Sports is the leading cause of injury in adolescents, and the Center for Disease Control and Prevention, United States estimates that one half of all sports injuries in children are preventable with proper education and use of protective equipment. Children and adolescents may be particularly at risk for sports-related overuse injuries as a result of improper technique, poorly fitting protective equipment, training errors, and muscle weakness and imbalance (Kyle & Wayhs, 2006). Musculoskeletal injuries in adolescents and young have been a cause of concern for various medical professionals since injuries and problems sustained at this age are often carried onto the adulthood resulting in decreased sports performance. At the high school level, a large percentage of students participate in active sports and are thus exposed to musculoskeletal injuries (Timothy, 1991). Injuries because of throwing or similar overhead arm movements are gaining greater relevance and importance as children are increasingly participating in many sports involving throwing action such as cricket, baseball, handball and javelin (Fahlstrom et al., 2006; Hoeven & Kibler, 2006).

Repeated throwing is one of the single most stressful activities in all sports in terms of the stress placed on the shoulder joint which results in a high incidence of shoulder injuries. Most of these shoulder injuries occur due to repetitive trauma to the shoulder and elbow. In order to minimize internal forces at the shoulder, the athlete’s body should function as a kinetic chain. The kinetic chain mechanism involves neuromuscular co-ordination in such a manner as to transfer energy up the body from the legs to the hips, trunk, upper arm, forearm, hand and finally the ball. More the body segments contribute to the sequential movement, the greater is the potential velocity of
the distal end where the object is released. The shoulder plays a crucial role in this chain
and the muscular forces developed in the shoulder are major determinants of overall
throwing performance. Therefore, it is important to understand the relevant anatomy and
biomechanics of the shoulder in throwing.

1.1 ANATOMY OF THE SHOULDER

Movements of the human shoulder represent a complex dynamic relationship of
many muscle forces, ligament constraints, and bony articulations. Static and dynamic
stabilizers allow the shoulder the greatest range of motion of any joint in the body and
position the hand and elbow in space. This extensive range of motion allows the
sportsperson to engage in a myriad of sports activities, but at the same time exposes the
shoulder to the risk of injuries.

The bony architecture of the gleno-humeral (GH) joint, with its large articulating
humeral head and relatively small glenoid surface, relies heavily on ligamentous and
muscular stabilizers throughout its motion arc (as opposed to the hip with its congruent
"ball & socket" anatomy). The gleno-humeral joint is inherently unstable and exhibits the
greatest amount of motion found in any joint in the human body (Williams & Warwick,
1986). Additionally, the gleno-humeral joint is the most commonly dislocated major joint
in the human body (Kazar & Relouszky, 1969; Cave et al., 1974). Thus, the shoulder
joint sacrifices stability for mobility.

Joint Articulations

The Gleno-humeral Joint

The gleno-humeral joint is suited for extreme mobility with its mismatched large
humeral head and small glenoid articular surface. At any given time, only 25% to 30% of
the humeral head is in contact with the glenoid fossa. However, despite this lack of
articulating surface coverage, the normal shoulder precisely constrains the humeral head
to within 1 to 2 mm of the center of the glenoid cavity throughout most of the arc of motion (Poppen & Walker, 1976; Howell et al., 1988; Howell & Galinat, 1989). This precise constraint of the center of rotation through a large arc of motion is the result of an interplay of static (no active energy required, i.e., capsule, labrum, ligaments) and dynamic (muscle) forces. The stabilizing effect of the articular surfaces and capsulolabral ligamentous complex is magnified by muscle forces, which produces a concavity compression effect directed towards the glenoid center (Lippitt et al., 1993).

The bony radius of the curvature of the glenoid is slightly flattened with respect to the humeral head. However, the glenoid articular cartilage is thicker at the periphery, thus creating significant articular surface conformity and resultant stability (Soslowsky et al., 1992). This resultant articular conformity additionally provides the foundation for the concavity compression effect provided by the rotator cuff and surrounding musculature.

