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HACETTEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

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Prof. Dr. Filiz CAN (PT, PhD, Full Prof.)

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This study has been accepted and approved as a Master / PhD dissertation by the examining committee, whose members are listed below.

Chair of the Committee and Advisor of the Dissertation:	**Prof. Dr. Filiz Can** **Hacettepe University**	(Signature)
Member:	**Prof. Dr. Ayşe Karaduman** **Hacettepe University**	(Signature)
Member:	**Prof. Dr. Zafer Erden** **Hacettepe University**	(Signature)
Member:	**Prof. Dr. Ulunay Kanatlı** **Gazi University**	(Signature)
Member:	**Assist. Prof. Emin Ulaş Erdem** **Bülent Ecevit University**	(Signature)

APPROVAL

This dissertation has been approved by the committee above in conformity to the regulations and bylaws of Hacettepe University Graduate Programs andhas been accepted by the Board of Directors of the Institute of Health Sciences.

(Signature)

Prof. Ersin FADILLIOĞLU, MD

Institute Director

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ÖZET

Dmitry Chan, Fizyoterapide Lokal ve Genel Kas-Eklem Uygulamalarının, Omuz Propriosepsiyonu Üzerine Olan Akut Fasilitasyon Etkileri, Doktora Tezi, Fizyoterapi ve Rehabilitasyon Programı, Ankara, 2015. Önceki çalışmalarda, bir kaç haftalık eğitim programı olarak uygulanan çeşitli egzersiz yaklaşımlarının, propriosepsiyonu geliştirmede etkili olduğu bildirilmiş; ancak egzersize dayalı yaklaşımların etkileri, genellikle kuramsal olarak verilmiştir. Bu nedenle bu çalışma, sağlıklı bireylerde tek seanslık farklı fizyoterapi ve egzersiz uygulamalarının, omuz propriosepsiyonu üzerine olan akut etkilerini incelemek amacıyla yapılmıştır. Çalışmada, propiosepsiyon üzerine olan akut etkilerin, hem büyüklüğü, hem de süresi ölçülmüştür. Yaşları 19-37 arasında değişen, 55 kadın, 50 erkek, toplam 105 sedanter sağlıklı birey çalışmaya alınmış ve randomizasyon yolu ile 6 uygulama ve bir kontrol grubuna (n=15) ayrılmıştır. Gruplar, Aktif Egzersiz Grubu (belirlenen bir hızda aktif hareketler), Pasif Egzersiz Grubu (pasif hareketler), Manual Terapi Grubu (omuza manual terapi uygulaması), Stabilizasyon Grubu (omuza stabilizasyon egzersizleri), Pliometrik Egzersiz Grubu (omuza pliometrik egzersizler) ve Genel Isınma Grubu (koşarak yapılan ısınma) olarak ayrıldıktan sonra tek seanslık fizyoterapi uygulaması yapılmıştır. Omuz propriosepsiyonu, tüm bireylerde kinestezi (hareket hissi) ve eklem pozisyon hissi olarak, "2.0" versiyon orjinal propriosepsiyon aleti kullanılarak ölçülmüştür. Dominant omuzda ROM'un % 50'si içinde, %70 iç rotasyon ve % 90 dış rotasyonda yapılan ölçümler, oturma pozisyonunda, ilk gün, uygulama öncesi, uygulama sonrası, uygulamadan 30 dakika, 1 saat ve 1 gün sonrasında tekrarlanmıştır. Kontrol grubundaki bireylerin propriosepsiyon değerlerindeki aşırı değişkenlik nedeniyle 105 bireyin tümünün propriosepsiyon değerleri ölçülmüş ve alınan bu baz değerler, her bir grup için karşılaştırma referansı olarak kullanılmıştır. Tek seanslık uygulamadan sonra Aktif Hareket Grubunda baz değerlere göre kinestetik duyuda belirgin bir azalma olmuştur ($p<0.05$). Hem Pasif Hareket, hem de Manuel Terapi grubundaki bireyler, uygulamadan sonra (çoğunlukla ROM sınırları içinde olmak üzere) uygulama öncesine göre ve baz değerlere göre propriosepsiyonda anlamlı gelişmeler göstermişlerdir ($p<0.05$). Buna karşılık Stabilizasyon Grubu ve Pliyometrik grup için, tek bir uygulama seansının propriosepsiyonu değiştirmeye yetmediği gözlenmiştir ($p>0.05$). Genel Isınma grubunda ise, bir sonuca varamayan bulgular ortaya çıkmıştır ($p>0.05$). Ek olarak tüm bireylerde, hareketin yönünün, pasif hareket algılama eşiğinin testi sırasında propriosepsiyon ölçümlerini etkilediği bulunmuştur ($p<0.05$). Ayrıca proprisepsiyon ölçümünde kullanılan kinestezinin (hareket hissi), eklem pozisyon hissine göre daha hassas bir ölçüm yöntemi olduğu sonucuna varılmıştır. Sonuç olarak, sağlıklı bireylerde tek seanslık bir fziyoterapi uygulaması, propriosepsiyonu anlamlı derecede etkilemek için yeterli olmayabilir. Pasif egzersiz ve manuel terapi uygulamaları ile bazı gelişmeler görülebilir. Aktif egzersiz uygulamaları sırasındaki kortikal adaptasyon ve öğrenmenin, mekanoreseptörlerin lokal stimulasyonundan daha önemli olabilir. Tekrarlayıcı aktif hareketler ile ortaya çıkabilecek kas yorgunluğu sonucunda propriosepsiyonda görülebilecek azalma, klinik uygulamalar sırasında daima gözönünde bulundurulmalıdır.

Anahtar Kelimeler: Propriosepsiyon, eklem pozisyon hissi, kinestezi, omuz, egzersiz, ısınma, pliyometrik egzersiz

ABSTRACT

Dmitry Chan, The Acute Facilitation Effects of General and Local, Muscular-Articular Interventions in Physical Therapy on Shoulder Proprioception, Doctoral Thesis in the Program of Physical Therapy and Rehabilitation, Ankara, 2015. Various exercise interventions applied as a course lasting for several weeks have been reported to be effective on improving proprioception. The underlying causes are only hypothesized about. This study aimed to investigate the acute effects of one time intervention derived from different aspects of exercises on shoulder proprioception of healthy subjects. Both the magnitude and the duration of effect were aimed to measured. 55 female and 50 male, a total of 105 sedentary healthy subjects aged between 19 and 37 years old, were randomly divided into 6 intervention and a control group (n=15). The groups were: Active Movement Group (active movement at predetermined speed), Passive Movement Group (passive movements), Manual Therapy Group (joint play of glenohumeral joint), Stabilization Group (shoulder stabilization exercises), Plyometric Exercise Group (shoulder plyometrics) and General Warm Up Group (warm up through jogging). Each group received single intervention. Shoulder proprioception has been assessed as Joint position sense, and kinesthesia using original proprioception testing device version 2.0. Dominant shoulder at 70% internal rotation, 90% external rotation and 50% of ROM were measured in sitting position on first day, pre, post, 30 minute, 1 hour and 1 day post interventions. Increased variability of proprioception in control group necessitated use of baseline proprioception values of all 105 subjects as comparison reference. In active movement group there was a decrease in kinesthetic sense compared to baseline after intervention ($p<0.05$). Subjects in both passive movement and manual therapy group showed improvements in proprioception mainly at the extremes of ROM, either within group or against baseline ($p<0.05$). Single session of intervention was not sufficient to change proprioception in stabilization and plyometric groups ($p>0.05$). Inconclusive results were seen in warm up group ($p>0.05$). Additionally the direction of movement during testing of threshold to passive movement detection was found to affect proprioception measurements ($p<0.05$). Furthermore, kinesthesia testing might be more sensitive test for proprioception then joint position sense test. In conclusion, one time intervention might not be sufficient to significantly affect proprioception in healthy subjects. Although some improvements may be seen with passive exercises and manual therapy, cortical adaptation and learning rather than local stimulation of mechanoreceptors might be more critical to increase proprioception with the other exercises. Clinicians should be aware of possible decrease in proprioceptive acuity with repetitive active movements due to muscle fatigue.

Key words: proprioception, joint position sense, kinesthesia, shoulder, exercise, warm-up, plyometric

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SYMBOLS AND ABBREVIATIONS

cm	centimeter
kg	kilogram
mm	millimeter
n/N	number
oPTD	Original Proprioception testing device
p	statistical significance value
sec	second
sig	significance
v	version
AC	Acromioclavicular
BMI	Body Mass Index
C	Cervical
CNS	Central Nervous System
EMG	Electromyography
ER	external rotation
F	female

GH	Glenohumeral
GTO	Golgi tendon organs
HR	heart rate
IGHL	Inferior Glenohumeral Ligament
IR	internal rotation
JPS	Joint position sense
L	left
LHB	Long head of biceps
M	male
Max	maximum
MGHL	Middle Glenohumeral Ligament
Min	minimum
N.	Nervous
PNF	Proprioceptive Neuoromuscular Facilitation
PNS	Peripheral Nervous System
PTD	Proprioception testing device
R	right
ROM	range of motion

SC	Sternoclavicular
SD	standard deviation
SGHL	Superior Glenohumeral Ligament
T	Thoracic
TTDPM	Threshold to detection passive movement
TTDPMD	Threshold to detection passive movement direction
ULTT	Upper Limb Tension test
VO_2	volume of oxygen
Z	statistical coefficient
α	Alpha
Ø	diameter
°	degree
γ	Gamma
%	percent
±	plus minus

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1 INTRODUCTION

A human movement is an intricate balance between external forces acting on the body and internal forced working within body to oppose external forces and to propagate voluntary or involuntary movements by a human. The responding units are muscles that span between skeletal bones and act through the joints causing movement of body parts and skeleton in total. The orchestration of movements is coordinated by various levels of the Central Nervous system (CNS), and is delivered to muscles by means of electrical signals via Peripheral Nervous System (PNS). Each joint in a human body can be viewed to be in two different states. One is immobile or static and the other one is moving or dynamic. Most joints are meant to be moved, therefore are inherently unstable in one or more directions. Therefore, in order for a joint to be immobile it should be stabilized. Muscles, ligaments and the shape of the joints act to provide stability of the joint. Similarly during motion, an internal or external force must be exerted over a body segment in order to move. An indiscriminate force will likely disrupt the joint movement rather than it will cause a functionally meaningful motion. Therefore, a dynamic stability of the joint is essential for coordinated motion. Once again muscles, ligaments and shape of joints function to provide the dynamic stability. The system responsible for providing functional stability of the joint, static or dynamic stability, is called sensori-motor system. Sensori-motor system works parallel and in the background of human locomotion or even while holding a static position(1).

Sensori-motor system can be divided into 3 distinctive components. The afferent system or proprioception that is responsible of sensing the position or movement of body segments as well as forces through the joints. The central integration or processing of signals coming from proprioceptive system, and the efferent output system or motor control(1-3).

While sensori-motor system functions are adequate and capable to cope with demands of daily living, its' functions can be disrupted during pathological conditions such as injury, pain, etc. Similarly state of fatigue negatively affects functional stability of the joint(1, 3-14). Vice versa a disrupted joint stabilization system might cause an injury or disruption. For an example, poor perception of movements in the ankle joint can predispose a person to have an inversion trauma of an ankle(15).

As it becomes evident, it can be beneficial to improve functioning of sensori-motor system to allow it to cope with wide range of activity demands. Three components of the system can be influenced. While in theory these three components are well defined, however, it is next to impossible to separate them and influence one by one in practice. In a human body sensori-motor system works as a whole. Recently many researchers have been focused on proprioception- the afferent component of sensori-motor system. How well does the human body is able to percept the forces, position or perturbations on the body segment or a joint might be critical in shaping the response to the stimuli.

From a physical therapy and athletic training point of view, exercise training is the most common tool of training and conditioning of human body. Many authors agree that proprioception can be affected by exercises(2, 3, 16-26). Several studies in the literature have been devoted to prove the effectiveness of one or another exercise based programs on proprioception. Various exercise programs have been tested lately, and some were found to be effective the others were not. Each time the researchers propose various theories to argue the obtained results. Some of the theories are in coherency with the others, while others are not. Therefore, it might be beneficial to deconstruct various exercises into basic characteristics and to test them against the proposed hypotheses. A good starting block would be to find out acute effects of single session physical therapy intervention or exercise on proprioception.

From a perspective of proprioception receptors, the afferent input can arise mainly either from joint receptors or from muscle receptors. The role of both has been already identified. Almost any exercise involves both the joint and the muscle. Joint receptors such as Pacinian corpuscle and Ruffini end organs as well as free nerve endings, do play role in proprioception(27). David Suprak found that at higher elevation angles of shoulder where there a greater capsular stretch the JPS, proprioception is more acute then in lower angles(28, 29). Furthermore, J. Munn's narrative review pointed out that ligament laxity associated with ankle instability negatively affected JPS in ankle(30). However, a hypothesised decreased viscosity of joint capsule and ligaments introduced via cold pack over joint for 20 minutes did not show to decreased joint proprioception in two studies(31, 32). Finally and most valuable the study by Ju focused on positive effects of repetitive passive joint motion on proprioception. Ju and colleagues found that at high angular velocity of 90 and 150 degrees per second, both JPS and kinaesthesia improved. However, this effect was not observed at low speed of 2 degrees per second. Such low speed might have not been sufficient to cause sufficient capsular and ligament stretch(33, 34). Some body of evidence exists suggesting that during mid ranges of motion of the joint the capsule and ligaments are not being stretch sufficient to cause discharge of joint mechanoreceptors(35, 36).

There is still lack of enough information in the literature regarding the effect of manual therapy on proprioception, although manual therapy has been using commonly for shoulder problems in the clinical practice. One interesting aspect of capsular stimulation without angular displacement via manual therapy joint play techniques was poorly studied up to date(37). However, knowing the proven effect of manual therapy on proprioception would be valuable in planning of physical therapy and rehabilitation program for the physical therapists. This may also clarify which mechanism would be more critical for stimulating of the joint receptors. Furthermore, it might enlighten to differentiate the effect of local stimulation of the mechanoreceptors.

The role of mechanoreceptors located in muscles and tendons during mid ranges of motion have been studied and revealed possible lack of stimulation of joint receptors in mid ranges. Muscle of mammals and humans have complex system of muscle spindles that are able to sense not only the stretch of muscle tissue, but also the rate of the stretch. Additionally, Golgi tendon organs located parallel to muscle tissue give feedback on the amount of stretch going through the muscle tissue(1, 3, 20, 30, 38-43). Stimulation of muscle itself was observed to have both positive and negative effects on proprioception. Nonetheless, the effects on proprioception in both cases are evident. Over stimulation of muscle to a point of fatigue was found to decrease proprioception(7, 8, 34, 44, 45). Lee Hung-Maan found that at 50% of maximal voluntary peak torque decline due to fatigue proprioception decreases(46). However, loading a muscle less than its fatigue level proves beneficial to proprioception. A study by David Suprak found that giving load to an arm in lifting task improves proprioception(47). Furthermore, in the earlier mentioned article, David Suprak argues that a greater tension associated with increased elevation angels is responsible for greater accuracy of JPS at extremes of range of motion(29). Otmar Bock applied vibration of 50Hz frequency to muscle tendon and observed perceived sense of motion due to interference with muscle spindles afferent output(48). Similarly degeneration of muscle and tendon in chronic supraspinatus impingement degraded force sensation and proprioception in several studies (5, 11).

Clinically many protocols aimed at improving proprioception focus on strength building(17, 18, 27, 49-51). Muscle bulk might be responsible for increased joint stability and proprioceptive afferent (52-54). Other valuable exercises are balancing and stability exercises. The proposed mechanism of benefit is the level of muscle co-contraction associated with these exercises. In order to provide active stability to a joint a simultaneous activation of agonists and antagonists is happening(2, 17, 27, 49-51). While this theory largely derives from clinical experience, there is still lack of scientific evidence aside from wobble board exercises supporting it. Wobble board exercises were found beneficial for increased muscle onset of peroneal muscles of a foot and subsequent functional stability(55). Another possible explanation is the cortical adaptation and learning effect evolved from increased afferent input from muscle spindles, as well as joint and articular receptors.

Some exercises cannot be classified as mainly affecting joints or muscles. The best examples are plyometric exercises. While originally plyometric exercises were aimed at explosive power training method, lately a beneficial effect was found to proprioception. K.Swanik studied effect of plyometrics on shoulder proprioception of female swimmers, and found great benefits of it(25). In accordance with the study of Swanik, we have observed similar benefits of plyometrics on JPS and kinesthesia on sedentary subjects in our previous study(26). According to these two studies, the proposed mechanism of action is the increased stimulation of muscle spindles under high load of eccentric and concentric contraction, as well as stimulation of joint receptors at the ends of range of motion through which a joint is brought at each plyometric exercise(25, 26).

Finally, a warm up effect associated with performance level should not be disregarded as a method to influence proprioception. Temperature increase of a body has been proven to cause many beneficial effects to human body, such as increase in metabolic activity of muscle cells, increase in nerve conduction velocity and overall improvements in muscle performance(56-60). There are two possible ways of raising body temperature, passive and active one. Passively, direct application of hot pack might increase skin, joint and muscle temperature. In turn, this application can aid in increased viscosity of a joint(57, 61, 62). However, actively exercising can have a similar increase in area temperature via repetitive active motion of the joint. The demands of muscle activity will cause a greater peripheral circulation and increased blood flow, which eventually will increase the temperature of muscle and joint itself. Much literature agrees that warm up exercises are beneficial for muscle activity and contract ability(43, 57, 63-66). Concentric warm ups showed to decrease soreness from eccentric activity(67). A leading cause of muscle soreness is a buildup of lactic acids in the muscles as waist products of its activity. These are the same lactic acids which are responsible for muscle fatigue and degradation of proprioception. Following this logic an active warm up exercises might be beneficial to proprioception. Subasi's study on health young subjects confirms this theory(68). Although majority of researchers focus of direct activity of joint in interest from warm up perspective, unfortunately, this method for this proposal is invalid due to possible overlap of effects with active or passive joint motions. Therefore, it might be valuable to approach a joint warm up as a part of whole body warm up achieved through aerobic activities such as running. These activities are also effective in raising body temperature. Not surprisingly, there is no study in the literature to this date on benefits of whole body warm-up exercises on proprioception of a joint not primarily involved in the activities.

In the literature, there is not enough study which assess both active and passive joint position sense using objective measurement devices for shoulder joint. Some authors have used measurement of passive joint position sense, whereas the others have claimed measurement of active joint position sense will give more accurate data for assessment of proprioception. However, both active and passive joint position senses may be more valuable parameters for measuring proprioception and would be helpful for discussion. Furthermore, there is still a debate on effect of various type of exercises like plyometrics, stabilization exercises, active or passive range of motion exercises for shoulder proprioception. It is also unclear the results of some physical therapy interventions such as manual joint mobilization, vibration or whole body warm up exercises which have never been studied to investigate the effectiveness of them on shoulder proprioception.

From a numerous proposed mechanisms that physical therapy interventions like manual therapy and various types of exercises might have an effect on proprioception, the aim of this study was to deconstruct a shoulder exercises and other physical therapy interventions like manual joint mobilization into various components and test each one in particular. In other words what affect, if any, does each component of exercise has on proprioception. It has been aimed to focus on proprioceptive system rather than learning component or central integration of the central nerve system. Therefore, the interventions were limited to acute effects of single time stimulus rather than a training protocol. Finally, this study based on not only the magnitude, but also the duration of the effect on proprioception is important to judge which component of exercise or intervention has the greatest effect. In addition to that comparing each intervention will be a sensible analysis to perform based on gathered data. This kind of detailed approach has not been attempted yet in any of the studies, and will help to gain deeper understanding of the mechanism in effect.

Based on outlined goals of the study, several research hypotheses were established.

H1- There will be difference in shoulder joint proprioception between intervention group and a control group immediately after interventions

H2- There will be difference in shoulder proprioception within intervention group between initial assessment and at a specific time interval after interventions

H3- There will be difference in shoulder proprioception between intervention groups immediately after interventions

H4- There will be difference in shoulder proprioception between intervention groups at specific time intervals after interventions

In order to test our hypotheses, multi group randomized control trial with variation of repeated measures study was designed. Glenohumeral joint of dominant arm was studied. The choice of investigating glenohumeral joint was made by considering functionality of shoulder joint which allows motion in great variety of planes and requires both capsular ligamental structures as well as muscles to stabilize the joint.

Six intervention groups and one control group comprised the study. The intervention groups were: active movement, manual joint mobilization, passive movement, plyometric exercises, stabilization, and general warm up. Each group consisted of 15 healthy sedentary subjects, who were recruited from university students, administration and academic population. Total number of participants was 105. The study was conducted at Physical Therapy and Rehabilitation Department, Institute of Health Sciences of Hacettepe University. The study typically lasted 3 days for each participant and took place between June 2014 and January 2015.

The results of this study will be beneficial to lay foundation for the effects of various components of exercises and other physical therapy interventions as manual therapy for shoulder joint on proprioception. Based on the results greater understanding could be reached about the physiology of proprioception and effects of exercises on it. Furthermore, clinician could benefit from knowing the magnitude and duration of particular exercises on shoulder proprioception and subsequently adjust the treatment program for shoulder based on treatment requirements.

2 GENRAL KNOWLEDGE

2.1 Shoulder joint anatomy and physiology

2.1.1 Bones

Shoulder girdle is a major part of human body, the main role of which is to put arm into functional positions for hand manipulations. The shoulder girdle is composed of three bones, numerous of muscles which make the arm move as well as moving the shoulder girdle itself in relation to thorax and several ligament structures that help to restrict the movements. Human typically needs to reach various objects in a great field in front, therefore shoulder girdle should allow great range of motion.

The three bones of shoulder girdle are clavicle, scapulae and humerus. The clavicle is a long slightly S-shaped bone having two articulations on each end. Proximal clavicle articulates with sternum, 1st and 2nd rib, making the only true joint between the shoulder girdle and the rest of the body(69-71). Sternoclavicular joint allows 40-45 degrees of elevation and 5° depression. 15° of anterior and posterior glide, and finally 30° to 50° of axial rotation. Distal end of clavicle meets with acromion of scapular bone forming acromioclavicular joint (35, 52, 69, 72). The role of the clavicle is to provide attachment of upper extremity to thorax as well as giving base for muscle attachment. Additional role of clavicle is to protect subclavial vascular and nervous structures from compression of hanging arm.

Scapular is thin, triangular bone. It serves as a major attachment site for muscles. Numerous prominences are notable on the scapular. Spine of scapular divides the bone into supraspinatus and infraspinatus fossas where the similar named muscle originate. The spine of scapular itself serves as attachment side for trapezius muscle acting as an effective lever arm for the muscle. From superior edge of scapular, laterally and anteriorly the acromion protrudes. The deltoid muscle broadly originates from acromion. Furthermore acromion articulates with clavicle. Acromion hangs over the head of humerus creating a space in between called subacromial space. Numerous rotator cuff tendons and biceps long head tendon pass in the subacromial space. The space is being protected by subacromial bursa. However, pathological conditions commonly arise if the subacromial space is compromised.

The coracoid process comes of the scapular upper anterior neck. It passes anterior and hooks to the lateral position. It functions as an origin of short head of biceps muscle and an insertion of pectorals minor muscle.

At the lateral corner of scapulae the final process called glenoid. The glenoid is a concave articulation surface of glenohumeral joint between scapulae and head of humerus. The shape of glenoid resembles a pear being narrower superiorly and wider at the base. The glenoid is tilted 3-5° superiorly and has 6-7.4°of retro tilt in relation to the sagital plane of scapulae(54, 71-73).

The position of scapulae and the motion with relation to the thorax is critical. 30° protraction forms an angle between scapulae plane and frontal plane. 3° of external rotation and 20° of anterior tilt is also present(35). While there is no true articulation between the scapulae and thorax, none the less by the actions of muscles between scapulae and thorax several motions of are possible: elevation, depression, adduction, abduction, upward and downward rotation. In addition to this, anterior and posterior tilts are present(35, 52, 74).

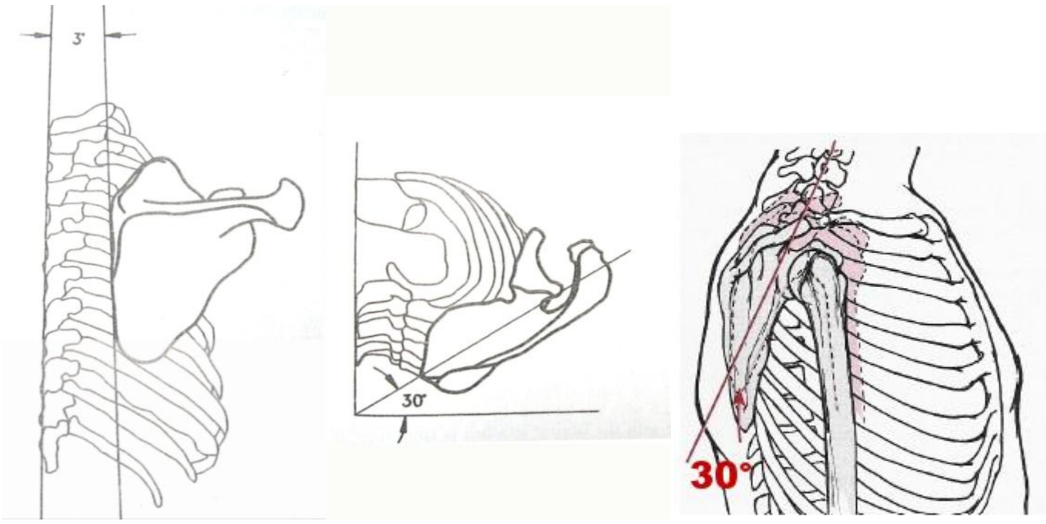


Figure 2.1. Scapular position(35)

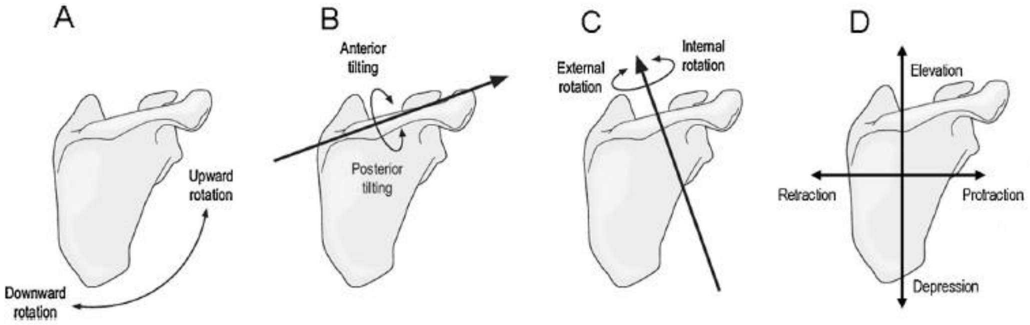


Figure 2.2. Motions of scapular(75)

The function of scapulae is to provide stable base of support for rotation of the humerus. In addition to that, the movement of the scapular bone ensures the proper orientation of glenoid fossa allowing the scapulohumeral muscles to retain optimal length-tension relationship. Furthermore scapular bone provides a platform for muscles attachments of muscles that move upper extremity as well as muscles that stabilize shoulder girdle on the thorax. Finally, movement of the scapulae on the thorax gives additional range of motion in shoulder without overstressing glenohumeral joint(35, 70-72).

Humerus is a long bone of upper arm. The proximal part of humerus has several prominent sites, humeral head, neck, greater and lesser tuberosities and intertubercular groove(71). The cartilage surface of greater head of humerous articulates with glenoid fossa having 135° medial inclination and 25±5° retroversion(35, 69-72). The lesser tuberosity lies anteriorly on the neck of the humerus, where as the greater tuberosity faces laterally. The grove in between is called intertubercular groove and causes passage of long head of biceps. Subscapularis muscle inserts at lesser tuberosity, while the greater tuberosity functions as insertion for supraspinatus, infraspinatus and teres minor muscles. This group of four muscles is called rotator cuff due to joint tendon that cuffs around humeral head. Furthermore, latisimus dorsi and pectoralis muscles insert at medial and lateral lips of humeral shaft respectively. Finally deltoid muscle attaches at the deltoid tuberosity(71).

2.1.2 Joint capsule and ligaments

Glenohumeral (GH) joint is the main articulation of shoulder girdle with the greatest range of motion. This is a synovial articulation comprised on one side of ball shaped head of humeruos and the pear shaped concave glenoid fossa of scapulae. The humeral head has diameter ranging from 37 to 55 mm, covered with cartilage tissue. On the concave side glenoid fossa is much smaller than humeral head with longitudinal measurement of about 41 mm or just 75% of head of humerous. Transversally only 25mm or 60% of humeral head is covered by glenoid fossae. Furthermore the convexity of humeral head is greater than concavity of glenoid fossae. This makes the glenohumeral joint rather unstable ball and socket joint(53, 72, 74).

In order to increase depth and the contact area of the joint fibrocartilage structure called glenoid labrum surrounds the glenoid fossa creating a rim. The glenoid labrum blends into articular capsule of the joint(35, 53, 54, 72, 74).

The glenohumaral capsule running from the glenoid labrum encircles surgical neck of humerous. The capsule is lax and allows traction of about 1 cm, however it performs valuable function of creating negative pressure inside the joint, which ensures joint integrity and provides additional stability(35, 53, 70, 72).

Number of intrinsic to the capsule ligaments of glenohumeral joint provide stability to the inherently unstable joint. The superior glenohumeral (GH) ligament runs over the long head of biceps whereas middle GH ligament lies under sub subscapularis tendon. The inferior GH ligament has 3 distinctive portions: anterior, posterior and inferior bands that have specific functions. The inferior band of GH ligament is being loose in resting position. The anterior band is becoming taut during abduction and external rotation, whereas posterior band of GH ligament is becoming taut in adduction and internal rotation. Inferior band of inferior GH ligament prevents inferior subluxation of humerus(35, 53, 54, 69, 70, 72).

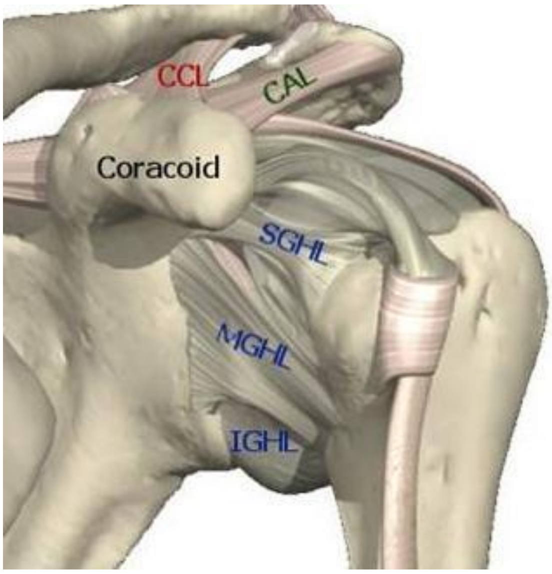


Figure 2.3. Ligaments of glenohumeral joint(76)

2.1.3 Muscles

Muscles perform the actions, which allow us doing all ranges of activities in our daily life. Aside from making the functional movements, muscles have a wide range of other activities, which are not appreciated. This is particular true for shoulder joint where muscles act as stabilizers of the joint, restrictors of the movement, shock absorbers, primary and secondary movers. Before considering interactions of shoulder muscles the review of each group of muscles of shoulder girdle should be done. Based on origin, insertion and isolated function muscles can be divided into ccapulothoracic muscles and glenohumeral muscles.

Scapulothoracic muscles:

Scapulothoracic muscle ensure position and movement of scapulae on the thorax. Trapezius muscle originates from spinal process C7-T12 and inserts along distal 1/3 of clavicle, acromion and spine of scapulae. The muscle has three distinct portions the descending part, transverse and ascending parts. If all portions of muscles fire together the retraction of the scapulae will occur. However, the coordinated contraction of upper and lower fibers create upward rotation of scapulae which is critical for scapulohumeral rhythm between the motion of scapulae and humerous is shoulder elevation(70, 72).

Rhomboid muscle consists of minor and major rhomboids also functions as scapular retractor and assists in scapular elevation. Levator scapulae acts to elevate superior angle of scapular bone. However, coupled with action of serratus anterior causes upward rotation of the scapulae. The serratus anterior is a broad muscle made of three slips originating from first till ninth rib. The serratus anterior muscle inserts along medial border of the scapulae from superior to inferior angles. Serratus anterior protracts scapula(70, 72). Furthermore during the elevation and in particular flexion of the arm the muscle keeps the medial border close to the thorax essentially limiting the winging of the scapulae. This action is particularly important for providing proper position of glenoid fossae and humerous(52, 70, 72). Pectoralis minor originates from anterior surface of second to fifth ribs and inserts into medial side of coracoid process. The function of this muscle is protraction of scapulae from the retraction position. In addition to that the muscle can cause downward rotation of scapular from upward rotated position(70).

Glenohumeral muscles:

Glenohumeral muscles, based on its name, act over glenogumeral joint to cause motion of the upper arm. Deltoid muscle is the largest prime mover of GH joint. It originates broadly from anterior lateral 1/3 of clavicle, acromion and spine of scapulae. All three branches have common insertion at deltoid tubercule of humerous. Anterior and middle deltoid causes elevation of humerus in scapular plane with a minor involvement of posterior deltoid at above 90° angle. Abduction movement in coronal plane performed by middle and posterior deltoid. Finally the flexion in sagital plane is a product of anterior and middle deltoid with assistance of clavicular portion of pectoralis major muscle. 60% of force produced for abduction is done by deltoid muscle(53, 70, 72).

A group of muscles called rotator cuff has a distinctive structure and a functional role. Structurally, the tendons of these muscles create a cuff that envelope humeral head, anteriorly, superiorly and posteriorly. The main action of these muscles is to provide stability to glenohumeral joint in different positions as well as causing primary movements in the joint itself.

Supraspinatus muscle originates in supraspinatus fossae inserting on the greater tuberosity of humerus. Insertion of supraspinatus is blended together and shared with two other rotator cuff muscles; infraspinatus and teres minor. Supraspinatus is active in elevation of the humerus with maximum strength exerted at 30° of elevation. With the positioning of the muscle and its tendon covering humeral head superiorly, the muscle creates force which is directly pointed into glenoid fossa, therefore compressing glenoid and humeral head together. This action is specifically important for stabilization of glenohumeral joint(35, 71).

Infraspinatus muscle with origin in infraspinatus fossae of scapular inserts just below the insertion of supraspinatus muscle at the greater tuberosity of humerous. Infraspinatus causes strong external rotation accounting to 60% of all external rotation force. Due to its orientation, the muscle together with teres minor, infraspinatus pulls humerus downwards. This pull is opposing the action of deltoid muscle, which pulls upwards to compress humerus and acromion together. The specific importance of downward pull is during initial elevation of the arm, where deltoid lever arm is yet short and large vector of deltoid muscle force is projected upwards. Infraspinatus has a major role of providing an opposing action and effectively stabilizing GH joint at various positions. Infraspinatus stabilize the joint against posterior subluxation in internal rotation by surrounding humeral head and acting as passive block. In contrast the muscle pulls to stop anterior subluxation in abduction and external rotation(35, 71, 72). Similarly to infraspinatus, teres minor is a strong external rotator causing up to 45% of force. It also pulls humerus downward and provides stability against anterior subluxation(71).

Subscapularis muscle is the anterior muscle of rotator cuff group. It originates from subclapularis fossae, which covers anterior surface of scapulae. The muscle inserts at the lesser tuberosity and just below it with 60/40% ratio. Subscapularis has a function of internal rotation as well as preventing of anterior subluxation of humerus by providing passive block. The lower fibers of the muscle act together with infraspinatus and teres minor to resist upward pull of deltoid. With coactivity of other rotator cuff muscles subscapularis provides centering force and compression of humerus into glenoid(35, 71, 72).

Teres minor, coracobrachialis, pectoralis major, latisimus dorsi and biceps are not rotator cuff muscles but these muscles cause movements in glenogumeral joint. Teres minor causes internal rotation, adduction and extension of the arm being active only against resistance. Coracobrachialis a small muscle from anterior running from choracoid process to antromedial surface of mid portion of humerus. It acts to flex and adduct arm(71).

Multi joint muscle the span across several joint cause movements in each joint simultaneously, Pectoralis major has three distinctive portions. Clavicular, medial and inferior portions originate from medial half of clavicle, mandibulum and anterior sternum, second - sixth ribs and external obligue fascia. The muscle inserts at and just below the lateral lip and bicipital groove. The actions of pectoralis major depend on the staring position of the arm. Clavicular portion can assist flexion of the arm, whereas lower portion would pull hand into extension till neutral position. Pectoralis major is a large adductor muscle. Latisimus dorsi – the large muscle originating from broad aponeurosis from dorsal spines of T7-L5, part of sacrum and crest of ilium wraps around teres major and inserts into medial floor of bicipital groove. It acts to retract and internally rotate, particularly from abducted position to adducted and extended arm and cause indirect scapular depression via pool on humerus. Finally biceps brachii, while being mainly elbow flexor, if no sufficient force is generated by supraspinatus, through the pull on the long head, causes downward and centering force to humeral head on to glenoid(71).

