apreleva, Fu and Woo (2002) studied the effect of the rotator cuff tears on reaction forces at the glenohumeral joint. They measured the magnitude and direction of glenohumeral joint reaction forces in intact, incomplete supraspinatus tear, complete supraspinatus tear, supraspinatus and infraspinatus tear and global tear conditions during active shoulder abduction in the scapular plane. They observed that reaction forces at glenohumeral joint steadily increased throughout abduction and peaked at maximum abduction for all conditions tested. Significant differences in reaction force magnitude could not be found between intact condition, incomplete tear and complete tear. However, extensions of tears beyond the supraspinatus tendon into the anterior and posterior aspect of the rotator cuff caused a significant decrease in the magnitude of joint reaction force and a significant change in direction of the reaction force at the G-H joint. These results suggest that joint reaction forces can be significantly affected by the integrity of the rotator cuff, specially, by the transverse force couple formed by the anterior and posterior aspects of the cuff.

2.3. Stability of the Shoulder Joint

Functional stability of the shoulder joint can be defined as the individual's ability to maintain the humeral head precisely centered within the glenoid fossa (William et al., 2001). As discussed in previous sections, the G-H joint is inherently unstable. This may result from the following features; (a) the glenoid cavity is relatively shallow and small, (b) the shoulder joint is subjected to moments and forces in highly variable directions and also significant magnitude due to the long lever of the arm (Andrews et al., 1999; Hammer, 1999; Prentice, 1999) and (c) the capsule and the ligaments are only streched at the extremes of G-H joint motions (Wülker et al., 2001).

The G-H joint stability is maintained by the coordinated and synchronous function of both static and dynamic stabilizers (Bigliani et al., 1996; Cain et al., 1987; Kelkar et al., 2001; Prentice, 1999). Static stabilizers restrict the range of motion at the shoulder, whereas, dynamic stabilizers provide the fine-tuning of G-H joint position. Both dynamic and static mechanisms together provide stabilization at the extremes of motion (Soderberg, 1997).

2.3.1. Static Stability

Static stabilization of the G-H joint has been provided by the glenoid labrum, the capsule, the ligaments and the negative intra-articular pressure (Nordin et al., 1989; Prentice, 1999). Besides, the bones and articular surfaces within the shoulder are positioned to contribute to static stabilty (Wülker et al., 2001; Prentice, 1999).

The main function of the glenoid labrum is to seal the circumference of the G-H joint. It increases the depth of the glenoid cavity by approximately 50% in all directions and increases surface area as well (Howell et al., 1989; William et al., 2001), so loading at a point decreases (Wülker et al., 2001). The other function of the glenoid labrum is to prevent translational forces. This function results in an increase of 20% glenohumeral stability with the joint loaded (Howell et al., 1989).

The other factor providing static stabilization is the capsule. The surface area of the shoulder joint capsule is twice that of the articular surface of the humeral head. Therefore, the stabilizing function of the capsule mainly occurs at the extremes of the motions (Richardson & Iglarsh, 1994; Soderberg, 1997; Wülker et al, 2001). The capsule restrains the humeral head opposite to the side of the displacement. It also prevents excessive rotational movements of the humeral head because rotations at the G-H joint tighten the capsule. The anterior and inferior parts of the capsule are strained particularly in maximum abduction, extension and external rotation of the arm. It must be stated that dislocation of the shoulder takes place most commonly in this position (Ferrari, 1990; Wülker et al., 2001). The posterior capsule is tight when the shoulder is in flexion, abduction and internal rotation or in any combination of these. The posterior capsule has the greatest tension while the shoulder is internally rotated (Bigliani et al., 1996; Prentice, 1999). The middle and proximal capsular structures restrain external rotation (Ferrari, 1990).

The ligaments play a very important role in providing shoulder stability as well as maintaining the integrity of the capsule. These are the coracohumeral ligament, the SGL, the MGL and the IGL (Ferrari, 1990; Hammer, 1999; O'Brien et al., 1990; Soslowsky, Carpenter, Bucchieri, & Flatow, 1997). Their functions depend on the current position of the G-H joint because their biomechanical properties such as stiffness and maximum force vary according to joint position (Halder, Halder et al., 2001; Wülker et al., 2001).

The coracohumeral ligament runs from the coracoid process to the greater and lesser tubercules of the humeral head. The function of the coracohumeral ligament is mainly to restrain the humeral head from excessive inferior translation (Burkart & Debski, 2002). It also restrains external rotation below 60° abduction (Ferrari, 1990).

The glenohumeral ligaments appear to produce a major restraint in shoulder flexion, extension and rotation. These ligaments are extremely important in resisting downward and the anterior displacement of the humeral head (Richardson & Iglarsh, 1994). The SGL runs superiorly at the glenoid labrum to the lesser tubercule. It has a major stabilizing effect on the humeral head against inferior displacement. There have also been studies indicating that this ligament is effective against anterior displacement (Bigliani et al., 1996; Burkart & Debski, 2002). The MGL runs at the anterior part of the glenoid to the lesser tubercule. It is tight when the arm is in flexion and external rotation up to 90°. The MGL works with the coracohumeral ligament to check external rotation from 0° to 60°. Because the support of the coracohumeral ligament is lost at 60° of external rotation, its function between 60° and 90°of external rotation is the most critical (Ferrari, 1990). This ligament also helps to prevent anterior and inferior displacement of the humeral head (Burkart & Debski, 2002; Prentice, 1999). The IGL runs from the glenoid labrum to the anatomical neck of the humerus. It has a primary check against both anterior and posterior dislocations of the humeral head (O'Brien et al., 1990; Prentice, 1990). The IGL is the primary static stabilizer when the shoulder is abducted to 90° and externally rotated. Therefore, the IGL is the most important stabilizing structure of the shoulder in overhead movements (Halder, Halder et al., 2001; Tsai et al., 1991).

The atmospheric (negative intra-articular) pressure is another important factor to provide and maintain shoulder stabilty (Tsai et al., 1991; William et al., 2001). It pushes the head of the humerus into the glenoid if no equivalent pressure is present within the joint. Negative intra-articular pressure has its maximal stabilizing effect at 20° of humeral abduction and neutral humeral rotation (Högfors et al., 1987; William et al., 2001).

2.3.2. Dynamic Stability

Dynamic stability is provided by muscles surronding the shoulder joint. The forces of muscles and the coordination of muscles activity are important to keep the shoulder joint stable (Bigliani et al., 1996; Nordin et al., 1989). Active muscle forces may stabilize the shoulder joint by the following mechanism; (a) activation of protective muscular contraction reflexes, (b) adjustment of muscle stiffness and (c) regulation of muscle co-contraction and coordination (Jawantanakul et al., 2001.

Rotator cuff muscles play very important roles in providing dynamic stability of the shoulder joint. This muscle group has unique functions. The first function is to cause the head of humerus roll in the glenoid while the prime movers raise the arm. The second function is to center the head of the humerus into the glenoid in various positions during fine movements (Bigliani et al., 1996; Davies, 1992). This mechanism is active in all glenohumeral positions but it is particularly important in the functional mid-range in which the capsule and ligaments are loose (Lazarus, Sidles, Harryman, & Matsen, 1996; William et al., 2001). Stabilization of the humeral head occurs mostly through co-contraction of the rotator cuff muscles. This situation creates a series of force couples that act to compress the humeral head into the glenoid, minimizing humeral head translation. A force couple involves the action of two opposing forces acting in opposite directions to impose rotation about an axis. These force couples can establish dynamic equilibrium of the glenohumeral joint regardless of the position of the humerus. This equilibrium occurs at two planes as the transverse and coronal planes (Prentice, 1999; William et al., 2001). Figure 2.3.2.1. represents the equilibrium at these two planes (Soderberg, 1997).