Figure 1.1: Bony articulating surfaces of the Gleno-humeral joint

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The glenoid labrum is a dense, fibrous structure, which is triangular in cross-section (Cooper et al., 1992). Located at the glenoid margin, the labrum serves to extend the conforming articular surfaces, thereby increasing contact surface area and adding to stability. The labrum also enhances stability by deepening the concavity of the glenoid socket, an average of 9 mm and 5 mm in the supero-inferior and antero-posterior planes, respectively (Howell & Galinet, 1996) and loss of the integrity of the labrum (through injury) decreases resistance to translation by 20% (Lippitt et al., 1993). The labrum also acts as an anchor point for the capsulo-ligamentous structures (Moseley & Overgaard, 1962). Bankart (1923) mentioned the detachment of the labrum from the anterior-inferior glenoid rim the "essential lesion" responsible for the high incidence of recurrent anterior dislocations.

The surface area of the capsule is approximately twice that of the humeral head, allowing for extensive range of motion. The capsule is truncated in shape, and the inferior portion, or axillary pouch, is redundant. The capsule tightens or "winds up" in various extremes of position, for example, the inferior pouch tightens in extreme abduction and external rotation, serving to stabilize the joint (O’Brien et al., 1990). The capsulo-ligamentous structures reciprocally tighten and loosen during rotation of the arm to limit translation. In the midrange of motion, these structures are relatively lax, and stability is mainly provided by the actions of the rotator cuff and biceps through the concavity-compression effect (Lippitt et al., 1993).

The Ligaments

The coracohumeral ligament is a thick band of capsular tissue originating from the base of the lateral coracoids and inserting into the lesser and greater tuberosities. This
ligament is taut with the arm in the adducted position and constrains the humeral head on
the glenoid (Warner et al., 1992). The superior gleno-humeral ligament extends from the
antero-superior edge of the glenoid to the top of the lesser tuberosity (Figure 1.2). It
parallels the course of the coraco-humeral ligament, and these two structures are
considered similar in function. Together, they constitute the rotator interval region
between the anterior border of the supraspinatus and the superior border of the
subscapularis (Basmajian & Bazant, 1959; Boardman et al., 1996).

![Figure 1.2: The Ligaments of the Shoulder Joint](users.rowan.edu)

The middle gleno-humeral ligament is the most variable of the three gleno-
humeral ligaments, being absent in 8% to 30% of patients. It originates from the
supraglenoid tubercle, superior labrum, or scapular neck and inserts on the medial aspect
of the lesser tuberosity. Its function is to limit anterior translation of the humeral head in
the lower ranges of abduction (60° to 90°) and inferior translation in the adducted
position at the side (Turkel et al., 1981). The inferior gleno-humeral ligament is the thickest and most consistent of the three gleno-humeral ligaments. It is often described as a complex containing an anterior band, axillary pouch, and posterior band. The anterior band extends from the antero-inferior labrum and glenoid lip to the lesser tuberosity of the humerus and is the thickest portion and the primary stabilizer against anterior translation of the humeral head in the throwing position of abduction and external rotation (Turkel et al., 1981; O'Brien et al., 1990).

**Dynamic Stabilizers**

The rotator cuff is a group of muscles consisting of the subscapularis, supraspinatus, infraspinatus, and teres minor, which act as a dynamic steering mechanism for the humeral head (Figure 1.3). Three dimensional movements or rotations of the humeral head are the result of the dynamic interplay between the muscles comprising the rotator cuff and the static stabilizers. Rotator cuff activation results in humeral head rotation and depression in positions of abduction. As a group, the rotator cuff muscles are smaller in cross-sectional area and size when compared with the larger, more superficial muscles such as the deltoid, pectoralis major, latissimus dorsi, and trapezius.

The supraspinatus originates from the supraspinous fossa to insert forward and laterally at the superior aspect of the greater tuberosity. The tendon blends into the joint capsule and infraspinatus tendon below. The supraspinatus stabilizes the gleno-humeral joint and serves, along with the deltoid, to elevate the arm. The infraspinatus originates from the infraspinous fossa and extends laterally to its tendinous insertion on the middle facet of the greater tuberosity. The infraspinatus, along with the teres minor, provides the primary external rotation force and also stabilizes the gleno-humeral joint against
posterior subluxation. The teres minor originates from the mid to upper regions of the axillary border of the scapula and extends laterally and superiorly to its insertion on the most inferior facet of the greater tuberosity. In concert with the infraspinatus, the teres minor is an external rotator (ER) and gleno-humeral stabilizer.