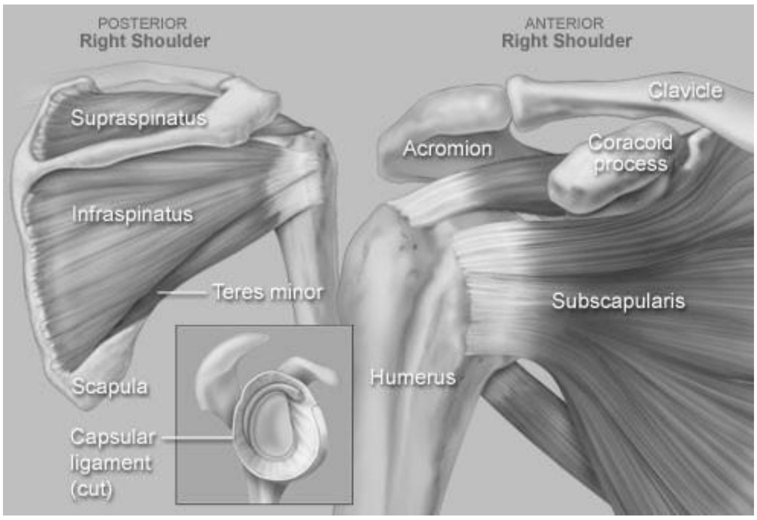


Figure 2.4. Rotator cuff muscles(77)

During flexion motion the arm is being brought in from of the body, within the visual field for hand manipulations. Therefore, flexion is arguably the most important movement of shoulder girdle. The movement of flexion is a complex interaction of movements in glenohumeral and scapulothoracic joints and is described by scapulohumeral rhythm. The exact ratio between the movements has been studied extensively. For the whole movement the ratio is considered to be 2:1 between GH and ST joints. However, the ratio changes depending of the angle of flexion. During first 25-30° of flexion a ratio 4:1 or 7:1 was noted with movement largely happening in glenohumeral joint. Following that, 5:4 or even 1:1 movements occur in glenohumeral and scapulotharacic joint. Furthermore scapulohumeral rhythm is affected by a speed of motion. During faster movements a motion in glenohumeral joint predominates in the beginning of flexion(35, 52, 53, 73, 74, 78, 79).

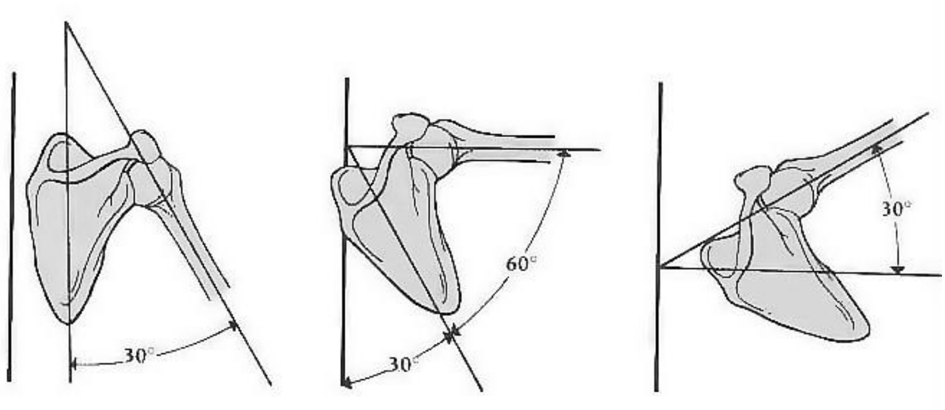


Figure 2.5. Scapulohumeral rhythm(80)

In addition to that lateral rotation and anteroposterior tilt occurs with the scapulae. During the first 90° of flexion, 6° of anterior tilt happens. Following that 16° of posterior tilt is takes place up to the full arm flexion. This gives a total of 10° posterior tilt at the maximum of arm flexion. Finally, external rotation is required during arm elevation in any plane anterior to a scapular plane. this is required to avoid the impingement of tuberosity against acromion. The other reason is that upon the rotation, inferior glenohumeral ligament becomes lax allowing more free movement. A humerus externally rotates a total of 35° in full arm flexion(35, 53).

In order to cause smooth scapulohumeral rhythm motion the action of numerous of muscles working as force couples is crucial. Lower trapezius, upper trapezius and serratus anterior muscles form the force couple responsible for upward rotation of the scapular during arm elevation. Acting over different portions of scapular simultaneous rotation of the scapular is ensured over approximate center of the bone(35, 52, 69, 72). Similarly rhomboid, teres major and latisimus dorsi muscle are force couple which is responsible for lowering the arm to the side of the body(72).

In addition to that, another force couple is responsible for elevation of the arm in glenohumeral joint. Anterior and middle portions of the deltoid muscle are mainly responsible for arm elevation. Nevertheless, teres minor, supraspinatus and infraspinatus are also active as force couples for deltoid muscle. Also, rotator cuff muscles are greatly responsible for centering of humeral head in glenoid, against shear pull of deltoid muscle at low angles of elevation(35, 52, 53, 69, 72).

2.2 Stability of glenohumeral joint

Glenohumeral joint stability is an delicate and complex task since the joint is inherently unstable . There are many factors that play a role, such as articular constraints, passive and active structures as well as its interrelationship that play a role in glenohumeral joint stability.

Articular structures. Glenoid covers only 24-30% of humeral head surface, which gives inherent instability to the joint. The ratio of glenoid length to humeral head length is 0.86 in sagital plane and 0.58 in transverse plane(35, 53, 54, 72). The apparent 7° retroversion of glenoid to the body of scapula contributes to stabilization against anterior dislocations. In addition, the shoulders with greater glenoid depth were found to be more stable(35, 53, 54, 69, 72).

Glenoid labrum which is made out of three layers of collagen is effectively deepens the glenoid and increases the contact area with humeral head. Up to 20% more translation force is needed to dislocate a shoulder with a healthy labrum(35, 50, 54, 72). In addition to that is was found that shoulders with neutral or up facing glenoid were more stable than the ones with down facing glenoid. Inferior stability of humerus was increased by bulk effect of rotator cuff muscles in upward facing glenoid(35, 69, 72).

Finally, intra-articular pressure has a contribution to shoulder stability. There is a negative pressure at all times found in the intra-articular space of shoulder joint. In case this pressure is compromised, the subluxation of shoulder joints occurs more readily (35, 69, 72).

Ligamental structures. Capsular-ligaments of shoulder are superior, middle and inferior portions of glenohumeral ligament, as well as extra-capsular coracohumeral ligament. Coracohumeral ligament was observed to have an inferior stabilization role while arm is in external rotation, but not in neutral or internal rotations(35, 53, 54, 69). Through a number of studies, superior glenohumeral ligament (SGHL) was confirmed to be an important inferior stabilizer. In accord to Dempster's global concept of stability, during inferior glide of humerus, the superior structures – SGHL are getting pulled on limiting the translation. The greatest tension on SGHL is exhibited at arm in adduction and external rotation(35, 53, 54, 69).

Middle glenohumeral ligament (MGHL) becomes most taut in external rotation and abduction. This structure provides greater stabilization against anterior dislocations in abduction and external rotation. However, there is low contribution to anterior stability from MGHL in neutral or internal rotation positions since the ligament is lax at these positions(35, 50, 69).

Careful examination of humeral capsule presents inferior glenohumeral ligament (IGHL) with 2 specific bands. Anterior band is present as a part of IGHL in all subjects, whereas posterior band is found in only 62.8% of cases. IGHL is found to be a primary anterior and inferior stabilizer in arm in external rotation and abduction. As a part of IGHL anterior band is most tight while arm is in external rotation and abduction, where as posterior band is tighter in abduction and internal rotation. IGHL is the most important static stabilizer of shoulder in anterior and inferior direction, and is plays its role while the hand is in abduction or flexion(35, 50, 53, 69, 73, 81).

Dynamic stabilizers. Muscles of shoulder have several ways to increase the stability of glenohumeral joint. Passive muscle tension from the bulk effect of the muscle, contraction that causes compression of articular surfaces, joint motions that cause secondary pulls on ligament restrains and the barrier effect of a contracted muscle. The most recognized active stabilizers of shoulder joint are rotator cuff muscle, which include supraspinatus, infraspinatus, teres minor and subscapularis, as well as long head of biceps muscle(35, 50, 52-54, 69, 72, 73, 78).

The subscapularis muscle, of rotator cuff group, is one of the most important stabilizer in anterior direction in wide variety of angles of hand elevation. The body of the muscle makes a barrier against anterior dislocation. It was also found that during arm elevation, posterior muscle – infraspinatus, teres minor and supraspinatus are being activated as well as subscapularis. Joined contraction of these muscles provides compression force of glenoid and humeral head that further increases joint stability. Furthermore, it was found that there is no even need of balanced activity of anterior and posterior cuff muscle for humeral head centering action(35, 53, 54, 69, 72, 73). Similarly to subscapularis, teres minor and infraspinatus also provide barrier against posterior dislocation(35, 53, 54, 69, 72, 73). Supraspinatus is known to be an inferior stabilizer of the shoulder joint, however this muscle also moves humeral head into external rotation and flexion. This action tightens the inferior glenohumeral ligament. Therefore, action of supraspinatus muscle gives also secondary stability to the joint via ligament structures(69, 72). In all cases rotator cuff muscles has shown to provide stability in both end and middle ranges of motion(72).

Long head of biceps (LHB) muscle was thought to provide joint stability by depressing humeral head and centering it in glenoid. However, further investigation shown that LHB to be electromyographically active only in unstable shoulders, while in stable ones there is no EMG activity of this muscle(35, 53, 69, 72).

There is interrelationship between passive and active stabilizers of the shoulder joint. The role of passive and active stabilizers of shoulder joint cannot be separated. The active structures provide greater stability at lower angles of movement, whereas passive structures play their role at the end ranges of motion. This is logical since at the lower angles of movement, the passive structures are not taut to provide greater stability(35, 36).

The position, movements, and load in the joint are detected by mechanoreceptors of passive as well as active structures. Through a reflex arch, the signal reaches active stabilizers, which in response contract and provide stability to the glenohumeral join. The critical process of recognition of position, motion or loading of a joint is called proprioception. In shoulder joint the proprioception is crucial aspect joint stability, since the dynamic stabilizers have so important role in stabilization of this joint (2, 3, 13, 14, 19, 35, 50, 82).

2.3 Proprioception and sensorimotor system

2.3.1 Homeostasis - human organism against external environment

Human body is a very complex and delicate organism which is able to operate effectively only within a narrow range of environmental conditions. While external environment exerts pressure on a human organism, human body works to preserve its most optimal working condition, this process is widely called homeostasis. Homeostasis is defined as the dynamic process by which an organism maintains and controls internal environment despite perturbations from external forces(1). In order for a human body to maintain homeostasis it must sense the environment, effectively comprehend it and produce the most appropriate response. Two different types of response control were identified. The first one is called feed backward response. In this type of response there is a reaction by the body to an external stimulus. The second response type is called feed forward, and is characterized by an anticipatory action of the body before the stimulus is sensed by the body. While some responses by human organism are automatic or reflex based, the others are more complicated and largely depend on learning process where most optimal response is refined(1).

Many different systems are responsible for homeostasis of human organism, such as thermoregulatory system made of sweat glands and circulation system, immune system etc. However, the greatest and the most effective interaction the human body has with the surrounding environment is through the movement. Every day we get up, sit, stand carry things around and more, with each movement the position of our body and body parts with respect to surrounding environment changes. Consequently the action of gravity on body part changes constantly.

2.3.2 Sensorimotor system

The sensorimotor system is a subcomponent of more global motor control system. Sensorimotor system is responsible for maintaining a joint stability during various activities of human and is crucial for execution of any movement by human, being it conscious or unconscious one (1, 2). The system can be subdivided into several parts; sensory, motor and central integration. Sensory component identifies afferent input from specific receptors, and sends afferent signals, which travel to Central Nervous System (CNS), where they are being recognized. Within CNS the afferent information is being integrated with other signals of sensory input and a common response signal is formed and is send via efferent pathways down to the movement organs – muscles (1-3, 13, 14, 19). The resultant efferent response is called – neuromuscular control (1, 3, 19). Despite anatomically the parts of sensorimotor system can be separated, the process however cannot be strictly divided into parts (1, 3). Sensorimotor system is involved in all activities of locomotor system, since for every movement there is a need for stabilization of joint. This is particularly important in a shoulder joint, which greatly rely on dynamic stabilizers(1-3, 13, 14, 17, 19). In order to produce the most appropriate response, one should sense the changes of or forces on locomotor system, therefore a well functioning sensory system which is called proprioception is crucial.

2.3.3 Definition of proprioception

Since 1906, the majority of physiology books adopted classification of sense by English physiologist Charles Sherrington. According to an original definition, proprioception is an afferent input from receptors of proprioceptive field. In turn proprioceptive field was defined as an area of the body screened from the environment by the surface cells which contained receptors specially adapted to register changes inside the organism of postural equilibrium, joint stability and muscle sense (1-3, 13, 14, 16, 17, 19, 38, 39, 83-87). More modern interpretation of definition of proprioception an afferent input from proprioceptors – the sensory organs, which are activated and transmit afferent information about mechanical stimuli generated within musculosceletal framework. The contemporary interpretation subdivides proprioception into 3 sub modalities of joint position sense, kinesthesia and sensation of resistance. Joint position sense (JPS) is defined as the ability of consciously to recognize the position of the joint in a free space. Kinesthesia is an ability to appreciate joint movement, and sense of resistance is defined as an ability to appreciate the force generated within a joint (2, 3, 14, 18, 19, 87-90).

2.3.4 Proprioceptors

A number of specific sensory organs located in muscles tendons and capsular structures initiate afferent signals regarding position and changes within musculoskeletal framework. These organs can be considered primary proprioceptors. Proprioceptors mainly sense the mechanical deformations within muscle, tendon, ligament or capsular structures (3, 27, 38, 39, 84-86, 91, 92). This deformation forces to open mechanically gated sodium channels on the membrane of receptor cell, which in turn generate action potential that is carried to CNS via afferent sensory pathways. An increase in deformation would lead to an increase of action potential formation and to increase of sensory input to CNS (1-3, 93-95).

Two commonly known receptors are located within capsuloligamental structures are Ruffini receptors and Pacinian corpuscles. Ruffini afferents are low-threshold and slow adapting organs which are believed to be stimulated by tensile force at the extremes of the motion. These properties make Ruffini afferents to be limit detectors of motion when ligaments become stretched. Pacinian corpuscles being low-threshold fast adapting organs are also mainly active within end of ranges of motion. Unlike Ruffini afferents, Pacinian corpuscles detect not only stretch but also compressive deformation of capsuloligamental structures. Deformation and stretching of the capsule and ligaments during motion of the joint stimulates Ruffini and Pacinian sensory organs (2, 3, 14, 39, 84-86, 91, 95-98). There is a body of evidence that points out that ligament and joint mechanoreceptors are being silent at mid ranges of motion and are only stimulated towards the limits of movement. Furthermore some studies point out that α-motor neuron activity is not being caused as a response to joint mechanoreceptors stimulation. However, numerous clinical studies show the diminished motor response when there is complete absence of mechanoreceptor input due to rupture of the tissues(9, 99-101). Instead, the ideas is proposed that afferent input from joint mechanoreceptors contributes to overall neural pool evoking γ motor neuron efferent, this in turn control the activity of muscle spindles and stiffness of the joint(3, 10, 13, 16, 19, 84, 102-105).

In addition to proprioceptors of capsuloligamental structures, two organs of musculotendon structure provide prorioceptive afferent information. Golgi tendon organs are located inside the tendons of the muscles and are sensitive to a stretch deformation. The Golgi tendon organs (GTO) are located inside musculo-tendon junction. GTO stimulated upon contraction of a muscle and pull of a tendon providing afferent information about musculotendon tension. GTO are mainly activated during an active muscle tension rather than a passive one. Another role of Golgi organs is a protective reflex function, which exhibits relaxation of agonist and stimulation of antagonist muscle during overstretch of musculotendon structure(1, 2, 13, 14, 38, 39, 87, 93, 94, 106).

Table 2.1. Joint mechanoreceptors adapted from Wyke and Hogervost(97, 102)

Type	Morphology	Physiology	Other Eponyms	Afferent fiber/ diameter (μm)	Location
I	Thinly encapsulated globular corpuscles in clusters of 3-6	Low threshold, Slowly adapting, static & dynamic	Ruffini, Golgi-Mazzoni	small, myelinated (5-8)	Joint capsule, periosteum, ligaments, tendons
II	Thickly encapsulated globular corpuscles (cylindrical or conical)in clusters of 2-4	Low threshold, rapidly adapting, dynamic	Pacini, Krause, Vater-Pacini	Medium, myelinated (8-12)	Joint capsule
III	Thinly encapsulated fusiform corpuscles	High threshold, slowly adapting, dynamic	Golgi, Golgi - Mazzoni	Large, myelinated (13-17)	Ligaments, tendons
IV	Plexuses and free nerve endings	High threshold, pain receptors		Very small, myelinated (0.5-5)	Joint capsule, periosteum, ligaments, tendons, blood vessels

Muscle spindles are one of the main mechanoreceptors of the body. Muscle spindles lie parallel to the main muscle fibers and are build around 3-12 small intrafusal muscle fibers. Each intrafusal muscle fiber is a very small skeletal muscle fiber. The ends of intrafusal muscle fiber can contract while the middle is no able to contract. The ends of intrafusal muscle fibers are innervated by γ motor neurons, which are different from α-motor neurons that normally innervate extrafusal – the rest muscle fibers. The main sensory component of muscle spindle lies within the middle of intrafusal muscle fiber – the non-contractile part (1-3, 38, 87, 91, 93, 101, 102).

There are two possibilities by which sensory part of muscle spindle can be activated. The first possibility is during the stretch of the whole muscle the intrafusal muscle fiber together with a middle portion is getting stretch, therefore giving stimulation to the afferent sensors of the middle part of interfusal muscle fiber. The second option is a contraction of contractile ends of intrafusal muscle fiber stimulated by γ motor neuron. During this stimulation, with disregard of the length change of the whole muscle, the middle portion of intrafusal muscle fiber is getting stretched and gives an afferent signal(38, 93, 106, 107).

There are two types of sensory endings found in the middle portion of muscle spindle. The primary ending is located at the centre of a sensory part of muscle spindle and usually sends a signal via fast type Ia nerve fiber to the spinal cord. Secondary sensory ending is usually located at one or both ends of sensory part of muscle spindle and send a signal via type II nerve fibers(107).

There are also two types of muscle spindle intrafusal muscle fibers. In the nuclear bag, muscle fiber. In the nuclear bag, the nucleus of one to three muscle fibers are located together in a bag at the middle of sensory part of muscle spindle. Alternatively, in nuclear chain fibers the nucleuses of three to nine fibers are positioned in a chain in the middle of receptor area. Primary endings are getting stimulated by both, nuclear bag and nuclear chain intrafusal muscle fibers; whereas secondary endings are exited only by nuclear chain fibers(93, 106, 107).

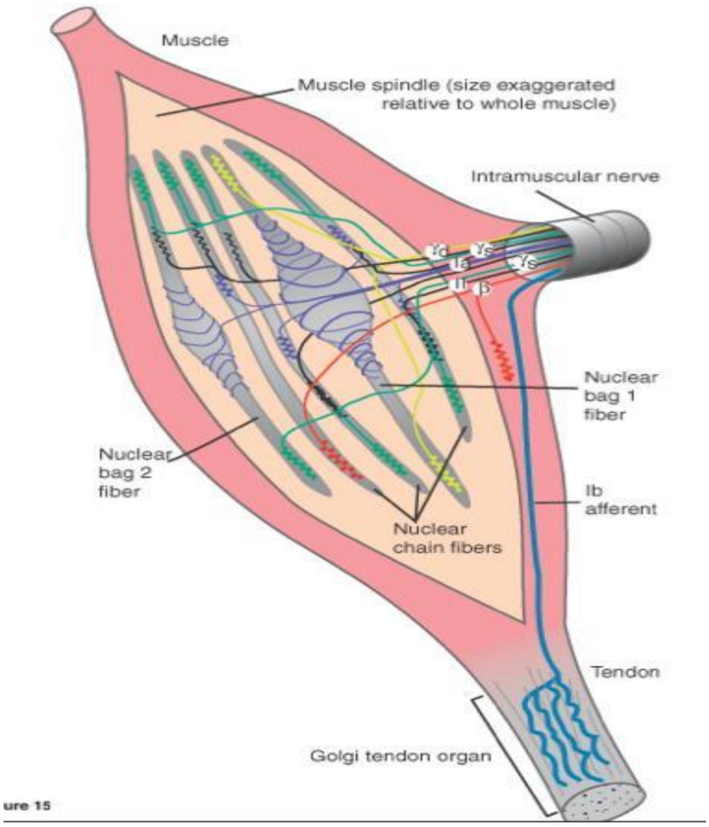


Figure 2.6. Muscle spindles(108)

During a slow stretch or contraction of a muscle both primary and secondary nerve endings are getting stimulated producing a prolonged signal. In case the muscle spindle remains stretched, this is called a static response. However, during a rapid change in length of muscle spindle primary endings are getting stimulated strongly. The strong signal is emitted as long as a fast length change of muscle spindle exist, and ceases when there is no more rapid change in length. The last process is a dynamic response to length change of muscle spindle(93, 107).

As mentioned previously, the afferent activity of muscle spindles is influenced by γ motor neurons, which stimulate and contract the contractile ends of muscle spindles. γ -d, derived from dynamic, motor neuron affect nuclear bag muscle fibers, tremendously increasing dynamic response of muscle spindles. Similarly γ -s, derived from static, afferent signal targets nuclear chain muscle fibers and increases static response of muscle spindles(40, 93, 107, 109).

In summary muscle spindle is a rather complex structure, which is able to detect the length change as well as a rate of length change of a muscle. In addition to that, uniquely, the properties and sensitivity of muscle spindles can be regulated /influenced by γ motor neuron activity(93, 107, 110-112).

2.3.5 Proprioceptive input

Integration of different sensory input is believed to be largely happening at the spinal level. The axons of neurons of proprioceptors enter the Central Nervous System (CNS) at a spinal level at dorsal horn. These axons synapse to interneurons. Interneurons in turn synapse with ascending tracts, which carry information to the higher centers of CNS. The essence of spinal integration of afferent input lies in the regulation of interneurons. Via descending afferents from cerebral cortex or brainstem the interneurons limit and filter the afferent input which will be conveyed to the ascending tracts (1, 93, 106).

An additional theory of common input was presented by Johanson et al. As mentioned previously the activity of muscle spindle is regulated by γ motor neuron activity. On the other hand, the activity of γ motor neuron is believed to be strongly influenced by a common descending input from muscle, skin and joint afferents. Therefore, the muscle spindle sensitivity is affected by signals of muscle length change integrated with afferents of other peripheral receptors(1, 105).

Proprioceptive information travels via two dorsal lateral tracts and spinocerebellar tract. According one of the theories the proprioceptive information gets coded and travels via range of ascending fibers rather than a specific ones. The coding provides specific recognition of proprioceptive input at higher level of CNS(1, 105, 106).

Dorsal lateral tracts convey information directly to the somatosensory cortex and are attributed for conscious appreciation of joint position sense or kinesthesia. A conscious appreciation of proprioception remains a largely unknown phenomenon. Various studies were successful and failed to establish relationship between specific propriorecepton and conscious appreciation of aspects of proprioception. One possible explanation could be in the complexity of integration of proprioceptive signal from different proprioceptors, which comprise a final proprioceptive afferent input. Processes such as coding as well as γ motor neuron activity regulation can be a factor(1, 38, 40, 85, 106, 109).

2.3.6 Central integration and afferent response

Spinocerebellar tract terminates at the different areas of cerebellum and is responsible for non-conscious recognition of joint position sense, kinesthesia and joint force recognition. At the cerebellum the integration and planning of unconscious, automatic and voluntary movements happens which produces efferent motor output. It is also known that a copy of efferent motor output is brought back from spinal level via spinocerebellar tract back to cerebellum for further integration and planning of motor activities(1, 2, 38, 85, 86).

Motor components of sensorimotor system are similar to the whole motor control of human body. A total of 3 main motor control and 2 associate motor control areas are responsible for efferent response of sensorimotor system. The main motor control areas consist of spinal cord, brain stem and cerebral cortex. Basal ganglia and cerebellum are two associate areas of motor control(1, 84, 107).

The main areas of motor control are organized in both hierarchical and parallel matter. In hierarchical organization, the higher centers of motor control can overwrite or adjust the final output or the output of lower motor centers. In parallel arrangement, independent signals of different levels of motor control provide its motor signals autonomous from each other(1, 84).

At the spinal level, the motor control is presented as a direct response – reflex activity to the efferent input from proprioreceptors. The proprioceptive signals arriving to the dorsal horn can directly synapse to either α or γ motor neurons giving a reflex activity at the muscle(1, 93, 107).

Arising from brainstem two major descending pathways transmit signals to the spinal level. The medial pathway influences the neurons responsible for innervations of axial and proximal muscles, whereas lateral is responsible for distal muscles of extremities. These descending pathways carry the signals that provide postural control. In addition to that, some axons of medial pathway have excitatory or inhibitory effects on spinal interneurons. By means of influence on γ motor neurons, lateral and medial pathways have an effect on muscle tone(1, 40, 84).

The three areas of cerebral cortex have relatively similar task of planning a motor activity and sending it directly to the motorneurons. The primary cortex upon receiving afferent input organizes a specific muscle activation as well as force coding and the direction of the movement. The premotor area also has a lot of afferent input and is responsible for preparation of motor commands. Finally, supplemental motor area is involved in planning complex movements involving groups of muscles. Though a directly descending corticospinal tract, cerebral cortex influences α and γ motor neurons activities(1, 2, 84, 107).

Cerebellum, operates completely in subconscious level, has also a role in motor control of sensorimotor system. As on/off associate areas, it is not able to provide direct activation of motor neurons. However, the role of cerebellum is the integration of proprioceptive information arriving via 4 spinocerebellar tracts with vestibular information and influencing the output of medial and lateral tracts originally arising from brainstem and cerebral cortex. Cerebellum compares the intended movement with the outcome of the movement providing necessary adjustments to the final common motor output(1, 84).

Basal ganglia were attributed to conscious modulation of motor output via its extensive number of connections with cerebral cortex(1, 84).

The above concludes general overview of sensorimotor system is shown to be a relatively complex system of afferent input (proprioception), central integration and final motor output. The system has complicated ongoing interaction of different components with only one main function of providing functional stability to the joint of musculoskeletal framework, and to assist in fluent executions of tasks required by a human being.

2.3.7 Methods to assess sensorimotor system

Once the role of sensorimotor system has received recognition within several past decades, the acute question has risen how to test it. Testing sensorimotor system can typically be done in two ways. First of the overall functioning of the system can be checked, which would give a good functional picture how well does the body respond to external mechanical stimulus. The drawback of this method is lack of inside into each component of sensorimotor system. Subsequently developing interventions to improve proprioceptions would be more difficult. On the other hand, scientists can try to test each component separately to recognize. The later is sometimes impossible due to close interaction of each component of sensorimotor system. Furthermore conducting experiments on vivo human models is often not feasible.

One of the possibilities of assessing proprioception is the evaluation of conscious recognition of different aspects of proprioception such as join position sense, kinesthesia and force appreciation.

Numerous measurement tools have been used to evaluate conscious appreciation of joint position sense. The principle of the evaluation is a variation of active reproduction of passive positioning, active reproduction of active positioning or passive reproduction of passive positioning. In all of the tests, the accuracy of reproduction is studied. The previously used tools are: Goniometer(90, 104, 113) which measure angle between various bone prominences of human body. Inclinometers is used for the same principle as goniometers but measure the angle between a limb or body part and vertical or horizontal. Therefore, careful positioning of subject is required for accuracy of the measurement (31, 113-116). Another method commonly used by researchers is an analysis of photographic or video images taken during the proprioception testing, usually reflective markers are placed on body prominences and the angles are calculated with computer software. Typically this analysis is performed in two dimensions(24, 82, 113, 117). For three dimensional analysis of JPS, electromagnetic motion tracing device is used in some laboratories. While the equipment is not widely available it gives the advantage of analysis of unrestricted movements in three dimensions(2, 3, 7, 28, 29, 47, 113, 118-120). In clinical use where sophisticated equipment is not available, proprioception is tested by means of visual analog scales or reproduction of limb position by contralateral side. This method is very subjective and tests not only proprioception, but functioning of whole sensorimotor system(113).

Possibly most common and widely used method of testing JPS is with proprioception testing devices. The devices are typically but not necessary derived from isokinetic systems such as Biodex. One common characteristic of proprioception testing devices is the streaked isolation of tested movement, by means of passive fixation of body parts. Typically the drive motor of proprioception testing device will be used for positioning or repositioning of the subjects limb(2, 3, 25, 26, 32, 46, 87, 89, 104, 113, 121-128). Unfortunately there are great number of different devices used by researchers who use different methods of testing proprioception at different angles of the joint. This causes difficulty in comparing the observations of the studies and drawing conclusion. Great advantage of proprioception testing devices is the versatility of their use which can easily be adapted for kinesthesia testing as well.

For the assessment of kinesthesia, the principles of appreciation of threshold to detect passive movement (TTDPM) or more specifically threshold to detect passive motion direction (TTDPMD) were utilized. The equipment for assessments of kinesthesia is usually based on a frame which moves the specific joint is one plane of movement with a very slow axial rotation speed of 0.5-2°/second. The lower speed is more favorable for accurate measurements. The recognition of movement can be attributed to slow adapting Ruffini endings and Golgi tendon organs(2, 3, 25, 34, 44, 46, 87, 89, 113, 122-126).

Assessment of appreciation of force in the joint is usually studied by means of reproduction of torques by the subject, measured by isokinetic system(5, 113, 114). Comparing to JPS and kinesthesia, appreciation of forces in the joint is well understudied subject and requires further research.

Evaluation of conscious appreciation of proprioception can be viewed as an assessment of integrity of propriception system as a whole. The more detailed and specific attribution of specific proprioreceptors to the whole proprioception is more difficult to study. There were attempts to limit the input of different proprioreceptor by means of anesthesia and ischemia. Also vibration was applied to muscle tendons in order to activate muscle spindles and to study its input to proprioception.

Nevertheless, the assessment of conscious appreciation of proprioception remains more of a clinical tool rather than a physiological studies domain.

Study of somatosensory evoked potentials evaluates integrity of afferent pathways. The principle is a specific stimulation of specific proprioreceptors or its pathways and monitoring the traveling signals along the different levels on the pathway of the signal(41-43, 95, 105, 113, 129).

An indirect way of measurement of proprioception system or the sensorimotor system as a whole lies in measurements of efferent response of the system.

In order to ensure that sensorimotor system works effectively, the pathways through which the signals are being sent must be intact. Nerve conduction testing is an objective method of assessing the function of peripherial α motor neuron. Similarly, to measurement of evoked somatosensory potentials, an electrical signal of known properties is send via efferent pathway. The afferent response on the specific muscle is being recorded at the same time by means of electromyographic equipment(113).

Electromyography is a tool widely used to evaluate muscular response. Typically the initiation, cessation and the magnitude of muscular response can be studied. In case of a number of muscles under investigation the pattern of activation of muscles with regard to specific task can be learned. Usually electromyographic equipment consists of surface electrodes for superficial or large muscle or fine-wire electrodes for deep muscles. The signal of muscle activity is received by electrodes, which are carefully position of the subject and transmitted to the amplifier. Following that, the signals of muscle activities can be studied, however numerous filters are applied for processing of signal making it more sensible. Electromyography helps to understand the biomechanics of a human motion a part of which is a sensorimotor system(2, 3, 113, 117, 130-132).

As it became apparent from previous information, muscle spindles through γ-innervation cause change in muscle stiffness and play major role in output of proprioceptive afferents. Therefore, much research is focused on studying muscle stiffness. Various attempts were made to measure muscle stiffness spanning across a joint, which would include a stiffness of musculotendinous structures and joint articular structures as well as stiffness of musculotendinous structures separately. Unfortunately, to this day, no single common method was developed for assessing muscles stiffness. The various methods used in studies, can be more attributed to muscle stiffness for specific joints(113).

Summarizing the presented methods to assess sensorimotor system, one could say that there is still need for further improvements as well as a common agreement on the measuring methods. This is particularly true in the field of physiology. Nevertheless, for clinical use there are objective methods to evaluate integrity of sensorimotor system and its components.

3 MATERIALS AND METHODS

3.1 Study design

The study design was multi group randomized control study with elements of repeated measure testing. The participants were randomly assigned into seven different groups including one control group. The independent variables were the type of intervention applied to glenohumeral joint or the participant. The dependent variable was proprioception of glenohumeral joint. The dependent variable was repetitively measured six times over standardized intervals of time before and after interventions.

The study was conducted in Hacettepe University, Institute of Health Sciences, Department of Physical Therapy and Rehabilitation. The general assessment was performed in Orthopedic Unit of the department. A total of 105 healthy subjects participated, 15 per group. All subjects were informed about the study and signed written consent to participate in the study. Ethical Committee of Hacettepe University has approved this study. The ethical committee's report number is GO 14/96 - 19.

3.2 Subjects

A total of 108 people volunteered to participate in the study. Out of this number three volunteers were eliminated from the study because of various shoulder pathologies found during initial assessment. Therefore, 105 people completed the study. There were no incidents of drop out of the study or other mishaps that would have forced to eliminate a subject from the study.

Majority of volunteers have come from students and academic staff of Hacettepe University. Among participants 50 (47.6%) were male and 55 (52.4%) were female. Their mean age was 24.3 years old with minimum being 19 and maximum 37. 90.5% or 95 subjects were right hand dominant with the rest 10 being left handed. The more detailed information about participants is displayed in figure 3.1.

At the designing stage of the study a number of inclusion criteria as well as exclusion criteria were set. These criteria were based on previous studies and were aimed to ensure the relative similarity of the subject, what would possible help to avoid extreme observations. Inclusion criteria were kept relatively broad to ensure that the results of the study can be applicable to wide variety of population.

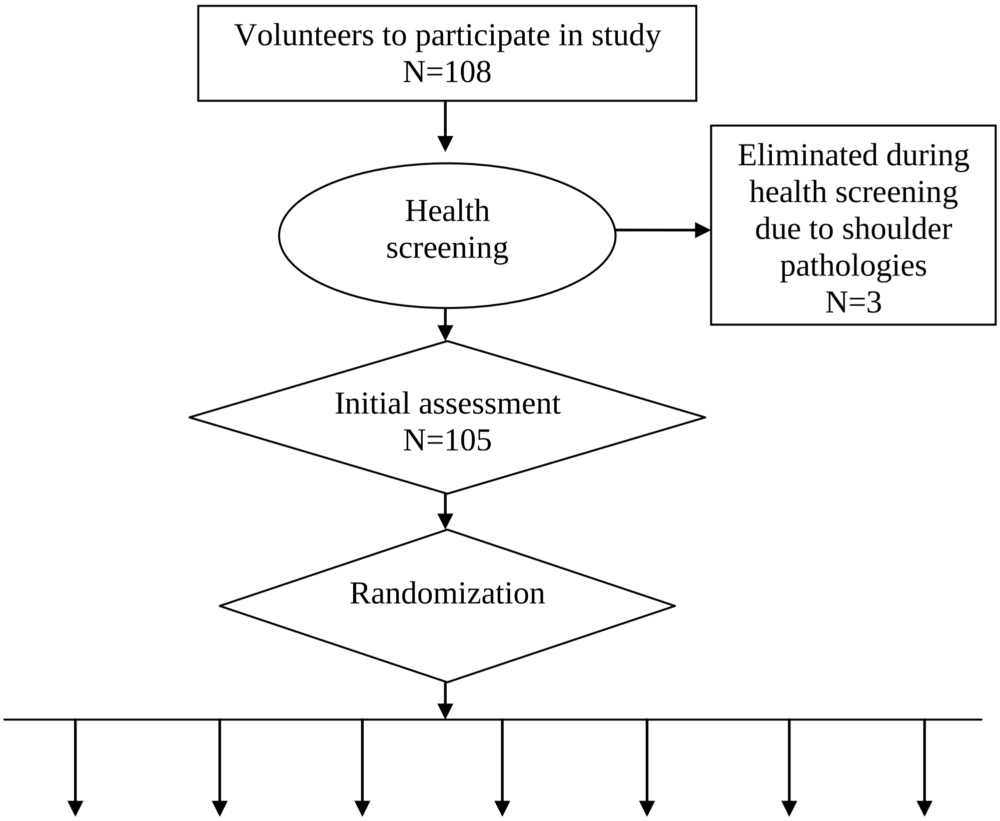
Inclusion criteria were:

- Aged between 18 and 40 years old
- Generally in good health and without shoulder pathologies.