In the transverse plane, a force couple exists between the subscapularis anteriorly and the infraspinatus and the teres minor posteriorly. The subscapularis acts to stabilize and roll the humeral head posteriorly in to the glenoid fossa. The infraspinatus and the teres minor acts to depress the humeral head and provide anterior stabilization (Soderberg, 1997). This causes a decrease in tension of the anterior glenohumeral joint capsule during the preparation phase of overhead activity (Wülker et al., 2001). As a result, co-contraction of the infraspinatus, the teres minor and the subscapularis muscles both depress and compress the humeral head into the glenoid cavity (Buschbacher & Braddom, 1994; Nordin et al., 1989; Prentice, 1999). One study has shown that the reduction of the rotator cuff force by 50% in a dynamic shoulder model leads to 30% increase of anterior-posterior displacement of the humeral head (Wülker et al., 2001).

In the coronal plane, there is a critical force couple between the deltoid and the inferior rotator cuff muscles. With the arm fully adducted, contraction of the deltoid produces a vertical force in a superior direction causing an upward translation of the humeral head relative to the glenoid. Co-contraction of the inferior rotator cuff muscles produces both a compressive force and a downward translation of the humerus that counterbalances the force of the deltoid, stabilizing the humeral head. The supraspinatus compresses the humeral head into the glenoid and along with the deltoid initiate's abduction on this stable base. Dynamic stability is created by an increase in joint compression forces from contraction of the supraspinatus and by the humeral head depression from contraction of the inferior rotator cuff muscles (Prentice, 1999).

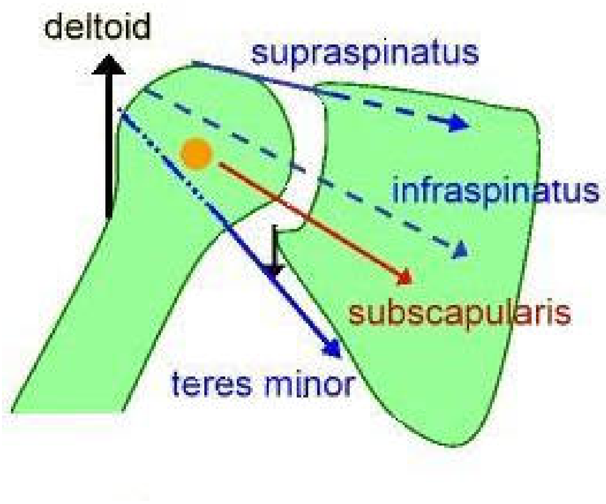

Figure 2.3.2.1. Dynamic Stability of Shoulder Joint

The long head of the biceps tendon also contributes to dynamic stability by limiting superior translation of the humerus during elbow flexion and supination (Prentice, 1999; Sodelberg, 1997; Wülker et al., 2001).

Few studies have focused on dynamic stabilizers of the glenohumeral joint in superior and inferior directions and the results of these studies are controversial. Halder, Halder et al. (2001) studied dynamic contribution of five shoulder muscles to inferior stability on glenohumeral joint in four joint positions. They investigated the functions of the deltoid, the supraspinatus, the short head of biceps, the coracobrachialis and the long head of the triceps in 0°, 30°, 60° and 90° abduction. This study presented the deltoid was most effective in providing inferior stability to the shoulder joint. It was also indicated that the coracobrachialis, the long head of the triceps and the short head of biceps provided inferior stability, translating considerably the humeral head superiorly, whereas, the supraspinatus showed the weakest effects. In another study, the effects of the rotator cuff, the latssimus dorsi, the pectoralis major, the deltoid and the biceps on superior shoulder stability were studied by Halder, Zhao, O'Driscoll, Morrey and An (2001) at the same abduction degrees as those in the previous study. The results have shown that the latissimus dorsi was most effective and the teres major had the second most effective effect on providing superior stability to the G-H joint, while the supraspinatus had a lesser effect.

It should be noted that the role of proprioceptive sense in providing dynamic stability of the GH joint is significant. Proprioceaptive sense provides dynamic stability contributing to the motor programming for neuromuscular control required for precision movements (Hammer, 1999; Myers & Lephart, 2002). Besides, it was indicated that neuroafferent receptors exist within the capsulo-tendinous junction and in muscle itself that may act through reflex arcs to help cortical feedback on shoulder position and translation. There are studies showing that the lack of proprioceptive sense results in functional instability, which could ultimately lead to further reinjury and decrease in performance (Lephart et al., 1997; Soderberg, 1997; Wülker et al., 2001).

2.4. Proprioceptive Sense

In order to behave effectively and achieve fine motor coordination, individuals must be able to control their movements. They can do this by knowing the relative position of different parts of body and maintaining a particular orientation toward gravity (Oxendine, 1968; Sage, 1977). Information on position and motion of the limbs is provided primarily by the eyes, ears and also from sensory receptors called proprioceptors. These proprioceptors are located in the periarticuler soft tissues; muscles, tendons, joints and joint capsule. The cuteneous sense is usually considered as a kind of proprioceptor (Clark, Burgess, Chapin, & Lipscomb, 1985; Gross, 1987; Matthews, 1988; Moore, 1984).

Although joint proprioceptive sensea, with the exception of the knee joint, has not been widely studied, it plays an important role in joint function and performance (Carpenter et al., 1998). It was indicated that the proprioceptive sense is essential for proper joint function in activities of daily living and sports by modulating of muscle function and initating of reflex stabilization (Gross, 1987; Lephart et al, 1997; Safran et al., 2001). Proprioceptors provide information about the spatial location of parts of body and their positions associated with the body, muscle tone, the velocity and direction of joint movement for the central nervous system (CNS) (Beers, Sitting, & Gon, 1998; Guyton, 1986; Moore, 1984). In other words, proprioceptors make the brain be aware of the physical state of the body at all times and they enable us to know unconsciously where our parts of body are in relation to our enviroment. Body posture can be maintained and a smooth and coordinated movement obtained by this way (Foss & Keteyian, 1998; Myers & Lephart, 2002; Lephart et al., 1997).

There are different definitions of the proprioceptive sense. Some scientisists define proprioceptive sense as information provided by the sensory receptors and cutenous receptors (Moore, 1984; Rosenbaum, 1991; Sage, 1977). However, it is generally defined as the ability to detect the sensation of joint motion (kinesthesia) and position of body parts with respect to each other (position sense) (Aydın et al., 2000; Pedersen et al., 1999; Safran et al., 2001; Warner, Lephart, & Fu, 1996).

The muscle spindle. Muscle spindles are the proprioceptive sense elaboration in skeletal muscles and contain small muscle fibers called intrafusal fibers (Foss & Keteyian, 1998; Guyton, 1986; Rosenbaum, 1991; Schmidt, 1988). The capsules of the spindles lie parallel to the main muscle fibers called extrafusal fibers and they are attached to them (Rosenbaum, 1991; Sage, 1997; Schmidt, 1988). While the muscle spindles are innervated by gamma motor neurons, the extrafusal fibers are innervated by alpha motor neurons (Foss & Keteyian, 1998; Guyton, 1986; Sage, 1997). The number of spindles in different muscle groups varies according to the muscles' size and the distrubition of spindles in muscles determine the degree of fine movement (Foss & Keteyian, 1998; Lephart et al., 1997; Rosenbaum, 1991; Sage, 1997).