The subscapularis muscle comprises the anterior portion of the rotator cuff. It originates from the subscapular fossa to extend laterally to its insertion on the lesser tuberosity of the humerus. The tendon of the subscapularis is intimately associated with the anterior capsule. The axillary nerve passes along the inferior border of the scapula and is, therefore, subject to trauma from anterior dislocation. The subscapularis functions as an internal rotator (IR), especially in maximum internal rotation.

Figure 1.3: The Rotator Cuff muscles

www.thewinger.com
The long head of the biceps functions intimately with the rotator cuff as a humeral head depressor (Figure 1.4). Rodosky et al. (1994) noted that contraction of the long head of the biceps during the late cocking phase of throwing can significantly reduce anterior translation and increase torsional rigidity of the joint resisting external rotation.

Figure 1.4: The Biceps Brachii Muscle

The Acromio-clavicular joint

The Acromio-clavicular joint is a diarthrodial joint between the lateral border of the clavicle and the medial edge of the acromion (Figure 1.5). The average joint size in the adult is 9 X 19 mm, and the joint is covered by a capsule. Because of the high axial loads transferred through this small surface area, contact stresses on the articular surface are high and may result in early failure, such as osteolysis in weight lifters or osteoarthritis. Stability of the acromio-clavicular joint is provided mainly through the static stabilizers composed of the capsule, intra-articular disc, and ligaments. (McCluskey & Todd, 1995).
The Sterno-clavicular Joint

The Sterno-clavicular (SC) joint represents the only true articulation between the upper extremity and the axial skeleton (Figure 1.6). It is a sellar (saddle) joint formed by the articulation of the medial end of the clavicle and the upper portion of the sternum. Given the great disparity in size between the large bulbous end of the clavicle and the smaller articular surface of the sternum, stability is provided by the surrounding ligamentous structures.
The Scapulo-thoracic Joint

Not a true joint, the scapulo-thoracic articulation represents a space between the convex surface of the posterior thoracic cage and the concave surface of the anterior scapula (Figure 1.6). It is occupied by neurovascular, muscular, and bursal structures that allow a relatively smooth motion of the scapula on the underlying thorax. With the scapula serving as the bony foundation of the shoulder girdle, the scapulo-thoracic articulation allows increased shoulder movement beyond the 120° offered solely by the gleno-humeral joint. On average, there are approximately 20° of gleno-humeral elevation for every 10° of scapulo-thoracic elevation, although the actual ratio can vary for any portion of the arc of motion. Seventeen muscles attach to or originate from the scapula and function to stabilize the scapula and provide motion (Sidles et al., 1991). Among these, the most important are the Serratus anterior, which maintains the medial angle against the chest wall, and the trapezius, which helps to rotate and elevate the scapula synchronously with gleno-humeral motion. Rehabilitation of the overhead or throwing athlete must include the scapular-stabilizing musculature for optimal results.

1.2 SHOULDER MECHANICS IN THROWING

The general throwing motion is similar among various sports including baseball, softball, football, team handball, javelin and water polo. Even the overhead throw in tennis, cricket, badminton smash or spike in volleyball have similar mechanics. Throwing motion can be divided into six phases - Windup, Stride, Arm cocking, Arm acceleration, Arm deceleration and Follow through (Figure 1.7).
Windup

The objective of the wind up phase is to put the thrower in a good starting position. The wind up begins when the athlete initiates the first motion and ends with maximum knee lift of the stride leg. It is the time from when the stance foot pivots to when the knee has achieved the maximum height and the thrower is in a balanced position. The lead leg is lifted by concentric contractions of the hip flexors and the lead side faces the target. The stance leg bends slightly, controlled by eccentric contractions from the quadriceps muscle and remains in a fairly fixed position. The shoulders are partially flexed and abducted and are held in this position by anterior and middle deltoid, the supraspinatus, and the clavicular portion of the pectoralis major. (Jobe et al., 1983 & 1984) In addition, elbow flexion is maintained by isometric contractions of the elbow flexors (Jacobs, 1987; Sisto et al., 1987).

Stride Phase

The stride phase begins at the end of the wind up, when the lead leg begins to fall and move towards the target and the two arms separate from each other. Eccentric
contractions of the hip flexors controls the lowering of the lead leg, while concentric contractions from the stance leg hip abductors helps lengthen the stride. As the lead leg falls forward and downwards, the lead leg begins to rotate externally and the stance leg begins to rotate internally (Fleisig et al., 1995). The stance hip begins to extend due to concentric contractions from the hip extensors. During the stride, both shoulders abduct, externally rotate, and horizontally abduct owing to concentric muscle action. At lead foot contact, shoulder abduction is approximately 80° to 100°. The deltoid and supraspinatus are responsible for abducting and holding the arm in this position. The upper trapezius and serratus anterior upwardly rotate and position the glenoid for the humeral head. This action is extremely important, since an improperly positioned scapula can lead to impingement and shoulder control problems.