Exclusion criteria were aimed to exclude groups of possible participants that might react different to interventions than normal subjects, subsequently skewing the results of the study.

Exclusion criteria were:

- Actively participating in sport activities ≥3 times per week or in upper extremity exercises >2 times per week.
- Having surgery on the shoulder joint within life time.
- Subjects with inborn or acquired abnormalities in shoulder joint which might influence sensory input or motor performance of the joint, such as winged scapulae, brachial plexus injury, general laxity.
- Subjects with other inborn or acquired abnormalities which might influence sensory input or motor performance of the shoulder joint, as rheumatologic disorder, cerebral vascular accident, peripheral nerve disorder or any other systemic or metabolic diseases.



Groups	Control	Active	Manual	Passive	Plyometric	Stabilization	Warm up
N	15	15	15	15	15	15	15
Age (years)	25.20 ±4.97	22.27 ±3.97	25.00 ±5.07	23.67 ±4.15	25.20 ±4.33	24.13 ±3.36	25.13 ±6.39
Gender M/F, % M/total	4/11 - 26.7%	10/5 - 66.7%	6/9 - 40.0%	8/7 - 53.3%	5/10 - 33.3%	11/4 - 73.3%	6/9 - 40.0%
Height (cm)	168.47 ±7.88	172.00 ±9.52	169.93 ±7.14	172.73 ±8.70	168.47 ±7.53	174.27 ±9.79	170.27 ±8.95
Weight (kg)	64.40 ±16.13	68.20 ±10.69	65.60 ±13.70	66.40 ±12.05	65.47 ±10.97	71.13 ±14.51	66.27 ±13.24
BMI (kg/m^2)	22.39 ±3.79	22.97 ±2.55	22.62 ±3.96	22.14 ±2.83	23.06 ±3.57	23.32 ±3.71	22.74 ±3.47
Dominant side R / L dominant, % R/total	12/3 - 80.0%	15/0 - 100%	14/1 - 93.3%	13/2 - 86.7%	14/1 - 93.3%	13/2 - 86.7%	14/1 - 93.3%

Figure 3.1. Chart elimination and distribution of subjects participated in study

3.3 Procedures

The first step after all the parameters and procedures of the study were finalized was the recruitment of the volunteers to participate in the study. Primary method of informing possible volunteers was a brief introduction to the study given by the author at various lectures with the permit and support of the lecturer of a course. The information about the objectives of the study, brief overview of the methods and basic inclusion and exclusion criteria for the study were typically provided. The contact information of the researcher was spread as well as the sign up list for volunteers was circulated. In addition to that the information about the study was spread by the word of mouth.

Typically study per participant was conducted over three days period. All participants were asked to wear comfortable cloth with loose sleeves or preferably sleeveless tops. On the first day each subject joined the study. After that the general health evaluation was conducted by the physical therapist. The aim of evaluation was to ensure that no hidden pathologies existed that would compromise the results of the study. In case some pathology was found the subject was dismissed from the study and referred to contact appropriate medical stuff to treat the condition. Three subjects were eliminated this way.

Once the volunteers approached the researcher, the detailed information about the study was provided in form of written consent, and if the volunteer agreed to all points of the consent, he or she signed the consent form.

Before a volunteer was included into the study a thorough physical therapy evaluation was conducted. Following information was asked and recorded from the participant:

- Name, surname, year of birth, gender
- Dominant extremity
- Current and past medical conditions if any, medications use

- Information about shoulder joint was asked such as lifelong shoulder injuries and pains, inborn shoulder abnormalities, history of shoulder surgeries, history of shoulder problems within past 6 months
- Level of sports participation and participation.

Physical examination included:

- General and local observations
- Posture and postural abnormalities, presence of scar tissues and atrophies
- Skin sensitivity was checked
- Supraspinatus tendon and biceps tendon were palpated
- Active and passive range of motion (ROM) with end feels of joints were recorded
- Any abnormalities of scapulohumeral rhythm were recorded
- Muscle provocation test as well as specific test of joint play, Upper Limb Tension Test and impingement Neer's and Hawking's test were performed to eliminate any possible hidden shoulder pathologies
- Proprioception testing.

If the subject was found in good health, the initial proprioception testing was conducted. The information from initial proprioception testing was recorded and is labeled "initial" throughout the study and this text.

After the completion of initial testing, the subject was randomly assigned to one of the six intervention groups or a control group. Randomization was concluding the first day of testing. Randomization to this study was made by the progressively variable chance. Since initially 105 or 15 per group participants for each intervention group were planned for the study, as the subjects joined and groups were filling the chance or being assigned to a group was varying based on how full were any of intervention groups. Recalculation of the chance was performed after every new subject. Furthermore Randomization program "Randomization Elite®" was used where the volunteer clicked a button and a random number was shown from 1-100, this number corresponded to a variable scale between different intervention groups. 6

different intervention groups and the control group. Intervention groups have been named as Active Exercise Group, Manual Therapy Group, Passive Exercise Group, Plyometric Exercise Group, Stabilization Group and Warm-up Group in addition to the Control Group. Each intervention group and the control group have been consisted of 15 participants.

Second day of study was typically the day following the first testing day, however tree to five days were allowed between first and second testing dates. On the second day the "pre" proprioception test was conducted. Immediately following this, the intervention was initiated. Promptly following intervention without any delay "post" proprioception test was conducted. 30 minutes after the completion of intervention the "30 minutes" proprioception test was performed, same as at 1 hour mark post intervention - "1 hour". During the break periods between tests, subjects were restfully sat on the chair and were not allowed to engage in and heavy activities of upper extremities. In the control group, since there was no intervention, "pre" and "post" test were joined in one, labeled as "pre" and the timer for "30 minute" test was started from the beginning of "pre test".

Third and final day of resting was conducted the following day after second day, approximately 24 hours after the intervention. During final day the proprioception test was conducted and this completed the participation of the subject in the study.

3.4 Equipment

For general assessment standard adjustable height physiotherapy table was used and for range of motion digital inclinometer "iGaging AngleCube Digital Level" was used. The accuracy of the tool is ± 0.2 degrees.

Figure 3.2. iGaging AngleCube Digital Level

In order to measure joint position sense and kinesthesia parameters of proprioception original proprioception device version 2 "oPTD v2.0" was used. The equipment was designed to test angular rotation of a joint in sagital place. Smooth and frictionless rotation in sagital plane was ensured by oPTD v2.0. Sensor for angular testing was "iGaging AngleCube Digital Level" with resolution of up to 0.05° and accuracy of 0.2°.

For shoulder joint, the oPTD was measuring internal or external rotation of shoulder joint at 90° abduction and with 90° elbow flexion. The special adapter of thermoplastic semi-cuff was used with oPTD v2.0 for shoulder testing. The adaptor ensured no deviations or slippage of proximal ulnar from the movement beam of the device, this further ensured proper alignment of rotational axis of oPTD v2.0 with humerus center of rotation on glenoid. In order to eliminate cuteneous sensory input from forehand, forehand was put into pneumatic sleeve and then attached to the oPTD v2.0.

Figure 3.3. oPTD v2.0

For this study the decision was made to test proprioception in sitting position, therefore a standard chair with 90° angled back was used. The subjects were sat in the chair and strapped in with a Velcro® straps for proper alignment. To accommodate for difference in height of subjects the height of oPTD v2.0 was possible to be adjusted.

For JPS testing the oPTD v2.0 was disconnected from the electrical drive motor, which allowed free and frictionless movement of internal and external rotations of shoulder joint. In order to compensate for weight of upper extremity of a subject, and to eliminate gravity the contra weight on the arm of oPTD was used. In JPS testing the subject was blindfolded and in order to eliminate surrounding audio distractions the headphones were used.

Figure 3.4. JPS testing with oPTD v2.0

To test kinesthesia oPTD v2.0 was used were the arm of the device was connected to an electric motor which provided < 0.5°/sec axial rotation of the arm of oPTD. The threshold to passive movement detection was tested as kinesthetic sense (kinesthesia) which is widely accepted as a common method of kinesthesia assessment in the literature(2, 3, 44, 89, 113, 126). Numerous studies suggest that speeds slower speeds of 0.5°/sec are more reliable for kinesthesia testing. In our test the subject was positioned the same as in JPS test. In order to eliminate any possible sound from the motor the subjects were wearing headphones with white noise playing.

The motor had 2 control switches, one was controlled by the researcher and the other by the subject. Therefore, the subject was always in control of the motor and was able to stop its motion at any given moment.

Figure 3.5. Kinesthesia testing with oPTD v2.0

Various equipment were used for different interventions.

For active movement the frame of oPTD was used. The modification of a grip handle was installed to the other side of the arm of oPTD, also a strap was used to fix the proximal side of the forehand. Two flexible limits were installed which checked the maximal external and internal rotations. The limits were calculated as 5% below of maximal ER and IR. A metronome model FZone FMT-600 was used to give visual and auditory information about the speed of movement. Digital count clicker was used to keep track of number of repetitions.

Figure 3.6. Metronome and digital counter

Similar set up of oPTD was used for providing passive movement to the joint. However, the arm of a subject was put into pneumatic sleeve and the testing side of oPTD arm. Similarly the limits of ROM were used and the metronome to control the movement by the researcher. The researcher through the oPTD was providing axial rotation of the subject's arm. Digital count clicker was used to keep track of number of repetitions.

For manual therapy a standard adjustable physiotherapy treatment table and a sand bag for stabilization of scapular were used.

The warm up group required several additional equipment available at various units of the Department of Physiotherapy and Rehabilitation. Biodex treadmill was used in the unit of Orthotics and Prosthetics. In addition to that Geonaute® On Rhythm 100 heart monitor was used to measure heart rate of the testing subjects.

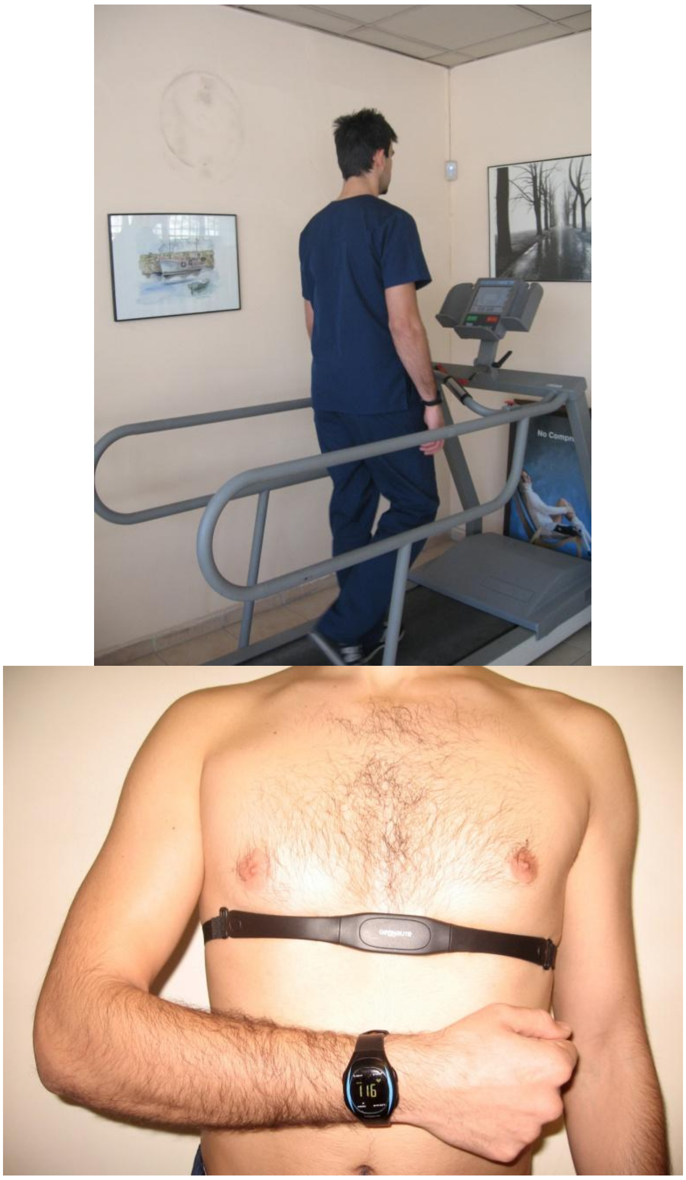


Figure 3.7. Treadmill and heart rate monitor

For stabilization exercise intervention group, a Ø 55cm gym ball was used. Furthermore an adjustable treatment table was used as well.

To perform plyometic exercises Theratubes® and medicine balls were used. Theratube® of blue color was used for man and of green color for women. All theratubes® were equipped with comfortable handles. Furthermore medicine balls of 2 and 1kilograms were used for man and women respectively. A wall was used for plyo pushups against the wall and a standard gym mat for any activities that required kneeling.

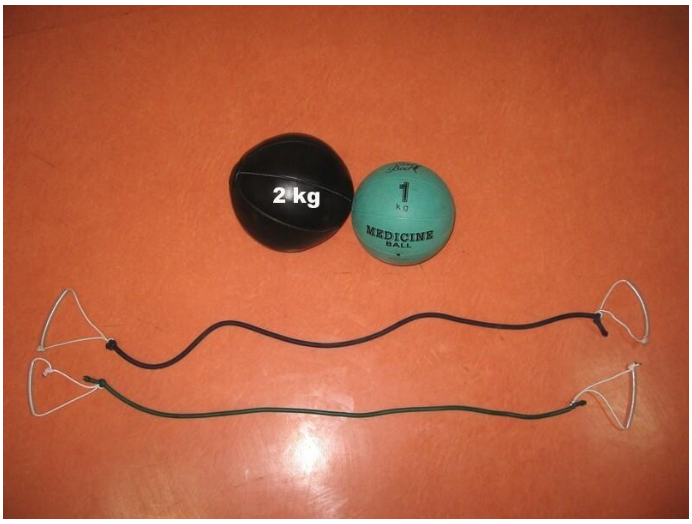


Figure 3.8. Medicine balls and theratubes® used for plyometric exercises

3.5 Proprioception testing

Two aspects of proprioception were tested in this study and were considered dependent factors. First aspect was Joint Position Sense, and the second was Kinesthetic Sense, tested as Threshold to Detection Passive Movement. Both tests were conducted using oPTD v2.0. Prior to conducting the tests, all of the testing procedures were thoroughly explained to the participants. Several trial attempts were made with each test to ensure that all equipment was comfortable, fitting well and all procedures were understood.

Both proprioception tests were performed in sitting position with participant sitting in a standard chair strapped by the VELCRO® belt at a waist level to prevent slouching in the chair. The height of the chair and oPTD was adjusted the way that the center of glenohumeral internal/ external rotation with shoulder at 90° abduction and 90° elbow flexion were to align with the axis of oPTD. In both tests dominant arm of a subject was put into a pneumatic sleeve. For kinesthesia testing the particular attention was given to avoid fingertips from touching the pneumatic sleeve in order to reduce tactile input. Therefore, subjects were asked to make a fist and then insert the forehand into the sleeve.

The proprioception of internal and external rotation of glenohumeral joint was tested. Before the initiating the proprioception tests, subject was positioned in the testing seat, his or her hand was put into pneumatic sleeve and attached to the extension of oPTD arm. Then, subject was asked to move shoulder into internal and external rotations. First of all this was made to ensure that the alignment was correct and comfortable. In case there was no discomforts and the alignment was right, subject was asked actively to move hand from 0° rotation or horizontal position into maximal internal and maximal external rotation. This method was used to calculate the ROM inside the equipment. Based on ROM the testing angles were calculated. 70% of internal rotation, 90% of external rotation and the midpoint or 50% of ROM were used as a testing angles. For both test a variation within 3° of testing angle was considered acceptable for the target position.

For joint position sense the subject, was set on the chair, as described, with arm at 90°-90° position , blindfolded and wearing headphones to limit external noises. From a 0° or horizontal position participant was asked to move hand slowly into internal or external rotation until command stop was given. Then the position had to be maintained for 10 seconds. During this time the researcher helped to maintain the position by fixing the leaver arm of the oPTD. The subject's role was to memorize the position during these 10 seconds. The command was given to bring arm back to approximately the staring position. The subject was told that the starting position was not critical and was not needed to be reproduced exactly. After returning to initial position the subject was asked to move and reproduce or find the target position where he or she just held hand for 10 seconds. At the moment when the position was found in subject's opinion, he or she had to verbally announce it and the angle was recorded by the researcher. Three trials to reproduce one target position were performed. A mean of absolute values of differences between the target position and the three trials of reproducing it was calculated as JPS. Same procedure was followed for other target angles. The sequence of testing between various target angles was random.

In order to test kinesthesia, subject was similarly positioned. In addition to that a switch was given to subject that controlled and stopped the action of motor of oPTD, essentially stopping the movement of rotation. Prior to the conduction of the test several customization trials were ran to ensure that subject was feeling the movement at speed of 0.5°/sec. During the actual test the arm of the participant was put at one of the testing angles and the command "start" was given. However, after the command was given the movement was not initiated by the researcher immediately but at a random moment after the "Start" command. The participant was aware of that and had to focus to recognize when the actual movement was started. As soon as subject recognized that the hand is moving, he or she had to press the button to stop the movement. The difference between angle of starting position and the angle where the movement was recognized was recorded as threshold to detection passive movement. The direction of the movement was also noted by the researcher. The above described just one movement. After the first recognition of the movement and deactivation of the system, in 2-3 seconds subject had to activate the system again, by switching it on. Then, the testing continued without further commands, at a random moment a second movement was initiated and the subject has recognized it. Subjects were aware that after engaging the system no further commands were to be given, and that they had to be ready to recognize the movement. A minimum of four activations of system were made to encounter two movements in both internal and external rotations. Due to the nature of the motor driving the oPTD the direction of the movement was random and uncontrollable. Same procedure was followed for other target angles. The sequence between target angles was random. A mean of all differences between staring and detection angles, at a particular target angle, were considered as TTDPM regardless of movement direction, additionally mean of movements differences in one particular direction was calculated when the direction was factored in.

3.6 Interventions

"The Control group" did not receive any intervention. Instead, the proprioception of subjects of control group was tested at the same intervals as if intervention groups. On the second day of testing, following the initial test, proprioception was tested 30 minutes later and 1 hour later. During the time in between of tests, similarly to subjects of other groups, controls were sat comfortably on the chair and were not allowed to perform any heavy upper extremity activities.

"Active Movement Intervention Group" intervention group was performing active internal and external rotation of shoulder at a fixed speed. The movements were limited and controlled by oPTD. As described in equipment section of the paper, the other end of arm of oPTD was used, where grip handle was fitted. Also a strap was fixating proximal end of forearm to control alignment of the extermity.

Figure 3.9. Adaptation of oPTD v2.0 for active movements through ROM at preset speed guided by metronome

The range of motion (ROM) was set between 5% below of each external rotation maximal ROM and internal rotation maximal ROM. The range of motion was limited by a flexible fixation which was providing feedback that the ends of ROM were reached. However, the limiter of ROM was not firm as to cause a shocking vibration through the hand.

The speed of movement was set standard at 90°/sec. Based on each subject's ROM for the movement the speed was converted to beats/minute scale and set on the metronome. A digital metronome was giving visual guidance in form of a moving arrow from left to right in addition to audio beeps as signal. Subject's task was to move shoulder into internal and external rotations so that the limiter was reached at the beep sound of metronome. The movement was repetitive and maximally uniform. Therefore, prior to initiating the interventions several practice attempts were allowed. 30 internal to external rotation movements were paused with 30 second break and were followed by another 30 repetitions. A total of 60 repetitions at 90°/sec through the range of motion were completed. No load or resistance for the movement other than a weight of own arm was given.

The protocol for "Passive Movement Intervention Group" was to replicate the active movement protocol with a single essential difference that the movement was passive. Same speed of 90°/sec and range of motion was set for passive intervention. Instead of using the other side of oPTD arm, the main side was used where the subject was wearing a pneumatic sleeve and the forearm was firmly attached to the oPTD. The Physical therapist was giving a passive propulsion to the movement at a speed of 90°/sec guided by the metronome. Meanwhile the subject was instructed to be relax and not to resist the movement. Similarly, 30 repetitions were interrupted by 30 seconds break and followed by another 30 repetitions.

The aim of "Manual Therapy Intervention Group" group was to provide mechanical input to the glenohumeral joint without functional or angular displacement of the joint. The subject was laying supine comfortably on a standard height adjustable treatment table. A small sandbag was used to support scapulae. The subject was instructed to be relaxed as much as possible. 6 minutes of anterior/posterior joint play mobilization was provided to the dominant shoulder of the subject by the researcher. The used technique was based on Cyriax and the joint play was between grade 2 and 3 outlined by Herling and Kessler(73).

Figure 3.10. Manual Therapy Intervention

"General Warm Up Intervention Group" has used Biodex treadmill available at the Unit of Orthotics and Prosthetics. Subjects randomized into this group were specifically asked to wear comfortable to run shoes. Participants had to wear a chest strapped heart monitor - Geonaute® On Rhythm 100 model. The electrodes of heart monitor were moisturized with water as instructed by the manual of the heart monitor.

The warm up protocol consisted of 5 minutes gradual increase of jogging speed until the 50% of estimated heart rate max was reached. This was followed by 5 minutes at speed of 50% estimated HRmax. Then the speed was increased to 60% of HRmax where it was held for another 5 minutes. A gradual decrease of speed within 1-1.5 minute was completing the warm up protocol. Totally 15-17 minutes of fast walking or jogging was performed by subjects of warm up protocol.

The protocol of "Stabilization Exercises Intervention Group" consisted of 4 exercises using gym ball. Two exercises were performed in standing and two in prone position with upper torso hanging of the treatment table.

For the first exercise the participant was standing facing a wall. The dominant arm or subject was at 90° flexion in shoulder and holding a Swiss ball between palm and a wall. The exercises focused of stabilizing a joint while a perturbation from 4 different directions were directed at the ball. The goal of a subject was not to allow the ball to move, however constant compression of the ball was discouraged, instead a reaction to a perturbation was deemed correct execution of exercise. A total of 2 sets of 5 perturbations in 4 directions were given with 30 second breaks between sets(2, 17, 133).

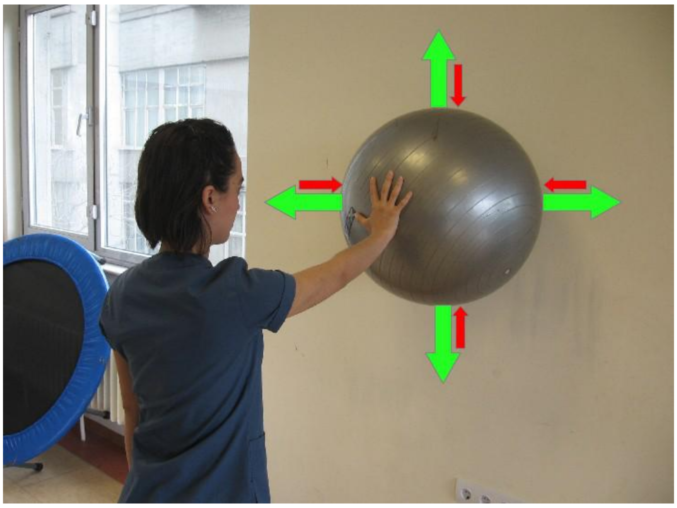


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Figure 3.11. Shoulder stabilization against perturbations at 90° shoulder flexion against wall

Second exercise was very similar to first one, but the position of 90° abduction instead of flexion was held. Likewise of 2 sets of 5 perturbations in 4 directions with 30 second breaks between sets was performed(2, 17, 133).

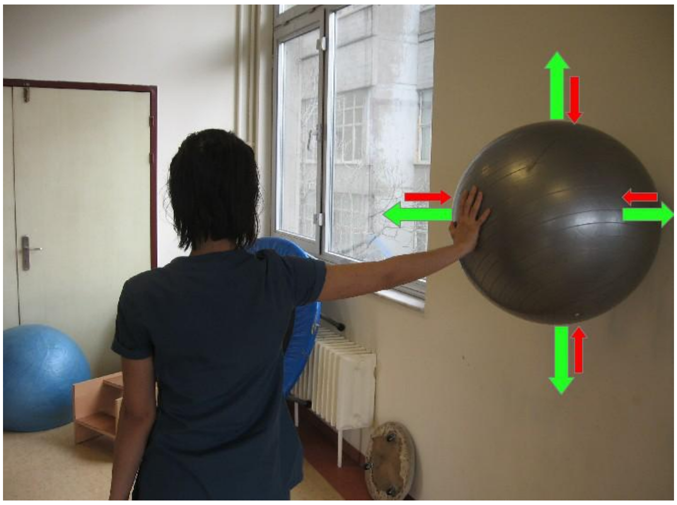

Figure 3.12. Shoulder stabilization against perturbations at 90° abduction against wall

For the third exercise subject had to lay prone on the treatment table with upper torso hanging of the side of the table. Both outstretched arms were placed on the gym ball in front of the table. Subject had to press on the ball and to move it into 4 directions, forward, backward, left and right. 2 sets of 5 movements in 4 directions were separated by 30 second braek.

Final exercise was similar to the 3rd exercise, but the pressure on the ball and movements had to be provided by the dominant hand only. Same number of sets and repetitions were used(2, 17, 133).

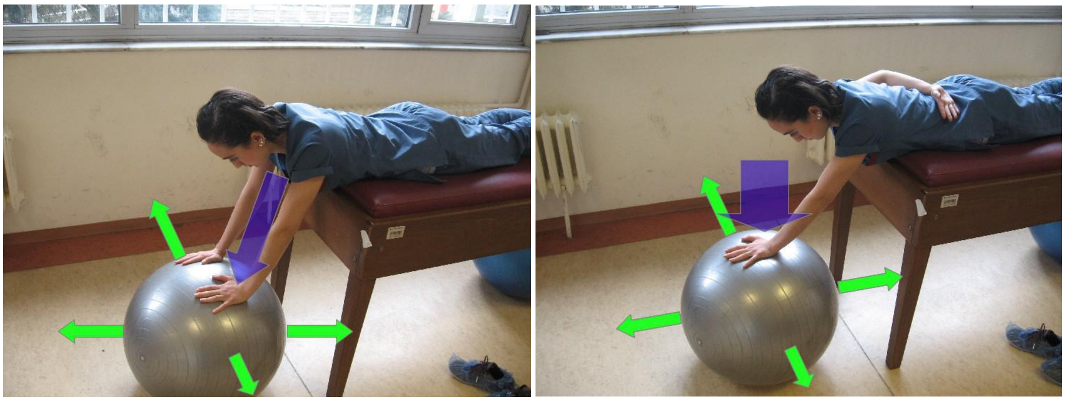

Figure 3.13. Two hand and single handed shoulder stabilization supporting body weight

"Plyometric Exercises Intervention Group" performed four exercises. The nature of plyometric exercises dictates that eccentric muscle contraction is followed by a very brief moment of static contraction and led by a forceful concentric contraction.

For the first plyometric exercises, a subject was in single kneeling or rifle man position with shoulder in 90° abduction and 90° elbow flexion. The subject was holding a theratube® by one end and the other end was held by the researcher standing several meters behind subject, stretching the theratube®. First, subject had to cock the theratube® by bringing hand into internal rotation, then a shoulder was to be released so that the theratube® to pull the arm into external rotation, this motion was to be controlled by subject, making it an eccentric contraction. At maximal external rotation, without any delay, subject had to pull forcefully into internal rotation - concentric contraction. This cycle was repeated 10 times for 2 sets with 60 seconds of rest in between(134-136).

The plyometric external rotation was performed similarly as internal rotation, however the subject was standing and the theratube® was held at ground level in front of subject. Similarly 2 sets of 10 repetitions were completed(134-136).

Figure 3.14. Plyometric internal and external rotations with theratube

For plyometric double handed overhead ball throw, the subject was in a rifleman position on the mat holding outstretched arms above the head. The researcher stood in front of the subject. He threw the medicine ball to the hands of the subject. In plyometric fashion, the subject caught the ball bringing it behind his/here's head. Immediately after that subject forcefully threw it back to the training mate, releasing the ball above the head. 2 sets of 10 throws with 30 second of rest in between were performed.

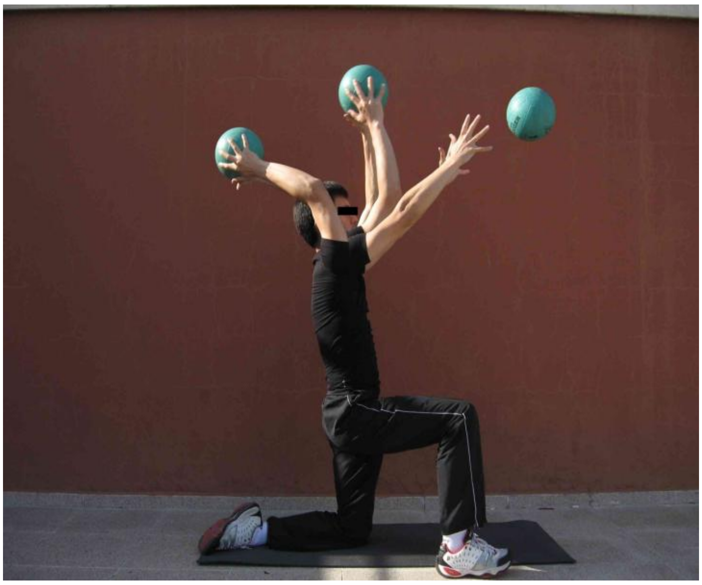

Figure 3.15. Plyometric ball overhead throw

The final exercise was plyometric push up. A participant standing in front of a wall, had to fall onto a wall with hand positioned as to perform pushups slowly allowing torso to come close to the wall. Then, a forceful push from the wall involving shoulder and pectoral muscles was performed. Researcher standing behind the subject was controlling that the subject was not falling backwards. As with the rest of exercises 2 sets of 10 repetitions were completed(134-138).

3.7 Data reduction, transformation and statistical analysis

During the experiment the raw data was recorded. For JPS the angular value of each target position and each attempt of replication, and for TTMPD the each starting angle and angle of perception the movement were recorded. For meaning analysis this data had to be transformed and converted. First of all, a difference between each target and each attempt of reproduction of target for JPS was calculated. This difference represented an JPS of each attempt of reproducing the target angle. Then, an average of three attempts was taken to calculate the JPS for a particular angle. This type of transformation was done for each subject at each specific angle of JPS testing and at every assessment point of the study. In order to calculate TTDPM, the difference between starting angle of the movement and the angle where the movement was perceived was calculated by subtraction, this was performed for each attempt at a specific angle. Then two various further calculations were performed. To calculate TTDPM disregarding the direction the mean of absolute values of several attempts was calculated, representing one value for each angle of TTDPM testing. However, to calculate TTDPM noting the direction in which the movement was felt, the distinction was made between positive and negative values, which represented movement into internal or external rotation. After this, the mean of absolute positives values and absolute negatives values was taken, giving two values: TTDPM into external rotation and TTDPM into internal rotation. The following data transformation was performed with Microsoft Office Excel program.

The below mentioned analysis was performed using Intel SPSS 20.0 statistical package. First of all, each parameter including age, height, weight, BMI, as well as dependent variables were analyzed for normality of data distribution. Therefore, observation of distribution curve of histogram against normally distributed histogram, normal Q-Q plot observation and statistical test of normality were considered. For groups of < 50subjects, Shapiro-Wilk, and for groups of >50 subjects Kolmogorov-Smirnov Test were used(139).

Additionally the observed data was reduced against extreme values which might have been obtained due to outside interference during experiment or other factors not under investigation in this study. After careful consideration the extremes were defined as values that lay outside 3 standard deviation in each direction from the mean. Furthermore since the groups in our study were relatively small, the extreme values were excluded only if they were laying outside of 3SD in both within the group and beyond 3SD of baseline initial assessment of 105 subjects. This ensured that truly extremes were excluded from the further analysis. The excluded values were replaced with missing value code in SPSS(140).

Based on analysis of distribution it has become evident that due to the nature of variables tested - JPS and TTDPM were positively skewed. The attempts to normalize data via transformation did not bring desirable result for further processing as normally distributed data. Therefore, descriptive information of this study has been presented as mean ± standard deviation and median value which is more representative of the data collected.

Due to earlier mentioned challenge of data not being normally distributed and the fact that our groups were comprised of relatively small number of subjects, just fifteen per each group, non-parametrical tests have been used for comparison within groups and between groups. Whenever groups were related "Freedman's 2-way ANOVA" and "Wilcoxon Matched-Pair Test" for post hoc analysis were used. Whenever independent groups were compared, "Kruskal-Wallis 1-way ANOVA" and "Mann -Whitney U Test" were used for comparison of 2 groups. Probability level $p \leq 0.05$ was accepted as statistical significance.

4 RESULTS

4.1 Demographics and general characteristics of subjects

105 participants of the study were randomized into 7 groups, as one control and six intervention groups. The following table shows the demographic characteristics of the subjects in the groups.

Table 4.1. Physical characteristics of subjects

	Age (years)	Gender	Height (cm)	Weight (kg)	BMI (kg/m^2)	Dominant side
Groups		M/F, % M/total				R / L dominant % R/total
Control	25.20±4.97	4/11 - 26.7%	168.47±7.88	64.40±16.13	22.39±3.79	12/3 - 80.0%
Active	22.27±3.97	10/5 - 66.7%	172.00±9.52	68.20±10.69	22.97±2.55	15/0 - 100%
Manual	25.00±5.07	6/9 - 40.0%	169.93±7.14	65.60±13.70	22.62±3.96	14/1 - 93.3%
Passive	23.67±4.15	8/7 - 53.3%	172.73±8.70	66.40±12.05	22.14±2.83	13/2 - 86.7%
Plyometric	25.20±4.33	5/10 - 33.3%	168.47±7.53	65.47±10.97	23.06±3.57	14/1 - 93.3%
Stabilization	24.13±3.36	11/4 - 73.3%	174.27±9.79	71.13±14.51	23.32±3.71	13/2 - 86.7%
Warm up	25.13±6.39	6/9 - 40.0%	170.27±8.95	66.27±13.24	22.74±3.47	14/1 - 93.3%

4.2 Initial proprioception values prior to any intervention

Proprioception of subjects within the groups and all subjects together is outlined in the following tables. First of all JPS is presented, then kinesthesia or TTDPM at three different angel of testing have been shown. Finally three tables show TTDPM with the direction of movement, each table represents one specific angle of testing.