The muscle spindle contains two types of sensory nerves; the group Ia afferent and the group II afferent. These sensory nerves respond mainly to the differences between the length of the extrafusal fibers and the length of the intrafusals fibers. They are also sensitive to the changes in these length differences over time. Studies have shown that the group II afferent is less sensitive than the Ia (Rosenbaum, 1991; Sage, 1977). The information supplied by these afferent groups ascends through the CNS pathways and ends in the cerebellum and somatosensory cortex (Foss & Keteyian, 1998; Lephart et al., 1997; Sage, 1977). As the muscle spindles contain both sensory receptors and muscle fibers, it has both sensory and motor functions. Thus, the muscle spindles are important in voluntary movements and in controlling the posture (Foss & Keteyian, 1998; Guyton, 1986; Lephart et al., 1997; Sage, 1977).

Golgi tendon organs (GTO). Golgi tendon organs are other receptors providing movement information. These structures are located in the muscle near the musculo-tendinous junction where the muscle blends into the tendon rather than in the tendon itself (Foss & Keteyian, 1998; Moore, 1984; Sage, 1977; Schmidt, 1988). They are located at the origin and insertion of a muscle and each GTO is related with 3-25 muscle fibers (Moore, 1984; Sage, 1977; Schmidt, 1988). GTO have one type of sensory nerves called Ib and impluses about tension in the tendon and the extent of muscle contraction into the CNS is transferred via the Ib (Foss & Keteyian, 1998; Moore, 1984; Rosenbaum, 1991). Previous studies indicated that GTO were less sensitive than muscle spindles and they needed to strongly stretch before they were activated (Sage, 1977). However, Moore (1984) has stated that GTO are encapsulated organs and they are more sensitive to a given amount of stimuli and more precise in localizing and relaying information to the CNS than noncapsuled receptors. In other words, these receptors are extremely sensitive to any degree of change in tension of muscle fibers they are attached to. When GTO are stimulated, alpha motor neuron stops firing and the muscle stops contracting. This mechanism is called laps-knife reflex. That is why stimulation of the golgi tendon organ, in contrast to the spindles which are facilatory, result in inhibition of the muscles in which they are located (Guyton, 1986; Sage, 1977).

The muscle spindles and GTO work together. The former causing just the right degree of muscular tension provides a smooth movement and the latter causing muscular relaxation prevents related structures from being injuried (Foss & Keteyian, 1998).

Joint receptors. Joint receptors found in tendons, ligaments, periosteum and joint capsule are other sources of proprioceptive information (Foss & Keteyian, 1998; Sage, 1977). Some authors call these kineshtetic receptors. They provide information to the brain, cerebellum, thalamus and to the somatic reflex on both velocity of movement and the angle of joint position when a joint is moved in any direction (Matthews, 1988).

There are actually three structually different types of receptor groups which are located in the tissue around joints. The first ones are ruffini endings. These endings are arranged in three dimensions in the connective tissue capsule of joints. This location makes them well suited to signal the rate, direction and extent of joint movement as well as the steady position of the joint. The second joint receptors are located in the ligaments of the joint and never found in unsupported areas of the capsule. The last ones are pacinian corpuscles. These receptors are found in capsule and connective tissues surronding joints and they are stimulated by deep deformation like heavy pressure (Foss & Keteyian, 1998; Lephart et al., 1997; Sage, 1977; Schmidt, 1988).

Previous studies (Sage, 1977; Schmidt, 1988) showed that as a joint is moved steadily, different receptors discharge signals at different angles. During movement, joint receptors begin sending information at a certain angle and send information gradually more rapidly for the next 10-15 degrees. They slow down and stop as the angle of peak stimulation for those particular receptors is passed, so different receptors discharge at different angles during the entire movement of that joint. When the joint is stopped at a certain joint angle, the receptors that normally send information at that angle adapt slightly within a few seconds. They maintain discharging indefinitely. Joint receptors are also sensitive to the angular velocity of movement, because the firing rate increases during movements toward the angle of maximum excitation and decreases during movement away from it, regardless of the actual direction of movement. In these ways, joint receptors provide accurate proprioceptive information on both the absolute values of the joint position and the angular velocity of movement over a wide range of joint angles.

Cutenous receptors. Cutenous receptors are located in various places in the skin. The sensory receptors that respond to mechanical deformation of the skin such as touch and deep pressure are called mechanoreceptors. Merkel's discs are a kind of mechanoreceptors stimulated by light touch and they are close to the hair follicules. There are also skin receptors responding to pain, temparature or chemical stimuli (Lephart et al., 1997; Rosenbaum, 1991; Sage, 1977). Mechanareseptors provide performing fine manipulations with hands and fingers and maintaining balance without visual feedback (Rosenbaum, 1991). In addition to these, pain sensations are certainly important for certain kinds of movement behaviours (Sage, 1977). All this information from cutenous receptors gives us a sense of awareness of our body and limb position, as well as providing us with automatic reflexes of posture (Foss & Keteyian, 1998).

2.5. Muscular Fatigue

Physiological processes associated with the development of muscle fatigue have received wide attention in the literature. In general terms, fatigue has been defined as a decline in maximal force generating capacity (Fitts, 1996; Fitts & Balog, 1996; Foss & Keteyian, 1998; Jensen et al., 2000; Pincivero et al., 2001). Moreover, another definition is the inability to maintain the required or expected power output (Fitts, 1994; Frontera et al., 1999; Pedersen et al., 1999; Westerbald & Allen, 1991). The first definiton has an advantage in terms of allowing differentiation between fatigue and exhaustion. The exhaustion occurs when the required force or exercise intensitiy can no longer be maintained whereas fatigue develops gradually from beginning of exercise (Jensen et al., 2000). However, whatever the definition of fatigue is, both definitions have indicated that fatigue results in an acute impairment of performance causing loss in force, power and velocity production (Fitts & Balog, 1996; Frontera et al., 1999).

Fatigue has frequently been classified as central and peripheral, depending on whether the causative agent affects the central nervous system or the muscle itself. Central fatigue is related to events of neural input to the higher brain center. The exact mechanism of muscle fatigue is not well known. It is proposed that as muscle fatigues, the local disturbances that occur within itself are signaled back to the central nervous system (brain) via sensory nerves. In turn, the brain sends out inhibitory signals to the nerve cells in the motor system, resulting in a declining muscular work output (Bompa, 1990; Foss & Keteyian, 1998; Frontera et al., 1999). It is thought that peripheral fatigue involves the neuromuscular junction, the process of excitation-contraction coupling, the release of calcium and the activation of the contractile elements (Bompa, 1990; Fitts, 1996; Fitts & Balog, 1996; Foss & Keteyian, 1998; Frontera et al., 1999). In this section, the causes of muscular fatigue will be discussed.

Fatigue within the muscle may be resulted generally from following factors; (a) accumulation of lactic acid (Bompa, 1990; Foss & Keteyian, 1998; Frontera et al., 1999), (b) depletion of muscle glycogen stores (Foss & Keteyian, 1998), (c) depletion of adenosine tri-phosphate (ATP) and phosphocreatine (PC) stores (Fitts, 1994; Foss & Keteyian, 1998; Garcia et al., 1991) and (d) lack of oxygen through inadequate blood flow (Bompa, 1990; Foss & Keteyian, 1998). It is also stated that decreased release of chemical transmitters from the nerve endings at the neuromuscler junction may also cause muscle fatigue (Foss & Keteyian, 1998).