During the stride phase, the throwing arm is positioned slightly behind the trunk (i.e. horizontally abducted) during throwing. The posterior deltoid, latissimus dorsi, teres major, and posterior rotator cuff muscles (infraspinatus and teres minor) are responsible for horizontally abducting the shoulder while the rhomboids and middle trapezius retract the scapula (DiGiovine et al., 1992).

Elbow flexion of the throwing arm at foot contact is approximately 80° to 100° while the forearm is rotated up, approaching a vertical position. Elbow flexor muscles of the throwing arm contact eccentrically and isometrically in controlling elbow flexion, while the supinator and biceps muscles supinate the forearm as the shoulder abducts and externally rotates. Electromyography has shown that the wrist and finger extensors have very high activity during this phase, causing the wrist to move from a position of slight flexion to a position of hyperextension (DiGiovine et al., 1992). These muscles contract
concentrically as they work against gravity, with the throwing palm and ball facing downward and the shoulder abducting. Consequently, they must overcome the mass of both the hand and the ball.

**Arm Cocking**

Arm cocking begins at lead foot contact and ends at maximum shoulder external rotation. In the arm cocking phase, the upper body is rotated to face the target. The quadriceps of the lead leg initially contracts eccentrically to decelerate knee flexion and then contracts isometrically to stabilize the lead leg during the arm cocking phase. At this time, the thrower’s body should be stretched out in the direction of the target and the ankle of the stance leg plantar flexes as it leaves contact with the rubber. This motion usually occurs concurrent with pelvic rotation, just after lead foot contact. As the trunk rotates to face the target, the throwing shoulder horizontally adducts moving from a position of 20° to 30° of horizontal abduction at lead foot contact to a position of 15° to 20° degree of horizontal adduction at the time of maximum shoulder external rotation (Dillman et al., 1993). The pectoralis major and the anterior deltoid are the primary shoulder horizontal adductors. These muscles initially contract eccentrically as the trunk rotates to face the target, thus limiting shoulder horizontal abduction.

The shoulder girdle muscles (levator scapulae, serratus anterior, trapezius, rhomboids, and pectoralis minor) are also important during the arm cocking phase. The serratus anterior is the most active, as it provides both stabilization and protraction to the scapula. The middle trapezius and rhomboids, which oppose the scapular motion created by the serratus anterior, have also been shown to be quite active. The levator scapula also displays high muscle activity. These muscles work together, helping to stabilize the
scapula and provide position of the glenoid for subsequent action of the humeral head. Dysfunction of these scapular muscles may cause additional stress to the anterior shoulder stabilizers. During late arm cocking, the serratus anterior is important in providing upward rotation and protraction of scapula, allowing the scapula to move with the horizontally adducting humerus.

**Arm Acceleration**

Arm acceleration begins at maximum shoulder external rotation and ends at ball release (Figure 1.7). The acceleration phase has been shown to have fairly very low muscle activity, even though the arm accelerates forward both linearly and angularly (Jobe et al., 1983 & 1984). Just prior to maximum shoulder external rotation, elbow extension begins. This movement is followed immediately by the onset of shoulder external rotation. The initiation of elbow extension before elbow internal rotation allows the thrower to reduce the rotational inertia about the arm’s longitudinal axis, therefore allowing greater internal rotation velocity to be generated. The shoulder internal rotators contract concentrically to help produce an extremely high maximal internal rotation velocity of approximately 7000° to 8000° per second in throwing. Maximal shoulder internal rotation angular velocity occurs at approximately ball release.

The rotator cuff muscles, trapezius, serratus anterior, rhomboids, and levator scapula, all demonstrate high level of activity during the acceleration phase. (DiGiovine et al., 1992). This implies that humeral head control and scapula stabilization are crucial during this phase. However, DiGiovine et al. (1992) demonstrated that rotator cuff activity is significantly different between professional and amateur pitchers. Muscle activity of the infraspinatus, teres minor, supraspinatus, and biceps was two to three times
higher in amateur pitchers. In contrast, the muscle activity of the subscapularis, serratus anterior, and latissimus dorsi was much greater in professional pitchers.