Table 4.2. JPS of all subjects at initial assessment

Groups / (°degrees)	JPS Initial 90% ER			JPS Initial 50% ROM			JPS initial 70% IR		
	Mean	Median	± *SD*	Mean	Median	± *SD*	Mean	Median	± *SD*
N=105	**4.77**	**3.33**	***3.75***	**5.24**	**3.52**	***4.71***	**4.59**	**3.87**	***3.02***
Active	5.62	4.62	*4.34*	4.05	3.18	*3.27*	3.85	3.43	*2.84*
Control	5.25	3.87	*4.83*	5.22	4.52	*2.97*	5.91	4.43	*3.13*
Manual	4.59	2.27	*3.75*	4.77	3.15	*5.51*	3.97	3.87	*1.81*
Passive	4.32	3.33	*4.44*	4.25	3.13	*2.86*	4.59	3.40	*3.09*
Plyometric	4.34	3.57	*1.75*	8.46	7.03	*7.24*	4.55	2.97	*3.67*
Stabilization	4.21	3.23	*3.03*	4.63	3.58	*2.77*	5.20	4.67	*3.37*
Warm up	5.08	3.30	*3.79*	5.28	3.43	*5.72*	4.04	2.88	*2.96*

Table 4.3. TTDPM of all subjects at initial assessment disregarding direction of movement

Groups / (°degrees)	TTDPM Initial 90% ER			TTDPM Initial 50% ROM			TTDPM Initial 70% IR		
	Mean	Median	± *SD*	Mean	Median	± SD	Mean	Median	± *SD*
N=105	**1.23**	**1.12**	***.73***	**1.19**	**1.01**	***.82***	**1.15**	**.97**	***.67***
Active	1.12	.90	*.48*	.86	.86	*.27*	1.04	1.07	*.28*
Control	1.13	1.13	*.47*	1.38	1.06	*.83*	1.01	.74	*.61*
Manual	1.41	1.41	*.61*	1.25	1.15	.31	1.53	1.53	*.61*
Passive	1.09	.67	*1.29*	1.21	.77	1.61	1.03	.77	*.97*
Plyometric	1.27	1.15	*.72*	1.25	1.22	.66	1.19	1.16	*.67*
Stabilization	1.10	.93	*.47*	1.22	.90	.78	1.05	.77	*.57*
Warm up	1.51	1.49	*.73*	1.15	1.01	.54	1.20	1.04	*.72*

Table 4.4. TTDPM at 90% of ER of all subjects at initial assessment accounting for direction of movement

Groups / (°degrees)	TTDPM Initial 90% ER			To ER			To IR		
	Mean	Median	± *SD*	Mean	Median	± SD	Mean	Median	± *SD*
N=105	**1.23**	**1.12**	***.73***	**.84**	**.73**	***.57***	**1.57**	**1.35**	***1.06***
Active	1.12	.90	*.48*	.71	.80	.26	1.45	1.10	*.97*
Control	1.13	1.13	*.47*	.73	.68	.32	1.46	1.58	*.71*
Manual	1.41	1.41	*.61*	.97	.95	.40	1.84	1.70	*1.01*
Passive	1.09	.67	*1.29*	.83	.48	1.05	1.29	.84	*1.57*
Plyometric	1.27	1.15	*.72*	.88	.70	.41	1.63	1.55	*1.10*
Stabilization	1.10	.93	*.47*	.63	.60	.29	1.55	1.46	*.87*
Warm up	1.51	1.49	*.73*	1.09	.93	.75	1.80	1.57	*1.13*

Table 4.5. TTDPM at 50% of ROM of all subjects at initial assessment accounting for direction of movement

Groups / (°degrees)	TTDPM Initial 50% ROM			To ER			To IR		
	Mean	Median	± *SD*	Mean	Median	± *SD*	Mean	Median	± *SD*
N=105	**1.19**	**1.01**	***.82***	**1.07**	**.80**	***.90***	**1.32**	**1.00**	***1.00***
Active	.86	.86	*.27*	.64	.59	*.25*	1.09	.95	*.52*
Control	1.38	1.06	*.83*	1.31	1.12	*.87*	1.38	1.05	*.90*
Manual	1.25	1.15	*.31*	1.22	1.22	*.57*	1.33	1.15	*.67*
Passive	1.21	.77	*1.61*	1.14	.67	*1.61*	1.29	.60	*1.70*
Plyometric	1.25	1.22	*.66*	1.15	1.14	*.71*	1.36	1.05	*.83*
Stabilization	1.22	.90	*.78*	.75	.70	*.36*	1.52	1.20	*1.18*
Warm up	1.15	1.01	*.54*	1.25	.94	*1.01*	1.25	.92	*.90*

Table 4.6. TTDPM at 70% of IR of all subjects at initial assessment accounting for direction of movement

Groups / (°degrees)	TTDPM Initial 70% IR			To ER			TO IR		
	Mean	Median	± *SD*	Mean	Median	± *SD*	Mean	Median	± *SD*
N=105	**1.15**	**.97**	***.67***	**.88**	**.70**	***.58***	**1.55**	**1.25**	***1.16***
Active	1.04	1.07	*.28*	.83	.93	*.36*	1.36	1.31	*.73*
Control	1.01	.74	*.61*	.91	.75	*.55*	1.09	.76	*.79*
Manual	1.53	1.53	*.61*	.96	.63	*.64*	2.25	2.07	*1.05*
Passive	1.03	.77	*.97*	.83	.60	*.83*	1.37	.75	*1.47*
Plyometric	1.19	1.16	*.67*	.96	.70	*.77*	1.43	1.51	*.97*
Stabilization	1.05	.77	*.57*	.80	.74	*.29*	1.53	1.12	*1.21*
Warm up	1.20	1.04	*.72*	.87	.68	*.48*	1.84	1.33	*1.47*

4.3 Comparison of proprioception at various moments of assessment within the groups

The following sets of table show proprioception within each group at different moments prior and past intervention. In the tables the result of statistical analysis comparing proprioception values at different times can be seen. Whenever there was significant difference between the assessment points, additional Post Hoc analysis has been performed and displayed below.

4.3.1 Analysis of proprioception within the "Active Movement Group"

Table 4.7. Within the "Active Movement Group" analysis of JPS

Active	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	5.62	4.62	*4.34*	15	4.05	3.18	*3.27*	15	3.85	3.43	*2.84*
Pre	15	5.29	5.30	*3.15*	15	5.48	2.78	*4.31*	15	4.72	4.47	*3.02*
Post	15	4.96	4.30	*3.34*	15	5.55	4.87	*4.40*	15	5.35	3.45	*4.29*
30min	15	5.54	4.83	*3.76*	15	5.69	5.03	*4.21*	15	4.76	3.40	*3.74*
1hour	15	4.16	3.10	*3.08*	15	6.04	4.37	*5.25*	15	2.30	1.62	*1.75*
1 day	15	4.51	4.80	*2.76*	14	4.48	3.23	*3.12*	15	5.03	3.72	*3.48*
p	.776				.975				.107			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Kinesthesia of "Active Movement Group" at different points of assessment disregarding the direction of movement.

Table 4.8. Within the "Active Movement Group" analysis of TTDPM disregarding direction of movement

Active	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.12	.90	*.48*	15	.86	.86	*.27*	15	1.04	1.07	*.28*
Pre	15	1.07	1.00	*.43*	15	.96	.85	*.38*	15	1.09	1.01	*.49*
Post	15	1.14	1.24	*.33*	14	1.30	1.32	*.41*	15	1.23	1.25	*.57*
30min	15	.94	.89	*.25*	15	1.17	1.16	*.41*	15	.99	.88	*.48*
1hour	15	1.14	1.10	*.34*	15	1.25	1.19	*.30*	15	1.09	1.13	*.31*
1 day	15	.96	.97	*.30*	15	1.00	.96	*.34*	15	.95	.82	*.42*
p	.543				**.001**				.540			
	Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Based on Post Hoc analysis at 50% of ROM TTDPM measured at initial, pre and post and at 1 hour post intervention assessments significantly differed ($p<0.05$) from assessments at other moments post intervention.

Table 4.9. Post Hoc analysis, comparison of TTDPM at 50% of ROM in "Active Movement Group" between specific assessment moments

Active movement TTDPM 50% ROM / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial				<	Post				**-3.045**	**.002**
15	.86	.86	*.27*		14	1.30	1.32	*.41*		
Initial				<	30 min				**-2.501**	**.012**
15	.86	.86	*.27*		15	1.17	1.16	*.41*		
Initial				<	1 hour				**-2.613**	**.009**
15	.86	.86	*.27*		15	1.25	1.19	*.30*		
Pre				<	Post				**-2.166**	**.030**
15	.96	.85	*.38*		14	1.30	1.32	*.41*		
Post				>	1 day				**-2.135**	**.033**
14	1.30	1.32	*.41*		15	1.00	.96	*.34*		
1 hour				>	1 day				**-2.215**	**.027**
15	1.25	1.19	*.30*		15	1.00	.96	*.34*		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.10. Within the "Active Movement Group" analysis of TTDPM at 90% of ER to ER and IR

Active	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.12	.90	*.48*	15	.71	.80	*.26*	15	1.45	1.10	*.97*
Pre	15	1.07	1.00	*.43*	14	.72	.65	*.32*	13	1.54	1.35	*.65*
Post	15	1.14	1.24	*.33*	14	.78	.77	*.27*	15	1.51	1.43	*.71*
30min	15	.94	.89	*.25*	15	.72	.65	*.23*	15	1.15	1.10	*.47*
1hour	15	1.14	1.10	*.34*	15	.92	.90	*.33*	15	1.36	1.43	*.49*
1 day	15	.96	.97	*.30*	15	.63	.60	*.21*	15	1.26	1.13	*.60*
p					**.033**				.587			
					Reject null hypothesis (p<0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Similar observations in Post Hoc analysis of TTDPM at 90% external rotation, moving into external rotation has been found (p<0.05).

Table 4.11. Post Hoc analysis, comparison of TTDPM at 90% of ER to ER in "Active Movement Group" between specific assessment moments

Active movement TTDPM 90% ER to ER / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Post				>	1 day				**-2.104**	**.035**
14	.78	.77	*.27*		15	.63	.60	*.21*		
1 hour				>	1 day				**-2.856**	**.004**
15	.92	.90	*.33*		15	.63	.60	*.21*		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.12. Within the "Active Movement Group" analysis of TTDPM at 50% of ROM to ER and IR

Active	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	.86	.86	*.27*	14	.64	.59	*.25*	15	1.09	.95	*.52*
Pre	15	.96	.85	*.38*	14	.75	.73	*.27*	15	1.18	1.03	*.69*
Post	14	1.30	1.32	*.41*	13	1.26	1.13	*.61*	15	1.59	1.40	*.83*
30min	15	1.17	1.16	*.41*	15	1.02	1.03	*.47*	14	1.33	1.29	*.49*
1hour	15	1.25	1.19	*.30*	14	1.14	1.17	*.53*	15	1.21	1.05	*.37*
1 day	15	1.00	.96	*.34*	15	.90	.90	*.35*	15	1.07	1.00	*.48*
p					.065				.113			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.13. Within the "Active Movement Group" analysis of TTDPM at 70% of IR to ER and IR

Active	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.04	1.07	*.28*	15	.83	.93	*.36*	14	1.36	1.31	*.73*
Pre	15	1.09	1.01	*.49*	15	.81	.78	*.33*	14	1.48	1.14	*.98*
Post	15	1.23	1.25	*.57*	15	.96	.93	*.46*	15	1.53	1.38	*.77*
30min	15	.99	.88	*.48*	15	.80	.68	*.41*	14	1.20	1.13	*.68*
1hour	15	1.09	1.13	*.31*	14	.94	.94	*.19*	15	1.27	1.30	*.51*
1 day	15	.95	.82	*.42*	15	.67	.60	*.19*	13	1.36	1.18	*.89*
p					.315				.946			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

4.3.2 Analysis of proprioception within the "Control Group"

Table 4.14. Within the "Control Group" analysis of JPS

Control	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	5.25	3.87	*4.83*	15	5.22	4.52	*2.97*	15	5.91	4.43	*3.13*
Pre	15	5.58	3.60	*4.80*	14	3.79	2.89	*2.23*	15	4.84	3.68	*3.92*
Post	15	5.58	3.60	*4.80*	14	3.79	2.89	*2.23*	15	4.84	3.68	*3.92*
30min	15	4.95	4.67	*2.89*	15	5.02	4.78	*3.32*	15	5.15	5.20	*2.99*
1hour	14	6.10	6.42	*2.83*	15	2.80	2.40	*1.68*	15	4.79	4.38	*3.92*
1 day	14	3.14	2.50	*1.93*	15	3.47	2.60	*2.70*	15	3.51	3.35	*2.25*
p	.065				**.048**				.212			
	Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

In subjects of "Control Group" JPS at 50% ROM was less at 1 hour assessment comparing to initial and 30 min assessment points ($p<0.05$).

Table 4.15. Post Hoc analysis, comparison of JPS at 50% of ROM in "Control Group" between specific assessment moments

Control group JPS 50% ROM / (°degrees)										
N	Mean	Median	SD		N	Mean	Median	SD	Z	p
Initial				>	1 hour				**-2.158**	**.031**
15	5.22	4.52	2.97		15	2.80	2.40	1.68		
30 min				>	1 hour				**-2.443**	**.015**
15	5.02	4.78	3.32		15	2.80	2.40	1.68		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.16. Within the "Control Group" analysis of TTDPM disregarding direction of movement

Control	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.13	1.13	*.47*	15	1.38	1.06	*.83*	15	1.01	.74	*.61*
Pre	15	.99	.94	*.46*	15	.97	.85	*.37*	15	1.17	1.00	*.66*
Post	15	.99	.94	*.46*	15	.97	.85	*.37*	15	1.17	1.00	*.66*
30min	15	1.02	.92	*.48*	15	.99	1.03	*.32*	15	.90	.79	*.46*
1hour	15	1.05	.91	*.43*	15	1.24	1.18	*.51*	15	.99	.83	*.42*
1 day	15	.97	.87	*.39*	15	1.19	1.05	*.66*	15	1.01	.86	*.51*
p	.610				**.032**				.184			
	Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Post Hoc analysis showed that TTDPM at 50% ROM at initial assessment was greater than prior to intervention and at 30 minute assessment point. Additionally kinesthesia at 30 minutes interval was less than at 1 hour assessment mark. Several comparisons were shaded since in there was no intervention "Control Group". Therefore, pre and post intervention values were the same and the shaded comparisons should be disregarded.

Table 4.17. Post Hoc analysis, comparison of TTDPM at 50% of ROM in "Control Group" between specific assessment moments

Control group TTDPM 50% ROM / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial				>	Pre				**-2.637**	**.008**
15	1.38	1.06	*.83*		15	.97	.85	*.37*		
Initial				>	Post				**-2.637**	.008
15	1.38	1.06	*.83*		15	.97	.85	*.37*		
Initial				>	30 min				**-2.272**	**.023**
15	1.38	1.06	*.83*		15	.99	1.03	*.32*		
Pre				<	1 hour				**-2.897**	**.004**
15	.97	.85	*.37*		15	1.24	1.18	*.51*		
Post				<	1 hour				**-2.897**	.004
15	.97	.85	*.37*		15	1.24	1.18	*.51*		
30 min				<	1 hour				**-2.215**	**.027**
15	.99	1.03	*.32*		15	1.24	1.18	*.51*		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.18. Within the "Control Group" analysis of TTDPM at 90% of ER to ER and IR

Control	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.13	1.13	*.47*	14	.73	.68	*.32*	15	1.46	1.58	*.71*
Pre	15	.99	.94	*.46*	15	.76	.70	*.42*	15	1.25	1.05	*.68*
Post	15	.99	.94	*.46*	15	.76	.70	*.42*	15	1.25	1.05	*.68*
30min	15	1.02	.92	*.48*	15	.86	.73	*.47*	15	1.21	1.00	*.87*
1hour	15	1.05	.91	*.43*	14	.87	.72	*.39*	15	1.17	1.07	*.59*
1 day	15	.97	.87	*.39*	15	.68	.65	*.27*	15	1.22	1.08	*.60*
p					.231				.613			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.19. Within the "Control Group" analysis of TTDPM at 50% of ROM to ER and IR

Control	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.38	1.06	*.83*	15	1.31	1.12	*.87*	15	1.38	1.05	*.90*
Pre	15	.97	.85	*.37*	15	.89	.75	*.39*	14	1.06	.95	*.54*
Post	15	.97	.85	*.37*	15	.89	.75	*.39*	14	1.06	.95	*.54*
30min	15	.99	1.03	*.32*	15	.94	.92	*.48*	15	1.01	.98	*.48*
1hour	15	1.24	1.18	*.51*	15	1.12	1.10	*.33*	15	1.33	1.28	*.68*
1 day	15	1.19	1.05	*.66*	15	1.10	.98	*.70*	13	1.13	1.08	*.73*
p					.064				.721			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.20. Within the "Control Group" analysis of TTDPM at 70% of IR to ER and IR

Control	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.01	.74	*.61*	15	.91	.75	*.55*	14	1.09	.76	*.79*
Pre	15	1.17	1.00	*.66*	15	.81	.78	*.41*	14	1.59	1.37	*1.00*
Post	15	1.17	1.00	*.66*	15	.81	.78	*.41*	14	1.59	1.37	*1.00*
30min	15	.90	.79	*.46*	15	.75	.63	*.48*	15	1.08	.95	*.56*
1hour	15	.99	.83	*.42*	13	.93	.93	*.37*	14	1.02	.85	*.55*
1 day	15	1.01	.86	*.51*	15	.81	.75	*.35*	15	1.23	1.05	*.76*
p					.430				**.002**			
					Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**			
Related samples Freedman's two way analysis of variance by ranks												

Additional Post Hoc tests show that values of TTDPM at 70% internal rotation when moving to internal rotation at initial assessment was less compared to pre intervention values. However, pre assessment was greater than TTDPM at 30 min and 1 hour marks. Once again shaded comparisons have to be ignored since pre and post assessment values are the same in the "Control Group".

Table 4.21. Post Hoc analysis, comparison of TTDPM at 70% of IR to IR in the "Control Group" between specific assessment moments

Control group TTDPM 70% IR to IR / (°degrees)										
N	Mean	Median	SD		N	Mean	Median	SD	Z	p
Initial				<	Pre				**-2.158**	**.031**
14	1.09	.76	.79		14	1.59	1.37	1.00		
Initial				<	Post				-2.158	.031
14	1.09	.76	.79		14	1.59	1.37	1.00		
Pre				>	30 min				**-2.323**	**.020**
14	1.59	1.37	1.00		15	1.08	.95	.56		
Pre				>	1 hour				**-1.992**	**.046**
14	1.59	1.37	1.00		14	1.02	.85	.55		
Post				>	30 min				-2.323	.020
14	1.59	1.37	1.00		15	1.08	.95	.56		
Post				>	1 hour				-1.992	.046
14	1.59	1.37	1.00		14	1.02	.85	.55		
Two related samples Wilcoxon Signed Ranks Test										

4.3.3 Analysis of proprioception within the "Manual Therapy Group"

Table 4.22. Within the "Manual Therapy Group" analysis of JPS

Manual	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	4.59	2.27	*3.75*	15	4.77	3.15	*5.51*	15	3.97	3.87	*1.81*
Pre	15	5.55	4.63	*3.72*	15	5.05	3.97	*3.33*	15	5.14	4.95	*2.26*
Post	15	4.06	2.70	*3.67*	15	3.27	2.07	*2.77*	15	5.38	4.70	*3.43*
30min	15	4.76	3.12	*4.38*	15	5.14	4.43	*3.32*	15	6.55	5.27	*4.41*
1hour	15	4.45	3.70	*2.87*	15	4.97	4.77	*4.35*	15	4.13	3.65	*2.66*
1 day	15	5.07	3.13	*4.99*	15	5.37	5.15	*3.04*	15	5.99	5.25	*4.07*
p	.724				.223				.416			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.23. Within the "Manual Therapy Group" analysis of TTDPM disregarding direction of movement

Manual	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.41	1.41	*.61*	15	1.25	1.15	*.31*	15	1.53	1.53	*.61*
Pre	15	.96	.88	*.51*	15	1.30	1.21	*.53*	15	1.12	1.10	*.51*
Post	15	1.07	1.11	*.39*	15	1.41	1.38	*.69*	15	1.34	.85	*.92*
30min	15	1.02	.90	*.46*	15	1.05	1.12	*.34*	15	1.03	.88	*.53*
1hour	15	1.15	1.01	*.64*	15	1.15	1.05	*.52*	15	1.11	1.10	*.44*
1 day	15	1.18	1.10	*.54*	15	1.06	.88	*.46*	14	.89	.85	*.33*
p	**.015**				.101				**.026**			
	Reject null hypothesis				Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.24. Post Hoc analysis, comparison of TTDPM at 90% of ER in the "Manual Therapy Group" between specific assessment moments

Manual therapy group TTDPM 90% ER / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial				>	Pre				**-3.351**	**.001**
15	1.41	1.41	*.61*		15	.96	.88	*.51*		
Initial				>	Post				**-2.386**	**.017**
15	1.41	1.41	*.61*		15	1.07	1.11	*.39*		
Initial				>	30 min				**-2.499**	**.012**
15	1.41	1.41	*.61*		15	1.02	.90	*.46*		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.25. Post Hoc analysis, comparison of TTDPM at 70% of IR in the "Manual Therapy Group" between specific assessment moments

Manual therapy group TTDPM 70% IR / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial				>	Pre				**-2.385**	**.017**
15	1.53	1.53	*.61*		15	1.12	1.10	*.51*		
Initial				>	30 min				**-2.669**	**.008**
15	1.53	1.53	*.61*		15	1.03	.88	*.53*		
Initial				>	1 hour				**-2.500**	**.012**
15	1.53	1.53	*.61*		15	1.11	1.10	*.44*		
Initial				>	1 day				**-3.108**	**.002**
15	1.53	1.53	*.61*		14	.89	.85	*.33*		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.26. Within the "Manual Therapy Group" analysis of TTDPM at 90% of ER to ER and IR

Manual	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.41	1.41	.61	15	.97	.95	.40	15	1.84	1.70	1.01
Pre	15	.96	.88	.51	15	.68	.80	.41	15	1.23	1.23	.70
Post	15	1.07	1.11	.39	15	.93	.90	.51	15	1.15	.98	.63
30min	15	1.02	.90	.46	12	.66	.65	.29	15	1.06	1.08	.52
1hour	15	1.15	1.01	.64	15	.80	.57	.58	14	1.33	1.26	.77
1 day	15	1.18	1.10	.54	14	.82	.68	.42	15	1.45	1.38	.80
p					.199				.005			
					Retain null hypothesis (p>0.05)				Reject null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.27. Post Hoc analysis, comparison of TTDPM at 90% of ROM to IR in the "Manual Therapy Group" between specific assessment moments

Manual therapy group TTDPM 90% ER to IR / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial				>	Pre				**-3.238**	**.001**
15	1.84	1.70	*1.01*		15	1.23	1.23	*.70*		
Initial				>	Post				**-2.442**	**.015**
15	1.84	1.70	*1.01*		15	1.15	.98	*.63*		
Initial				>	30 min				**-3.140**	**.002**
15	1.84	1.70	*1.01*		15	1.06	1.08	*.52*		
30 min				<	1 day				**-1.988**	**.047**
15	1.06	1.08	*.52*		15	1.45	1.38	*.80*		
Two related samples Wilcoxon Signed Ranks Test										

Table 4.28. Analysis of TTDPM within the "Manual Therapy Group" at 50% of ROM to ER and IR

Manual	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.25	1.15	*.31*	13	1.22	1.22	*.57*	15	1.33	1.15	*.67*
Pre	15	1.30	1.21	*.53*	15	1.30	1.05	*.66*	14	1.35	1.28	*.64*
Post	15	1.41	1.38	*.69*	14	1.49	1.50	*1.11*	15	1.36	1.35	*.66*
30min	15	1.05	1.12	*.34*	15	1.01	1.00	*.45*	15	1.12	1.23	*.39*
1hour	15	1.15	1.05	*.52*	14	1.19	1.15	*.38*	15	1.10	1.05	*.67*
1 day	15	1.06	.88	*.46*	14	.98	.78	*.56*	14	1.18	1.09	*.56*
p					.209				.463			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.29. Within the "Manual Therapy Group" analysis of TTDPM at 70% of IR to ER and IR

Manual	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.53	1.53	.61	15	.96	.63	.64	14	2.25	2.07	1.05
Pre	15	1.12	1.10	.51	15	.70	.62	.27	15	1.61	1.63	1.02
Post	15	1.34	.85	.92	14	.71	.58	.43	14	1.80	1.24	1.21
30min	15	1.03	.88	.53	15	.67	.74	.31	15	1.43	1.08	.91
1hour	15	1.11	1.10	.44	14	.83	.66	.44	15	1.41	1.38	.66
1 day	14	.89	.85	.33	15	.78	.72	.39	15	1.54	.95	1.54
p					.923				.052			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

4.3.4 Analysis of proprioception within the "Passive Movement Group"

Table 4.30. Within the "Passive Movement Group" analysis of JPS

Passive	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	4.32	3.33	*4.44*	15	4.25	3.13	*2.86*	15	4.59	3.40	*3.09*
Pre	15	4.07	3.10	*2.91*	15	4.95	2.83	*4.20*	15	2.43	1.93	*1.55*
Post	15	5.27	5.27	*2.85*	15	6.16	5.37	*4.06*	15	2.68	1.00	*2.44*
30min	15	4.69	4.10	*2.61*	15	5.29	4.87	*1.89*	15	3.27	2.80	*2.11*
1hour	15	5.87	6.43	*3.45*	15	6.22	6.50	*4.08*	15	3.38	3.00	*1.68*
1 day	15	4.05	3.77	*3.30*	15	5.92	5.33	*4.05*	15	3.46	3.00	*2.54*
p	.568				.320				.161			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.31. Within the "Passive Movement Group" analysis of TTDPM disregarding direction of movement

Passive	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.09	.67	*1.29*	15	1.21	.77	*1.61*	15	1.03	.77	*.97*
Pre	15	1.13	.86	*.80*	14	.87	.76	*.51*	14	.89	.80	*.49*
Post	15	1.07	.89	*.63*	15	1.17	.76	*.80*	15	1.09	.65	*.93*
30min	14	.82	.67	*.41*	15	.82	.66	*.39*	15	1.09	.83	*.79*
1hour	15	.96	.87	*.40*	15	1.03	.90	*.54*	15	1.01	.70	*.69*
1 day	15	.91	.78	*.47*	15	.94	.80	*.50*	15	.76	.65	*.40*
p	.210				.541				.141			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.32. Analysis of TTDPM within the "Passive Movement Group" at 90% of ER to ER and IR

Passive	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.09	.67	1.29	15	.83	.48	1.05	15	1.29	.84	1.57
Pre	15	1.13	.86	.80	15	.96	.65	.85	14	1.11	1.02	.60
Post	15	1.07	.89	.63	15	.71	.58	.43	15	1.46	1.28	.87
30min	14	.82	.67	.41	14	.80	.60	.58	15	1.20	.78	1.06
1hour	15	.96	.87	.40	15	.81	.65	.55	15	1.11	.98	.57
1 day	15	.91	.78	.47	15	.75	.58	.43	15	1.03	.95	.56
p					.941				.060			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.33. Within the "Passive Movement Group" analysis of TTDPM at 50% of ROM to ER and IR

Passive	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.21	.77	*1.61*	15	1.14	.67	*1.61*	15	1.29	.60	*1.70*
Pre	14	.87	.76	*.51*	14	.76	.75	*.31*	14	.95	.78	*.78*
Post	15	1.17	.76	*.80*	15	1.04	.78	*.62*	15	1.32	.99	*1.01*
30min	15	.82	.66	*.39*	15	.77	.69	*.55*	15	.87	.78	*.36*
1hour	15	1.03	.90	*.54*	15	.86	.75	*.43*	15	1.16	1.05	*.74*
1 day	15	.94	.80	*.50*	15	.85	.70	*.55*	15	.92	.63	*.61*
p					.306				.489			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.34. Within the "Passive Movement Group" analysis of TTDPM at 70% of IR to ER and IR

Passive	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.03	.77	.97	15	.83	.60	.83	15	1.37	.75	1.47
Pre	14	.89	.80	.49	15	.83	.67	.62	14	1.07	.88	.74
Post	15	1.09	.65	.93	15	.91	.70	.78	15	1.27	.80	1.20
30min	15	1.09	.83	.79	15	.70	.53	.47	15	1.40	1.00	1.11
1hour	15	1.01	.70	.69	15	.72	.54	.45	13	1.42	1.12	1.05
1 day	15	.76	.65	.40	15	.62	.58	.28	15	.94	.78	.61
p					.227				.283			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

4.3.5 Analysis of proprioception within the "Plyometric Exercise Group"

Table 4.35. Within the "Plyometric Exercise Group" analysis of JPS

Plyo	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	4.34	3.57	*1.75*	15	8.46	7.03	*7.24*	15	4.55	2.97	*3.67*
Pre	15	3.59	2.98	*2.22*	15	3.99	3.65	*2.46*	14	3.21	2.70	*1.67*
Post	15	3.50	2.88	*2.32*	15	4.88	3.98	*3.84*	15	4.18	2.50	*4.03*
30min	15	3.63	3.47	*2.29*	15	4.31	4.03	*2.23*	15	4.33	3.33	*2.94*
1hour	15	5.11	4.57	*2.65*	15	4.20	4.12	*3.05*	15	3.55	3.03	*3.04*
1 day	15	3.17	2.17	*2.32*	15	4.51	3.33	*3.19*	15	3.95	4.12	*1.74*
p	.064				.925				.585			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.36. Within the "Plyometric Exercise Group" analysis of TTDPM disregarding direction of movement

Plyo	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.27	1.15	*.72*	15	1.25	1.22	*.66*	15	1.19	1.16	*.67*
Pre	14	1.09	1.01	*.39*	15	1.43	1.36	*.52*	15	1.16	1.09	*.56*
Post	15	1.31	.98	*.70*	15	1.17	1.30	*.38*	15	1.22	1.15	*.55*
30min	15	1.19	1.09	*.47*	15	1.08	1.06	*.40*	15	1.19	1.11	*.57*
1hour	15	1.45	1.51	*.77*	15	1.46	1.40	*.77*	15	.94	.81	*.40*
1 day	15	1.26	1.10	*.59*	15	1.27	1.21	*.47*	15	1.14	1.15	*.46*
p	.509				.325				.546			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.37. Within the "Plyometric Exercise Group" analysis of TTDPM at 90% of ER to ER and IR

Plyo	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.27	1.15	*.72*	15	.88	.70	*.41*	15	1.63	1.55	*1.10*
Pre	14	1.09	1.01	*.39*	14	.68	.64	*.34*	14	1.69	1.42	*1.07*
Post	15	1.31	.98	*.70*	15	.93	.74	*.48*	14	1.74	1.68	*1.06*
30min	15	1.19	1.09	*.47*	14	.87	.80	*.50*	15	1.53	1.55	*.54*
1hour	15	1.45	1.51	*.77*	15	1.09	.92	*.75*	15	1.81	1.56	*1.00*
1 day	15	1.26	1.10	*.59*	15	.87	.80	*.38*	14	1.51	1.30	*.73*
p					.059				.935			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.38. Within the "Plyometric Exercise Group" analysis of TTDPM at 50% of ROM to ER and IR

Plyo	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.25	1.22	*.66*	14	1.15	1.14	*.71*	15	1.36	1.05	*.83*
Pre	15	1.43	1.36	*.52*	15	1.24	1.28	*.49*	14	1.55	1.47	*.87*
Post	15	1.17	1.30	*.38*	15	1.38	1.08	*.94*	15	1.06	1.07	*.42*
30min	15	1.08	1.06	*.40*	15	1.20	1.15	*.55*	15	1.05	.90	*.55*
1hour	15	1.46	1.40	*.77*	15	1.66	.92	*1.32*	15	1.32	1.30	*.68*
1 day	15	1.27	1.21	*.47*	14	1.34	1.33	*.70*	15	1.23	1.05	*.72*
p					.429				.526			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.39. Within the "Plyometric Exercise Group" analysis of TTDPM at 70% of IR to ER and IR

Plyo	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.19	1.16	.67	15	.96	.70	.77	15	1.43	1.51	.97
Pre	15	1.16	1.09	.56	15	.94	.68	.64	14	1.41	1.23	.87
Post	15	1.22	1.15	.55	14	.71	.66	.32	15	1.76	1.73	.76
30min	15	1.19	1.11	.57	15	.93	.80	.55	14	1.55	1.41	.60
1hour	15	.94	.81	.40	15	.85	.75	.37	12	1.24	1.28	.43
1 day	15	1.14	1.15	.46	15	.84	.75	.37	15	1.65	1.68	.80
p					.977				.409			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

4.3.6 Analysis of proprioception within "Stabilization Exercise Group"

Table 4.40. Within the "Stabilization Exercise Group" analysis of JPS

Stabl	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	4.21	3.23	*3.03*	15	4.63	3.58	*2.77*	15	5.20	4.67	*3.37*
Pre	15	5.04	3.78	*3.36*	15	6.22	4.87	*4.60*	15	2.99	2.55	*2.07*
Post	15	5.28	5.52	*3.78*	15	6.14	4.87	*3.46*	15	3.89	2.65	*3.94*
30min	15	6.06	5.07	*3.75*	15	5.32	3.40	*4.00*	14	2.54	2.31	*1.45*
1hour	15	5.90	4.53	*4.38*	15	5.14	4.97	*2.80*	15	3.68	3.43	*2.65*
1 day	15	5.25	4.37	*3.82*	15	4.04	3.63	*2.75*	15	3.83	4.03	*2.48*
p	.832				.811				.335			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.41. Within the "Stabilization Exercise Group" analysis of TTDPM disregarding direction of movement

Stabl	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.10	.93	*.47*	15	1.22	.90	*.78*	15	1.05	.77	*.57*
Pre	15	.89	.83	*.34*	15	1.12	.89	*.71*	15	1.11	1.10	*.37*
Post	15	1.09	1.09	*.40*	15	1.04	1.00	*.40*	15	.98	.83	*.39*
30min	14	1.15	1.10	*.47*	15	1.02	.89	*.52*	15	.95	.89	*.27*
1hour	15	1.02	1.03	*.51*	15	1.16	1.05	*.50*	15	.93	.86	*.44*
1 day	15	.95	.83	*.41*	15	1.08	1.03	*.59*	15	.89	.74	*.52*
p	.214				.282				.414			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.42. Within the "Stabilization Exercise Group" analysis of TTDPM at 90% of ER to ER and IR

Stabl	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.10	.93	.47	15	.63	.60	.29	15	1.55	1.46	.87
Pre	15	.89	.83	.34	15	.58	.55	.24	15	1.20	1.03	.63
Post	15	1.09	1.09	.40	15	.66	.60	.27	15	1.41	1.35	.58
30min	14	1.15	1.10	.47	14	.71	.72	.32	15	1.76	1.67	1.04
1hour	15	1.02	1.03	.51	14	.60	.53	.28	15	1.35	1.23	.68
1 day	15	.95	.83	.41	15	.58	.55	.31	15	1.16	1.00	.49
p					.732				.128			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.43. Within the "Stabilization Exercise Group" analysis of TTDPM at 50% of ROM to ER and IR

Stabl	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.22	.90	*.78*	15	.75	.70	*.36*	15	1.52	1.20	*1.18*
Pre	15	1.12	.89	*.71*	15	1.13	.85	*.81*	15	1.18	.90	*.93*
Post	15	1.04	1.00	*.40*	15	.90	.68	*.58*	15	1.20	1.08	*.69*
30min	15	1.02	.89	*.52*	15	.86	.70	*.55*	15	1.12	.93	*.54*
1hour	15	1.16	1.05	*.50*	15	.95	.85	*.51*	15	1.32	1.25	*.60*
1 day	15	1.08	1.03	*.59*	15	.88	.65	*.58*	15	1.21	.85	*.72*
p					.573				.525			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.44. Within the "Stabilization Exercise Group" analysis of TTDPM at 70% of IR to ER and IR

Stabl	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Initial	15	1.05	.77	.57	15	.80	.74	.29	14	1.53	1.12	1.21
Pre	15	1.11	1.10	.37	15	.84	.75	.39	14	1.53	1.65	.58
Post	15	.98	.83	.39	15	.71	.65	.33	14	1.34	1.25	.53
30min	15	.95	.89	.27	15	.70	.65	.29	13	1.29	1.28	.51
1hour	15	.93	.86	.44	15	.74	.57	.41	15	1.17	1.07	.68
1 day	15	.89	.74	.52	15	.65	.53	.33	15	1.12	.80	.79
p					.204				.183			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

4.3.7 Analysis of proprioception within "Warm Up Exercise Group"

Table 4.45. Within the "Warm Up Exercise Group" analysis of JPS

Warm up	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	5.08	3.30	*3.79*	15	5.28	3.43	*5.72*	15	4.04	2.88	*2.96*
Pre	15	3.68	2.70	*2.47*	15	6.51	5.90	*5.18*	15	3.48	2.73	*2.58*
Post	15	4.16	2.98	*3.51*	15	4.03	4.27	*3.17*	15	2.72	1.95	*2.45*
30min	15	4.40	2.23	*4.48*	15	3.91	3.30	*2.44*	15	4.73	4.00	*2.63*
1hour	15	3.15	2.93	*1.80*	15	5.78	4.07	*4.64*	14	2.84	2.13	*2.01*
1 day	15	3.81	3.60	*2.26*	15	5.63	4.27	*4.25*	15	3.60	2.60	*3.05*
p	.804				.344				.082			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.46. Within the "Warm Up Exercise Group" analysis of TTDPM disregarding direction of movement

Warm up	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.51	1.49	*.73*	15	1.15	1.01	*.54*	15	1.20	1.04	*.72*
Pre	15	1.49	1.52	*.66*	15	1.11	1.21	*.45*	15	1.50	1.32	*.76*
Post	15	1.11	.91	*.42*	15	1.15	1.03	*.66*	15	1.29	1.22	*.54*
30min	15	1.39	1.22	*.97*	15	1.24	1.12	*.55*	15	1.32	1.09	*.69*
1hour	15	1.25	1.13	*.51*	15	1.29	1.14	*.54*	15	1.36	1.03	*.67*
1 day	15	1.17	1.08	*.40*	15	1.31	1.30	*.62*	15	1.42	1.07	*.95*
p	.326				.257				.561			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.47. Within the "Warm Up Exercise Group" analysis of TTDPM at 90% of ER to ER and IR

Warm up	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.51	1.49	*.73*	15	1.09	.93	*.75*	15	1.80	1.57	*1.13*
Pre	15	1.49	1.52	*.66*	15	.83	.65	*.44*	15	2.03	1.75	*1.12*
Post	15	1.11	.91	*.42*	15	.82	.78	*.41*	15	1.37	1.28	*.51*
30min	15	1.39	1.22	*.97*	15	1.12	1.22	*.65*	13	1.32	1.19	*.50*
1hour	15	1.25	1.13	*.51*	15	.97	.82	*.43*	15	1.60	1.55	*.73*
1 day	15	1.17	1.08	*.40*	15	1.03	.83	*.56*	15	1.36	1.40	*.42*
p					.504				.940			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.48. Within the "Warm Up Exercise Group" analysis of TTDPM at 50% of ROM to ER and IR

Warm up	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.15	1.01	*.54*	15	1.25	.94	*1.01*	15	1.25	.92	*.90*
Pre	15	1.11	1.21	*.45*	15	1.11	1.05	*.65*	15	1.08	1.15	*.47*
Post	15	1.15	1.03	*.66*	15	1.13	.87	*.62*	15	1.24	.98	*.89*
30min	15	1.24	1.12	*.55*	14	1.31	1.04	*.86*	15	1.20	1.09	*.64*
1hour	15	1.29	1.14	*.54*	15	1.14	1.30	*.55*	15	1.42	1.25	*.84*
1 day	15	1.31	1.30	*.62*	14	1.18	.89	*.71*	15	1.48	1.40	*.76*
p					.706				.099			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

Table 4.49. Within the "Warm Up Exercise Group" analysis of TTDPM at 70% of IR to ER and IR

Warm up	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Initial	15	1.20	1.04	*.72*	15	.87	.68	*.48*	15	1.84	1.33	*1.47*
Pre	15	1.50	1.32	*.76*	14	.91	.79	*.42*	15	1.96	1.62	*1.00*
Post	15	1.29	1.22	*.54*	15	.96	.90	*.48*	15	1.72	1.83	*.83*
30min	15	1.32	1.09	*.69*	15	.91	.79	*.56*	15	2.05	1.73	*1.22*
1hour	15	1.36	1.03	*.67*	15	.98	.68	*.56*	15	1.78	1.55	*.89*
1 day	15	1.42	1.07	*.95*	15	.88	.68	*.60*	15	2.07	1.75	*1.74*
p					.620				.805			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Related samples Freedman's two way analysis of variance by ranks												

4.4 Between group comparison at specific moments of assessment pre and post interventions

The following part shows comparison of proprioception between different intervention groups at each assessment point. Whenever the difference between the groups was observed with multiple group comparison, additional analysis was performed to identify which specific groups differs from others.