The idea that lactic acid accumulation is involved in the fatigue process is supported by many studies (Bompa, 1990; Fitts, 1994; Foss & Keteyian, 1998; Frontera et al., 1999). Relationship between lactic acid and intracelluler pH or hydrogen ion concentration has been searched and it was shown that with increases in lactic acid, hydrogen ion concentration increses and pH decrases. Increases in hydrogen ion result in both hindering the excitation-contraction coupling process by decreasing the amount of calcium ion released from sarcoplasmic reticulum and interfering with the calcium ion-troponin binding capacity. Failure of excitation-contraction coupling may be a major mechanism of skeletal muscle fatigue. Furthermore, an increased hydrogen ion concentration inhibits the activity of phosphofructokinase, which is a key enzyme involved in anaerobic glycolysis. This mechanism causes muscle fatigue, reducing the avaibility of ATP for energy. It is believed that severe glycogen depletion is another cause of contractile fatigue (Foss & Keteyian, 1998). The relationship between muscle glycogen depletion and muscular fatigue has not been determined clearly. However, some researchers (Bompa, 1990; Garcia et al., 1991) indicated that even though plenty of fatty acids and glucose (from the liver) are still available as fuels to the muscle fibers, these other fuels could not fully meet the energy demand of the glycogen-depleted muscle fibers. Similarly, now that the immediate source of energy for muscular contraction are ATP and PC for the activities of very high intensity and a short duration, complete depletion of these stores in the muscle would certainly limit the ability of the muscle contract and results in muscle fatigue (Bompa, 1990). Since organism fails to supply enough oxygen to muscles and to remove inflamatory substances released during contraction, inadequate blood flow contributes to muscler fatigue (Bompa, 1990; Foss & Keteyian, 1998). Besides, there are some evidences for the idea that local muscular fatigue is caused by failure at the neuromuscular junction. This type of fatigue appears to be more common in Type II motor units and may account, in part, for the greater fatigability of these fibers when compared with Type I fibers. Failure of the neuromuscular junction to relay nervous impulses to the muscle fibers is most likely due to decreased release of acetylcholine (ACh); the excitatory chemical transmitter at the neuromuscular junction (Foss & Keteyian, 1998). There have also been studies (Bompa, 1990; Fitts, 1994; Fitts, 1996; Frontera et al., 1999) showing that the increasing inorganic phosphate (Pi) concentration causes a decrease in force production by increasing the fraction of actin-myosin cross bridges in the weakly bound pre-power stroke state.

The causative factors in muscle fatigue depend on the state of fitness, the intensity and duration of the exercise, the fibre type composition of the recruited muscles, the dietary status of the individual and also contraction type (Fitts, 1996; Fitts & Balog, 1996; Foss & Keteyian, 1998). It was showed that after eccentric exercise, greater and longer lasting fatigue occurs, whereas, fatigue affects isometric less than isokinetic force production (Foss & Keteyian, 1998). On the other hand, Hortobagyi, Tracy, Hamilton and Lambert (1996) indicated that fatigue following isometric and concentric exercise was significantly more than fatigue with eccentric exercise. Hortobagyi et al. (1996) also showed following 10 minutes of recovery, compared with baseline, eccentric strength was at baseline level whereas isometric and concentric strength recovered to 90% and 88% of baseline.

It is believed that muscular fatigue affects proprioceptive information and cortical control. There are some evidences that the output of muscle receptors changes in fatigue. The study conducted on animals showed that receptors were affected by increased intramuscular concentrations of contraction metabolites and inflammatory substances (lactic acid, bradykinin, arachidonic acid and serotinin) released during muscle contractions. Increased concentrations of these substances are known to affect the proprioceptive inflow from muscle spindle negatively (Pedersen et al., 1999). Thus, it is likely to damage the whole body posture control as well as movement paterns. Yaggie and McGregor (2002) researched on the effects of ankle fatigue on the maintenance of balance and postural limits in healthy young men and showed that fatigue of plantar flexors and dorsiflexors significantly influences sway parameters and ranges of postural control. Johnston, Howard, Cawley and Losse (1998) supported these results. They found that lower extremity fatigue affects the ability of an individual to balance on an unstable platform and motor control performance decreases significantly after fatigue compared with before. Lepers, Bigard, Diard, Gouteyran and Guezennec (1997) conducted a study on postural control after prolonged exercise and they found the ability to maintain postural stability decreased after exercise. Similarly, Sparto, Parnianpour, Reinsel and Simon (1997) evaluated the effect of fatigue on multi joint kinematics during a repetitive lifting test and significant decrease was observed in postural stability. One study showed that muscle fatigue after prolonged cycle exercise causes the reduction in neuromuscular capacity both reducing neural input to the muscles and give harm to peripheral contractile mechanism and induces changes in movement patterns (Lepers, Hausswirth, Maffiuletti, Brisswalter, & Hoecke, 1997). Lattanzio, Petrella, Sproule and Fowler (1997) investigated the effect of fatigue on knee proprioceptive sense in eight healthy men and in eight healthy women. Three seperates fatigue protocols were performed; ramp test, continous test and interval test. The results of the study revealed that exercise for fatigue caused proprioceptive decline at significant levels. On the other hand, Marks and Quinney (1993) researched the effects of fatiguing maximal isokinetic quadriceps contractions on ability to estimate knee-position. They found no cahange in accuracy of knee positioning post-exercise. Sharpe and Miles (1993) found similar results on elbow joint proprioceptive sense. They examined position sense at the elbow after fatiguing contractions and they did not find significant difference between the estimate of the angle of the elbow joint before fatigue and after fatigue. The study by Chabran, Maton and Fourment (2002) indicated that postural fatigue by a low-level isometric contraction has no effect on voluntary movement and requires no dramatic adaptation in postural control.

Clinically, the relationship of injury and disease conditions with proprioceptive sense and the effects of impaired proprioceptive sense on function have been studied in other joints; however, few studies have measured proprioceptive sense at the shoulder joint and have searched for the effects of fatigue on proprioceptive sense. It was indicated that localized muscle fatigue decreases the acuity of the movement sense in the human shoulder (Pedersen et al., 1999). Carpenter, Blaiser and Pellizzon (1998) carried out a study on the effects of muscle fatigue on shoulder joint position in volunters with no shoulder abnormalities. Results showed that the threshold to detection of movement increased 73% after fatigue compared with before fatigue. They also indicated that this significant increase in threshold occurred with both internal and external rotation. Voight, Hardin, Blackburn, Tippett and Canner (1996) found similar results. They also examined the relationship between arm dominance and shoulder propriocepiton. No significant difference was detected between dominant and nondominant extremities. The studies by Aydın, Yıldız, Yanmış, Yıldız and Kalyon (2000) and Warner, Lephart and Fu (1996) supported this result. On the other hand, Sterner, Pincivero and Lephart (1998) assessed the influence of muscler fatigue on active and passive shoulder proprioceptive sense within midrange of rotation. Sterner et al. (1998) compared recreationally active men with randomly assigned control group and found that shoulder proprioceptive sense was not affected by short-duration, high-intensity exercises. Le, Liau, Cheng, Tan and Shih (2003) studied shoulder muscles fatigue on joint proprioceptive sense in internal and external rotation direction. Shoulder proprioceptive sense was measured during active and passive reproduced shoulder positions. Significant difference was observed only between before and after fatigue shoulder external rotation during active repositioning, whereas, no significant difference was found between before and after fatigue shoulder internal rotation during active repositioning. It was also indicated that there is no significant difference between before and after fatigue shoulder internal and external rotation during passive repositioning.

CHAPTER III

METHODS AND PROCEDURE

3.1. Participants

24 experienced and 22 inexperienced totally 46 male volleyball players (n= 46) volunteered to participate this study. Two of the participants who had a history of shoulder joint instability and four of them having previous shoulder surgery were excluded. A personal information sheet on shoulder injury and surgery was distributed and collected among volunteers for this reason (See Appendix A). The final number of participants was 20 experienced and 20 inexperienced. Descriptive information on age, body weight, height, body mass index (BMI), years of sports experience and average training hours per week and year are presented in Table 3.1.1.