The final segment to impart force to the ball is the hand, which moves from the hyper extended wrist position at maximum shoulder external rotation to a neutral wrist position at ball release. The wrist flexors have been shown to be active during this phase of throwing. Their activity may initially be eccentric in order to slow down the hyperextending wrist at the beginning of the acceleration phase. However, as they continue to fire, they concentrically contract and flex the wrist as ball release is approached.

**Arm Deceleration**

This phase, which lasts between 0.03 and 0.05 seconds goes from ball release to maximum shoulder internal rotation (Figure 1.7). The trunk and hips continue to flex, and the lead knee and throwing elbow continue to extend until almost full extension is reached. Large eccentric loads are needed at both the elbow and the shoulder joints to decelerate the arm. Also the pronator teres is quite active as the forearm pronates during the deceleration phase (Zachazewski et al., 1996). The biceps and separator muscles are also eccentrically loaded to decelerate the rapidly pronating forearm. Also, the brachialis is also active during this phase. The similar firing patterns of the biceps and brachialis suggest that the primary functions of the biceps during this phase is to decelerate the elbow extension.

The posterior muscles of the shoulder have been identified as having a paramount role in resisting shoulder distraction and anterior subluxation forces. (Jobe et al., 1983 & 1984; Jacobs, 1987) Specifically, these muscles include the infraspinatus, supraspinatus,
teres major, minor, latissimus dorsi and posterior deltoid (Jacobs, 1987). Contraction of the teres major, latissimus dorsi, and posterior deltoid also helps decelerate the shoulder abduction which occurs during this phase.

**Follow Through**

The follow-through phase begins at the time of maximum shoulder internal rotation and ends when the arm completes its movement across the body and a balanced position is obtained. In the follow-through phase, energy in the throwing arm continues to be dissipated back through the kinetic chain. A long arm of deceleration from the throwing arm, as well as sufficient forward tilting of the trunk, allows energy to be absorbed by the large musculature of the trunk and legs. As in the deceleration phase, the posterior shoulder muscles continue to be eccentrically active throughout the follow-through, continuing to decelerate the horizontally adducting shoulder. Shoulder and elbow joint forces and torques generated during the follow-through are generally lower than joint forces and torques generated during deceleration phase.

The kinetic analysis of throwing mechanics has been studied by various authors who have reported that in the wind up phase of throwing, humeral external rotators, posterior deltoid, infraspinatus, teres minor, shoulder abductors, middle deltoid, supraspinatus, shoulder flexors, anterior deltoid, coracobrachialis, and pectoralis major are the most active muscles. Biomechanical analysis have demonstrated high muscle activity of rotator cuff during arm cocking both to stabilize the humeral head within the glenoid fossa and to control the large external rotation of the shoulder that occurs. The acceleration phase is initiated by muscle contraction of the shoulder internal rotators, Pectoralis major and minor, subscapularis, teres major, latissimus dorsi and anterior
deltoid. Jobe et al. (1983 &1984) reported that after the initial burst of muscular activity serving to internally rotate the shoulder, the rest of the acceleration phase of the pitching cycle is without muscle activity. During the arm deceleration the rotator cuff once again shows high amounts of eccentric work to control the high speed of the internal rotation in this phase. Thus external and the internal rotators of the shoulder play a vital role in the throwing mechanism and any alteration in their activity is likely to have a major effect on the throwing performance (Jobe et al., 1984; Bradley & Tibone, 1991). In addition to this, these muscles play a critical role in providing stability and mobility to the gleno-humeral joint, particularly in overhead athletes (Ramsl et al., 2004)

This phenomenon has been partially explained by Toyoshima et al.(1974) who stated that 50% of throwing speed is the result of sequential body rotations, while the remainder is the result of muscular activity in the arm. Interestingly, Jobe et al. (1983 & 1984) reported that the follow-through phase is the most active phase of the pitching act. The subscapularis is internally rotating the shoulder while the remaining rotator cuff and deltoid muscles are probably firing eccentrically in an attempt to decelerate the arm in space. Because the role of the external rotator muscles is not only to decelerate the arm but also to maintain dynamic stabilization of the gleno-humeral joint. An objective evaluation of their functional strength compared with that of the internal rotator muscles is important for injury prevention and rehabilitation (Jobe 1983 & 1984; Glousman, 1993).