4.4.1 Comparison of groups at initial assessment

For JPS at initial assessment there were no differences between the groups at all angles. Based on Independent Samples Kruskal-Wallis Test at 90% ER (p=.877), at 50% of ROM (p=.290), and at 70%IR (p=.419). However, there were differences between groups in terms of TTDPM at 90% ER (p= .039), at 50% ROM and 50% ROM moving into external rotation (p=.044) and (p=.020) respectively. Finally at 70% internal rotation moving into internal rotation the difference was observed with (p=.036). The descriptive values of JPS and TTDPM of different groups were not displayed below since this information was available at within the group analysis section of results. Below, tables show Post Hoc comparisons of the groups where the difference in proprioception was found at initial assessment.

Table 4.50 Post Hoc comparison of TTDPM at 90% of ER between the groups at Initial assessment

Comparison of group's TTDPM 90% ER at initial assessment / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Manual				>	Passive				-2.738	**.006**
15	1.41	1.41	*.61*		15	1.09	.67	*1.29*		
Warm up				>	Passive				-2.717	**.007**
15	1.51	1.49	*.73*		15	1.09	.67	*1.29*		
Mann-Whitney U Test										

Table 4.51. Post Hoc comparison of TTDPM at 50% of ROM between the groups at Initial assessment

Comparison of group's TTDPM 50% ROM at initial assessment / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Active				<	Control				**-2.303**	**.021**
15	.86	.86	*.27*		15	1.38	1.06	*.83*		
Active				<	Manual				**-3.320**	**.001**
15	.86	.86	*.27*		15	1.25	1.15	*.31*		
Control				>	Passive				**-1.970**	**.049**
15	1.38	1.06	*.83*		15	1.21	.77	*1.61*		
Manual				>	Passive				**-2.530**	**.011**
15	1.25	1.15	*.31*		15	1.21	.77	*1.61*		
Mann-Whitney U Test										

Table 4.52. Post Hoc comparison of TTDPM at 50% of ROM to ER between the groups at Initial assessment

Comparison of group's TTDPM 50% ROM to ER at initial assessment / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Active				<	Control				**-2.598**	**.009**
15	.64	.59	*.25*		15	1.31	1.12	*.87*		
Active				<	Manual				**-2.719**	**.007**
15	.64	.59	*.25*		15	1.22	1.22	*.57*		
Active				<	Plyometric				**-2.114**	**.034**
15	.64	.59	*.25*		15	1.15	1.14	*.71*		
Active				<	Warm uo				**-2.446**	**.014**
15	.64	.59	*.25*		15	1.25	.94	*1.01*		
Manual				>	Stabilization				**-2.305**	**.021**
15	1.22	1.22	*.57*		15	.75	.70	*.36*		
Warm up				>	Stabilization				**-1.993**	**.046**
15	1.25	.94	*1.01*		15	.75	.70	*.36*		
Mann-Whitney U Test										

4.4.2 Comparison of groups at Pre assessment

Table 4.53. Comparison of JPS between the groups at Pre assessment

Pre	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	5.29	5.30	*3.15*	15	5.48	2.78	*4.31*	15	4.72	4.47	*3.02*
Control	15	5.58	3.60	*4.80*	14	3.79	2.89	*2.23*	15	4.84	3.68	*3.92*
Manual	15	5.55	4.63	*3.72*	15	5.05	3.97	*3.33*	15	5.14	4.95	*2.26*
Passive	15	4.07	3.10	*2.91*	15	4.95	2.83	*4.20*	15	2.43	1.93	*1.55*
Plyometric	15	3.59	2.98	*2.22*	15	3.99	3.65	*2.46*	14	3.21	2.70	*1.67*
Stabiliz.	15	5.04	3.78	*3.36*	15	6.22	4.87	*4.60*	15	2.99	2.55	*2.07*
Warm up	15	3.68	2.70	*2.47*	15	6.51	5.90	*5.18*	15	3.48	2.73	*2.58*
p	.474				.709				**.010**			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**			
Independent Samples Kruskal-Wallis Test												

Table 4.54. Post Hoc comparison of JPS at 70% of IR between the groups at Pre assessment

Comparison of group's JPS 70% IR at Pre intervention / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Active				>	Passive				**-2.219**	**.026**
15	4.72	4.47	*3.02*		15	2.43	1.93	*1.55*		
Control				>	Passive				**-2.136**	**.033**
15	4.84	3.68	*3.92*		15	2.43	1.93	*1.55*		
Manual				>	Passive				**-3.215**	**.001**
15	5.14	4.95	*2.26*		15	2.43	1.93	*1.55*		
Manual				>	Plyometric				**-2.597**	**.009**
15	5.14	4.95	*2.26*		14	3.21	2.70	*1.67*		
Manual				>	Stabilization				**-2.675**	**.007**
15	5.14	4.95	*2.26*		15	2.99	2.55	*2.07*		
Manual				>	Warm up				**-2.385**	**.017**
15	5.14	4.95	*2.26*		15	3.48	2.73	*2.58*		
Mann-Whitney U Test										

Table 4.55. Comparison of TTDPM between the groups at Pre assessment

Pre	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.12	.90	*.48*	15	.86	.86	*.27*	15	1.04	1.07	*.28*
Control	15	1.13	1.13	*.47*	15	1.38	1.06	*.83*	15	1.01	.74	*.61*
Manual	15	1.41	1.41	*.61*	15	1.25	1.15	*.31*	15	1.53	1.53	*.61*
Passive	15	1.09	.67	*1.29*	15	1.21	.77	*1.61*	15	1.03	.77	*.97*
Plyometric	15	1.27	1.15	*.72*	15	1.25	1.22	*.66*	15	1.19	1.16	*.67*
Stabiliz.	15	1.10	.93	*.47*	15	1.22	.90	*.78*	15	1.05	.77	*.57*
Warm up	15	1.51	1.49	*.73*	15	1.15	1.01	*.54*	15	1.20	1.04	*.72*
p	.126				**.008**				.265			
	Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.56. Post Hoc comparison of TTDPM at 50% of ROM between the groups at Pre assessment

Comparison of group's TTDPM 50% ROM at Pre intervention / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Active				<	Manual				**-2.323**	**.020**
15	.86	.86	*.27*		15	1.25	1.15	*.31*		
Active				<	Plyometric				**-2.635**	**.008**
15	.86	.86	*.27*		15	1.25	1.22	*.66*		
Control				>	Manual				**-2.075**	**.038**
15	1.38	1.06	*.83*		15	1.25	1.15	*.31*		
Control				>	Plyometric				**-2.594**	**.009**
15	1.38	1.06	*.83*		15	1.25	1.22	*.66*		
Manual				>	Passive				**-2.662**	**.008**
15	1.25	1.15	.31		15	1.21	.77	*1.61*		
Passive				<	Plyometric				**-2.946**	**.003**
15	1.21	.77	*1.61*		15	1.25	1.22	*.66*		
Stabilization				<	Plyometric				**-2.054**	**.040**
15	1.22	.90	*.78*		15	1.25	1.22	*.66*		
Mann-Whitney U Test										

Table 4.57. Comparison of TTDPM at 90% of ER to ER and IR between the groups at Pre assessment

Pre	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.07	1.00	*.43*	14	.72	.65	*.32*	13	1.54	1.35	*.65*
Control	15	.99	.94	*.46*	15	.76	.70	*.42*	15	1.25	1.05	*.68*
Manual	15	.96	.88	*.51*	15	.68	.80	*.41*	15	1.23	1.23	*.70*
Passive	15	1.13	.86	*.80*	15	.96	.65	*.85*	14	1.11	1.02	*.60*
Plyometric	14	1.09	1.01	*.39*	14	.68	.64	*.34*	14	1.69	1.42	*1.07*
Stabiliz.	15	.89	.83	*.34*	15	.58	.55	*.24*	15	1.20	1.03	*.63*
Warm up	15	1.49	1.52	*.66*	15	.83	.65	*.44*	15	2.03	1.75	*1.12*
p					.732				.099			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.58. Comparison of TTDPM at 50% of ROM to ER and IR between the groups at Pre assessment

Pre	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.96	.85	*.38*	14	.75	.73	*.27*	15	1.18	1.03	*.69*
Control	15	.97	.85	*.37*	15	.89	.75	*.39*	14	1.06	.95	*.54*
Manual	15	1.30	1.21	*.53*	15	1.30	1.05	*.66*	14	1.35	1.28	*.64*
Passive	14	.87	.76	*.51*	14	.76	.75	*.31*	14	.95	.78	*.78*
Plyometric	15	1.43	1.36	*.52*	15	1.24	1.28	*.49*	14	1.55	1.47	*.87*
Stabiliz.	15	1.12	.89	*.71*	15	1.13	.85	*.81*	15	1.18	.90	*.93*
Warm up	15	1.11	1.21	*.45*	15	1.11	1.05	*.65*	15	1.08	1.15	*.47*
p					**.034**				.130			
					Reject null hypothesis (p<0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.59. Post Hoc comparison of TTDPM at 50% of ROM to ER between the groups at Pre assessment

Comparison of group's TTDPM 50% ROM to ER at Pre intervention / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Active				<	Manual				**-2.577**	**.010**
14	.75	.73	*.27*		15	1.30	1.05	*.66*		
Active				<	Plyometric				**-2.772**	**.006**
14	.75	.73	*.27*		15	1.24	1.28	*.49*		
Control				<	Plyometric				**-1.992**	**.046**
15	.97	.85	*.37*		15	1.24	1.28	*.49*		
Manual				>	Passive				**-2.360**	**.018**
15	1.30	1.05	*.66*		14	.76	.75	*.31*		
Passive				<	Plyometric				**-2.620**	**.009**
14	.76	.75	*.31*		15	1.24	1.28	*.49*		
Mann-Whitney U Test										

Table 4.60. Comparison of TTDPM at 70% of IR to ER and IR between the groups at Pre assessment

Pre	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.09	1.01	*.49*	15	.81	.78	*.33*	14	1.48	1.14	*.98*
Control	15	1.17	1.00	*.66*	15	.81	.78	*.41*	14	1.59	1.37	*1.00*
Manual	15	1.12	1.10	*.51*	15	.70	.62	*.27*	15	1.61	1.63	*1.02*
Passive	14	.89	.80	*.49*	15	.83	.67	*.62*	14	1.07	.88	*.74*
Plyometric	15	1.16	1.09	*.56*	15	.94	.68	*.64*	14	1.41	1.23	*.87*
Stabiliz.	15	1.11	1.10	*.37*	15	.84	.75	*.39*	14	1.53	1.65	*.58*
Warm up	15	1.50	1.32	*.76*	14	.91	.79	*.42*	15	1.96	1.62	*1.00*
p					.887				.182			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

4.4.3 Comparison of groups at Post assessment

Table 4.61. Comparison of JPS between the groups at Post assessment

Post	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	4.96	4.30	*3.34*	15	5.55	4.87	*4.40*	15	5.35	3.45	*4.29*
Control	15	5.58	3.60	*4.80*	14	3.79	2.89	*2.23*	15	4.84	3.68	*3.92*
Manual	15	4.06	2.70	*3.67*	15	3.27	2.07	*2.77*	15	5.38	4.70	*3.43*
Passive	15	5.27	5.27	*2.85*	15	6.16	5.37	*4.06*	15	2.68	1.00	*2.44*
Plyometric	15	3.50	2.88	*2.32*	15	4.88	3.98	*3.84*	15	4.18	2.50	*4.03*
Stabiliz.	15	5.28	5.52	*3.78*	15	6.14	4.87	*3.46*	15	3.89	2.65	*3.94*
Warm up	15	4.16	2.98	*3.51*	15	4.03	4.27	*3.17*	15	2.72	1.95	*2.45*
p	.381				.172				.056			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.62. Comparison of TTDPM between the groups at Post assessment

Post	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.14	1.24	*.33*	14	1.30	1.32	*.41*	15	1.23	1.25	*.57*
Control	15	.99	.94	*.46*	15	.97	.85	*.37*	15	1.17	1.00	*.66*
Manual	15	1.07	1.11	*.39*	15	1.41	1.38	*.69*	15	1.34	.85	*.92*
Passive	15	1.07	.89	*.63*	15	1.17	.76	*.80*	15	1.09	.65	*.93*
Plyometric	15	1.31	.98	*.70*	15	1.17	1.30	*.38*	15	1.22	1.15	*.55*
Stabiliz.	15	1.09	1.09	*.40*	15	1.04	1.00	*.40*	15	.98	.83	*.39*
Warm up	15	1.11	.91	*.42*	15	1.15	1.03	*.66*	15	1.29	1.22	*.54*
p	.794				.217				.244			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.63. Comparison of TTDPM at 90% of ER to ER and IR between the groups at Post assessment

Post	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.14	1.24	*.33*	14	.78	.77	*.27*	15	1.51	1.43	*.71*
Control	15	.99	.94	*.46*	15	.76	.70	*.42*	15	1.25	1.05	*.68*
Manual	15	1.07	1.11	*.39*	15	.93	.90	*.51*	15	1.15	.98	*.63*
Passive	15	1.07	.89	*.63*	15	.71	.58	*.43*	15	1.46	1.28	*.87*
Plyometric	15	1.31	.98	*.70*	15	.93	.74	*.48*	14	1.74	1.68	*1.06*
Stabiliz.	15	1.09	1.09	*.40*	15	.66	.60	*.27*	15	1.41	1.35	*.58*
Warm up	15	1.11	.91	*.42*	15	.82	.78	*.41*	15	1.37	1.28	*.51*
p					.565				.541			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.64. Comparison of TTDPM at 50% of ROM to ER and IR between the groups at Post assessment

Post	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	14	1.30	1.32	*.41*	13	1.26	1.13	*.61*	15	1.59	1.40	*.83*
Control	15	.97	.85	*.37*	15	.89	.75	*.39*	14	1.06	.95	*.54*
Manual	15	1.41	1.38	*.69*	14	1.49	1.50	*1.11*	15	1.36	1.35	*.66*
Passive	15	1.17	.76	*.80*	15	1.04	.78	*.62*	15	1.32	.99	*1.01*
Plyometric	15	1.17	1.30	*.38*	15	1.38	1.08	*.94*	15	1.06	1.07	*.42*
Stabiliz.	15	1.04	1.00	*.40*	15	.90	.68	*.58*	15	1.20	1.08	*.69*
Warm up	15	1.15	1.03	*.66*	15	1.13	.87	*.62*	15	1.24	.98	*.89*
p					.324				.270			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.65. Comparison of TTDPM at 70% of IR to ER and IR between the groups at Post assessment

Post	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.23	1.25	*.57*	15	.96	.93	*.46*	15	1.53	1.38	*.77*
Control	15	1.17	1.00	*.66*	15	.81	.78	*.41*	14	1.59	1.37	*1.00*
Manual	15	1.34	.85	*.92*	14	.71	.58	*.43*	14	1.80	1.24	*1.21*
Passive	15	1.09	.65	*.93*	15	.91	.70	*.78*	15	1.27	.80	*1.20*
Plyometric	15	1.22	1.15	*.55*	14	.71	.66	*.32*	15	1.76	1.73	*.76*
Stabiliz.	15	.98	.83	*.39*	15	.71	.65	*.33*	14	1.34	1.25	*.53*
Warm up	15	1.29	1.22	*.54*	15	.96	.90	*.48*	15	1.72	1.83	*.83*
p					.290				.206			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

4.4.4 Comparison of groups at 30 minute assessment

Table 4.66. Comparison of JPS between the groups at 30 minute assessment

30 min	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	5.54	4.83	*3.76*	15	5.69	5.03	*4.21*	15	4.76	3.40	*3.74*
Control	15	4.95	4.67	*2.89*	15	5.02	4.78	*3.32*	15	5.15	5.20	*2.99*
Manual	15	4.76	3.12	*4.38*	15	5.14	4.43	*3.32*	15	6.55	5.27	*4.41*
Passive	15	4.69	4.10	*2.61*	15	5.29	4.87	*1.89*	15	3.27	2.80	*2.11*
Plyometric	15	3.63	3.47	*2.29*	15	4.31	4.03	*2.23*	15	4.33	3.33	*2.94*
Stabiliz.	15	6.06	5.07	*3.75*	15	5.32	3.40	*4.00*	14	2.54	2.31	*1.45*
Warm up	15	4.40	2.23	*4.48*	15	3.91	3.30	*2.44*	15	4.73	4.00	*2.63*
p	.309				.768				**.034**			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				**Reject null hypothesis (p<0.05)**			
Independent Samples Kruskal-Wallis Test												

Table 4.67 Post Hoc comparison of JPS at 70% of IR between the groups at 30 minute assessment

Comparison of group's JPS 70% IR at 30 min post intervention / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Control				>	Stabilization				**-2.379**	**.017**
15	5.15	5.20	*2.99*		14	2.54	2.31	*1.45*		
Manual				>	Passive				**-2.406**	**.016**
15	6.55	5.27	*4.41*		15	3.27	2.80	*2.11*		
Manual				>	Stabilization				**-2.903**	**.004**
15	6.55	5.27	*4.41*		14	2.54	2.31	*1.45*		
Warm uo				>	Stabilization				**-2.401**	**.016**
15	4.73	4.00	*2.63*		14	2.54	2.31	*1.45*		
Mann-Whitney U Test										

Table 4.68. Comparison of TTDPM between the groups at 30 minute assessment

30 min	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.94	.89	*.25*	15	1.17	1.16	*.41*	15	.99	.88	*.48*
Control	15	1.02	.92	*.48*	15	.99	1.03	*.32*	15	.90	.79	*.46*
Manual	15	1.02	.90	*.46*	15	1.05	1.12	*.34*	15	1.03	.88	*.53*
Passive	14	.82	.67	*.41*	15	.82	.66	*.39*	15	1.09	.83	*.79*
Plyometric	15	1.19	1.09	*.47*	15	1.08	1.06	*.40*	15	1.19	1.11	*.57*
Stabiliz.	14	1.15	1.10	*.47*	15	1.02	.89	*.52*	15	.95	.89	*.27*
Warm up	15	1.39	1.22	*.97*	15	1.24	1.12	*.55*	15	1.32	1.09	*.69*
p	.085				.157				.411			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.69. Comparison of TTDPM at 90% of ER to ER and IR between the groups at 30 minute assessment

30 min	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.94	.89	*.25*	15	.72	.65	*.23*	15	1.15	1.10	*.47*
Control	15	1.02	.92	*.48*	15	.86	.73	*.47*	15	1.21	1.00	*.87*
Manual	15	1.02	.90	*.46*	12	.66	.65	*.29*	15	1.06	1.08	*.52*
Passive	14	.82	.67	*.41*	14	.80	.60	*.58*	15	1.20	.78	*1.06*
Plyometric	15	1.19	1.09	*.47*	14	.87	.80	*.50*	15	1.53	1.55	*.54*
Stabiliz.	14	1.15	1.10	*.47*	14	.71	.72	*.32*	15	1.76	1.67	*1.04*
Warm up	15	1.39	1.22	*.97*	15	1.12	1.22	*.65*	13	1.32	1.19	*.50*
p					.440				.063			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.70. Comparison of TTDPM at 50% of ROM to ER and IR between the groups at 30 minute assessment

30 min	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.17	1.16	*.41*	15	1.02	1.03	*.47*	14	1.33	1.29	*.49*
Control	15	.99	1.03	*.32*	15	.94	.92	*.48*	15	1.01	.98	*.48*
Manual	15	1.05	1.12	*.34*	15	1.01	1.00	*.45*	15	1.12	1.23	*.39*
Passive	15	.82	.66	*.39*	15	.77	.69	*.55*	15	.87	.78	*.36*
Plyometric	15	1.08	1.06	*.40*	15	1.20	1.15	*.55*	15	1.05	.90	*.55*
Stabiliz.	15	1.02	.89	*.52*	15	.86	.70	*.55*	15	1.12	.93	*.54*
Warm up	15	1.24	1.12	*.55*	14	1.31	1.04	*.86*	15	1.20	1.09	*.64*
p					.168				.198			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.71. Comparison of TTDPM at 70% of IR to ER and IR between the groups at 30 minute assessment

30 min	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.99	.88	*.48*	15	.80	.68	*.41*	14	1.20	1.13	*.68*
Control	15	.90	.79	*.46*	15	.75	.63	*.48*	15	1.08	.95	*.56*
Manual	15	1.03	.88	*.53*	15	.67	.74	*.31*	15	1.43	1.08	*.91*
Passive	15	1.09	.83	*.79*	15	.70	.53	*.47*	15	1.40	1.00	*1.11*
Plyometric	15	1.19	1.11	*.57*	15	.93	.80	*.55*	14	1.55	1.41	*.60*
Stabiliz.	15	.95	.89	*.27*	15	.70	.65	*.29*	13	1.29	1.28	*.51*
Warm up	15	1.32	1.09	*.69*	15	.91	.79	*.56*	15	2.05	1.73	*1.22*
					.707				.111			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

4.4.5 Comparison of groups at 1 hour assessment

Table 4.72. Comparison of JPS between the groups at 1 hour assessment

1 hour	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	4.16	3.10	*3.08*	15	6.04	4.37	*5.25*	15	2.30	1.62	*1.75*
Control	14	6.10	6.42	*2.83*	15	2.80	2.40	*1.68*	15	4.79	4.38	*3.92*
Manual	15	4.45	3.70	*2.87*	15	4.97	4.77	*4.35*	15	4.13	3.65	*2.66*
Passive	15	5.87	6.43	*3.45*	15	6.22	6.50	*4.08*	15	3.38	3.00	*1.68*
Plyometric	15	5.11	4.57	*2.65*	15	4.20	4.12	*3.05*	15	3.55	3.03	*3.04*
Stabiliz.	15	5.90	4.53	*4.38*	15	5.14	4.97	*2.80*	15	3.68	3.43	*2.65*
Warm up	15	3.15	2.93	*1.80*	15	5.78	4.07	*4.64*	14	2.84	2.13	*2.01*
p	.122				.166				.260			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.73. Comparison of TTDPM between the groups at 1 hour assessment

1 hour	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.14	1.10	*.34*	15	1.25	1.19	*.30*	15	1.09	1.13	*.31*
Control	15	1.05	.91	*.43*	15	1.24	1.18	*.51*	15	.99	.83	*.42*
Manual	15	1.15	1.01	*.64*	15	1.15	1.05	*.52*	15	1.11	1.10	*.44*
Passive	15	.96	.87	*.40*	15	1.03	.90	*.54*	15	1.01	.70	*.69*
Plyometric	15	1.45	1.51	*.77*	15	1.46	1.40	*.77*	15	.94	.81	*.40*
Stabiliz.	15	1.02	1.03	*.51*	15	1.16	1.05	*.50*	15	.93	.86	*.44*
Warm up	15	1.25	1.13	*.51*	15	1.29	1.14	*.54*	15	1.36	1.03	*.67*
p	.298				.493				.265			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.74. Comparison of TTDPM at 90% of ER to ER and IR between the groups at 1 hour assessment

1 hour	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.14	1.10	*.34*	15	.92	.90	*.33*	15	1.36	1.43	*.49*
Control	15	1.05	.91	*.43*	14	.87	.72	*.39*	15	1.17	1.07	*.59*
Manual	15	1.15	1.01	*.64*	15	.80	.57	*.58*	14	1.33	1.26	*.77*
Passive	15	.96	.87	*.40*	15	.81	.65	*.55*	15	1.11	.98	*.57*
Plyometric	15	1.45	1.51	*.77*	15	1.09	.92	*.75*	15	1.81	1.56	*1.00*
Stabiliz.	15	1.02	1.03	*.51*	14	.60	.53	*.28*	15	1.35	1.23	*.68*
Warm up	15	1.25	1.13	*.51*	15	.97	.82	*.43*	15	1.60	1.55	*.73*
p					**.037**				.223			
					Reject null hypothesis (p<0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.75. Post Hoc comparison of TTDPM at 90% of ER to ER between the groups at 1 hour assessment

Comparison of group's TTDPM 90% ER to ER at 1 hour / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Active				>	Stabilization				**-2.842**	**.004**
15	.92	.90	*.33*		14	.60	.53	*.28*		
Control				>	Stabilization				**-2.325**	**.020**
14	.87	.72	*.39*		14	.60	.53	*.28*		
Plyometric				>	Stabilization				**-2.358**	**.018**
15	1.09	.92	*.75*		14	.60	.53	*.28*		
Warm up				>	Stabilization				**-2.652**	**.008**
15	.97	.82	*.43*		14	.60	.53	*.28*		
Mann-Whitney U Test										

Table 4.76. Comparison of TTDPM at 50% of ROM to ER and IR between the groups at 1 hour assessment

1 hour	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.25	1.19	*.30*	14	1.14	1.17	*.53*	15	1.21	1.05	*.37*
Control	15	1.24	1.18	*.51*	15	1.12	1.10	*.33*	15	1.33	1.28	*.68*
Manual	15	1.15	1.05	*.52*	14	1.19	1.15	*.38*	15	1.10	1.05	*.67*
Passive	15	1.03	.90	*.54*	15	.86	.75	*.43*	15	1.16	1.05	*.74*
Plyometric	15	1.46	1.40	*.77*	15	1.66	.92	*1.32*	15	1.32	1.30	*.68*
Stabiliz.	15	1.16	1.05	*.50*	15	.95	.85	*.51*	15	1.32	1.25	*.60*
Warm up	15	1.29	1.14	*.54*	15	1.14	1.30	*.55*	15	1.42	1.25	*.84*
					.333				.772			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.77. Comparison of TTDPM at 70% of IR to ER and IR between the groups at 1 hour assessment

1 hour	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Active	15	1.09	1.13	.31	14	.94	.94	.19	15	1.27	1.30	.51
Control	15	.99	.83	.42	13	.93	.93	.37	14	1.02	.85	.55
Manual	15	1.11	1.10	.44	14	.83	.66	.44	15	1.41	1.38	.66
Passive	15	1.01	.70	.69	15	.72	.54	.45	13	1.42	1.12	1.05
Plyometric	15	.94	.81	.40	15	.85	.75	.37	12	1.24	1.28	.43
Stabiliz.	15	.93	.86	.44	15	.74	.57	.41	15	1.17	1.07	.68
Warm up	15	1.36	1.03	.67	15	.98	.68	.56	15	1.78	1.55	.89
p					.212				.091			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

4.4.6 Comparison of groups at 1 day assessment

Table 4.78. Comparison of JPS between the groups at 1 day assessment

1 day	JPS 90% ER				JPS 50% ROM				JPS 70% IR			
°degrees	N	Mean	Median	SD	N	Mean	Median	SD	N	Mean	Median	SD
Active	15	4.51	4.80	2.76	14	4.48	3.23	3.12	15	5.03	3.72	3.48
Control	14	3.14	2.50	1.93	15	3.47	2.60	2.70	15	3.51	3.35	2.25
Manual	15	5.07	3.13	4.99	15	5.37	5.15	3.04	15	5.99	5.25	4.07
Passive	15	4.05	3.77	3.30	15	5.92	5.33	4.05	15	3.46	3.00	2.54
Plyometric	15	3.17	2.17	2.32	15	4.51	3.33	3.19	15	3.95	4.12	1.74
Stabiliz.	15	5.25	4.37	3.82	15	4.04	3.63	2.75	15	3.83	4.03	2.48
Warm up	15	3.81	3.60	2.26	15	5.63	4.27	4.25	15	3.60	2.60	3.05
p	.626				.402				.278			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.79. Comparison of TTDPM between the groups at 1 day assessment

1 day	TTDPM 90% ER				TTDPM 50% ROM				TTDPM 70% IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.96	.97	*.30*	15	1.00	.96	*.34*	15	.95	.82	*.42*
Control	15	.97	.87	*.39*	15	1.19	1.05	*.66*	15	1.01	.86	*.51*
Manual	15	1.18	1.10	*.54*	15	1.06	.88	*.46*	14	.89	.85	*.33*
Passive	15	.91	.78	*.47*	15	.94	.80	*.50*	15	.76	.65	*.40*
Plyometric	15	1.26	1.10	*.59*	15	1.27	1.21	*.47*	15	1.14	1.15	*.46*
Stabiliz.	15	.95	.83	*.41*	15	1.08	1.03	*.59*	15	.89	.74	*.52*
Warm up	15	1.17	1.08	*.40*	15	1.31	1.30	*.62*	15	1.42	1.07	*.95*
p	.128				.252				.097			
	Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.80. Comparison of TTDPM at 90% of ER to ER and IR between the groups at 1 day assessment

1 day	TTDPM 90% ER				TTDPM 90% ER to ER				TTDPM 90% ER to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.96	.97	*.30*	15	.63	.60	*.21*	15	1.26	1.13	*.60*
Control	15	.97	.87	*.39*	15	.68	.65	*.27*	15	1.22	1.08	*.60*
Manual	15	1.18	1.10	*.54*	14	.82	.68	*.42*	15	1.45	1.38	*.80*
Passive	15	.91	.78	*.47*	15	.75	.58	*.43*	15	1.03	.95	*.56*
Plyometric	15	1.26	1.10	*.59*	15	.87	.80	*.38*	14	1.51	1.30	*.73*
Stabiliz.	15	.95	.83	*.41*	15	.58	.55	*.31*	15	1.16	1.00	*.49*
Warm up	15	1.17	1.08	*.40*	15	1.03	.83	*.56*	15	1.36	1.40	*.42*
p					.101				.218			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.81. Comparison of TTDPM at 50% of ROM to ER and IR between the groups at 1 day assessment

1 day	TTDPM 50% ROM				TTDPM 50% ROM to ER				TTDPM 50% ROM to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	1.00	.96	*.34*	15	.90	.90	*.35*	15	1.07	1.00	*.48*
Control	15	1.19	1.05	*.66*	15	1.10	.98	*.70*	13	1.13	1.08	*.73*
Manual	15	1.06	.88	*.46*	14	.98	.78	*.56*	14	1.18	1.09	*.56*
Passive	15	.94	.80	*.50*	15	.85	.70	*.55*	15	.92	.63	*.61*
Plyometric	15	1.27	1.21	*.47*	14	1.34	1.33	*.70*	15	1.23	1.05	*.72*
Stabiliz.	15	1.08	1.03	*.59*	15	.88	.65	*.58*	15	1.21	.85	*.72*
Warm up	15	1.31	1.30	*.62*	14	1.18	.89	*.71*	15	1.48	1.40	*.76*
p					.215				.345			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

Table 4.82. Comparison of TTDPM at 70% of IR to ER and IR between the groups at 1 day assessment

1 day	TTDPM 70% IR				TTDPM 70% IR to ER				TTDPM 70% IR to IR			
°degrees	N	Mean	Median	*SD*	N	Mean	Median	*SD*	N	Mean	Median	*SD*
Active	15	.95	.82	*.42*	15	.67	.60	*.19*	13	1.36	1.18	*.89*
Control	15	1.01	.86	*.51*	15	.81	.75	*.35*	15	1.23	1.05	*.76*
Manual	14	.89	.85	*.33*	15	.78	.72	*.39*	15	1.54	.95	*1.54*
Passive	15	.76	.65	*.40*	15	.62	.58	*.28*	15	.94	.78	*.61*
Plyometric	15	1.14	1.15	*.46*	15	.84	.75	*.37*	15	1.65	1.68	*.80*
Stabiliz.	15	.89	.74	*.52*	15	.65	.53	*.33*	15	1.12	.80	*.79*
Warm up	15	1.42	1.07	*.95*	15	.88	.68	*.60*	15	2.07	1.75	*1.74*
p					.429				.097			
					Retain null hypothesis (p>0.05)				Retain null hypothesis (p>0.05)			
Independent Samples Kruskal-Wallis Test												

4.5 Comparison of proprioception of each group at various moments of assessment against 105 subject baseline

Due to notable differences between the intervention groups at the initial assessment and significant variations within "Control Group" which had no obvious explanations, after careful consideration the additional analysis was deemed necessary to analyze the observed data more carefully. In the additional analysis the proprioception values of all subjects at the initial assessment - prior to any intervention were grouped together to represent a baseline. Then proprioception of each group prior to intervention and at each moment post intervention was compared against this broad baseline. This method of comparison was aimed to reducing the variability associated with small group sample.

In order to establish validity to baseline assessment of all 105 subjects the initial assessment was compared to an assessment prior to intervention. All 105 subjects did not receive any intervention between these two moments of proprioception testing therefore should have not differed. The statistical analysis for comparing all subjects at initial assessment and prior to intervention showed confirmation of the validity of the baseline in all but one instance. At 90% ER TTDPM at initial and pre assessment differed significantly ($p<0.05$).

Table 4.83. Comparison of JPS of all 105 subjects at Initial and Pre assessments

JPS / (°degrees)	Initial assessment				Pre intervention				Z	p
	N	Mean	Median	*SD*	N	Mean	Median	*SD*		
90% ER	105	4.77	3.33	*3.75*	105	4.69	3.57	*3.33*	-.082	.935
50% ROM	105	5.24	3.52	*4.71*	104	5.15	3.77	*3.91*	-.266	.790
70% IR	105	4.59	3.87	*3.02*	104	3.84	3.13	*2.67*	-1.793	.073
Related samples Freedman's two way analysis of variance by ranks										

Table 4.84. Comparison of TTDPM of all 105 subjects at Initial and Pre assessments

TTDPM / (°degrees)	Initial assessment				Pre intervention				Z	p
	N	Mean	Median	*SD*	N	Mean	Median	*SD*		
90% ER	105	1.23	1.12	*.73*	104	1.09	.97	*.55*	**-2.135**	**.033**
to ER	104	.84	.73	*.57*	103	.75	.65	*.47*	-1.648	.099
to IR	105	1.57	1.35	*1.06*	101	1.43	1.26	*.84*	-.557	.577
50% ROM	105	1.19	1.01	*.82*	104	1.11	.98	*.52*	-.247	.805
to ER	101	1.07	.80	*.90*	103	1.03	.88	*.57*	-.377	.706
to IR	105	1.32	1.00	*1.00*	101	1.19	1.03	*.72*	-.260	.795
70% IR	105	1.15	.97	*.67*	104	1.15	1.02	*.57*	-.452	.651
to ER	105	.88	.70	*.58*	104	.83	.70	*.45*	-1.305	.301
to IR	101	1.55	1.25	*1.16*	100	1.53	1.31	*.91*	-.270	.787
Related samples Freedman's two way analysis of variance by ranks										

Arbitrary the proprioception at initial assessment was chosen as main wide baseline. The following analysis within each group has compared proprioception of each group at different moments of assessment pre and post intervention against this baseline of 105 subjects.