Table 3.1.1. Descriptive Information of the Participants.

	Inexperienced Players		Experienced Players	
Parameter	Mean	SD	Mean	SD
Age	17.1	1.0	20.7	2.8
Body Weight (kg)	77.5	6.4	80.6	7.2
Height (m)	1.9	.0	1.9	.0
BMI (kg/m²)	21.3	1.5	21.6	1.3
Sports Experience (year)	4.8	2.1	7.6	3.1
Training Hours/Week (hr/week)	13.3	3.3	13.8	2.8
Training Hours/Year (hr/year)	555	114.6	697.5	186.2

3.2. Data Collection

At the beginning of the study, relevant teams' coaches were contacted to inform them on the purpose of the study. They were also asked for the availability of their training program for measurements and to motivate their players to participate in this study. Having the permission from their coaches and sports clubs, all participants were informed on the inventory, which was used during data gathering procedure. All participants were also requested to sign the informative consent approved by The Faculty of Medicine, The University of Ankara (See Appendix B for a copy of informative consent).

3.3. Personal Information Sheet (PIS)

Personal information sheet was distributed to gather data on the date of birth, age, height, body weight, years of sport experience, the history of shoulder injury and average training hours per week and year. BMI was calculated using the following formula; BMI: kg/m² (Ergun & Baltacı, 1997) (See Appendix A for a copy of PIS).

3.4. Proprioceptive Sense Measurement

Shoulder proprioceptive sense was evaluated by Biodex isokinetic system 3 pro (Biodex Medical Systems, Inc., New York, USA). The system has isokinetic, isometric, isotonic, passive, reactive eccentric exercise modes and also proprioceptive sense measurement protocols. Concentric velocities range from 30 to 500 deg/s while eccentric velocities range from 10 to 300 deg/s. Maximum torque values are 500 foot-pounds for concentric contraction and 300 foot-pounds for eccentric contraction. Position range is 330 degrees. This system also has lift and closed chain attachments. The Biodex isokinetic system can measure high-speed concentric activity and it can be set up easily for strengthening diagonal planes. Besides, it generates a comprehensive report after isokinetic evaluation. Biodex facilitates proprioceptive measurement by having 2 deg/s measurement speed and goniometer showing the degrees of the given joint (Perrin, 1993; Prentice, 1999). The reliability and validity of the Biodex system has been demonstrated in previous studies (Frisiello, Gazaille, O'Halloran, Palmer, & Waugh, 1994; Holmback, Porter, Downham, & Lexell, 1999; Malerba, Adam, Harris, & Krebs, 1993).

Shoulder proprioceptive sense was determined by measuring the participant's perception of joint position (Aydın et al., 2000; Jawantanakul et al., 2001; Safran et al., 2001; Smith & Brunolli, 1989). Participants were tested in a seated position and they were blindfolded and had headsets placed over the ears to eliminate the contribution of visual and auditory clues (Aydın et al., 2000; Lee et al., 2003). At the beginning of the measurement procedure two starting positions were selected; (a) the shoulder joint was positioned at 90° abduction and 90° external rotation and the elbow was flexed to 90°, (b) the shoulder joint was positioned at 90° abduction and at neutral rotation and the elbow was flexed to 90°. Figure 3.4.1. represents the position of shoulder proprioceptive sense measurement.


(a) (b)

Figure 3.4.1. Positions of Shoulder Proprioceptive Sense Measurement

The perception of joint position is assessed by measuring reproduction of active positioning at previously presented joint angles (Aydın et al., 2000; Safran et al., 2001; Smith & Brunolli, 1989). Measurements were made at 2 deg/s and 10°, 15° and 20° in directions of internal and external rotation. This speed was thought to be sufficient to provide the contribution of muscle receptors (Lee et al., 2003; Voight et al., 1996). Small angles were selected in order to minimize contribution of other receptors in ligaments and capsule (Brindle, Nyland, Shapiro, Caborn, & Stine, 1999; Carpenter et al., 1998). Measurements were made before and after fatigue.

First, the shoulder joint was tested at the former position. When participants were ready, the limb was moved passively to 10° of internal rotation. The shoulder was positioned in the presented angle for 10 seconds and the participants were asked to concentrate on this position. The limb was then moved back passively by the device from the present to the starting position. After 10 seconds of static positioning at the starting position the participant was asked to reproduce joint angles that were previously presented actively in order to stimulate muscle receptors (Aydın et al., 2000). Participants manipulated the handheld on/off switch when he thought his joint had reached the previously presented position. The difference between the presented and the repositioned positions was considered as the error of reproduction. After recording the score of error, the limb was repositioned at 90° abduction and 90° external rotation and the elbow was flexed to 90° (Aydın et al., 2000; Safran et al., 2001; Smith et al., 1989). Likewise, the shoulder joint was repositioned at the starting position and the same procedure was executed at 15° and 20° angular positions. Tests were repeated at 10°, 15° and 20° in external rotation. The mean of two trials for test condition was calculated to determine the average score of error.

3.5. Fatigue Protocol

Maximal rotator cuff muscle strength was determined. Participants were tested in a seated position to enable normal scapulothoracic function (Brindle et al., 1999; Carpenter et al., 1998). The shoulder was positioned at 90° abduction and 90° external rotation and the elbow was flexed to 90°. This position was chosen to enhance the function of the rotator cuff muscle (Carpenter et al., 1998; Davies, 1992; Ivey & Calhoun, 1985). Figure 3.5.1. represents (a) the starting position and (b) ending position of rotator cuff strength measurement. The Biodex system was arranged according to guidelines in the user’s manual for measurement of shoulder internal and external rotation. Stabilization of the participant on the chair was established by strapping was placed across the thigh, waist, chest and arm. Before the measurement, participants performed ten repetitions of shoulder movement ranging from 90° external rotation to neutral rotation and vice versa at 90 deg/s to warm up and familiarize with the testing device (Davies, 1992; Sirota et al., 1997). Maximal muscle strength measurement was made while the shoulder was being exercised from external to internal and then internal to external rotation at 60 deg/s (Davies, 1992; Prentice, 1999; Sirota et al., 1977). The participants were instructed to perform maximal effort for ten repetitions. Internal rotation maximal peak torque was determined by this way.

(a) (b)

Figure 3.5.1. Position of Rotator Cuff Muscle Strength Measurement

Fatigue protocol was practiced. Participants were instructed to perform maximal effort in the sequence of external to internal rotation and vice versa at 60 deg/s. The fatigue protocol was terminated when the internal rotation maximal peak torque decreased by 50% consistently (Carpenter et al., 1998; Sterner et al., 1998).

3.6. Data Analysis

In comparing both groups' independent samples, *t* test was conducted.

Differences among proprioceptive sense at three angles were assessed by Friedman Two-Way analysis of variance and Multiple Comparison Test was used to differ average error score.

Wilcoxon Signed-Ranks Test evaluated comparison between before and after fatigue proprioceptive sense.

Mann-Whitney U Test was used to compare between experienced and inexperienced volleyball players' proprioceptive sense (Siegel & Castellan, 1988).

CHAPTER IV

RESULTS

4.1. Descriptive Findings

There was significant difference between experienced and inexperienced volleyball players on age (*t*= -5.3; p< .001), sports experience (*t*= -3.3; p< .01) and training hours per year (*t*= -3.0; p< .01). However, no significant difference was observed between experienced and inexperienced volleyball players in means of body weight, height, BMI and training hours per week (Table 4.1.1.).

Table 4.1.1. *t* Test Scores of the Participants.