1.3 MEASUREMENT OF SHOULDER MUSCLE FUNCTION

Muscle function in sportspersons can be measured by a variety of methods such as iso-inertial, isokinetic and isometric testing modalities. Also the type of muscle activity (concentric, eccentric, or isometric) and velocity may vary in testing.
Isometric evaluation of muscle behavior, measures a muscle’s maximum capacity to produce static force. Isometric force evaluation has been used in exercise science for many years. It typically involves a maximal voluntary contraction performed at a specified joint angle against an unyielding resistance which is in series with a strain gauge, cable tensiometer, force platform or a similar device whose transducer measures the applied force. These tests have shown high reliability in both single and multi-joint test protocols (Bohannon & Andrews, 1987; Wilson & Murphy, 1996). Isometric tests are easy to perform as they require only a single maximal contraction and relatively simple equipment.

In the dynamic strength assessments, one of the very commonly used methods is 1-RM strength which is the greatest amount of weight that an individual can lift only one time for a specific exercise (Fleck & Kramer, 1997). For exercise prescription, assessment, and goal setting it is helpful to know the 1-RM. However, 1-RM testing has increased risks of injury (Braith et al., 1993; Mayhew et al., 1993). In addition to the Isometric and isotonic (1RM) methods of strength assessments, Isokinetic methods are available which are quite common ever since its inception (Hislop & Perrine, 1967). In this method the angular velocity of the bony component is preset and kept constant by a mechanical device throughout the joint ROM. This form of exercise has been thought to be a valuable tool for assessment and evaluation of muscular function and pathology.

Extensive work has been done by various authors on measurement of shoulder rotator muscles specifically External and Internal rotator strength in different types of sports persons. Isokinetic strength measurements have been used by various authors to predict and study performance, stability, injury patterns and strength differences between
dominant and non-dominant upper extremity (Aldenrink & Kuck, 1986; Chandler et al., 1992; McMaster et al., 1992; Stickley et al., 2008; Andrade et al., 2010). Lot of differences exist in the testing methodologies of rotator muscles strength with regards to the position of the shoulder, test speeds and modes of contraction in these studies (Plotnikoff & MacIntyre, 2002). Majority of work done on shoulder strength in overhead athletes has been done using isokinetic type of muscle work in the concentric and eccentric mode clearly due to the reason that a isokinetic measurements allows high reproducibility ($r=0.82–0.96$) (Pincivero et al., 1997) and measurements at high speeds with accommodating resistance which was thought of as having more relevance to function. Proper balance between agonist and antagonist muscle groups is thought to provide dynamic stabilization to the shoulder joint. To provide proper muscle balance, the external rotator muscles should be at least 65% the strength of the internal rotator muscles which has been studied isokinetically but has not been specified for the age group in our study.

1.4 ISOTONIC STRENGTH TESTING

Among the main indirect tests applied for evaluation of Iso-inertial or Isotonic muscular strength are the one maximal repetition (1RM) and multiple repetitions (6-10 RM) tests. The 1-RM test despite being one of the most widely used and mentioned by the literature, may be influenced by countless factors, in that it requires great concentration and previous knowledge of the performance technique from the evaluated subject, besides other important characteristics (Ware et al., 1995). The use of 1 repetition maximum (RM) testing in resistance training has been applied to quantify strength in order to prescribe training programs by health and fitness professionals,
athletic trainers, rehabilitation specialists, and strength coaches. The use of 1RM testing has become a reliable method of strength assessment in trained and untrained subjects (Landers, 1985; Mayhew et al., 1993; Arnold et al., 1995; Ware et al., 1995; Chapman et al., 1998). However, for some populations, age and pre-existing medical conditions may be contraindications to the safe completion of 1RM testing. Moreover, the performance of exertions with maximal workloads may lead to high muscular, bone and ligament stress, triggering important metabolic alterations (Brzycki, 1993).