In the "Active Movement Group" the only difference between values of each assessment and baseline values of 105 subjects was observed at 70 internal rotation JPS. Post Hoc analysis showed difference between baseline and JPS at 1 hour assessment point (Z = -3.250, p= .001) based on Mann-Whitney U Test. At 1 hour JPS at 70% internal rotation of "Active Movement Group" was lower than of baseline comparing mean 2.30±1.75° and median 1.62° against mean of 4.59±3.02° and median of 3.87°.

Table 4.85. Comparison of proprioception of "Active Movement Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.752
JPS 50% ROM	.965
JPS 70 IR	**.047**
TTDPM 90% ER	.520
TTDPM 90% ER to ER	.212
TTDPM 90% ER to IR	.595
TTDPM 50% ROM	.071
TTDPM 50% ROM to ER	.221
TTDPM 50% ROM to IR	.273
TTDPM 70% IR	.627
TTDPM 70% IR to ER	.137
TTDPM 70% IR to IR	.905
Independent Samples Kruskal-Wallis Test	

In "Control Group" no difference was found between the values of proprioception at each moment of assessment and the baseline values.

Table 4.86. Comparison of proprioception of "Control Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.120
JPS 50% ROM	.111
JPS 70 IR	.796
TTDPM 90% ER	.503
TTDPM 90% ER to ER	.857
TTDPM 90% ER to IR	.216
TTDPM 50% ROM	.580
TTDPM 50% ROM to ER	.569
TTDPM 50% ROM to IR	.803
TTDPM 70% IR	.718
TTDPM 70% IR to ER	.652
TTDPM 70% IR to IR	.378
Independent Samples Kruskal-Wallis Test	

No difference between proprioception in "Manual Therapy Group" and baseline values was observed.

Table 4.87. Comparison of proprioception of "Manual Therapy Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.821
JPS 50% ROM	.310
JPS 70 IR	.327
TTDPM 90% ER	.486
TTDPM 90% ER to ER	.662
TTDPM 90% ER to IR	.218
TTDPM 50% ROM	.323
TTDPM 50% ROM to ER	.091
TTDPM 50% ROM to IR	.709
TTDPM 70% IR	.814
TTDPM 70% IR to ER	.773
TTDPM 70% IR to IR	.870
Independent Samples Kruskal-Wallis Test	

In "Passive Movement Group" numerous differences from the baseline values were observed ($p<0.05$).

Table 4.88. Comparison of proprioception of "Passive Movement Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.399
JPS 50% ROM	.323
JPS 70 IR	**.009**
TTDPM 90% ER	**.040**
TTDPM 90% ER to ER	.900
TTDPM 90% ER to IR	**.021**
TTDPM 50% ROM	.071
TTDPM 50% ROM to ER	.600
TTDPM 50% ROM to IR	.136
TTDPM 70% IR	.057
TTDPM 70% IR to ER	.216
TTDPM 70% IR to IR	.183
Independent Samples Kruskal-Wallis Test	

Post Hoc analysis showed further differences at various angles ($p<0.05$).

Table 4.89. Post Hoc comparison of proprioception of "Passive Movement Group" at specific points of assessment against baseline proprioception

"Passive Movement Group" / (°degrees)												
	N	Mean	Median	*SD*			N	Mean	Median	*SD*	Z	p
Baseline JPS 70% IR	105	4.59	3.87	*3.02*	>	Pre intervention	15	2.43	1.93	*1.55*	**-2.908**	**.004**
					>	Post intervention	15	2.68	1.00	*2.44*	**-2.480**	**.013**
Baseline TTDPM 90% ER	105	1.23	1.12	*.73*	>	30 min post intervention	14	.82	.67	*.41*	**-2.681**	**.007**
					>	1 day post intervention	15	.91	.78	*.47*	**-2.008**	**.045**
Baseline TTDPM 90% ER to IR	105	1.57	1.35	*1.06*	>	30 min post intervention	15	1.20	.78	*1.06*	**-2.270**	**.023**
					>	1 day post intervention	15	1.03	.95	*.56*	**-2.337**	**.019**
Baseline TTDPM 50% ROM	105	1.19	1.01	*.82*	>	Pre intervention	14	.87	.76	*.51*	**-2.004**	**.045**
					>	30 min post intervention	15	.82	.66	*.39*	**-2.412**	**.016**
Baseline TTDPM 70% IR	105	1.15	.97	*.67*	>	1 day post intervention	15	.76	.65	*.40*	**-2.710**	**.007**
Baseline TTDPM 70% IR to IR	101	1.55	1.25	*1.16*	>	1 day post intervention	15	.94	.78	*.61*	**-2.102**	**.036**
Mann-Whitney U Test												

No variation from baseline was observed in "Plyometric Exercise Group" at any point of assessment.

Table 4.90. Comparison of proprioception of "Plyometric Exercise Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.203
JPS 50% ROM	.984
JPS 70 IR	.445
TTDPM 90% ER	.792
TTDPM 90% ER to ER	.453
TTDPM 90% ER to IR	.805
TTDPM 50% ROM	.140
TTDPM 50% ROM to ER	.060
TTDPM 50% ROM to IR	.629
TTDPM 70% IR	.649
TTDPM 70% IR to ER	.938
TTDPM 70% IR to IR	.366
Independent Samples Kruskal-Wallis Test	

Comparing proprioception at multiple assessment points of "Stabilization Exercise Group" with baseline revealed difference in JPS at 70% of IR.

Table 4.91. Comparison of proprioception of "Stabilization Exercise Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.605
JPS 50% ROM	.378
JPS 70 IR	**.046**
TTDPM 90% ER	.261
TTDPM 90% ER to ER	.082
TTDPM 90% ER to IR	.390
TTDPM 50% ROM	.880
TTDPM 50% ROM to ER	.881
TTDPM 50% ROM to IR	.866
TTDPM 70% IR	.384
TTDPM 70% IR to ER	.397
TTDPM 70% IR to IR	.390
Independent Samples Kruskal-Wallis Test	

Post Hoc analysis showed that baseline JPS at 70% of IR has differed from pre intervention 30 minutes post intervention values in "Stabilization Exercise Group" at the same angle. Additionally baseline differed from 1 day post intervention at TTDPM at 90% of ER moving to external rotation of this group.

Table 4.92. Post Hoc comparison of proprioception of "Stabilization Exercise Group" at specific points of assessment against baseline proprioception

"Stabilization Exercise Group" / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Baseline JPS 70% IR				>	Pre intervention				**-2.091**	**.037**
105	4.59	3.87	*3.02*		15	2.99	2.55	*2.07*		
				>	30 min post intervention				**-2.507**	**.012**
					14	2.54	2.31	*1.45*		
Baseline TTDPM 90% ER to ER				>	Pre intervention				**-1.958**	**.050**
104	.84	.73	*.57*		15	.66	.60	*.27*		
				>	1 day post intervention				**-2.170**	**.030**
					15	.58	.55	*.31*		
Mann-Whitney U Test										

Finally JPS at 70% internal rotation of "Warn Up Group" subjects was lower than of baseline immediately post intervention and at 1 hour post intervention. Also some difference from baseline was observed at pre intervention assessment at 70% IR TTDPM.

Table 4.93. Comparison of proprioception of "Warm Up Exercise Group" at various assessment points against baseline proprioception

Hypothesis: the distribution is the same	p
JPS 90% ER	.602
JPS 50% ROM	.705
JPS 70 IR	**.004**
TTDPM 90% ER	.488
TTDPM 90% ER to ER	.294
TTDPM 90% ER to IR	.464
TTDPM 50% ROM	.594
TTDPM 50% ROM to ER	.646
TTDPM 50% ROM to IR	.602
TTDPM 70% IR	.196
TTDPM 70% IR to ER	.823
TTDPM 70% IR to IR	.160
Independent Samples Kruskal-Wallis Test	

Table 4.94. Post Hoc comparison of proprioception of "Warm Up Exercise Group" at specific points of assessment against baseline proprioception

<table>
<tr><td colspan="11">"Warm Up Exercise Group" / (°degrees)</td></tr>
<tr><td>N</td><td>Mean</td><td>Median</td><td>SD</td><td></td><td>N</td><td>Mean</td><td>Median</td><td>SD</td><td>Z</td><td>p</td></tr>
<tr><td colspan="4">Baseline JPS 70% IR</td><td rowspan="2">></td><td colspan="4">Post intervention</td><td rowspan="2">-2.845</td><td rowspan="2">.004</td></tr>
<tr><td rowspan="3">105</td><td rowspan="3">4.59</td><td rowspan="3">3.87</td><td rowspan="3">3.02</td><td>15</td><td>2.72</td><td>1.95</td><td>2.45</td></tr>
<tr><td rowspan="2">></td><td colspan="4">1 hour post intervention</td><td rowspan="2">-2.606</td><td rowspan="2">.009</td></tr>
<tr><td>14</td><td>2.84</td><td>2.13</td><td>2.01</td></tr>
<tr><td colspan="4">Baseline TTDPM 70% IR</td><td rowspan="2"><</td><td colspan="4">Pre intervention</td><td rowspan="2">-2.000</td><td rowspan="2">.046</td></tr>
<tr><td>105</td><td>1.15</td><td>.97</td><td>.67</td><td>15</td><td>1.20</td><td>1.04</td><td>.72</td></tr>
<tr><td colspan="11">Mann-Whitney U Test</td></tr>
</table>

4.6 Additional analysis role of joint angle on proprioception

Additional analysis was performed investigating specific aspects of proprioception of all subjects. For this purpose Initial and pre intervention assessments results were employed. Analyzing JPS, at initial evaluation, no difference between angles was determined. However, the difference became evident during evaluation just prior to intervention.

Table 4.95. Comparison of JPS between various angles of all 105 subjects at Initial and Pre assessments

Comparison of JPS at various angels / (°degrees)										
N	Mean	Median	SD		N	Mean	Median	SD	Z	p
Initial assessment										
90% ER				=	50% ROM				-.897	.370
105	4.77	3.33	3.75		105	5.24	3.52	4.71		
90% ER				=	70% IR				-.003	.997
105	4.77	3.33	3.75		105	4.59	3.87	3.02		
50% ROM				=	70% IR				-.304	.761
105	5.24	3.52	4.71		105	4.59	3.87	3.02		
Pre intervention assessment										
90% ER				=	50% ROM				-.717	.474
105	4.69	3.57	3.33		104	5.15	3.77	3.91		
90% ER				>	70% IR				**.1.964**	**.050**
105	4.69	3.57	3.33		104	3.84	3.13	2.67		
50% ROM				>	70% IR				**-2.158**	**.031**
104	5.15	3.77	3.91		104	3.84	3.13	2.67		
Wilcoxon signed rank test										

Similar results of no difference in threshold to passive movement detection between various angles were observed (p>0.05).

Table 4.96. Comparison of TTDPM disregarding direction of movement between various angles of all 105 subjects at Initial and Pre assessments

Comparison of TTDPM at various angels / (°degrees)										
N	Mean	Median	SD		N	Mean	Median	SD	Z	p
Initial assessment										
90% ER				=	50% ROM				-.796	.426
105	1.23	1.12	.73		105	1.19	1.01	.82		
90% ER				=	70% IR				-1.026	.305
105	1.23	1.12	.73		105	1.15	.97	.67		
50% ROM				=	70% IR				-.675	.500
105	1.19	1.01	.82		105	1.15	.97	.67		
Pre intervention assessment										
90% ER				=	50% ROM				-.722	.470
104	1.09	.97	.55		104	1.11	.98	.52		
90% ER				=	70% IR				-.972	.331
104	1.09	.97	.55		104	1.15	1.02	.57		
50% ROM				=	70% IR				-.396	.692
104	1.11	.98	.52		104	1.15	1.02	.57		
Wilcoxon signed rank test										

While there was no difference in TTDPM between various tested angles, at each specific angle the direction of movement did play an important role in determining TTDPM. This tendency was obvious at both initial assessment and prior to intervention. Following several tables will explore these differences.

Table 4.97. Comparison of TTDPM at 90% of ER accounting for direction of movement between various angles of all 105 subjects at Initial and Pre assessments

Comparison of 90% ER TTDPM accounting the direction of movement / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial assessment										
Without direction				>	to ER				**-7.755**	**.000**
105	1.23	1.12	*.73*		104	.84	.73	*.57*		
Without direction				<	to IR				**-7.551**	**.000**
105	1.23	1.12	*.73*		105	1.57	1.35	*1.06*		
to ER				<	to IR				**-7.684**	**.000**
104	.84	.73	*.57*		105	1.57	1.35	*1.06*		
Pre intervention assessment										
Without direction				>	to ER				**-6.993**	**.000**
104	1.09	.97	*.55*		103	.75	.65	*.47*		
Without direction				<	to IR				**-6.843**	**.000**
104	1.09	.97	*.55*		101	1.43	1.26	*.84*		
to ER				<	to IR				**-6.994**	**.000**
103	.75	.65	*.47*		101	1.43	1.26	*.84*		
Wilcoxon signed rank test										

Table 4.98. Comparison of TTDPM at 50% of ROM accounting for direction of movement between various angles of all 105 subjects at Initial and Pre assessments

Comparison of 50% of ROM TTDPM accounting the direction of movement / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial assessment										
Without direction				>	to ER				**-3.590**	**.000**
105	1.19	1.01	*.82*		101	1.07	.80	*.90*		
Without direction					to IR				**-3.015**	**.003**
105	1.19	1.01	*.82*		105	1.32	1.00	*1.00*		
to ER				<	to IR				**-3.328**	**.001**
101	1.07	.80	*.90*		105	1.32	1.00	*1.00*		
Pre intervention assessment										
Without direction				=	to ER				-1.672	.095
104	1.11	.98	*.52*		103	1.03	.88	*.57*		
Without direction				=	to IR				-1.536	.125
104	1.11	.98	*.52*		101	1.19	1.03	*.72*		
to ER				=	to IR				-1.609	.108
103	1.03	.88	*.57*		101	1.19	1.03	*.72*		
Wilcoxon signed rank test										

Table 4.99. Comparison of TTDPM at 70% of IR accounting for direction of movement between various angles of all 105 subjects at Initial and Pre assessments

Comparison of 70% IR TTDPM accounting the direction of movement / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Initial assessment										
Without direction				>	to ER				**-6.013**	**.000**
105	1.15	.97	*.67*		105	.88	.70	*.58*		
Without direction				<	to IR				**-5.947**	**.000**
105	1.15	.97	*.67*		101	1.55	1.25	*1.16*		
to ER				<	to IR				**-6.090**	**.000**
105	.88	.70	*.58*		101	1.55	1.25	*1.16*		
Pre intervention assessment										
Without direction				>	to ER				**-6.316**	**.000**
104	1.15	1.02	*.57*		104	.83	.70	*.45*		
Without direction				<	to IR				**-6.187**	**.000**
104	1.15	1.02	*.57*		100	1.53	1.31	*.91*		
to ER				<	to IR				**-6.384**	**.000**
104	.83	.70	*.45*		100	1.53	1.31	*.91*		
Wilcoxon signed rank test										

Based on the results a TTDPM was less at maximal external rotation whenever the movement occurred into external rotation and much greater if the movement was happening into internal rotation. Similar tendency is maintained at 50% of ROM and 70% of internal rotation. The following clustered boxplot demonstrates this visually. The boxplot also provides good visual aid to observe distribution of gathered data about subjects' kinesthesia.

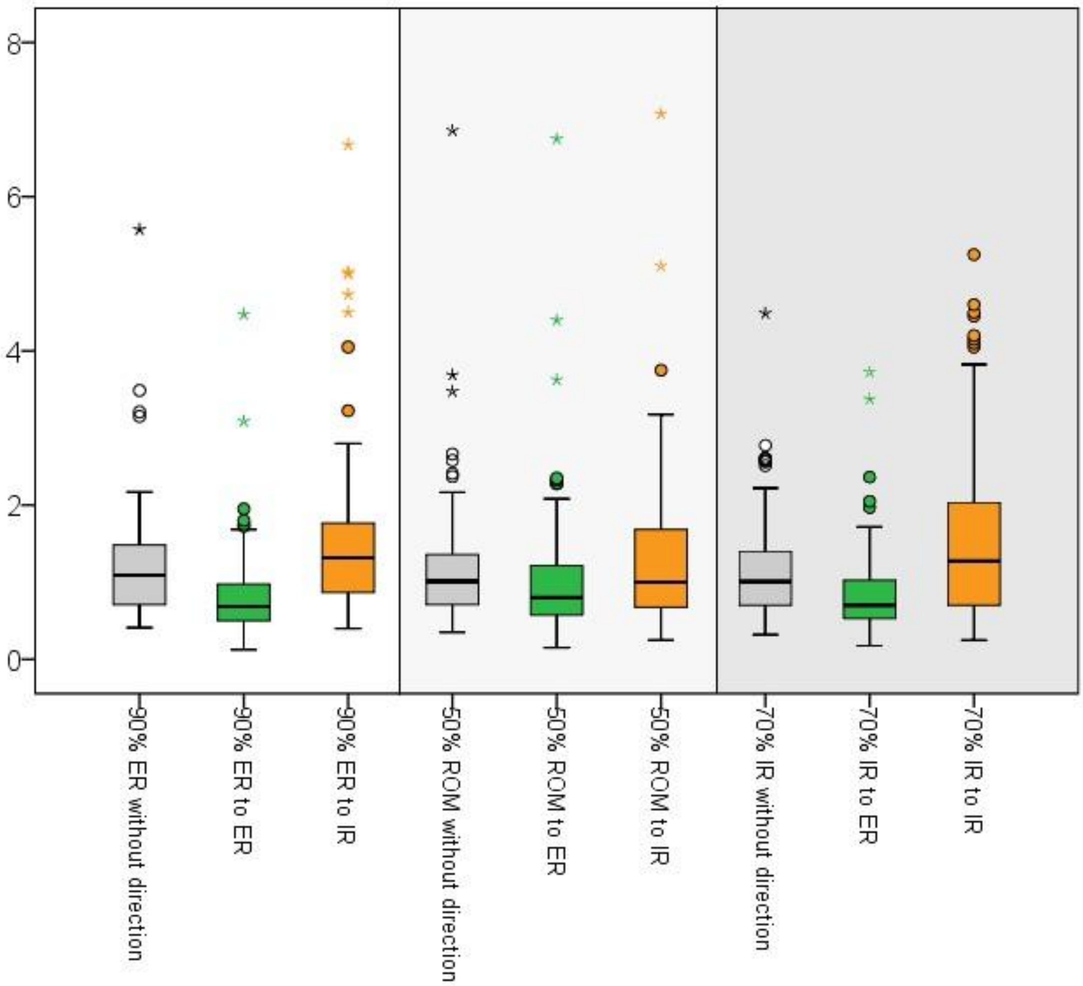

Figure 4.1. Boxplot of TTDPM at initial assessment of 105 subjects accounting for direction of movement

4.7 Additional analysis gender differences

Additionally we analyzed to see if gender had any influence on proprioceptive acuity. For JPS at the initial assessment there were differences between man and women at 90% of ER and 50% ROM. These differences were not seen on pre intervention assessment

Table 4.100. Comparison of JPS between genders at Initial and Pre assessments

Comparison of JPS between genders / (°degrees)										
N	Mean	Median	*SD*		N	Mean	Median	*SD*	Z	p
Male					Female					
Initial										
90% of ER									**-2.746**	**.006**
50	3.89	3.00	*3.26*	<	55	5.58	4.30	*4.01*		
50% of ROM									**-2.733**	**.006**
50	4.18	3.18	*3.82*	<	55	6.20	4.33	*5.25*		
70% of IR									-1.036	.300
50	4.26	3.85	*2.98*	=	55	4.89	3.87	*3.06*		
Pre										
90% of ER									-.738	.461
50	4.46	3.33	*3.14*	=	55	4.89	3.75	*3.51*		
50% of ROM									-.781	.435
50	5.13	3.28	*4.42*	=	54	5.17	4.04	*3.42*		
70% of IR									-.381	.703
50	3.73	3.32	*2.21*	=	54	3.93	2.98	*3.06*		
Mann-Whitney U Test										

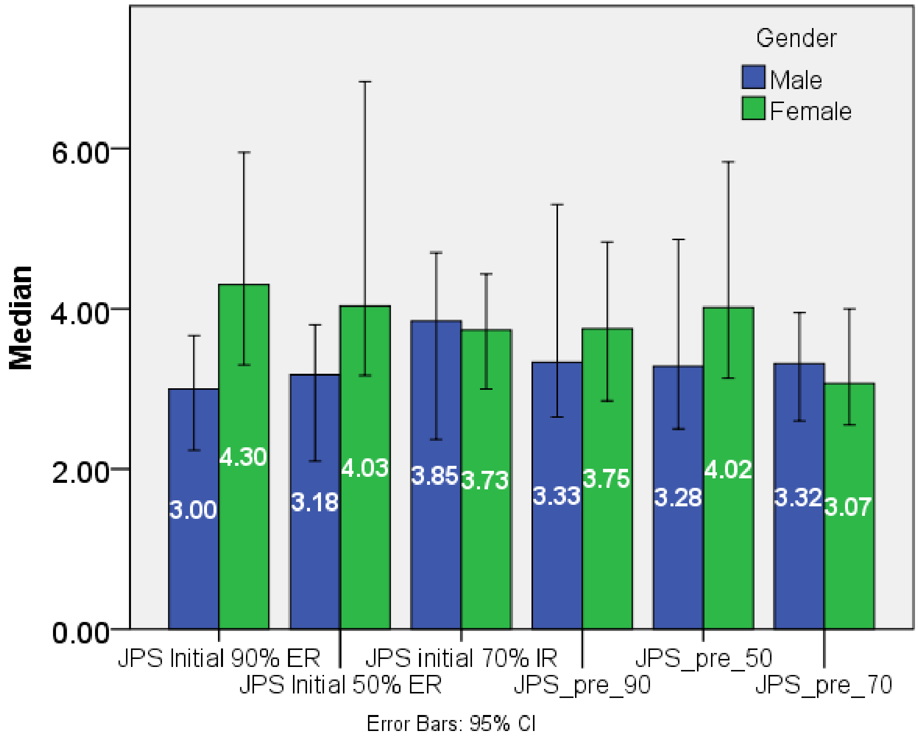

Figure 4.2. Bar plot gender differences of JPS at initial and pre evaluation of 105 subjects

Based on gender, subjects have differed in kinesthetic sense as well at the initial assessment.

Table 4.101. Comparison of TTDPM between genders at Initial and Pre assessments

Comparison of TTDPM between genders / (°degrees)										
N	Mean	Median	SD		N	Mean	Median	SD	Z	p
Male					Female					
Initial										
90% of ER									-1.043	.297
50	1.15	.98	.60	=	55	1.30	1.28	.82		
50% of ROM									**-2.515**	**.012**
50	1.00	.88	.49	<	55	1.36	1.15	1.01		
70% of IR									**-2.313**	**.021**
50	.97	.85	.46	<	55	1.31	1.14	.78		
Pre										
90% of ER									-1.048	.294
49	1.04	.88	.52	=	55	1.13	1.00	.58		
50% of ROM									-1.305	.192
50	1.05	.91	.48	=	54	1.17	1.16	.55		
70% of IR									-1.734	.083
50	1.04	.98	.48	=	54	1.25	1.19	.63		
Mann-Whitney U Test										

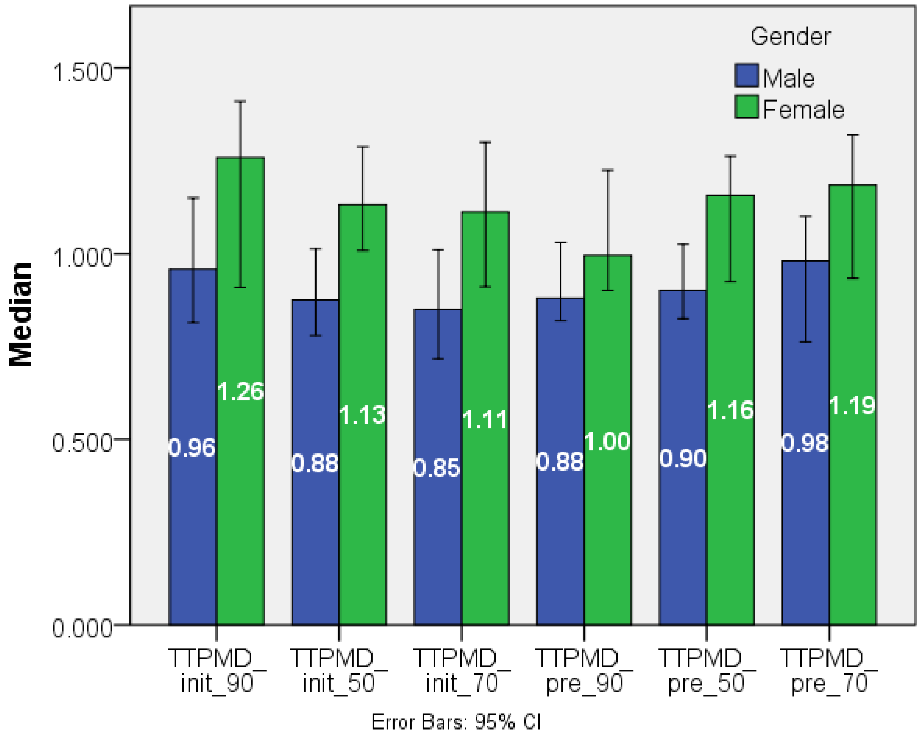

Figure 4.3. Bar plot gender differences of TTDPM at initial and pre evaluation of 105 subjects

5 DISCUSSION

5.1 Study design

It is worth starting the discussion of the thesis from the study design. Unconventionally, this study combines elements randomized control trial and repeated measure design. First of all, the subjects recruited to the study have been randomly assigned to seven different groups (six intervention and one control group). All measures were taken to control all factors that might affect the dependent variable or proprioception. The main aim of the study was to deconstruct physical therapy and rehabilitation interventions including various exercises into different components and observe which one causes most change in proprioception. Therefore, controlling surrounding effects on joint and muscles were crucial for the success of the study. The study incorporated second type of design - repeated measure. Proprioception was measured not only prior and post interventions, but also at set intervals of time after intervention. The idea behind this was to test not only the magnitude of change of proprioception, but also the effect duration after intervention. Clinically, this might be more significant.

While the absolute majority of studies have aimed at testing the effects of specific exercise protocol or intervention on proprioception and have discussed the hypothetical mechanism responsible for the observed effect or lack of one, this study has a completely opposite approach. Without specific predisposition about any particular exercises protocol, each component of each exercise or intervention was tested for the possible effect on proprioception. Furthermore, in order to eliminate the learning effect or any neural adaptation that might occur centrally or in CNS, only the acute effects of single intervention were measured. This approach would provide a solid foundation of physiological mechanisms and would be beneficial for future studies.

5.2 Subjects and general assessment

The subjects for this study have been chosen from general population ages ranging from 18 to 40 years old. The age limit was set based on several criteria. First of all, the lower age limit was set with the idea in mind that the subjects should be well physiologically developed and be legally independent to sign the consent to participate in the study. We were not able to locate any studies that the differences in proprioception in adult population and children or teenagers. The upper age limit excluded subjects in whom degradation of proprioception may have been caused by natural aging process. Several study reports have shown that proprioception is worse in elderly people in comparison to adults(18, 88, 104, 141, 142). 40 year old limit was cautiously set, to include only subjects in their physiological prime.

Healthy sedentary volunteers participated in the study. Interview as well as an extensive health screening by physical therapist was performed to ensure all participants had no hidden injury or trauma. Numerous studies which assessed different joints in the body revealed that musculosceletal pathologies can cause degradation of proprioceptive system acuity(9, 10, 12, 13, 143-146). Furthermore, pain by itself might cause alterations of proprioceptive acuity(11, 145, 147, 148). Performing detailed physical therapy assessment with array of specific test has been shown to be valuable method to ensure homogeneity of the group. Although several subjects have reported that they have no problems in their shoulders, general assessment revealed that they have pain and to be positive on provocation tests. Most subjects have displayed signs of shoulder impingement or carpal tunnel syndrome. These volunteers were excluded from the study. Many studies including full text dissertation works on proprioception have mentioned the criteria for selecting healthy participant, but a very few have explained in the details if the screening was made verbally or actual physical assessment took place. Our experience from this study, shows the necessity of actual medical evaluation to take in order to ensure that subjects are healthy.

Another critical criteria of the study was to eliminate participants who participated in sports more than three times per week. Numerous studies show that sportsmen or people performing sports on a regular basis might have increased proprioception compared to the rest (18).

Based on previous studies, 15 subjects per group were considered to be sufficient. Unfortunately, due to unconventional design of the study a-priory sample size analysis was not possible to perform. Similar studies investigating proprioception typically have recruited 10 - 25 subjects for each intervention group. While similarities can be drawn, one should keep in mind that majority of studies have included one intervention and one control group, with only pre and post assessments of dependent variable. Our study however had 6 intervention groups and one control group. Additionally, dependent variables of proprioception were measured repetitively. None of them had six separate intervention and control groups. Therefore, comparison with earlier published studies can be done only to some extent. None the less for the sake of drawing parallels between study, our research can be viewed as seven separate studies with one intervention and one control groups.

All subjects in our study have followed randomization protocol to be assigned into the groups. Their age, height weight and BMI between groups was similar. External rotation, internal rotation and total range of motion were also equal between groups. However, male to female ratio within the group comparing to the other groups differed (see Table 4.1.). This was particularly notable on the example of Stabilization Exercise Group and Active Movement Group where the majority of participants were male, where as in the rest of the groups the majority were female. In Passive Movement Group there were 8 males and 7 female participant making it almost even split. Interestingly, no studies have made a comparison in proprioception between male and female participant. Some authors, like Alegrucci(44), Safran(89), Tripp(118-120) have focused on only male population whereas others focused on female subjects, Hosp (149), Swanik (25), Cho (144) meanwhile others either have disregarded gender or have tried to match groups(22, 31, 141), yet no attempt of comparing two genders has been done till today.

JPS of groups was similar at all angles at the initial assessment which meant that all groups were similar. However, some differences between groups were noted when kinesthesia has been tested. Differences between groups were recorded at 90% of external rotation and 50% of ROM. Although the difference in JPS at maximal external rotation was not due to the direction of movement, the difference for 50% of ROM between groups was mainly due to variation between TTDPM moving into external rotation. It is difficult to speculate for the nature of these observations. Possibly a level of variability in proprioception combined with relatively small sample size per group and increased number of groups may have caused these differences. Nevertheless, this presents a challenge in comparing proprioception in the subjects of all intervention groups.

Partial solution for this problem will be discussed at the session about control group.

5.3 Proprioception testing method and device

The other important subject for the discussion is the method of testing proprioception employed in this study in comparison to methods used by other researchers in published literature. Immediately there is a great variety of proprioception testing protocols and methods which makes the comparison of the results troublesome.

The methods which employs various motion analysis systems like Vicon or electromagnetic motion analysis systems stand out in the class of their own. Numerous authors such as Anderson, Barden, Li and Tripp have employed these methods(11, 82, 88, 119). Typically subject replicates a movement pattern or a position where a motion tracking system will calculate in three dimensions the alternation from an original position of the limb. The advantage of these types of systems is that they do not restrict the movement to a specific anatomical plane. They also provide opportunity for functional patterns of movements to be assessed. Disadvantage of the 3D motion analysis systems is the complexity of the movements that are not restricted to a specific joint. Therefore, the researcher cannot specify the proprioception of which joint is actually contributes to replication of the position, the glenohumeral, the scapulothoracic or sternoclavicular joint during testing of cocking movement in baseball since the movement is being comprised of movements in all of the above mentioned joints. One can argue that replication of a movement pattern tests not only the proprioception, but the sensorimotor system as a whole(1, 113). While sensing well the original position of a limb is important, it is also important to execute well coordinated motor output in order to replicate the limb position. Additionally, many researchers might have chosen different movement patterns or limb positions which make the outcomes of the studies incomparable.

A simplification of 3D motion analysis is 2D analysis of a specific motion with photographic of video analysis of angles between reference points on the limb/limbs marked by reflection markers on anatomical landmarks. Typically, an active reproduction of active position in JPS either in close kinetic or open kinetic chain is being tested. Many knee JPS testing protocols employ this technique(24, 26, 88, 149). With careful planning and monitoring of movement pattern this method might resolve the issue of combination of movements in multiple joint, limiting the observation to one specific joint. For example, with testing knee flexion/extension, the movement can be limited to one joint, but shoulder flexion cannot be isolated since shoulder flexion is comprised of movements in GH and ST joints. The issue of elimination of motor control component in from proprioception testing is not resolved by this testing method. However, another great advantage of 2D photographic proprioception testing method is relative simplicity and low cost. Typically a good camera, tripod reflective markers and some software are only needed. The author of this thesis has gained experience with this method of proprioception testing during his previous study of "The effects of plyometric versus strength training exercise program on shoulder proprioception". Several important attention points must be brought out for researchers who wish to employ 2D photographic method(26). Careful planning and strict protocol of movement, camera position height and distance must be followed. Alternation of one of the parameters might cause a parallax effect which would cause the measured angle to be false and jeopardize the results of the study. Additionally, uniformity of movements and movement angles tested will significantly aid in comparison between studies.

Clinically, practical and cheap method of assessing JPS is with inclinometer or goniometer. For example, Dover used this method to assess propioception in his study(31). Other authors as well have uses this method frequently(17, 90, 113, 114, 144). The extend of limitation of compensatory movements varies with the different movements, however it might play significant role. This method is best to be used if visually noticeable deficiencies in proprioception are observed and similar scale improvements with interventions are excepted in clinical settings.

Many researcher employ various proprioception testing devices which are typically based on drive engines of isokinetic equipments such as Biodex or others. A tested limb is connected to the moving arm of the device and a specific anatomical movement is tested(2, 3, 5, 17, 32, 44, 46, 104, 113, 121, 125, 126, 147, 150, 151). The main advantage of these kind of systems is ability to specifically test the joint of interest. The equipment allows to isolate a single joint. Majority of authors in the literature tested internal and external rotation for assessing proprioception of glenohumeral joint. However, Zuckerman et al. managed to test proprioception of shoulder flexion and abduction(104). The later seems questionable since it is known that there is great involvement of scapular motion in shoulder flexion and some degree of external rotation is necessary to avoid impingement of supraspinatus tendon in shoulder abduction. In our study in accordance with authors like Lephart, Myers and many others we also tested internal and external rotation of GH joint, where the shoulder is placed in 90° abduction, 90° elbow flexion(2, 3, 25, 126).

Some equipment advocated by Lephart and colleagues have tested proprioception with subject in supine position, whereas few others tested in sitting position(2, 3, 5, 25, 104, 128). No argument was given for or against each testing position, in fact up to now only one study by Janwantanakul dedicated to measure if positioning of the subject plays any role in proprioception testing(124). Janwantanakul and colleagues administered exactly the same JPS testing protocols to the 15 right handed healthy man without history of trauma and not actively involved in upper extremity sports, in two different positions supine and sitting. The outcomes showed that lower matching error variance was seen when subjects were sitting compared to laying. No effect of position was seen on kinesthetic sense(124). While developing protocol for our study we respected the results of Janwantanakul and we also considered sitting to be more functional position with subject's body and head in upright position. Therefore, we have tested our subjects in sitting position.

There are various methods to test JPS with proprioception testing devices. These methods can be put into three categories. First of all JPS of passive repositioning of passive position, where a joint is passively brought to a target position, held for n number of seconds and passively returned to a starting position. Following which a joint will be again passively moved to the direction of earlier movement and once the subject perceives that the joint position is at the target position, he or she will press the button to stop the movement. The angle difference between target position and perceived position will be recorded as JPS. The typical speed of movement is set between 2-5°/sec(23, 46, 89, 104, 125, 128, 151). Some authors change the speed of movement in order to limit time counting to the position which tested subjects might employ as a trick to show better results(89, 125). No author has provided the answer to a dilemma if the subject would recognize that the movement had already passed the perceived target point. Solution for this might be in allowing the subject to control the movement direction of the equipment.

Another method of JPS is passively bringing a joint to the target position and passively returning to a starting position followed by active repositioning by subject the target point. This method allows a level of freedom for a tested person to seek for the target position. Ju and several others used described method(10, 25, 34, 123).

Finally, active positioning to active repositioning can be employed. The subject slowly moves arm to the desired direction followed by a command stop at the target angle. After a brief period of memorization, subject moves back to a starting position and then actively reproduces the target position(24, 121). This method can be accused for testing motor control rather than JPS of proprioception.