	Inexperienced & Experienced Players		
Parameter	*t*	df	p
Age	-5.3	38	.000**
Body Weight	-1.4	38	.163
Height	-1.0	38	.322
BMI	-.6	38	.554
Sports Experience	-3.3	38	.002*
Training Hours/Week	-.5	38	.615
Training Hours/Year	-3.0	38	.005*

*p< .01. **p< .001.

To examine the results of the study, descriptive statistics for inter and intra-group scores in internal and external rotations at 10º, 15º and 20º were conducted. Assessments for proprioceptive sense before and after fatigue scores at three angles were made by “Friedman Two-Way Anova”. “Wilcoxon Signed Ranks Test” was conducted to evaluate differences between before and after fatigue proprioceptive sense intra-group results. To differentiate experienced and inexperienced volleyball players, both groups were compared by “Mann-Whitney U Test”. Table 4.1.2. represents groups’ before and after fatigue scores in internal rotation at 10°, 15° and 20°. Table 4.1.3. represents groups’ before and after fatigue scores in external rotation at 10°, 15° and 20°.

Table 4.1.2. Before and After Fatigue Scores of Inexperienced and Experienced Volleyball Players in Internal Rotation.

	10°			15°			20°		
Group	Mean	SD	Median (min-max)	Mean	SD	Median (min-max)	Mean	SD	Median (min-max)
Inexperienced Players									
Before Fatigue	4.5	3.8	3.5 (0.5-16)	3.1	1.7	2.7 (1-7.5)	4.7	2.3	3.7 (1.5-9)
After Fatigue	8.1	5.7	7.5 (1.5-23.5)	5.6	4.4	4.2 (0-19)	5.1	5.7	3.5 (1.0-26)
Experienced Players									
Before Fatigue	5.2	3.4	4.5 (1-14)	4.2	2.6	4.2 (0-10.5)	3.8	2.3	3.5 (0-10.5)
After Fatigue	6.5	4	5.7 (1-17)	5.7	4.6	5.5 (0.5-15.5)	6.1	3.8	5.5 (0.5-15)

Table 4.1.3. Before and After Fatigue Scores of Inexperienced and Experienced Volleyball Players in External Rotation.

	10°			15°			20°		
Group	Mean	SD	Median (min-max)	Mean	SD	Median (min-max)	Mean	SD	Median (min-max)
Inexperienced Players									
Before Fatigue	2.3	2.1	1.7 (0-10)	3.1	2.1	2 (0-7)	4.6	3.3	3.7 (0-12)
After Fatigue	2.8	1.9	2.2 (0.5-7)	2.9	1.8	2.7 (0-8)	4	2.8	3.5 (1-11.5)
Experienced Players									
Before Fatigue	3.5	3.4	2.5 (0.5-13.5)	4	2.6	3.2 (1-11)	4.6	3.4	4 (0.5-12)
After Fatigue	3.6	2.4	4 (0-9)	4.3	3.2	3.2 (0-11.5)	5.0	4.2	4.2 (0.5-18)

4.2. The Results of Comparison among Intra-Group Proprioceptive Sense Scores at Three Angles.

Findings indicated that experienced volleyball players' proprioceptive sense remained similar at 10°, 15° and 20° in both directions before and after fatigue. In addition, noticeable difference was not observed among inexperienced volleyball players' proprioceptive sense at 10°, 15° and 20° in internal rotation before and after fatigue. However, there was significant difference between proprioceptive sense of inexperienced volleyball players at 10°-20° ($\chi^2 = 13.9$; $p < .01$) and 15°-20° ($\chi^2 = 13.9$; $p < .05$) in external rotation before fatigue. No significant difference was found among proprioceptive sense of inexperienced volleyball players at 10°, 15° and 20° in external rotation after fatigue (Table 4.2.1. and Table 4.2.2.).

Table 4.2.1. Friedman Two-Way Anova Scores Before Fatigue.

		Internal Rotation			External Rotation		
Group	n	χ^2	df	p	χ^2	df	p
Inexperienced Players	20	3.9	2	.142	13.9	2	.001*
Experienced Players	20	.1	2	.951	3.6	2	.165

*The difference was significant between 10°-20° ($p < .01$) and 15°-20° ($p < .05$).

Table 4.2.2. Friedman Two-Way Anova Scores After Fatigue.

		Internal Rotation			External Rotation		
Group	n	χ^2	df	p	χ^2	df	p
Inexperienced Players	20	3.4	2	.176	1.6	2	.449
Experienced Players	20	1.5	2	.466	2.7	2	.249

4.3. The Results of Comparison Between Before and After Fatigue Proprioceptive Sense Scores at Three Angles Separately.

The difference between before and after fatigue proprioceptive sense of experienced volleyball players at 20° (z= -2.3; p< .05) was found as statistically significant. In addition to this, there was significant difference between before and after fatigue proprioceptive sense of inexperienced players at 10° (z= -2.7; p< .01) and 15° (z= -2.5; p< .05). But, no significant difference was observed between before and after fatigue proprioceptive sense at 20°. The effect of fatigue on proprioceptive sense was also evaluated on experienced and inexperienced volleyball players in external rotation. The difference was not significant between before and after fatigue proprioceptive sense of both groups at 10°, 15° and 20° (Table 4.3.1. and Table 4.3.2.).

Table 4.3.1. Wilcoxon Signed-Ranks Test Scores in Internal Rotation.

		10°		15°		20°	
Group	n	z	p	z	p	z	p
Inexperienced Players	20	-2.7	.005**	-2.5	.011*	-.9	.360
Experienced Players	20	-1.2	.197	-1.4	.161	-2.3	.021*

*p< .05. **p< .01.

Table 4.3.2. Wilcoxon Signed-Ranks Test Scores in External Rotation

		10°		15°		20°	
Group	n	z	p	z	p	z	p
Inexperienced Players	20	-1.2	.212	-.1	.861	-.7	.481
Experienced Players	20	-.8	.422	-1.4	.161	-.3	.747

4.4. The Results of Comparison between Inexperienced and Experienced Volleyball Players' Proprioceptive Sense Scores.

There was no significant difference between experienced and inexperienced volleyball players' proprioceptive sense scores at 10°, 15° and 20° in both directions before and after fatigue (Table 4.4.1. and 4.4.2.).

Table 4.4.1. Mann-Whitney U Test Scores Before Fatigue.

		Internal Rotation		External Rotation	
Group	n	z	p	z	p
Inexperienced & Experienced Players-10°	40	-.9	.322	-1.1	.241
Inexperienced & Experienced Players-15°	40	-1.3	.178	-1.1	.265
Inexperienced & Experienced Players-20°	40	-1.1	.253	-.0	.945

Table 4.4.2. Mann-Whitney U Test Scores After Fatigue.

		Internal Rotation		External Rotation	
Group	n	z	p	z	p
Inexperienced & Experienced Players-10°	40	-.6	.524	-1.0	.313
Inexperienced & Experienced Players-15°	40	-.0	.946	-.9	.334
Inexperienced & Experienced Players-20°	40	-1.5	.132	-.3	.694

CHAPTER V

DISCUSSION

The aim of this study was to evaluate the effect of different joint positions, the rotator cuff muscle fatigue and experience on shoulder proprioceptive sense among male volleyball players. 20 experienced and 20 inexperienced male volleyball players participated this study.

Findings of the study demonstrated that there was no significant difference between 10°, 15° and 20° internal and external rotations in terms of proprioceptive sense among experienced volleyball players before and after fatigue. Significant difference was not also observed between 10°, 15° and 20° internal rotation in terms of proprioceptive sense among inexperienced volleyball players before and after fatigue. However, there was significant difference between 10°-20° and 15°-20° external rotation in proprioceptive sense of inexperienced volleyball players before fatigue. The difference was not significant between 10°, 15° and 20° external rotation in terms of proprioceptive sense among inexperienced volleyball players after fatigue.