Conversely, multiple repetition tests are able to be much more applicable to different populations in several situations. It is worth mentioning that the recommendation for prescription of training programs with weights published by the Kraemer et al. (2002) for healthy adults emphasizes the utilization of multiple repetitions, especially for strength, strength endurance, hypertrophy and muscular power development. Thus, the use of multiple repetition tests may relatively reproduce to the demands of the very regular training sessions, contrary to what is observed during the application of 1-RM tests. The validity of the estimation equations for the 1RM values through sub-maximal tests, instead of the application of the 1RM traditional test has attracted the interest of researchers. Among them, Bryzcki’s 1 RM prediction equation has been found to be a reliable and valid tool for estimating 1 RM by performing multiple repetitions (Nascimento, 2007).

Although many researches studying the shoulder strength ratios have been done on isokinetics, many others have measured the strength isometrically also. Donatelli et al.(2000) used isometric strength measurements for the shoulder rotators and reported muscle imbalance between the internal and external rotators. The pitching arm’s internal
rotators, when tested in abduction, were significantly stronger than non-pitching arm. The non-pitching arm’s external rotators in the plane of scapula and in abduction were significantly greater than those of the pitching arm. Stone et al. (2004) also reported a strong relationship between isometric strength and explosive strength and performance. Stone et al. (2003) suggested that maximum strength or Isometric Peak Force (IPF) is strongly associated with Dynamic peak Force (PF). In addition, maximum strength is strongly associated with peak power (PP) even at relatively light loads such as those associated with sport-specific dynamic explosiveness. In spite of various researches relating Isometric and dynamic performance, it has been questioned whether static strength measures provide strength data that are specific to activities of interest. There are conflicting results in the literature as to whether isometric testing is predictive of dynamic performance (Wilson & Murphy, 1996). However, isometric strength testing has been shown to provide information predictive of occupational injuries associated with dynamic lifting tasks by Chaffin et al. (1978) and Komi & Karlson (1978). Further, conflicting results regarding static versus dynamic relationships may be a reflection of the joint angle used during isometric testing (Osternig, 1986).

Folland et al. (2005) reported strength training with isometric contractions produces large but highly angle-specific adaptations. To contrast the contractile mode of isometric versus dynamic training, but diminish the strong angle specificity effect, they compared the strength gains produced by isometric training at four joint angles with conventional dynamic training. It was found that the strength gains tested isokinetically in both groups were similar. Isometric strength was more in the group that underwent isometrics.
Although Isokinetics is a preferred mode of muscle function in sportspersons, it is interesting to note that the maximal velocity allowed by isokinetic apparatus reaches only 40% of the maximal velocity that can be developed by leg extensor muscles during ballistic motion (Bosco et al, 1982) and only 10% of the maximal velocity obtained by shoulder during throwing motion (Pappas et al., 1985). In addition to this, Isokinetic testing does not always predict the performance differences between athletes possessing different skill levels (Fry et al., 1991; Hurley et al., 1988). Isokinetic strength was found to be related to Isometric measurements in a study by Lord et al., (1992). Furthermore, isometric measurements using hand dynamometers and strain gauge have a high test-retest reliability in comparison to manual muscle testing and are reported to be comparable to isokinetic testing in some studies (Kuhlman et al., 1992; Magnusson et al., 1990; Malerba et al., 1993). This indicates that isometric testing in sports has the potential to predict performance, analyze effects of injury and guide the rehabilitation process.

1.5 NEED OF THE STUDY

It is evident that a lot of research work has been done related to muscle strength and imbalances between Isokinetic External Rotators (ER) and Internal Rotators (IR) of the shoulder in adult throwers, shoulder injuries in throwing and their rehabilitation, there is a paucity of research linking throwing performance and Isometric and Isotonic Shoulder rotator muscles strength. Also, it would be interesting to observe the effects of Isometric strength training near and ranges on throwing performance amidst conflicting reports on importance of Isometric training for improving dynamic performance. Thus, this study has been undertaken to see the relationship between Isometric and Isotonic
strength and strength ratios of the shoulder rotators and throwing performance in the age group of 16-18 years.

1.6 RESEARCH QUESTION

1) Is isometric strength ratio of the external and internal rotators of the shoulder related to throwing performance in the age group of 16-18?

2) Is isotonic strength (1 RM) ratio of the external and internal rotators of the shoulder related to throwing performance in the age group of 16-18?

3) Does Isometric strength training of shoulder rotators near functional positions to improve strength and imbalance of shoulder rotators leads to better throwing performance?