A preliminary pilot study designed by Chan D and Can F was conducted titled "Comparison of Three Variations of Joint Position Sense Assessment". The study compared three methods of JPS testing, of glenohumeral joint, the passive positioning and passive repositioning, passive positioning and active repositioning and active positioning followed by active repositioning to the target joint angle. Passive positioning was performed at 5°/sec speed. Sample size consisted of 12 healthy subjects selected on the same inclusion and exclusion criteria as the thesis study. In active positioning to active repositioning test the JPS values were significantly less than in other testing methods as was as variance was less, which indicated that active positioning to active repositioning test was more precise than others. Additionally, in the other tests due to longer period of time the tests took place subjects complained of forgetting the target position by the third attempt of repositioning.(152)

Taking into considerations the results and experience obtained during the preliminary pilot study active positioning to active repositioning method of JPS testing was chosen for the thesis study. Additionally, in our opinion, the way the target position was obtained should resemble the way it was reproduced, which would make the test more specific. Furthermore it gives greater control to the subject.

As it is clear, even for testing JPS, there is a great variety of methods used. Typically, unless the study was conducted by the same researcher, the likelihood that the same testing protocol has been used is rather low. This makes it difficult to compare the results and outcomes of studies, so some leniency should be taken with interpretation of the results.

There is greater uniformity in testing kinesthesia. Threshold to passive movement detection is being tested. The speed of movement is between 0.5 to 2°/sec with lower speeds known to produce more reliable results(2, 113, 126). Some evidence indicate that at very low speed > 0.01 °/sec a human is not able to recognize presence of a movement, therefore a limb can be brought though rather large range of motion with subject in not being aware of it(16). In accordance to the widely accepted method we also tested TTDPM of shoulder internal and external rotations at the speed of 0.5°/sec(18, 25, 44, 46, 89, 125). Once again, we employed sitting position rather than supine position. Riemann, in his review of proprioception measurement techniques, has mentioned like Lephart and Barrak, who test Threshold to detection passive movement direction (TTDPMD), where the subject must recognize the direction of movement to count for the recognition of movement. Same principle was used by Janwantanakul(124). In case the subject wrongly recognizes the direction of movement that particular attempt is disregarded(113). In numeric values it is obvious that TTDPM (threshold to detection passive movement) values will be smaller than TTDPMD. In our study we recorded only the TTDPM, but we have also noted and considered in which direction the movement was happening. This has resulted in additional level or analysis which will be discussed later.

Observing the equipment used by some authors and proposed by Myers, Lephart and Riemann we noted one possible flaw which might cause the able readings of the equipment not to correlate well with actual joint angles. In their systems, forearm was attached to the moving frame with mainly distal flexible connection though the inflatable sleeve. Proximal connection at subject's elbow was not rigid and looked to allow for some motion. Without actually having hand on the equipment used by above mentioned authors it is not possible to judge the amount of free movement at the elbow, however with proprioception testing where even 0.5° displacement might cause difference in results. This type of displacements should be eliminated. Therefore, we have used a rigid fixation along the whole length of the forearm in our study. With a plastic sleeve made from thermoplastic we ensured no translation possible. The pneumatic sleeve has allowed for elimination of tactile input. No subject has complained of discomfort of the system.

With proprioception testing, no matter if JPS or kinesthesia is being tested ,and what exact testing protocol is used the angle of the joint is very important. One must have anatomical and physiological considerations with choosing angle of the joint. While Safran used neutral rotation, 75° external and 75% of external rotation angles(89), Lee et al. measured proprioception at 45° internal and 75° external rotation angles(46). Mid ranges and an angle of maximal external rotation are usually tested in shoulder joint. Few studies like Chu and Lee have tested shoulder joint in internal rotation(46, 121). Majority of the researchers have chosen fixed angles to test proprioception. For a example, Zuckerman selected 40°, 70°, 130° of flexion and abduction as well as 10° of internal and 30°of external rotation as testing angles(104). However, one must recognize that subjects differ greatly in ROM, therefore an angle of 75° external rotation will be at the very limit of external rotation for one person and not for another. Therefore, in our study we have decided to employ relative to the person's ROM testing angles. 90% of external rotation recorded from anatomical 0° position placed glenohumeral joint capsule in rather taught state. A midpoint or 50% of whole range of motion was the second testing angle and finally 70% of internal rotation for anatomical 0° rotation position was target angle for internal rotation. Our approach was similar to Chu and Janwantanakul(121, 124). By this method, we have ensured relative uniformity of ligament and capsule stretch at each position across subjects.

The final point regarding materials, methods and analysis of the obtained data discusses the interpretation and statistical analysis of proprioception data. The following criticism can cast a shadow of doubt on the results of most studies in the field of proprioception. Analyzing published literature and having access to several full length thesis dissertations for doctorate in philosophy degree, one fact came to light: very few authors, for example Anderson(11), has mentioned the analysis of data distribution for normality. This critical step is important in making the decision which further statistical test to use. Typically authors treat JPS and TTDPM values as parametric data with normal distribution(31, 33, 34, 44, 104, 121, 128, 144, 153). Contrary to this, our observations showed that both JPS and TTDPM were not normally distributed and significantly skewed to the right. Simple logical analysis of proprioception data with measurement tools have dictated that proprioception data is skewed to the right by its nature and cannot have normal distribution. For example, taking an average JPS at 50% of ROM angle of 5.22° and standard deviation of 2.97°, one should realize that values of some subjects can be outside of standard deviation. For example, JPS error of 11.00° which is 5.78° or nearly at two standard deviations from mean to the left is very easily possible observations in a subject with poor proprioception. However, similar deviation to the other side of mean value will be beyond 0° mark and will be simply impossible. To summarize, it is important to recognize the proprioception data by nature is skewed to the right. Subsequently, further statistical analysis like one way ANOVA might not be appropriate. The solution of the problem might be a transformation of the raw data, yet there is no mentioning of such transformation in the literature. Similarly sphericity is another requirement for one way ANOVA test, but none of the authors have mentioned testing for it.

Due to relative small sample size within each intervention group and recognizing skewed distribution of data we were forced to abandon parametric tests in favor of no parametric ones. Furthermore, it was sensible to present both values of mean and median for proprioception.

5.4 Control group

Analysis of the results of this study we have to start from the Control group - the group which did not receive any interventions and in theory must serve as a reference to compare the effect of interventions against. Similar to all other groups proprioception of the subjects in the control group was measured, on the first day - "initial", one the second day - "Pre" or "Post", and after 30 minutes, 1 hour and 1 day. Unfortunately, the observations at different points in time did not match and significant difference existed. For an example, JPS at initial assessment at 50% of ROM was 5.22±2.97°(median 4.52°) differed from 1 hour later assessment of 2.80±1.68°(median 2.40°). Furthermore, JPS of same angle at 1 hour assessment was lesser than at 30minute assessment of 5.20±3.32°(median 4.78°).

More significantly, during testing of kinesthesia, the difference was seen even between TTDPM at 50% ROM at "initial" and "pre", "30 min". Differences in the values between "pre", "30min" and "1hour"assessment points were measured. It is hard to speculate as of to the nature of these observations. Possibly, the issue lays in the sample of control group. It was very critical to note that there were no differences between "initial" and "pre" assessments values in the other groups.

Making cross group comparison at "initial" and "pre" intervention assessment points have revealed a level of variability, even though no intervention was performed between these two assessment moments. While there was no difference in JPS at "initial assessment between groups, there were differences in TTDPM at various angles. Besides, values at "pre" intervention assessment mark had similar variations between the groups at 70% IR ROM of JPS and at 50% ROM TTDPM and 50% ROM TTDPM moving into ER.

It was not possible to compare our findings to other studies due to the fact that we have employed 7 groups, whereas other studies typically used 2 groups as intervention and control ones. For example, Swanik did not observe any difference prior to intervention between groups(25, 87).

We have observed variability, which might have arisen from small sampling size, inherent variability of proprioception or other unaccounted factors. In order to limit the observed variability, the solution was found in increasing sample size and establishing a broad baseline of normative proprioception values against which post intervention values of the intervention groups can be compared. For that purpose proprioception of all 105 participant of the study at "initial" assessment point was taken as broad baseline. Additionally, to ensure the validity and consistency of baseline proprioception values, "Initial" proprioception of all subjects was compared to proprioception of all subjects "pre" intervention. No difference in values was observed for JPS at any angle and only at 90% of ER TTDPM "Initial" values were slightly greater than at "Pre" assessment values. Furthermore, this difference dissipated after the direction of movement in which the TTDPM was recorded has been accounted for.

It is important to compare findings of our study with the findings of proprioception values reported in literature.

Chu and colleagues, studying the effect of neoprene shoulder stabilizer on active JPS in subjects with stable and unstable shoulders. They reported proprioception values of control group or subjects with stable shoulder without brace application. This groups was very similar in demographics to ours. Furthermore, both the testing protocol of active positioning and active repositioning JPS test and the angles of 10° from maximal external rotation, internal and 30° external rotation were very close to the testing angles we used in our study(121).

In stable (healthy) un braced group the JPS values closely resemble the values observed in our study for 30° ER - 5.45±0.6° versus 5.24±4.71° at 50%ROM in our study. 10° from maximal IR JPS was 5.37±0.6° against 4.59±3.02° at 70% IR in our observations. The results of studies have differed at maximal ER where Chu observed high values of 8.10±1.0 whereas we found JPS to be 4.77±3.75° at 90% ER. The cause for difference might be due to testing position. Chu has measured JPS in supine whereas we did in sitting. One can speculate that cocking motion of near maximal external rotation might be less pleasant and familiar in supine position than in sitting. Furthermore, it is not clear from the article wherever gravity was eliminated by JPS testing device, since gravity force might had an effect on shoulder and consequently on JPS(121).

Janwantanakul and colleagues explored the effects of body position, supine or sitting on kinesthesia. 15 healthy right handed males were measured who were similar in demographics to our subjects. JPS test or repositioning matching has greatly differed from our test due to fact that passive repositioning of passive position was tested. Although the testing positions were similar to ours, test for kinesthesia have been performed using much greater speed of 3°/sec versus 0.5°/sec in our study. While the testing angles were well described and closely matched testing angles in this study, in the result session of the article no indication was given about the specific angle for which the results were presented. Nonetheless JPS was recorded at 4.2±2.2° in sitting as an mean of absolute values of errors of repositioning and 2.7±1.2° TTDPM to external and 2.2±.09° to internal rotations(124). Values reported by Janwantanakul and colleagues seem so be similar to ours for JPS, and greater for TTMPD. However, the differences in testing methods and lack or precise results reporting make comparisons difficult.

In the study of Nissen and colleagues, only the values of control group can be compared to baseline values of our subjects. Nissen and colleagues used passive reproduction of passive position of JPS at 10° internal, 10°, 20° and 40° external rotation with shoulder at 60° abduction. The testing angles are within a range of 50% of ROM for our subjects. Values reported by Nissen and colleagues have ranged from 2.66±1.36° to 2.92±1.74° for JPS which are less than 5.24±4.71° (median 3.52°) for JPS at 50%ROM in our study. This difference between results might be due to using different type of JPS testing method in the studies(125).

In the same study, TTDPM was measured from neutral or 0° humeral rotation with values of1.83±1.09° moving into internal rotation and 1.71±0.85° to external rotation. Once again the testing angle is comparable to 50% ROM in our study. However, we found TTDPM to be less 1.19±0.82° disregarding the direction or 1.07±0.90° and 1.32±1.00° to external and internal rotations respectively(125).

The final study which is worth to compare with our baseline proprioception values is the study by Kathleen Swanik. Although the subjects participated at the Swanik's study have differed greatly by being collage female swimmers, the other parameters of study closely resembled ours; including sitting position of JPS test and speed of TTDPM - kinesthesia test. Tested angles were 0°rotation, 75° external and 90% of external rotation. JPS of Control Group pretest was 3.25±2.09° to IR and 3.92. ±2.71°to ER at 0°rotation and 3.58±2.15 to IR and 3.33±1.61 to ER at 75° ER against 5.24±4.71 (median 3.52) at 50%ROM in our study(25). In the Swanik’s study which used active repositioning of passive position, more accurate values or better values in acuity of JPS might be due to athletic nature of subjects. Closer similarities were found for kinesthetic values between Swanik's and our studies. Similarly, the direction of movement was accounted for, but subjects did not have to nominate the direction. At 0° of rotation 1.31±0.63° to IR and 1.11±0.48°to ER and at 75°ER 1.19±0.57° to IR and 1.17±0.53° to ER can be compared to 1.32±1.00° to IR and 1.07±0.9° to ER at 50% ROM. Furthermore at the same angle of 90% of ER: 1.44±0.58 to IR versus 1.57±1.06° and 0.92±0.33° to ER versus 0.84±0.57°(25). It is interesting to find that the TTDPM consistently seems to be greater to internal rotation than to external rotation as in our study, although Swanik did not officially test this aspect

Judging from the four studies (Chu, Janwantanakul, Nissen and Swanik) that closely resemble our study, in measuring techniques the proprioception of all 105 subjects in our study is similar and lies within margins of proprioception values reported by other researches. It is worth to mention that 105 subject of us were the greatest sample used for proprioception testing so far in the literature. Based on this knowledge, it is safe to assume that proprioception values of our 105 subjects can be used as baseline of normal proprioception values. It was helpful for us to use this baseline to compare the changes in proprioception due to interventions in our groups. This baseline values may also be considered as a normal distribution of the proprioception for healthy people and may be used as a key for normative data if there need to check any deterioration or degradation in proprioceptive acuity in some pathologic conditions.

We hope the other fact became clear to the reader how difficult it is of find similar studies in measuring techniques to compare results. In the proprioception studies testing protocols, testing positions of body orientation, speed and most importantly tested joint angles vary greatly. It is very unlikely to find two same studies to compare the results. Therefore, approximation are necessary, which unfortunately reduce strength of drawn conclusions.

5.5 Active movement intervention and the role of musculotendonous structures

The following sections are going to discuss the effects of three interventions: the active movement, passive movement and manual therapy or joint play on proprioception. The idea behind this was so study the exact effect on proprioception. If there was any, the aim was to determine active versus passive or muscular component of repetitive angular motion of joint versus passive component of articular motion with capsular and ligament stretches. Finally, the effect of pure capsuloligamental stretch without angular displacement via manual therapy of joint mobilization and joint play might have effect on proprioception.

The expected effects from interventions can come from three different levels of proprioception system. First one is the receptors. Second one is the pathways to spinal level and to upper centers processing can be affected. Third one is the central integration and perception of proprioceptive input. Especially third one can be affected by interventions in our study. Additionally, the proposed mechanism of influence of muscle spindles γ-motor neuron from muscle stretch and casulo-ligamentous afferents can play role in proprioception changes. Although, there are many studies which showed positive effects on proprioception were expected and indicated, there are also some studies that might argue for negative effects on proprioception.

In our study, subjects of "Active Movement Group" have shown degradation of TTDPM at 50% ROM at immediately post, 30min and 1 hour post intervention in comparison to initial proprioception values of the same group. Additionally, post intervention values were greater than the values taken immediately pre intervention.

It is important to note that on the following day, the proprioception values for the tested angles have returned back to normal values and were significantly less than TTDPM at post and 1 hour post intervention. At 90% of external rotation moving into external rotation similar effect has been noted. One day post intervention, TTDPM was less than immediately post and 1 hour post movement. No changes in JPS at any level was observed after putting arm though 60 active movements without resistance at 90°/sec speed. Comparing JPS and TTDPM of "Active Movement Group" against broad baseline revealed following: JPS at 70% IR was less 2.30±1.75° and median 1.62° than of baseline 4.59±3.02° and median of 3.87°. Although difference in kinesthesia at the angle of 50% of ROM did not reach significant level, there was a tendency for difference. Once again, post hoc analysis revealed tendency for TTDPM at post and 1 hour measurement mark to be greater than of base α=0.69 and α=0.74 for respective angles.

The role of muscles on proprioception is known and has been documented in previous literature(36). Physiologically, the effect is addressed to Golgi tendon receptors located in tendons and muscle spindles. Since early studies of Burke et al. and Ribot and colleagues have learned about the role of muscle spindles in proprioception, they have observed perceived movement when a vibration of 20-200Hz was applied to tendon of a muscle. The vibration through muscles and tendon causes stimulation of muscle spindles and subsequent perception of movement(41, 42). Since discovering this property of muscle spindle to be stimulated, has been explored to understand the exact role of proprioception coming from muscle spindles have on motor control. Bock found that disrupting proprioceptive input via vibration to flexors and extensors of forearm caused impaired ability to use hand for active angle matching task(48). While disruptions in motor control were seen with vibrations to muscles, a person was able to adapt to using other senses. Pipereit, Bock and Vercher have found that whenever proprioceptive signals greatly differ from visual signals people disregard proprioceptive senses in favor for visual ones to adapt to motor task. However, when the proprioceptive information does not greatly differ from visual input, then proprioceptive input is used to further enhance adaptive recalibration of senses(154). Proprioceptive efferents from muscle spindles and golgi tendons are similar to efferents from joint/ligament mechanoreceptors accent by dorsal column lateral lemnisci to cerebral cortex - this pathway is more likely to be responsible for conscious perception of proprioceptive afferents. However, there is a secondary pathway which is unconscious and leads via spinocerebellar tract to ipsilateral cerebellum (38, 109). Further projections between cerebellum and cerebral cortex are believed to exist. It is thought that cerebellum is responsible for integration of different senses and motor output coordination. The role of cerebellum was further explored by Block et al. They have claimed that healthy subject and cerebellar impaired ones have the ability to adapt to visual and proprioceptive disturbances. Interestingly Block and Bastian found that cerebellum is critical for motor adaptation, however, sensory adaptation was not disrupted in patients with cerebellar dysfunctions(155). Therefore, other mechanism outside of cerebellum shoulder be proposed for integration of proprioceptive and other sensory input. As a part of this task modulation of γ motor neuron efferent is modulated at cerebellum level(40). This modulation of γ motor neuron efferent is believed to be occurring not independently for the stretched muscles, but as complex response with consideration of proprioceptive input from agonist, antagonist muscles as well as motor command to α motor neurons(1). This opinion is reinforced by the fact that notable decrease of spontaneous firing of γ motor neuron and decrease of stretch sensitivity of muscle spindle, lasted beyond the introduced vibration to the muscle(43).

Since the role of muscles in proprioception has been established the following question is whatever the role of muscle is positive or negative one. Numerous studies have shown that fatigue of involved muscles cause decrease in proprioception(18). These effect was reported for different joints, including knees(34, 151), shoulders(7, 46, 132) and ankles(8). Work of Lee et al. has shown that no difference in passive repositioning of passive position for JPS between pre and post fatigue was observed for dominant shoulder joint. However, during active repositioning of passive position to external rotation subjects showed significantly decreased JPS after the fatigue protocol(46). Decreased proprioception due to muscular fatigue leads to subsequent disruptions of motor control. Huysmans and colleagues showed that tracking performance by wrist was severely decreased after fatiguing wrist extensor protocol(45). Fatiguing activities such as repetitive throwing showed to decrease acuity of positioning of shoulder for throwing - cocking task(7). Furthermore, changes in glenogumeral and scapulothoracic kinematics after fatiguing protocol were seen on with electromagnetic sensors and EMG. Scapulothoracic motion has dominated over glenohumeral motion in scapulohumeral rhythm after muscles became fatigued(132). These alterations might lead to pathological conditions if a movement is repetitively continued.

The opposite relation also exist, disruptions to musculotendinous structures have negative effect on proprioception. Patients with rotator cuff tendinopathy tended to overshoot target of 50%MVC on force reproduction task(5). Similarly to force sense, impaired JPS has been measured in subjects with chronic rotator cuff pathology(11). It is worth pointing out that Anderson observed that JPS was more impaired at higher angles of elevation(11). On the other hand, according to study of Suprak (2006), JPS in healthy subjects improves with shoulder elevations (28, 29). He also observed improvements in JPS when external load was applied to arm and unconstrained task of shoulder flexion was tested for JPS(28, 47). In both studies of Suprak, JPS has been tested at elevations up to 110° of flexion in scapular plane. Alpert et al. analyzed electomyographic activities of deltoid and rotator cuff muscles and they have indicated that rotator cuff muscles activity increased up to 120° of flexion and decreased beyond that point. They have commented that this is due to decreased demand of rotator cuff muscle to stabilize glenohumeral joint against transition force of deltoid(130). Analyzing the results of five above mentioned studies it is fair to speculate that in healthy subjects increased muscle activity of rotator cuff muscles positively contribute to proprioceptive sense, whereas during injury or pathologic condition of rotator cuff significant decrease in proprioceptive sense occurs.

The negative effects of muscle fatigue and injury to muscle-tendon structures on proprioception are established, however several other studies point out that there are also positive effects of active muscle contraction or exercises on proprioception as well. The exact mechanisms of effects are not clear nor agreed on yet. Therefore, proposed mechanisms by authors of each study are important to be discussed. Bouet and Gahery have investigated whether knee position sense changes after 10 minutes pedaling on cycle ergometer. In order to avoid fatigue of muscles no imposed cadence was imposed. Rather unorthodox method of testing position sense was used in the study involving several different modes of active, passive positioning, and position matching to other leg and visual indicators. The results of the study shows that following moderate muscular exercises improvements in joint position sense were seen in kinesthetic task and the task where active positioning and active repositioning of limb were tested. The authors have argued that observed improvements in motor control must be not only due to more efficient motor control but also due to kinesthetic sense improvements(22). Authors had no further speculations on the exact mechanism and level at which improvements had occurred.

Well designed study by Friemert and colleagues has assessed JPS of knee using passive preproduction of passive positioning. For subjects after ACL repair, two interventions of continuous active motion and continuous passive motion was applied for seven days post operatively. As can be expected, patients with ACL ruptures have showed deficient JPS. However, after seven days of active motion intervention JPS of subjects significantly improved and nearly restored to the values of non-injured reference limb. Subjects of passive continuous motion did not show similar improvements in JPS(23). The results of this study greatly differ from our observations where TTDPM following active bound of exercises - contractions through ROM at specific speed degraded where as passive movements at same speed seemed to improve TTDPM at various angles in comparison to broad baseline. However, is it critical to point out many differences in the studies, since proprioception of different joints have been tested. In the study of Friemert, subjects with ruptured and reconstructed ACLs (anterior cruciate ligament) were studied, whereas we used health subjects. Furthermore, the time scale of interventions and testing methods differed significantly. Friemert and colleagues had difficulties in pointing out the exact mechanism of the observed improvements. They have argued that the improvements in JPS were unlikely to be caused by mechanoreceptors in ACL grafts since morphologically the receptors were found to appear later than 4 weeks post surgery. The authors have proposed that early neuromuscular rehabilitation of knee control coupled with improved function of other proprioceptive receptors of knee may be underlie the improvements in JPS after continues active motion intervention early post operatively(23).

A combination of various warm up exercises, that included jogging, forward and backward running, jumping and stretch exercises have caused immediate improvements in knee JPS of young karatekas measured by closed kinetic chain JPS assessment with photographic method. No differences were seen by Open Kinetic Chain JPS assessment method(24). Similar results have been reported by other study by Bartlett and Warren, testing knee JPS of healthy rugby players after 4 minutes of similar active warm up exercises program(21).

Unfortunately, due to complexity of warm up exercises and great variability of different exercises in warm up programs of Magalheas, Bartlett and Warren, these studies are not very beneficial in the discussion of the effect of acute bound of active muscle contraction on proprioception measured immediately post exercises. This is due to lack of specificity of intervention. We were no able to find any similar studies for shoulder joint to make a direct comparison.

To summarize the results of the effect of active muscle contractions on proprioception, both positive effects and negative effects have been recorded in many studies. In our study, we observed the immediate effects of active muscle contraction at specific speed and without external load. Results partially showed that degradation of proprioceptive sense was achieved in majority of cases predominately for TTDPM at mid ROM. Critically the return to normal values was seen 1 day later. The observed results have resembled the effects of muscle fatigue on proprioception reported by many above outlined authors. In our study we did not specifically account for fatigue level, neither did any subjects mentioned or complained about muscle fatigue while doing the exercises. Unfortunately, there is lack of studies investigating acute or immediate effect of active muscle contractions on proprioception in the literature. More commonly, the studies have shown positive effects of complex exercises program administered over a period of time on proprioception. Ashton-Miller and colleagues questions whether proprioception can be improved by exercises in their review article. The authors argue that no changes at the joint receptor level were observed to this point that might increase proprioceptive input. The only exception are muscle spindles which sensitivity is can be controlled to some extent. Therefore, central integration at cerebral or cerebellum level where proprioceptive input is integrated to form motor control are the more likely location for observed improvements(16). Unfortunately, due to difficulty of separating proprioceptive system from motor control system at cerebral and cerebella level the decisive conclusions cannot be drawn at this point(16).

5.6 Passive movement and manual therapy effects of joint mechanoreceptors

The following session will deal with the joint and ligament mechanoreceptors presumably stimulated via passive rhythmical movement of shoulder joint through ROM and though manual joint mobilization as joint play of anterior posterior with grade 1-2, without angular displacement of glenohumeral joint. We wish to acknowledge we were aware that during passive movement through ROM and joint play there was some level of passive stretch of musculotendinous structures that might subsequently be stimulated. With the type of experiment conducted for this study, there was no way to eliminate this important factor. Efforts were taken to limit this input from muscles and tendons in form of instructions for subjects to relax shoulder muscles during the interventions. The following discussion will focus on joint and ligament mechanoreceptors and its effects on proprioception.

Findings of our study showed that no changes in proprioception in the subjects of “Passive Movement Group” have been found following intervention or at any moment of measurement. However, when comparison was made against broad baseline, JPS at 70% of IR pre and post intervention was less than of baseline. At 90% ER and at the same angle moving into internal rotation, measurements taken 30 minutes and 1 day post interventions were also less than of baseline. Similarly at 50% of ROM baseline values were greater than pre and at 30 minutes post intervention. Finally at 70% internal moving to internal rotation at test of TTDPM, 1 day post intervention proprioception was more accurate than of baseline subjects.

In manual therapy group, rather different observations were made. Once again, effects were seen predominately in kinesthetic sense. Within the group at 90%ER disregarding movement direction TTDPM at initial assessment was greater than prior, post and 30 minutes post intervention. Similar results were seen at the same angle, but moving into internal rotation. Additionally at 30minute TTDPM was less then at 1 day after intervention. At the other extreme of ROM of 70% IR, kinesthesia initially was less than prior, 30 minutes, 1 hour and 1 day post intervention. No difference was seen at mid range of 50% of ROM at any moment of testing. However, when manual therapy group was compared against baseline proprioception (taken from 105 subjects), there was no difference or any effect found for any test, tested angle or at any moment of measurement.

In order to consider the effects of joint mechanoreceptors on individual's proprioception, anatomical considerations should be taken into account. There is much controversy about distribution of joint mechanoreceptors in shoulder and its possible afferents. Bresch and Nuber have used different histological technique to analyze Human glenohumeral ligament for location and distribution of mechanoreceptors. They found that type I and III small, low threshold slowly adapting (Ruffini, Golgi-Mazzoni) and large high threshold slowly adapting (Golgi and Golgi-Mazzoni) mechnoreceptors were mainly located close to labrum. Type II - medium, low threshold rapidly adapting (Pacini, Krause, Vater-Pacini) and type IV - very small, high threshold pain receptors (free nerve endings) were located in the body of ligaments. Interestingly, the greatest concentration of type IV receptors were at the acticular side of the tissue(96, 97, 102). Also, more of type IV receptors were seen in inferior GHL (glenohumeral ligament)compared to middle portion(96). Gohlke and colleagues have studied distribution and morphology of mechanoreceptors in rotator cuff and Coracoacromial ligament. Their findings indicated that dense ligament tissues are almost completely aneural, Pacini-like corpuscles were found in anterior inferior part of capsule. Rotator cuff corpuscular receptors were found close to coraco acromial ligament. Type I golgi tendons were found only in musculotendinous junction of rotator cuff. Similar to Bresch and Nuber type III receptors were found in inner layers facing subscapularis muscle(103). As it is evident, there are different receptors found in different areas of GHL capsule, which is likely to reflect on the functions of these receptors and the afferent input transmitted.

The classic physiology knowledge suggests that stimulation of capsuloligamental structures should evoke reflex reaction of α motor neuron. Solomonow showed that electrical stimulation of nerve branches that innervate capsule mechanoreceptors resulted in electromyographic activity in various shoulder muscle. Stimulation of suprascapular articular nerve that innervates superior and inferior aspects of posterior capsule resulted in electromyographic discharge in biceps and infraspinatus muscles. While stimulation of subscapular articular nerve showed discharges in subscapularis, biceps, supraspinatus and infraspinatus muscles. The Study was conducted on vivo cats. Furthermore resection of subsequent nerve branches caused disruption of the reflex arch(98). Functional implications of these findings in human were questioned. First of all, the response to electrical stimulation and the response to natural stretching generated by mechanoreceptor might be different from each other, since various mechanoreceptors exist in joint capsule and electrical stimulation is nonspecific to this type of afferent receptors. Therefore, this functional implication of α motor neuron motor reflex arch can be questioned about its functional implication, especially for human shoulder. Furthermore, numerous kinesiology studies indicate that capsule of glenohumeral joint is relatively lax at the mid ranges of motion where typical functional activities of person manipulating object in visual field take place does not sufficiently stretch capsule of glenohumeral joint. In addition to that relatively high load should be placed on joint capsule to provoke α-motor neuron reflex arch. Consequently, this mechanism is unlikely to have role at low and mid ranges of motion(50, 54, 81). Diederichsen and colleagues among whom is Michel Voigt reviewed shoulder reflexes, making several valuable comments about the reflexes elicited from various ligaments of shoulder and its affect on muscles of both humans and cats. Cats are commonly used to conduct experiments when performing similar experiments on humans will be unethical. The review mostly reflects on effects caused by electrical stimulation of ligament afferents and clearly state that this afferent causes alternations in muscular activities. Great difference is between cats and humans, where in first the latency of reflex is very short 2.7-3.1ms and in second very long 300ms. Based on such a great latency in humans, the authors suggest that afferent from joints are not involved in ongoing modulation of muscular activity, but in feed foreword system modifying motor upcoming motor commands(100). In the review authors refer to the earlier work of Michel Voigt where he implemented non-noxious electrical stimulation to glenohumeral joint capsule resulted in strong inhibition of active shoulder muscles(101). It must be pointed out that electrical stimulation of the joint capsule causes none specific stimulation of the nerve, therefore presumably all afferents of each types of mechanoreceptors are stimulated. Based on this fact, it is important to question which afferents from which mechanoreceptor would cause inhibition of muscle activity. At this point we cannot answer this question. Logically stimulation of free nerve endings which carry noxious afferent or pain would cause inhibition on muscular activity in order not to cause further stretch and damage to the structures, but considering that afferents of pain travel via Aδ and C fiber types whereas proprioceptive information travels via Aα and Aδ, subsequently the proprioception input will be arriving faster to mediate reflex activation. Since pure logic does not correlate to the evidence obtained through studies, alternative theories should be proposed to explain the phenomenon and further studies carried out. Possibly, coding of afferent input makes a difference or there is more complex processing of afferents from joint mechanoreceptors prior to efferent reflex output.

There is an alternative hypothesis for the role of joint mechanoreceptors on joint stability. According to this hypothesis, afferents from ligaments and capsule cause modulation of muscular activity via γ-motor neuron activity essentially affecting stiffness muscles and sensitivity of muscle spindles. Great number of researchers considers this mechanism is more plausible and functional(10, 102, 105). This mechanism seem to be none specific to a joint, for example in knee after ACL rupture due to possible loss of mechanoreceptors in ACL the neuromuscular control of the joint degrades and does not restore normal levels even after specific rehabilitation(9, 99, 146). This does not mean that neuromuscular rehabilitation is not important but acknowledgment of limitations should be made. In particular this is important in stability of shoulder joint which is controlled not only by joint and capsule but also by muscles of rotator cuff. Tibone and colleagues have showed that the proprioceptive afferent from capsular mechanoreceptors are present even in unstable joint, observed by cortical evoked potentials after electrical stimulation of capsule (143). However, the decreased stimulation of these afferents in lax or unstable joint causes functional instability of the glenohumeral joint. Two studies of Sullivan and Warner confirmed that functional joint position sense in functionally unstable shoulder joints is decreased in comparison to healthy or contr-lateral sides. After surgical stabilization by means of open, arthroscopic or thermal capsulorrhaphy the JPS restores to normal(10, 14, 128, 150). Sullivan have reported that JPS of shoulder after open and thermal capsulorrhaphy is even sharper than in healthy subjects(128).

One specific condition that mainly affects joint structure and has very high prevalence is osteoarthritis. The condition causes degeneration articular surface of joint as well as capsule and ligaments of the joint. Several studies focused on the effects on osteoarthritis on shoulder and knee. Review by Knoop and colleagues summarizes following findings that proprioceptive accuracy is decreased in OA patients when compared to healthy age matched subjects. Even though poor proprioception might play role in progression of the disease, authors argued against the causal relationship between poor proprioception and the onset of the disease (145). Reviewers were not certain about the exact mechanism that causes the deficiency in proprioceptive accuracy(145). Similar finding were reported by Cuomo, Birdzell and Zuckerman for shoulder joint. Additionally, after performing total shoulder arthroplasty proprioception if forms of JPS and kinesthesia have restored to normal values 6 month post operation in their study(122). Once again the authors did not propose any specific mechanism to explain degradation in proprioception. As we know, articular cartilage of the shoulder is aneural structure and cannot cause any disruption in neural afferents. It is possible to speculate that structural changes of articular surface cause increased pressure on the capsule evoking pain in the joint. The pain in turn might cause loss in proprioception. Interesting experiment has been conducted by Sole and friends to specifically test if pain alone would cause decrease in proprioception. Experimentally, subacromial pain has been induced in healthy subjects' shoulder to the level of 7 out of 10, and then proprioception has been tested by means of passive repositioning of JPS and kinesthesia. The results have showed that JPS had tendency to get worse with pain onset but did not reach significant level to make decisive conclusions. Contrary to that, kinesthetic sense has increased at 20° external rotation. Authors decided that due to pain, a subject might be more sensitive to passive movements in the joint to mediate protective neuromuscular response to avoid further injury(147). While for JPS studies by Cuomo and Sole were in agreement, for kinesthetic sense the findings were diametrically opposite, even thought the testing positions, angles and protocols were very similar. The only difference was the age of participants of the study. Further research should be made to explain the difference between the opposing findings.

Based on the information above it is clear that there is role of joint mechanoreceptor in proprioception, even though this role is ambiguous and the exact mechanism is not clear. For the purpose of this study, we aimed to investigate whether a repetitive stretch of glenohumeral joint capsule and ligament will affect proprioception. A few studies prior to our study had posed this specific question. Therefore, comparison of the results will be difficult. Ju and colleagues from National Taiwan Sport University report that rapid 90°/sec, repetitive - 60 repetitions passive movement of the knee caused improvements in active repositioning of JPS and kinesthetic sense. Significant improvements were seen in both the young adults and the elderly. However, there was persistent difference between young subjects, whose proprioception was better than their older colleagues in the experiment(33). Above described study closely resembles the repetitive passive motion protocol used in our study, the only difference was the measured joint. In contrast, we did not manage to see the similar effects in shoulder joint after the intervention within the group. When comparison was made with 105 subject baseline, the positive effect was seen for 70% internal rotation immediately post intervention and at 90% ER and 50% ROM for kinesthetic sense. Interestingly, the positive effect was seen not immediately but 30 minutes post intervention. For kinesthesia at 70% internal rotation, the improvement was recorded only 1 day post intervention. Ju did not make repeated measurements post intervention therefore the results cannot be compared.

The other perspective of our study was to see if there is a difference between passive mechanoreceptor stimulation with functional movement where angular displacement is present and stimulation of joint mechanoreceptors by means of passive mobilization and joint play without angular displacement. Contrary to "Passive Movement Group", the effect was seen for extremes of ROM - TTDPM at 90%ER and 90%ER moving to Internal rotation and 70% IR when comparison was done within the group. Kinesthetic sense was sharper post and 30 minute after passive movement. No effect was seen for JPS of TTDPM at mid ROM when comparison was made against baseline of 105 subjects.

Direct comparison of these two intervention groups (Passive Movement Group and Manual Therapy Group) has shown that there was a difference between the groups at 70% of IR. JPS of Passive group (mean: 2.43±1.55°, median: 1.93°) was less than the Manual Therapy Group (mean: 5.14±2.26°, median: 4.95°), although the groups were similar at initial assessment, at pre assessment. This difference persisted post intervention until 1 hour post intervention when difference even out. Therefore, it is not possible to say definitively if the difference is due to intervention or due to samples. However, immediately post intervention, JPS of Manual Therapy Group (mean:3.27±2.77° and median 2.07°) was less that of Passive Movement Group (mean: 6.16±4.06° median 5.37)at 50%of ROM° ($p = 0.026$). Analyzing the results for similar comparison of kinesthetic sense, it is much harder to draw any conclusions since the groups have differed in initial and pre- intervention assessment. However, this difference has disappeared after the intervention. We tend to attribute these findings to possibly having relatively small samples groups being different at the randomization by chance.

Unfortunately we were not able to track any studies exploring the effects of manual therapy on proprioception, in particular for peripheral joints. Pickar et al. have discusses neurophysiological effect of spinal manipulation. Authors have argued that manipulation to spine produces sufficient stimulation of mechanoreceptors and nociceptive afferents that affect neural integration either at reflex activity or more centrally where motor integration occurs. No exact mechanism is known yet. However, the results of this stimulation will be followed by some changes in somatomotor and visceromotor activities (156). This point of view is supported by the findings of Goss and colleagues. They found that non-thrust manual therapy reduces short stretch latency reflex asymmetries of erector spinae muscles in patients with chronic low back pain(157). Goss et al. have suggested that the mechanical stimulation of spinal joint mechanoreceptors regulates gain to muscle spindles and therefore regulating stretch reflex of the muscle(157). The author of above mentioned study with accordance to many other researchers takes point that joint mechanoreceptors play indirect role in motor control via modulating γ-motor neuron activity of muscle spindles and subsequent it's sensitivity.

To summarize the discussion about the role of joint mechanoreceptors in proprioception and effects of repetitive stimulation of receptors and subsequent effects, we can say that the majority of authors have consensus that joint mechanoreceptors do not play direct role in mediating neuromuscular or reflex response, instead the afferents play role in modulating activity of γ-motor neurons of muscles spindles and it's sensitivity. Therefore, it might be a good idea to shift our focus from purely investigating the role of joint mechanoreceptors to role of mechanoreceptor on muscle spindle sensitivity. Based on our study and the other studies there are indications that repetitive stretch of joint mechanoreceptors, performed even passively might lead to enhanced proprioception, especially for proprioceptive sense at the ends of ROM. Unfortunately the findings are not definitive and therefore, clear conclusions are too early to be made, and more studies should be done. Our study was not able to provide answer whatever repetitive passive angular motion or just none functional joint stimulation via manual therapy is more effective in increasing proprioception.

5.7 Stability exercises and proprioception

Since the rise of popularity and understanding of proprioceptive system in rehabilitation, the term proprioceptive exercises was coined. Even though the purpose of these exercises is clear as to improve the functioning of proprioceptive system, the nature and characteristics of these exercises are not as clear. Typically, authors like Davies, Myers, Lephart as well as Karatsolis have reviewed of proprioceptive exercises would describe various exercises such as open chain, close chain, balance etc., and they have reported their beneficial effects on proprioception in literature (2, 17, 51). Unfortunately, this does not help to clarify the physiological nature and characteristics of proprioception exercises. To give a contrasting example the definition of close chain exercises is very simple and straight forward "Close kinetic chain" exercises is an exercises where distal segment of extremity is fixed and proximal motion takes place in multiple planes"(127). Therefore, the opinion of the author of this thesis, the term proprioceptive exercises may be abandoned until further consensus on the nature of exercises can be reached and a term such as "exercises that have effect on proprioception" might be used instead.

Among various exercises that have been found to have an effect on proprioception, one common stands out, the balance type exercise preferably can be performed in close kinetic chain(2, 17, 49, 51). In rehabilitation, the final functional goal may not be to improve/ increase proprioceptive input, but to improve sensorimotor output and improve stability of a joint. From functional point of view, this is much more reasonable goal making difference in the rehabilitation of a patient and return to daily or sport activities. The proposed physiological principle underlying the balance and wobble boards and close kinetic chain exercises is the idea that greater approximation of articular surfaces occurs during these exercises. Furthermore, co-activation of muscles on opposite sides of the joint happens causing for improved stability of the joint. The above described mechanism is particularly well accepted for structurally unstable joints such as shoulders, knees and ankles.

The value of balance or wobble board type exercises on improving joint stability of functionally unstable ankles is probably the most researched area. Hughes and Rochester have reviewed the effects on prorioceptive exercises and taping on functionally unstable ankles. The main conclusion by the authors was to indicate that there is lack of quality studies about this subject. Some researchers have pointed out that there is a positive effect on functionally unstable ankles, but other researcher have not found any effects(158). Typically, the method of proprioception or stability testing in ankle greatly differentiates from the method used for the shoulder. A study by Clark and Burden indicated that there is a positive effect of wobble board exercises on perceived stability and decreased onset latency of foot muscles in functionally unstable ankles(55). One major difference of mentioned studies from our study was the duration of proprioceptive training. Most studies have investigated the effects of several weeks of training on proprioception whereas we have wanted to find out the immediate effects of single session of intervention. With a prolonged training, a different aspects of proprioceptive training or improvements may exist - the learning effect and cortical adaptation to stimulations of mechanoreceptors while person is performing wobble board exercises. In our experiment it is fair to say that we did not expect to observe cortical adaptations.

Only one study in the literature has investigated effects of one session of proprioceptive training on an unstable platform on monopodal stabilometry. Ankle joint has been studied. However, the principle of intervention was similar to ours - to test the effects of single intervention over period of time. The intervention of the study has consisted of conventional warm up of slow running, dynamic stretches and specific running exercises. After that only experiment group completed 25 minute Swiss ball and BOSU hemiball exercises. Unlike our study, all subjects were athletes. Assessment on monopodal stabilometer was performed immediately post training, 30 minutes, 1 hour, 6 hours and 24 hours post intervention. The overall results of the study has indicated that there were significant fluctuations of center of pressure in a control groups in both anterioposterior and mediolateral directions which were not seen in subjects that performed balance exercises. Furthermore, throughout the testing sessions, balance training subjects showed the center of pressure to be consistently closed to the middle than in the control group. Based on these findings, authors made conclusion that proprioception training on unstable platforms after a warm ups program stabilize center of pressure in both tested directions and improves the stability in short terms(159). As it is obvious there are many differences between mentioned study and our study. The studies differ greatly in terms of tested joint, subjects and testing methods. Nevertheless it is important to note that the observations in studies were different. We did not observe any positive effect of stabilization exercises on shoulders. The characteristic of the difference between the studies can be explored with the further studies. It is also critical to learn if the findings about ankle joint could be applicable to the shoulder joint.

There are several studies focused on shoulder and unstable platforms training. In subject with prior history of anterior shoulder dislocations a 4 week wobble board training program has caused significant improvements in movement discrimination. This effect was only seen in the subjects who dislocated their shoulder. The subjects without dislocation acting as a control group did not have any benefits from the same wobble board exercises(160). This might indicate that inputs from the muscle and joint mechanoreceptors is decreased in pathological condition which can be activated with the wobble board exercises or balance exercises in comparison to the normal joints. Meanwhile, in healthy subjects, proprioceptive system work naturally and further improvements are not seen with the balance exercises. An aspect of joint approximation during close kinetic chain exercises and its effects on joint position sense has been studied by Rogol and colleagues. The comparison has been made between two groups of healthy subjects where one group has been performing open chain exercises and the other one has been doing close chain pushups for total of 6 weeks training period. The findings of Rogol et al. indicated that both groups have shown similar improvements in JPS at 30° internal, 30°external and 10° to maximal external rotation. However, there was no difference between groups(127).

The opinion that performing a close kinetic chain exercises on an unstable surface causes greater recruitment and co-activation of shoulder muscles is controversial. There are studies to support and oppose this opinion. De Oliviera has reported that performing axial loading stability exercises on a medicine ball caused increased activity of deltoid and trapezius muscles. Muscles of serratus and biceps brachii did not show increased activity with these exercises(133). Unfortunately, the authors did not measure the muscle activity of rotator cuff muscles which are directly in charge of shoulder stability. The findings of Oliviera's study differ from Lehman and colleagues. Later did not observe increased muscle activity in upper and lower trapezius, serratus anterior and similarly to the study of Oliviera in biceps brachii when pushups on stable surface were compared to pushups on amedicine ball (161). Another study by Lehman and friends titled "Shoulder muscle EMG activity during push up variations on and off" has reported that only some muscles like triceps and rectus abdominis reacted with increased muscle activation level when pushup was performed on a Swiss ball(162). In criticism to the earlier mentioned study the placement of electrodes were not specifically on shoulder muscles, therefore, the title can be partially misleading.

In accordance with other studies that investigated activities of shoulder muscles such as trapezius, serratus anterior, biceps brachii, teres major, with exclusion of rotator cuff muscles Kalantari and Ardestani have found that the activity of listed muscles did not increase as the base of support decreased. In their study a healthy subject assumed static position of load bearing with body being in horizontal position supported over two outstretched hands at 90° flexion. Then the same position was maintained while in increasingly less stable positions such as dominant hand on wobble board, dominant hand on ball centered wobble board, body on Swiss ball and hands on stable surface, body on Swiss ball and dominant hand on wobble board, and finally body on Swiss ball and dominant hand on ball centered bobble board. Surprisingly the findings of the study indicated that greatest muscle activity was found in the most stable position of legs on the ground and both hands on a stable surface(163). In the other study which looked closely not on the level of muscle activity measured by EMG, but on the onset of muscle activity with various loads and unstable base of support while doing pushups the following was found. With 4% of body weight of load there was decreased onset of lower trapezius and biceps brachii. With unstable surface upper and lower trapezius showed decreased onset of activity(164). This might indicate that, in order to keep shoulder girdle in a stable position with activities beyond than normal loading, the body possible responds not with the increased level of muscle activity, but with a rapidr response to the loading conditions. In the mentioned study, the EMG was not taken from rotator cuff muscles.

EMG from infraspinatus, supraspinatus, anterior deltoid and pectoralis major muscles has been measured in one study. In this study, healthy volunteers have performed active range of motion of shoulder with and without contact to a wall. The results revealed that there was a greater muscle activity in supraspinatus in unsupported conditions than in supported positions(165). These findings might indicate that there is greater demand on rotator cuff muscles, particularly on supraspinatus to stabilize and steer joint against gravity without any reference contact. The exercises performed in study do not resemble close kinetic chain exercises, therefore it is not possible to conclude that close chain exercises will place greater demand on rotator cuff muscles.

To summarize the discussion about the effects of stability and wobble board type of exercises on shoulder proprioception we must admit that there is still lack of evidence to support this theory. There are some indications that wobble board exercise help to improve proprioception in pathological conditions and some evidence points out that stability of the joint might be improved by performing exercises on unstable surfaces. However, the results can be seen typically after long term training (several weeks). That might indicate that cortical adaptation and learning underlie at the physiological basis of the improvement. Furthermore, there is lack of evidence that the principle of muscle co-contraction and greater activity, proposed as the cause of improved stability, while doing these exercises takes place. In our study we were not able to see any beneficial effect of single session of stability exercises on shoulder proprioception. Alternative theories, such as timing of the muscles and detailed assessment of subjects, will need to take place.

5.8 Plyometric exercises

Another type of exercise which was claimed to be beneficial in improving shoulder joint stability and possibly shoulder proprioception is plyometric exercise (2, 17, 19, 25, 87, 134). Prior to going into discussion about the effects of plyometric exercises on proprioception, it is worth to clarify some background information about the characteristics of plyometric exercises. Plyometric exercises came into the world of rehabilitation from athletic training. Originally exercises have been used by Russian athletes with purpose of developing explosive, maximal strength and had limited specific application. Gradually the intensity of the exercise was decreased from maximal to sub-maximal and integration into rehabilitation protocols started to happen(3, 19, 166, 167).

According to modern definition plyometric exercises are the activities of maximal or sub maximal effort which involves stretch-shortening cycle. A more demonstrating definition would be the activity where involved muscle of the joint, first undergoes eccentric contraction immediately followed by forceful concentric one. The words "plyometric" and "stretch-shortening cycle" are often used synonymously. However, terminology wise, it should be said, that plyometric is more referred to an exercise activity, whereas stretch-shortening cycle is more of the physiological term(134, 137, 166, 168). The stretch-shortening cycle is typically divided into three phases: loading phase, coupling, and unloading phases(134, 166, 169).

"Loading phase" is the first phase, and often described as eccentric contraction, deceleration or yielding. During this phase, musculotendonous structure undergoes eccentric contraction from external loading. This loading can come from gravitational force acting on quadriceps or gastronemius and soleus, for example, in landing activity of jumping down. Alternatively, external loading can come from a ball caught by the athlete. Within loading phase, the kinetic energy of external loading is converted into potential energy, which is stored in muscle-tendon units of the muscle. This stretch and loading phase is the most descriptive of plyometric exercises, allowing athlete to produce higher explosive force in later unloading phase (26, 87, 134, 137, 166, 168, 170, 171). Several physiological processes accompany loading phase. First process is called muscle potentiation. This process alters muscle contractile properties allowing it to produce higher force. Increase of cross-bridges attached to actin increase, as well as decrease of cross-bridge detachment rates happen during potentiation process(134, 166). The other process involves stretch reflex or myotatic reflex. During muscle stretching, muscle spindles are stimulated. This signal passes though monosynaptic reflex loop to produce stretch reflex, which intern contracts the stretched muscle(134, 166, 169). The third mechanism involved in the loading phase is storage of potential energy within elastic components of the muscles. The tendon has been found to be able to stretch for a limited length and then contract to preexisting length. This might come as a contrast to well known effect of reflex activity of Golgi tendon organ, which postulate that upon stretch of tendon and stimulation of Golgi tendon organ – inhibitory reflex signal would be sent to the contracting muscle. However, some research indicates that this reflex does not happen in sub maximal efforts of plyometric activities(25, 87, 134, 135, 166, 168, 169, 172, 173).

"Coupling phase" is a phase of translation from eccentric contraction to a strong concentric one. During this phase, no actual stretching or contraction of the muscle-tendon unit appears. However, this phase is very definitive of plyometric exercises. In case this phase is prolonged, the exercise lose its plyometric nature. Some researchers indicate that if no immediate concentric contraction follows the eccentric one, the stored potential energy is turned into heat(134, 137). The briefness of coupling phase is also evident in a stretch reflex where force production is found to start within 50-55 milliseconds of the initiation of reflex in lower extremities. It was found that energy loss starts to happen when coupling phase last longer than 25 milliseconds, with optimal coupling phase being 15 or less milliseconds (25, 26, 134, 135, 166, 168, 170-172, 174, 175).

The "unloading phase" is the final phase of stretch-shortening cycle is and is often also called shortening phase, rebound or propulsion phase and it follows coupling phase immediately. During this phase concentric contraction and shortening of muscle-tendon units happens. Unloading is the result and the release of stored potential energy in muscle-tendon units. Higher forces produced by plyometric exercises suggest that effective summation of elastic energy, muscle potentiation and stretch reflex play occurs(25, 26, 134, 135, 137, 166, 168, 170-172, 174, 175).

Majority of the studies on plyometric training were conducted on lower extremities focused on developing maximal strength and height of vertical jump. General consensus point out that plyometric exercises are effective in developing maximal strength and increase in vertical jump height(137, 166-168, 176, 177). However, there are authors who argue against implementation of plyometric exercises. Bruce-Low's review points out that plyometric training might be effective in developing specific fast speed maximal strength only and does not cause carry over effect to lower speed activities. Furthermore, he argues that there are increased risks of trauma with the plyometric exercises. Therefore, strength training at lower speed exercises might be safer choice(178). His point of view is shared by Katherine Burgess and colleagues explaining that similar effects on tendon stiffness and muscle output can be seen with the plyometric and maximal explosive isometric plantar flexion exercises. Therefore, since plyometric exercises cause more stress and risk of injury this type of training is less desirable(173).

Aside from developing pure strength, other aspects of plyometric training were studied. Several authors have found some benefits of plyometric training on strengthening of hamstrings and subsequently decreasing risk of ACL rupture(172, 179). Furthermore, Chimera and colleagues have also found that plyometric exercises contribute to increase abductor/adductor co-activation of hip, so adding to stabilization of whole lower extremity(169). Even though there seem to be beneficial effects of plyometric exercises Komi warns that repetitive stimulation of muscle spindles and activation of proprioceptive inhibition might lead to decreased stretch reflex sensitivity and deteriorate muscle stiffness causing damage to muscle structures(180). Among warnings of increased risk of injury associated with plyometric exercises, in case of considering implementation of this kind of training one should remember the general instructions of plyometric training that clearly state that plyometric exercises can only be implemented in health well conditioned subjects who are ready for these kinds of high impact training(26, 134, 137, 166, 168). Additionally, plyometric training should be supplemented by other forms of exercises and should come as extensive program rather than isolated exercise (26, 135, 177).

Through the studies of Davies, Pretz and some others, the plyometric exercises for upper extremities have became well known(134, 137, 170, 171, 181). When we were planning the plyometric exercise program for this study, we took guidance and inspiration from "Ballistic six" plyometric program developed by Pretz and plyometric exercises described by Carter, Pezzullo, Swanik and Vossen(25, 135, 138, 170, 171, 181). Besides, our experience came from our previous study titled " The effects of plyometric versus strength training exercise program on shoulder proprioception", where an effective plyometric program has been developed (26). This experience was very beneficial in developing plyometric exercises program for this study.

In upper extremities similar to lower extremities conflicting evidence exists on the effect of plyometric exercises on developing strength. Carter has found that "Ballistic six program" was beneficial for improving throwing speed and for increasing strength of concentric internal rotation when they have analyzed within the study group. However, the results in the study were not significantly different from control group. Thus author has concluded that "Ballistic six program" can be beneficial supplement to college baseball players(181). More definitive benefits of plyometric exercises of the shoulder internal rotators have been shown by Fortun and Kernozek, as well as Swanik(25, 123). Measuring strength isometrically plyometric program showed to be as effective as general strength training program in our previous study(26). Furthermore, plyometric exercises and plyometric pushups showed to be effective in developing triceps strength, chest press strength test and medicine ball push distance(138, 182). Only one study by Heiderscheit has reported that there was no increase in shoulder strength in plyometric group. The other intervention of Heiderscheit was isokinetic training which showed to be effective in increasing strength(115). The strength in the study was also measured by isokinetic equipment therefore it is possible that isokinetic strengthening was more specific to the testing method. Furthermore Heiderscheit employed only one plyometric exercise in his training which might have not been sufficient to show increase in strength.

In regard to effects of plyometric exercises on proprioception, few studies explored this issue. In upper extremities to our knowledge only three studies were conducted so far by Swanik, Heiderscheit, and Chan or the author of this thesis as part of master thesis(25, 26, 87, 115). Theoretical rationale behind positive effects of plyometric exercises on proprioception is the desensitization of Golgi tendon receptors and repetitive stimulation of muscle spindles and joint receptors might lead to increase in proprioceptive acuity(2, 3, 17, 19, 25, 26, 87). Reviewing the available literature, Heiderscheit was not able to observe any changes to joint position sense after 8 weeks of one plyoback system exercise training(115). However, Swanik hasobserved improved JPS of shoulder at angles of 0°, 75° and 90° of external rotation moving into external and internal rotation directions, the only exception was 0° rotation moving into internal rotation, where no improvements have been found. Furthermore, in the same study, training program for six weeks, twice a week has improved kinesthetic sense in form of decreased threshold to detection of passive movement seen at all above mentioned angles (25, 87). In our study we compared the effects of plyometric exercises with general strengthening exercises using elastic tube, we have observed improvements in JPS of "Plyometric Group" at 30° internal rotation and 90% of maximal external rotation. Additionally, “Plyometric Group” had lower threshold to detection passive movement at all three testing angles of 30° internal, 30° external and 80° external rotation, while no improvements in kinesthetic sense was seen in the “Strengthening Group"(26).

In this study, even though we had implemented similar exercises to our previous study, we could not see any changes to JPS of kinesthetic sense in shoulder joints. The most likely explanation for observed results is that one single session of plyometric exercises might not be enough to elicit any changes at the organ level or central processing to improve proprioception. Furthermore we doubt that in one session a subject can effectively learn how to perform plyometric exercises correctly. One observation worth noting is that even though in our study plyometric exercises were most likely the most strenuous and demanding of all intervention the fatigue effect seen in active group, did not cause deterioration in proprioception. We can only guess that additional stimulation of joint mechanoreceptors might have compensated for muscle fatigue and associated decline in proprioceptive acuity.

5.9 General warm up effects

The aim of last intervention method was to observe if general warm up delivered through light aerobic activities such as running would cause any changes to shoulder proprioception. Up to now, a very few attempts have been carried out to explore how warm up exercises would affect proprioception. When the attempts have been made like in the studies of Bartlett or Subasi, the warm up protocols have involved the joint which the authors wanted to investigate(21, 24, 68). For the purpose of this study similar method was not acceptable because of lack of specificity of the results. If the warm up involved the joint under investigation the change in proprioception could have come from passive, active movement of joint or warn up itself.

Fundamentally the effects of warm up exercises come from two distinct mechanisms. First one is the temperature or thermal effect. It is well documented that repetitive active muscle contraction as can be seen in warm up exercises like running cause temperature increase(59). This in turn increases oxygen delivery to muscles via right hand shift of oxyhaemoglobin dissociation curve and vasodilatation of blood vessels(57). Some evidence also indicates that increased temperature speeds up nerve conduction velocity which is relevant to our topic(57, 58). The second mechanism is of beneficial effect of warm up is attributed to metabolic changes. For example reduced oxygen tension, increased K^+ concentration as well as H^+ concentration might lead to vasodilatation and improved blood flow to muscles. Additionally, residual metabolic acidemia from warm up exercises lead to increase muscle perfusion during exercises and speeds up VO_2 kinetics(57). All mechanism mentioned above focus on improving muscle performance such as during running or jumping. Furthermore, outlined mechanisms usually describe effects of warm up on the muscle in focus, whereas effects in the other surrounding tissues are underreported.

In our study we wished to have a brief outline if above mentioned mechanism have general effect on the joint proprioception without causing any movement of the shoulder joint and contraction of the shoulder muscles directly. To know more details on the effect and the extent of warm up exercises were completely beyond this study and this was out of our scope. Therefore, there is need for future studies which might also take account local circulation, superficial and deep temperature monitoring etc. We incorporated general warm up protocol commonly used based on percentage of age predicted heart rate max(58). In our study, subjects have responded as predicted to warm up protocol and felt warmed up of their body, subjectively and increased body temperature, but none of them reported feeling of fatigue.

Within group analysis of "Warm up Group" did not show any changes in proprioception. When comparison was made with broad baseline of 105 subjects at

70% internal rotation at immediately post and 1 hour post intervention, JPS values were less in the "Warm up Group". It is difficult to judge if the observed results were right or coincidental. Few studies with common title of warn up effects on proprioception have reported following findings. Bartlett reports that joint position in the knee of rugby players improved after 4 minute warm up of jogging and stretches(21). Similar findings have been shown by Magalhae and Subasi(24, 68). The later had two different warm up protocols lasting 5 and 10 minutes. Longer warm up exercise training caused greater improvements in proprioception(68). Finally FIFA 11+ and HarmoKnee prevention and warm up programs shoed to be beneficial in improving proprioceptive acuity(183). In all of three above mentioned studies, warm up programs were comprehensive and have greater or lesser extend were activity specific. Furthermore, in all studies the knee joint was involved in warm up activities such as running and stretches. Therefore, interventions used by these authors are more similar to active or passive movement interventions used in our study. We have specifically avoided using tested joint and just have focused on an aerobic warm up protocol. Based on this it is most likely not correct to compare our study to the outlined literature.

Surprisingly, there are more which have investigated the effects of cryotherapy on proprioception in the literature. The results of these studies were very conflicting with similar number of studies reporting negative effects as studies reporting no effects at all(18). For example, Dover and colleagues have reported that cryotherapy does not impair shoulder joint position sense(31). Contrary to these authors, Wassinger stated that there are significant increase in deviation of path of joint motion replication and decrease in functional throwing performance after 20 minute ice bag application to a joint(32).

To summarize, the effect of aerobic general warm up on proprioception is still unclear and not enough studied area. Our study was not able to indicate that general warm up through running might affect shoulder proprioception, however as we can see on the example of cryotherapy the outcomes of one study are not enough. Therefore, detailed assessment should be conducted on this subject measuring the physiological processes that accompany general aerobic warm up exercises, analyzing its effects on proprioception of not only the involved but of other joints as well.

5.10 Comparison of intervention groups

The secondary objective of this study was to compare interventions between each others. Unfortunately due to relatively great variability of the obtained data within the groups and relatively small sample of the groups, it is difficult to draw conclusion. It is likely that due to small samples the proprioception values between groups distributed unequally causing the groups to be incomparable. The argument in favor of this reasoning can be observed partly since of some difference between the groups in terms of kinesthetic sense at the initial assessment. These differences have persisted at pre intervention assessment where still no interventions took place and therefore there were no reasons for the groups to differ. Interestingly, these differences have disappeared immediately after the interventions making groups equal in terms of JPS and kinesthesia. At 30 minutes and 1 hour post interventions there was a trend that proprioception values of the subjects who performed stabilization exercises were more accurate than of majority of other groups. Whatever this is the indication that stabilization exercises might be more effective that the other intervention, it is difficult to conclude especially in light of not observing effect of stabilization exercises when comparison was made within the group and with 105 subject reference group. Due to a unique nature of the study it is not possible to make comparison with findings of other studies. To conclude this section we wish to say that results of this study did not sufficient to claim any of employed interventions was more or less effective in improving proprioception at any moment of the assessment. Several factors might have played role and accounting for then in future might be beneficial. Therefore, the suggestion to future studies would be to increase the group size and limit the number of intervention groups to two or three, subsequently decreasing chance of variability between the groups.

To summarize analysis of the acute effects of interventions on shoulder proprioception, we were able to see some degradation of kinesthetic sense in "Active Movement Intervention Group". We think this may be due to negative effects of muscle fatigue on proprioception which has been already reported in the literature. In contrary, repetitive passive movement used for "Passive Movement Group" and manual joint play or mechanical stimulation of joint capsule used for "Manual Therapy Group" have shown some improvements in proprioception. Other interventions like stability exercises and plyometric exercises have been found not to have effect on shoulder proprioception when administered only for a single session of intervention. Our opinion is that, one single session of intervention was not sufficient enough to cause central adaptation and learning effect of CNS in order to improve proprioception as seen in other studies.

5.11 Additional analysis

Having obtained date from 105 subjects at initial assessment and prior to interventions has provided us with an opportunity to make additional analysis of subjects' proprioception which was not earlier studied in the literature.

First of all, we wanted to see whether the subjects' proprioceptive acuity was different at different testing angles or not. Values of JPS were not different between the testing angles at the initial assessment. 4.77±3.75° (median 3.33°) at 90% of external rotation versus 5.24±4.71° (median 3.52°) at 50% of ROM and versus 4.59±3.02° (median 3.87°) at 70% of internal rotation. Meanwhile on the following day, prior to interventions, some difference between testing angles has been observed. JPS at 70% of internal rotation was less than at 90% of ER and 50% of ROM, with no difference between later two. Our findings contrast to findings of Suprak who has analyzed shoulder joint position sense with unconstrained tasks. His findings indicate that gradual increases in JPS was seen up to the point of 90° flexion. Following that sharp decline of JPS between 90° and 110° was noted. The role of motion plans at which shoulder flexion was performed in the experiment did not show to play role. The authors have associated these findings with increased joint torque that peak at 90° flexion and subsequent increase in muscle activity and joint position sense(28, 29). We wish to comment on difference in testing methods used in our study and study of Suprak, where later did not make any attempts to eliminate the factor of gravity with shoulder flexion. Therefore rationale of increase torque at 90° flexion is a valid one.

Chu has reported some findings which are similar to ours prior to the intervention. Testing Active joint position sense in a set up very close to ours but in supine, he found that JPS at 10° to maximal external rotation (7.5±0.562°) was greater - less accurate than at 30° of external (5.6±0.492°) or 30° internal rotations(4.6±0.314°). There was no difference between the later two angles(121). Finally Zuckerman and colleagues tested proprioception of normal healthy subjects for by meant of passive position reposition JPS and TTDPM test of three movements: flexion, abduction and rotation at 0° shoulder abduction. Their findings concurred with the findings of Chu indicating that at 130° flexion JPS values are greater than the values measured at 70° or 40° flexion(104). Even though tested movements were different, correlation can be drawn nonetheless. Zuckerman also tester internal and external movement, where he found that only in older population JPS at 10° internal rotation was less than at 20° external rotation(104). The correlation between the angle of rotation and the JPS were not seen in the younger subjects(104). These findings of Zuckerman resemble to our findings which we had observed prior to interventions.

The role of angle on the second aspect of proprioception - the kinesthesia was also tested. No difference in TTDPM between the different angles has been seen when the direction of the movement was disregarded. These findings were confirmed on the following day when the same tests were performed prior to any intervention. When the direction of the movement was accounted for, however, we have found very different and interesting results. For all angles values of TTDPM disregarding movement direction significantly differed from the values when the direction of the movement was accounted for. At 90% of external rotation TTDPM moving to external rotation was less (.84±.57° median.73°) than moving to internal rotation (1.57±1.06° median .97°). Same significant difference was seen on the following day of testing. Similar findings were seen at mid range of motion or 50% of ROM. Once again TTDPM was less when moving to external rotation in comparison to moving to internal rotation. During the pre intervention testing, the tendency was the same, but did not reach significance level. Finally at 70% of internal rotation moving to external rotation was sensed still faster than when the movement occurred to internal rotation (.83± .45° median .70°) versus (1.53± .91° median 1.31°).

A few studies have explored kinesthetic sense in such detail to produce similar reports. Earlier mentioned study by Zuckerman and colleagues did not observe effect of angle on kinesthetic sense(104). Contrary to Zuckerman and us, Allegrucci has reported increased kinesthetic sense in the athletes who participate in upper extremity sports at 75° external rotation than at neutral position(44). The only author who has measured and reported on kinesthesia with account of direction of the movement was Safran and his colleagues. They have observed a trend of enhanced kinesthesia in testing baseball pitchers when they were moving from 75° external rotation or 75% of maximal external rotation into external rotation direction(89). Our observations concurred with the observations of Safran et al.

We suspect that the developed tension in the capsule and subsequent changes in the tension when movement occurs into external rotation might be a cause for these observations. Secondly, external rotation compared to internal rotation might be more functional movement for a person therefore a person might be more sensitive to the movements in this direction. Our findings should prompt further investigations into the issued. Also for authors of future studies it might be beneficial to account the direction in which kinesthesia is being tested for more in-depth analysis of results.

Final additional analysis of this study was to compare proprioception of male and female subjects. The two groups were similar in numbers 55 females versus 50 males. The results Initial assessment indicate that male subjects had better JPS at mid and external rotation and better kinesthetic sense at mid and internal rotation angles. However, at the pre intervention assessment the subjects were similar in terms of JPS and only trend of difference persisted for kinesthesia. Although, some authors had an opportunity to compare proprioception of males and females based on their samples, up to now, such analysis has not been reported. Therefore, comparing our findings and speculating on the cause of our observations would be without any fundamental basis. Therefore, we wish to report our findings to others in this field and urge to conduct more research on this subject to establish more reliable and comparable findings.

6 CONCLUSION

Observation of the acute effects of six various interventions, including, active repetitive movement, passive repetitive movement, manual mobilization and joint play, stabilization exercises, plyometric exercises and general warm up through jogging on shoulder proprioception of healthy subjects showed following results.

1. Great variability in JPS and kinesthesia was seen among the healthy subjects.
2. Two subsequent assessments of all subjects without any intervention showed consisted and similar results reflecting on reliability of chosen methods of proprioception testing.
3. Significant skewing to the right was seen in both JPS and TTDPM measurements mandating none parametric analysis of data.
4. Level of degradation of kinesthetic sense after repetitive active movements through range of motion at 90°/sec speed, particularly observed within the groups.
5. In "Active Movement Group" proprioception values, 1 day post intervention, have recovered to values equal to initial assessment and to broad baseline of 105 subjects.
6. Manual therapy of joint play of glenohumeral joint showed to be effective in improving kinesthetic sense at the extremes of range of motion, lasting for up to 1 day post intervention for internal rotation, as measured within the group.
7. Rhythmic passive movement through ROM at 90°/sec speed, was beneficial to improve JPS at 70% internal rotation and at all angles for kinesthesia. Best effect was seen 30 minutes after the intervention.
8. The observations were inconclusive or showed no effects for stabilization, plyometric and general warm up exercises on shoulder proprioception.
9. No significant and consisted difference between the intervention groups was seen at any point after intervention.
10. No difference in JPS between any of the joint angles was seen with the implemented method of assessment in 105 subjects measured prior to interventions used as baseline values of proprioception.

11. No difference in TTDPM was seen between the various angels of 105 subjects prior to intervention when the direction of movement is disregarded.
12. Direction of movement during TTDPM test was identified as a new factor that played major role in testing of proprioception. At extremes of ROM TTDPM moving to external rotation was persistently, over 2 days of assessment was less than moving to internal rotation.

Based on the obtained results of the study following can be concluded regarding established hypothesis for this study.

H1- There will be difference in shoulder joint proprioception between intervention group and a control group immediately after interventions - rejected based on lack of difference in JPS and kinesthesia between intervention groups and the control group immediately after interventions.

H2- There will be difference in shoulder proprioception within intervention group between initial assessment and at a specific time interval after interventions - partially confirmed on the example of "Active Movement Intervention", "Manual Therapy Intervention" groups were there was difference between proprioception at initial assessment and the assessments after interventions.

H3- There will be difference in shoulder proprioception between intervention groups immediately after interventions - rejected, no difference in proprioception between intervention groups was observed immediately post intervention.

H4- There will be difference in shoulder proprioception between intervention groups at specific time intervals after interventions - partially confirmed, differences in proprioception between intervention groups has been observed at 30 minutes and 1 hour, post interventions.

6.1 Study limitations

It should be noted that several study limitation we encountered. First of all, we have recruited 15 healthy individuals per intervention group, making a total of 105 individuals in the study. 15 subjects for each intervention group were good enough, but it was not enough to have most sensitive results. If we could have managed to increase the number of participants for each group, we would have reached to more beneficial and sensitive results to decrease the variance between the groups. Secondly, due to unique study design and statistical distribution of dependent variable it was not possible to perform power analysis of the study.

Measuring participant's concentration level and level of fatigue would have brought another dimension to the study, but was not planned at the initial study design. Finally, in "Warm up Intervention Group" additional measurement of actual increase in temperature or circulation would have been beneficial but due to time limitations imposed by need of immediate proprioception testing post intervention and limited measurement recourses these measurements were beyond the scope of this study.

6.2 Directions for future research

There are several directions for the future studies based on both this study and in the field of proprioception in general.

- It will be beneficial to establish a series of studies where each proposed in our study intervention is implemented repetitively through standardized protocol similar to clinical intervention with the aim at determining when there is possible cortical adaptation and the interventions become effective to improve proprioception. These studies will essentially make a bridge between the laboratory experiments and the clinical trials.
- Testing the exact relationships between joint mechanoreceptor afferents and muscle tone efferents and muscle spindle afferent at spinal, cortical and cerebellar levels would be a great ground breaking contribution to our understanding of sensori-motor system.

- Up to now no studies measuring proprioception accounted for the role of attention, which we think might play role in measured proprioception values.
- Detailed analysis of temperature effects both passively and actively induced on tissues and body as a hole and its effect on proprioception should be investigated.

6.3 Clinical relevance

Clinically much efforts have been spent on increasing proprioceptive sense in order to improve functioning of sensorimotor system by means of exercises. Many authors have claimed that different exercise protocols are effective in increasing proprioception, however the exact mechanism of effect is usually only hypothesized about. This study about the acute effects of general and local musculoskeletal interventions typically used in physical therapy will help to bring the deeper understanding the effect mechanisms behind the observed clinical results. For the first time each different component of exercise has been scrutinized and analyzed on the possible effects on proprioception through stimulation of joint and muscle mechanoreceptors. This study can serve as a long overdue fundamental stepping stone on development the most effective exercise intervention to improve proprioception.

Clinicians should be aware of possible fatigue brought by even a single intervention of rhythmic active movement and the subsequent negative effects on proprioception. While some improvements in proprioception can be expected with joint mechanoreceptors simulation, single intervention is usually not sufficient to significantly improve proprioception. Therefore, learning and cortical adaptation through repetitive training is likely to be essential to substantially improve proprioception.

For laboratory studies in the field of proprioception a new parameter of direction of movement during kinesthesia testing in form of threshold to passive movement detection was identified. Furthermore this study was possibly the largest study assessing proprioception of healthy subjects. The obtained results could serve as a reference values for others. Finally, we hope that authors of future studies on proprioception will pay greater attention on proper use of statistical tests and extensive analysis of raw data prior to implementing further tests.

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T.C.
HACETTEPE ÜNİVERSİTESİ
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ARAŞTIRMA PROJESİ DEĞERLENDİRME RAPORU

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GÖREVLİ
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GÖREVLİ
14. Prof. Dr Leyla Dinç (Üye)

GÖREVLİ
15. Yrd. Doç. Dr. H. Hüsrev Turnagöl (Üye)

16. Av. Meltem Onurlu (Üye)