Mechanoreceptors in tissues are activated by tension exerted on them, so mechanoreceptors' activation would be expected to vary at different points in the ROM as the tension in tissues around the joint varied. Thus, position sense may alter from one joint position to another. Different positions were used to evaluate position sense in previous studies (Jawantanakul et al., 2001; Lee et al., 2003; Safran et al., 2001). Janwantanakul et al. (2001) found that the characteristic of shoulder position sense alters across ROM and there is greater position sense acuity at extreme positions of ROM. Safran et al. (2001) stated that the tension on the capsuloligamentous complex might begin to play a role on proprioceptive sense when the joint approaches the end of movement especially after 75° of external rotation. Thus, an increase in the contribution of capsuloligamentous structures to shoulder proprioceptive sense at the extreme positions may cause to perceive positions well. Janwantanakul et al. (2001) also indicated that when a joint approaches the limit of movement, increased stretch of antagonist muscles and tension in the tendons of agonist muscles cause an increase in discharge of muscle spindles and GTO. Lee et al. (2003) presented that the larger angular changes could stimulate mechanoreceptors in muscle more accurately and contribute to improvement of position sense.

The results of our current study were in partial agreement with the findings of the previous studies (Brindle et al., 1999; Jawantanakul et al., 2001; Lee et al., 2003, Safran et al., 2001). In these studies, bigger angles than those in the current study were selected to evaluate shoulder proprioceptive sense. In this study, small angles were selected to prevent possible contribution of capsuloligamentous receptors. The possible explanation why there was no significant difference between positions in terms of proprioceptive sense is that angles were very close to each other. It is thought that there was not sufficient difference between angles to stimulate different portions of muscle receptors to affect proprioceptive sense as much as it can be measured. Additionally, the differences between angles in means of proprioceptive sense were observed in external rotation. This finding was consistent with previous studies (Carpenter et al., 1998; Lee et al., 2003). These studies indicated that the shoulder joint was more sensitive to external rotation than to internal rotation because of a relative tightening of the capsular ligaments and activation of rotator cuff muscles as the shoulder externally rotates from the abducted externally rotated position. The studies showed that internal rotation from the externally rotated position towards the neutral position relaxes the capsule and rotator cuff muscle. This may explain why there was significant difference between 10°-20° and 15°-20° in external rotation proprioceptive sense of inexperienced volleyball players before fatigue. It is also known from earlier study (Pedersen et al., 1999) that a small voluntary contraction resisting on imposed movement increases the afferent output from the muscles, mainly from the muscle spindle afferents. Since our participants were instructed to produce movement against gravity in external rotation, this is likely to cause further contraction of the muscles. Thus, the contribution of the muscle spindles to the proprioceptive inflow might increase. Because no previous study has investigated shoulder proprioceptive sense at smaller angles (10º, 15º and 20º), further research is needed to correlate the muscle activation with shoulder proprioceptive sense.

Another finding of the current study was that there was statistically significant difference between before and after fatigue proprioceptive sense of experienced volleyball players at only 20° and between before and after fatigue proprioceptive sense of inexperienced volleyball players at 10° and 15° in internal rotation. The difference was not significant between before and after fatigue proprioceptive sense of both groups at 10°, 15° and 20° in external rotation.

The decrease in proprioceptive sense with muscle fatigue plays a role in decreasing athletic performance as fatigue will impair neuromuscular control of shoulder function (Sharpe & Miles, 1993). Unfortunately, literature has not obtained common conclusion related to the effect of fatigue on proprioceptive sense. It is believed that the rotator cuff muscle fatigue may reduce joint position sense as it is likely to be one of the sources of proprioceptive signals (Carpenter et al., 1998). It has been shown that increased concentration of metabolites and inflammatory substances released during muscle contraction affect the muscle spindle output negatively (Pedersen et al., 1999). However, a few studies (Carpenter et al., 1998; Pedersen et al., 1999; Sharpe & Miles, 1993; Sterner et al., 1998; Voight et al., 1996) investigating the effect of fatigue on proprioceptive sense presented conflicting results. Studies conducted on the effect of fatigue on shoulder proprioceptive sense showed a decrease in proprioceptive sense in the presence of shoulder muscle fatigue (Carpenter et al., 1998; Pedersen et al., 1999; Voight et al., 1996). On the other hand, Sterner et al. (1998) presented shoulder proprioceptive sense was not affected by fatigue. Similarly, it was indicated that progressive fatigue does not systematically alter the estimate of the angle at the elbow (Sharpe & Miles, 1993) and the knee joint

(Marks & Quinney, 1993). Inflammatory substances in serum and tissue were not measured in our current study.

The current study indicated that the effect of fatigue on shoulder proprioceptive sense in internal rotation was excessive than that of external rotation. Current results supported the literature partially (Lee et al., 2003; Johnston et al., 1998) regarding the effect of fatigue on shoulder proprioceptive sense in internal rotation. The reason why there is no significant difference between before and after fatigue proprioceptive sense in both groups at 10°, 15° and 20° in external rotation may be related to the extended time between the fatigue protocol and measurements in external rotation. Literature indicated that there is a rapid recovery in the first two minutes following fatigue (Fitts, 1996; Lee et al., 2003) and muscle torque recovers within 90-95% of the initial torque output by the third and fourth minute (Lee et al., 2003). Then, a slow recovery occurs and complete muscle torque recovery may take as long as 10 minutes or more, depending on the type of contraction performed (Fitts, 1996; Lee et al., 2003). In the current study, it appeared that participants were able to begin to recover from their fatigue during proprioceptive sense measurements in external rotation. This was a limitation of the study.

In this study, three positions (10º, 15º and 20º) were tested. The findings showed that fatigue affected shoulder proprioceptive sense at different angels according to the experience of volleyball players. Literature indicated that specific stimulus presented during training may result in perceptual learning (Ahissar & Hoschstein, 1993; Gold et al., 1999). Perceptual learning is the improvement of sensory discriminative capacity and causes temporary changes in synaptic effectiveness (short term) and structural changes in synaptic connections (long term).

Thus, it may lead to an improvement of signal processing in a position of familiar activity and results in enhanced position sense (Janwantanakul et al., 2001). Ahissar & Hoschstein (1993) stated that perceptual learning is improved with practice. This improvement is highly specific to basic attributes of the trained stimulus and the practiced directions, so it is not transferred to new motion directions (Ahissar & Hoschstein, 1993; Gold et al., 1999).

When the overhead movements of G-H joint are considered in volleyball, the acceleration of the arm towards external rotation is to only carry of the extremity weight without resistance. This shoulder movement requires fine neuromuscular control. At the end of acceleration, the movement is performed against the ball and a great force from the ball is delivered from the wrist to the forearm may also be transferred to the shoulder joint (Wang & Cochrane, 2001). Mostly, force transfer from ball to the hand occurs in front of the head and at similar angles (Neville, 1990; Scates, 1976). In the current study, it was found that the proprioceptive sense was affected in different joint angles according to experience. Thus, these specific angles can be considered as contact time of the hand with the ball. The finding was consistent with the study by Janwantanakul et al. (2001). They evaluated shoulder proprioceptive sense in the middle rotation ranges (50º, 70º). The comparison of position sense between these two positions showed that shoulder proprioceptive sense tented to be better at the 50º because daily activities are usually performed around the middle of total ROM. Besides, this result supported previous reports by Ahissar & Hoschstein (1993) and Gold et al. (1999).