1.7 HYPOTHESIS

Keeping in view the earlier studies done on throwing and strength of shoulder rotators, the following hypothesis are formulated:

- There will be a positive co-relation between isometric strength ratio of the external and internal rotators of the shoulder and throwing performance in the age group of 16-18 years.

- There will be a positive co-relation between isotonic strength ratio of the external and internal rotators of the shoulder and throwing performance in the age group of 16-18 years.

- Isometric strength training of shoulder rotators near functional positions will improve imbalance of shoulder rotators leading to better throwing performance.
1.8  NULL HYPOTHESIS

- There will be no co-relation between isometric strength ratios of the external and internal rotators of the shoulder and throwing performance in children.
- There will be no co-relation between isotonic strength ratios of the external and internal rotators of the shoulder and throwing performance in children.
- Isometric muscle training of shoulder rotators near functional positions will not lead to improved ratios and thus better throwing performance in children.

1.9  OBJECTIVES OF THE STUDY

1. To find out the Isometric strength and strength ratio of Shoulder in children.
2. To find out the Isotonic strength and strength ratio of Shoulder rotators in children.
3. To find out the correlation between Isometric strength ratio of shoulder rotators and throwing performance.
4. To find out the correlation between Isotonic strength ratio of shoulder rotators and throwing performance.
5. To find out the effect of Isometric strengthening of shoulder rotators on throwing performance.

1.10  SIGNIFICANCE OF THE STUDY

High school is crucial stage of one’s sporting career. The results of our study will provide crucial data about muscle imbalance between external and internal rotators of the throwing shoulder and whether it is a performance limiting factor in the age group of 16-18 years.
In the Indian scenario, high tech gadgetry for measurement of dynamic muscular performance like Isokinetics is still hard to find at novice and amateur level. Isometric measurements are relatively economical and are very reliable but their applicability to sports is a debatable topic. Results of this study could be extremely helpful to various professionals who are involved in training for overhead games since isometric measurements and training can be performed easily without using high tech gadgetry and infrastructure, yet scientifically.

1.11 OPERATIONAL DEFINITIONS

1. SHOULDER ROTATORS: The shoulder joint has rotations in the form of External Rotators (ER) and Internal rotation (IR). The External rotation is performed primarily by the Inraspinatus and teres minor and posterior fibres of deltoid. The Internal Rotation is performed by the Subscapularis, Pectoralis major, Latissimus Dorsi and Teres major muscles.

2. THROWING PERFORMANCE: Throwing is essentially kinetic chain movement which involves neuromuscular coordination i.e. sequential movements of body segments in such a manner as to transfer energy up the body from the legs to the hips, trunk, upper arm, forearm, hand and finally the ball. It involves phases of windup, stride, arm cocking, arm acceleration, arm deceleration and follow through. Biomechanical analysis have demonstrated high muscle activity of rotator cuff during arm cocking both to stabilize the humeral head within the glenoid fossa and to control the large Internal rotation of the shoulder that occurs. The performance in throwing can be measured by throwing speed and/or distance of throwing an object of fixed weight.
3. **ISOMETRIC STRENGTH**: Isometric evaluation of muscle behavior, measures the muscle’s maximum capacity to produce static force. It typically involves a maximal voluntary contraction performed at a specified joint angle against an unyielding resistance which is in series with a strain gauge, cable tensiometer, force platform or a similar device whose transducer measures the applied force.

4. **ISOTONIC STRENGTH**: Also referred to as Isoinertial type of muscle work, Isotonic strength is a dynamic strength assessment of a specific muscle or a muscle group and involves lifting weights for a specified number of repetitions. The objective evaluation is based on the number or repetitions and the amount of weight lifted.

5. **1 RM (1 REPETITION MAXIMUM)**: It is the maximum amount of weight that can be lifted using a muscle or muscle group through the complete Range of Motion for only 1 repetition.

6. **STRAIN GAUGE**: A device used to measure muscular performance. Load applied in the form of tension, compression or shear causes a change in the geometric configuration of the material. Deformation of the material is caused by a load and is called strain. This deformation is reflected as a reading on the meter, which is actually representative of the load.

7. **ISOKINETICS**: It is a type of muscle work in which the velocity of muscle shortening and lengthening is predetermined and is held constant by a rate limiting device known as Isokinetic dynamometer. In this type of muscle work or exercise the velocity of limb movement is manipulated and not the load as in Isotonic exercise. It has also been referred to as Accommodating Resistance exercise.