When volleyball skills are taken into consideration, the overhead hitting movements play a significant role in success, so training programs must include teaching methods and practices to perform these movements properly. Experienced volleyball players with extensive competitive and training experience are likely to have more advantages than those of inexperienced players to perform overhead skills. Besides, it might be that they have better proprioceptive sense than that of inexperienced volleyball players at smaller angles which overhead skills are usually performed (Neville, 1990). It may be the reason why experienced players had not fatigue effect, whereas, inexperienced players had fatigue effect on proprioceptive sense in smaller angles.

Finally, the study revealed that there was no significant difference between experienced and inexperienced volleyball players in respect to proprioceptive sense at each angle separately in both directions before and after fatigue.

The major characteristic of volleyball is that specific game phases, passing serve, setting, attacking or blocking, occur repeatedly at regular intervals. Thus, players must identify a particular game condition and various possibilities for action quickly during the match in order to execute proper action against opponent players (Fröhner, 1998). This process requires mainly high skills of decision-making. An important performance measure indicating the speed and effectiveness of decision-making is reaction time and the amount of practice. The amount of experience is one of the most important factors affecting reaction time (Schmidt, 1991). In addition to this, the ability of checking information received through the sensory organs during performance has an effect on reaction time as well as performing proper movement (Fröhner, 1998). So, experienced players with extensive practices have more advantages than those of inexperienced players in decision-making. In this study, as long as participants were divided into two groups as experienced and inexperienced, the main criteria for this division was the league they play. However, when we analyzed the demographic characteristics of participants, it can be said that the groups were almost similar in respect to their mean heights, body weights, BMI and training hours per week. This can be an explanation for not finding significant difference between groups in terms of their proprioceptive senses. Since no previous study has evaluated the effect of experience on shoulder proprioceptive sense among male volleyball players, further investigation is needed to substantiate this finding before a final conclusion can be reached.

According to the findings of the study, it can be concluded that the effect of fatigue on proprioceptive sense is related with experience and on the other hand experience has no effect on proprioceptive sense.

The results related to the effect of different positions on shoulder proprioceptive sense are inconsistent with each other. It is technically difficult or impossible to measure the participation of different proprioceptors in any movement. Furthermore, the evaluation of the same receptors before and after fatiguing contraction in human beings is also devastating. This can be the reason why there were contradictory results in the current study and also the literature. The Biodex system 3 pro facilities to measure proprioceptive sense at slow speeds (e.g. 2 deg/s) and to apply fatigue analysis safely, however, measurements executed by more sensitive machines will enable scientists to reach more reliable results in the future. The possibility that subjects may recover from fatigue in external rotation is believed to be a potential problem with this study’s methodology. It is recommended to decrease the number of angles of tests so that measurements can be accomplished within three minutes after fatigue. The current study was executed on 20 experienced and 20 inexperienced male volleyball players. A larger number of participants in future studies will be beneficial. Besides, investigating proprioceptive sense among female volleyball players and the relationships between male and female volleyball players will help to understand the effect of gender factorson shoulder proprioceptive sense.

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APPENDICES

APPENDIX A

PERSONAL INFORMATION SHEET

(PIS)

Tarih:

Ad-Soyad:	Boy:
Yaş:	Kilo:
BMI:	Oynadığı takım:
Telf. num:	İmza:

1. Kaç yıldır spor yapıyorsunuz?
....

2. Bugüne kadar dominant omuzunuzdan sakatlık geçirdiniz mi? Cevabınız evet ise, yaralanmanın adını ve yaralanma tarihini belirtiniz lütfen!

- Evet sakatlık geçirdim;

....

....
....
....

- Hayır hiçbir sakatlık geçirmedim.

3. Haftada ortalama kaç saat antrenman yapıyorsunuz?
....……
4. Yılda ortalama kaç saat antrenman yapıyorsunuz?
……………………………

APPENDIX B

INFORMATIVE CONSENT

Omuz ekleminin, fonksiyonel gerekliliklerini yerine getirebilmesi için geniş bir hereket açısı başka bir ifadeyle esnekliği vardır.Bu esnekliği oluşturan faktör ise omuz ekleminin kemik desteğinin az olmasıdır. Bu nedenle günlük yaşam ve spor aktiviteleri sırasında eklemin stabilitesi yani humerus başını glenoid kaviteye merkezlenmesi daha çok eklemi çevreleyen bağlar, kapsül ve kaslar tarafından sağlanmaktadır. Kapsül ve bağların gevşek olup eklem stabilitesine katkıda bulunmadığı mid-range pozisyonda ise bu görev omuz ekleminin primer hareket ettirici kasları olan rotator cuff kas grubu tarafından sağlanmaktadır.

Yaşın ilerlemesi ve omuz ekleminde meydana gelen tekrarlı hareketler, omuz ekleminde yaralanma riskinin artmasına neden olmaktadır. Bu risk başüstü kol hareketlerin çok kullanılduığı voleybol, basketbol, hentbol gibi spor dallarıyla uğraşan sporcularda çok daha fazla artmakta ve sakatlanmaya neden olarak sporif perfonmansın düşmesiyle sonuçlanmaktadır.

Tüm bunlardan yola çıkılarak hem sportif performansın arttırılması hemde yaralanma oranını düşürülmesi amacıyla çeşitli araştırmalar yapılmış ve omuz eklem yapısını güçlendirmeye yönelik çalışmalar geliştirilmiştir. Bu çalışmalar omuz kas kuvvetinin ve desteğinin artırılması yanında omuz propriocepsiyon duyusunun artırılmasına yönelik olmuştur.

Propriosepsiyon duyusu, kinestezi (eklem hareket hızının ve miktarının algılanması) ve statik eklem pozisyon hissinin algılanması şeklinde tanımlanabilir. Algılamayı sağlayan kas, eklem, bağ ve tendonlarada bulunan ‘reseptör’ dediğimiz alıcılardır. Bu algılamalar sonucunda elde edilen bilgilere göre vücut kas tonusunu düzenleyen motor cevabı oluşturarak, statik ve dinamik hareketler sırasında vücudun stabilitesini sağlayıp, çevreye göre vücudun konumunu koruyabilmesini sağlamaktadır. Diğer bir deyişle vücut, propriosepsiyon duyusu sayesinde dışarıdan gelen kuvvetlere karşı kasları anında kasarak dengeyi ve doğru hareketi sağlamaktadır.

Tüm bu bilgiler gözönüne alındığında propriosepsiyon duyusu, hem doğru hareket paterninin oluşturulması ve hemde omuz eklemi stabilitesinin sağlanmasını sağlayarak sportif performans açısından çok önemlidir. Geliştirilmesi kadar kaybının önlenmesi de hedef olmalıdır. Bu amaçtan yola çıkarak yapmış olduğumuz ba çalışmada, değişik hareket açılarının, yorgunluğun ve spor tecrübesinin omuz propriosepsiyon duyusu üzerine etkisini araştırarak, elde ettiğimiz bulgularla sportif performansın artılrılması için bu alanda çalışan disiplinlere yol göstermektir. Testler sırasında kullanılan hareket paternlerinin ve ölçüm için kullanılan 'Biodex System' isokinetik cihazın sporcunun sağlığını olumsuz yönde etkileyen hiçbir özelliliği bulunmamaktadır.

Sonuçlar çalışmanın tamamlanmasından sonra size ulaştırılacaktır.Çalışmamıza katıldığınız için teşekkür ederiz.

Fzt. Nilüfer KABLAN

▪▪

Yukarıda verilmiş olan bilgiler doğrultusunda bu çalışmaya gönüllü olarak katılmayı kabül ediyorum.

Ad-Soyadı: İmza: