Chapter 2
REVIEW OF LITERATURE

2.1 ROLE OF SHOULDER MUSCLES IN THROWING

Understanding when and how much specific shoulder muscles are active during throwing is extremely important for professionals involved in sports such as trainers, coaches, physiotherapists and physicians in order to provide appropriate training, treatment and rehabilitation to sportspersons. Lawrence & DeLuca (1983) reported that when interpreting EMG data for muscle activity in sports, it should be emphasized that while the EMG amplitude does correlate reasonably well with muscle force for isometric contractions, it does not correlate well with muscle force as muscle contraction velocities increase, or during muscular fatigue (both of which occur in sport). However, EMG analyses are helpful in determining the timing and quantity of muscle activation throughout a given movement.

Shoulder muscle activity during throwing has been examined extensively by various authors, (Jobe et al., 1983 & 1984; Gowan et al., 1987; Glousman et al., 1988; Escamilla & Andrews, 2009). According to Fleisig et al., (1995, 1996a & 1996b) and Escamilla et al.(1998 & 2007), in order to interpret the applicability and meaningfulness of shoulder EMG data, EMG data should be integrated with shoulder joint kinematics (linear and angular shoulder displacements, velocities and accelerations) and kinetics (shoulder forces and torques) in sporting activities when these data are available. Using 56 healthy males (college and professional pitchers), DiGiovine et al. (1992) quantified shoulder muscle activity during baseball pitching (Table I). To help generalize phase comparisons in muscle activity, 0–20% of a maximum voluntary isometric contraction
(MVIC) was considered low muscle activity, 21–40%, MVIC was considered moderate muscle activity, 41–60% MVIC is considered high muscle activity and >60% MVIC was considered very high muscle activity. From these initial reports, the baseball pitch was divided into several phases, which later were slightly modified by Fleisig et al. (1995) and Escamilla et al. (2007) and as the wind-up, stride, arm cocking, arm acceleration, arm deceleration and follow-through phases (Figure 1).

Table 2.1: Shoulder activity by muscle and phase in throwing (DiGiovine et al., 1992)

<table>
<thead>
<tr>
<th>Muscles</th>
<th>No of subjects</th>
<th>Phase</th>
<th>wind-up&lt;sup&gt;a&lt;/sup&gt; (% MVIC)</th>
<th>stride&lt;sup&gt;b&lt;/sup&gt; (% MVIC)</th>
<th>arm cocking&lt;sup&gt;c&lt;/sup&gt; (% MVIC)</th>
<th>arm acceleration&lt;sup&gt;d&lt;/sup&gt; (% MVIC)</th>
<th>arm deceleration&lt;sup&gt;e&lt;/sup&gt; (% MVIC)</th>
<th>follow-through&lt;sup&gt;f&lt;/sup&gt; (% MVIC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scapular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Upper trapezius</td>
<td>11</td>
<td>wind-up</td>
<td>18 ± 16</td>
<td>64 ± 53</td>
<td>37 ± 29</td>
<td>69 ± 31</td>
<td>53 ± 22</td>
<td>14 ± 12</td>
</tr>
<tr>
<td>Middle trapezius</td>
<td>11</td>
<td>stride</td>
<td>7 ± 5</td>
<td>43 ± 22</td>
<td>51 ± 24</td>
<td>71 ± 32</td>
<td>15 ± 17</td>
<td>15 ± 14</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>13</td>
<td>arm cocking</td>
<td>13 ± 12</td>
<td>39 ± 30</td>
<td>38 ± 29</td>
<td>76 ± 55</td>
<td>17 ± 33</td>
<td>25 ± 15</td>
</tr>
<tr>
<td>Serratus anterior (6th rb)</td>
<td>11</td>
<td>arm acceleration</td>
<td>14 ± 13</td>
<td>44 ± 35</td>
<td>69 ± 32</td>
<td>60 ± 53</td>
<td>51 ± 30</td>
<td>32 ± 18</td>
</tr>
<tr>
<td>Serratus anterior (4th rb)</td>
<td>10</td>
<td>arm deceleration</td>
<td>20 ± 20</td>
<td>40 ± 22</td>
<td>106 ± 56</td>
<td>51 ± 32</td>
<td>41 ± 24</td>
<td>41 ± 24</td>
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<td>Rhomboids</td>
<td>11</td>
<td>follow-through</td>
<td>11 ± 7</td>
<td>35 ± 24</td>
<td>41 ± 26</td>
<td>71 ± 35</td>
<td>45 ± 28</td>
<td>14 ± 20</td>
</tr>
<tr>
<td>Levator scapulae</td>
<td>11</td>
<td></td>
<td>6 ± 5</td>
<td>35 ± 14</td>
<td>72 ± 54</td>
<td>76 ± 28</td>
<td>33 ± 16</td>
<td>14 ± 13</td>
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<tr>
<td>Glenohumeral</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Anterior deltoid</td>
<td>16</td>
<td>wind-up</td>
<td>15 ± 12</td>
<td>40 ± 20</td>
<td>28 ± 30</td>
<td>27 ± 19</td>
<td>47 ± 34</td>
<td>21 ± 16</td>
</tr>
<tr>
<td>Middle deltoid</td>
<td>14</td>
<td>stride</td>
<td>9 ± 8</td>
<td>44 ± 19</td>
<td>12 ± 17</td>
<td>36 ± 22</td>
<td>59 ± 19</td>
<td>16 ± 13</td>
</tr>
<tr>
<td>Posterior deltoid</td>
<td>18</td>
<td>arm cocking</td>
<td>6 ± 5</td>
<td>42 ± 26</td>
<td>28 ± 27</td>
<td>69 ± 66</td>
<td>60 ± 28</td>
<td>13 ± 11</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>16</td>
<td>arm acceleration</td>
<td>13 ± 12</td>
<td>60 ± 31</td>
<td>49 ± 29</td>
<td>51 ± 46</td>
<td>19 ± 43</td>
<td>10 ± 9</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>16</td>
<td>arm deceleration</td>
<td>11 ± 9</td>
<td>30 ± 18</td>
<td>74 ± 34</td>
<td>31 ± 28</td>
<td>17 ± 20</td>
<td>20 ± 16</td>
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<td>Teres minor</td>
<td>12</td>
<td>follow-through</td>
<td>5 ± 5</td>
<td>23 ± 15</td>
<td>71 ± 24</td>
<td>54 ± 50</td>
<td>44 ± 52</td>
<td>25 ± 21</td>
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<td>Subscapularis (lower 3rd)</td>
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<td></td>
<td>7 ± 9</td>
<td>26 ± 22</td>
<td>62 ± 19</td>
<td>56 ± 31</td>
<td>41 ± 23</td>
<td>25 ± 18</td>
</tr>
<tr>
<td>Subscapularis (upper 3rd)</td>
<td>11</td>
<td></td>
<td>7 ± 8</td>
<td>37 ± 26</td>
<td>99 ± 55</td>
<td>115 ± 82</td>
<td>60 ± 36</td>
<td>16 ± 15</td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>14</td>
<td></td>
<td>6 ± 6</td>
<td>11 ± 13</td>
<td>56 ± 27</td>
<td>54 ± 24</td>
<td>39 ± 18</td>
<td>31 ± 21</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
<td>13</td>
<td></td>
<td>12 ± 10</td>
<td>33 ± 33</td>
<td>50 ± 37</td>
<td>88 ± 53</td>
<td>59 ± 35</td>
<td>24 ± 18</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>13</td>
<td></td>
<td>4 ± 6</td>
<td>17 ± 17</td>
<td>37 ± 32</td>
<td>80 ± 40</td>
<td>54 ± 23</td>
<td>22 ± 18</td>
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<td>Biceps brachii</td>
<td>13</td>
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<td>8 ± 8</td>
<td>22 ± 14</td>
<td>26 ± 20</td>
<td>20 ± 16</td>
<td>44 ± 32</td>
<td>16 ± 14</td>
</tr>
</tbody>
</table>

<a>Data are given as means and standard deviations, and expressed for each muscle as a percentage of an MVIC.</a>

<b>From initial movement to maximum knee lift of stride leg.</b>

<c>From maximum knee lift of stride leg to when lead foot of stride leg initially contacts the ground.</c>

<d>From when lead foot of stride leg initially contacts the ground to maximum shoulder external rotation.</d>

<e>From maximum shoulder external rotation to ball release.</e>

<f>From ball release to maximum shoulder internal rotation.</f>

<g>From maximum shoulder internal rotation to maximum shoulder horizontal adduction.</g>

MVIC = maximum voluntary isometric contraction.
Wind-Up Phase

Shoulder activity during the wind-up phase, which is from initial movement to maximum knee lift of stride leg (Figure 2.1), is generally very low. From Table 2.1, it can be seen that the greatest activity is from the upper trapezius, serratus anterior and anterior deltoids. These muscles all contract concentrically to upwardly rotate and elevate the scapula and abduct the shoulder as the arm is initially brought overhead, and then contract eccentrically to control downward scapular rotation and shoulder adduction as the hands are lowered to approximately chest level. The rotator cuff muscles, which have a dual function as gleno-humeral joint compressors and rotators, have their lowest activity during this phase. Because shoulder activity is low, it is not surprising that the shoulder forces and torques generated are also low (Fleisig et al., 1995; Escamilla et al., 1998). Consequently, very few shoulder injuries occur during this phase.

Stride Phase

During the stride phase the hands separate, the scapula upwardly rotates, elevates and retracts, and the shoulders abduct, externally rotate and horizontally abduct due to concentric activity from several muscles, including the deltoids, supraspinatus, infraspinatus, serratus anterior and upper trapezius. It is not surprising that there are many more muscles are activated and to a higher degree during the stride as compared to windup phase. Interestingly, the supraspinatus has its highest activity during the stride phase as it works not only to abduct the shoulder but also helps to compress and stabilize the gleno-humeral joint. The deltoids exhibit high activity during this phase in order to initiate and maintain the shoulder in an abducted position (DiGiovine et al., 1992).
Arm Cocking Phase

During this phase the kinetic energy that is generated from the larger lower extremity and trunk segments is transferred up the body to the smaller upper extremity segments (Toyoshima et al., 1974; Fleisig et al., 1996a; Escamilla et al., 1998). High to very high shoulder muscle activity is needed during this phase in order to keep the arm moving with the rapidly rotating trunk, as well as control the resulting shoulder external rotation (Table I), which peaks near 180°. Activity from the pectoralis major and anterior deltidoid is needed during this phase to horizontally adduct the shoulder with a peak angular velocity of approximately 600°/sec, from a position 20° of horizontal abduction at lead foot contact to a position of approximately 20° of horizontal adduction at maximum shoulder external rotation. Moreover, a large compressive force of > 80% bodyweight is generated by the trunk onto the arm at the shoulder to resist the large ‘centrifugal’ force that is generated as the arm rotates forward with the trunk (Fleisig et al., 1995). The supraspinatus, infraspinatus, teres minor and subscapularis achieve high to very high activity to resist gleno-humeral distraction and enhance gleno-humeral stability (DiGiovine et al., 1992).

While it is widely accepted that strength and endurance in posterior shoulder musculature is very important during the arm deceleration phase to slow down the arm, posterior shoulder musculature is also important during arm cocking. The posterior cuff muscles (infraspinatus and teres minor) and latissimus dorsi generate a posterior force to the humeral head that helps resist anterior humeral head translation, which may help unload the anterior capsule and anterior band of the inferior gleno-humeral ligament (Jobe, 1983; Glousman et al., 1988; Fleisig et al., 1995). The posterior cuff muscles
(infraspinatus and teres minor) also contribute to the extreme range of shoulder external rotation that occurs during this phase.

A peak shoulder internal rotation torque of 65–70N m is generated near the time of maximum shoulder external rotation (Fleisig et al., 1995; Escamilla et al., 2002). High to very high activity is generated by the shoulder internal rotators (pectoralis major, latissimus dorsi and subscapularis), which contract eccentrically during this phase to control the rate of shoulder external rotation (DiGiovine et al., 1992).

For example, the pectoralis major and subscapularis contract concentrically to horizontally adduct the shoulder and eccentrically to control shoulder external rotation. This dual function of these muscles helps to maintain an appropriate length-tension relationship by simultaneously shortening and lengthening, which implies that these muscles may be maintaining a near constant length throughout this phase. High activity from scapular muscles is needed in order to stabilize the scapula and properly position the scapula in relation to the horizontally adducting and rotating shoulder.

Werner et al. (1993) reported the highest triceps activity during arm cocking because elbow extensor torque peaks during this phase (Feltner & Dapena, 1986). High eccentric contractions by the triceps brachii are needed to help control the rate of elbow flexion that occurs throughout the initial 80% of this phase. High triceps activity is also needed to initiate and accelerate elbow extension, which occurs during the final 20% of this phase as the shoulder continues externally rotating (Escamilla et al., 1998).

Gowan et al. (1987) demonstrated that subscapularis activity is nearly twice as great in professional pitchers compared with amateur pitchers during this phase. In contrast, muscle activity from the pectoralis major, supraspinatus, serratus anterior and biceps brachii was 50% greater in amateur pitchers as compared to the professional
pitchers. Glousman et al. (1988) and colleagues compared shoulder muscle activity between healthy pitchers with no shoulder pathologies to pitchers with chronic anterior shoulder instability due to anterior glenoid labral tears. Pitchers diagnosed with chronic anterior instability exhibited greater muscle activity from the biceps brachii and supraspinatus and less muscle activity from the pectoralis major, subscapularis and serratus anterior.

Decreased activity from the pectoralis major and subscapularis, which contract eccentrically to decelerate the externally rotating shoulder, may accentuate shoulder external rotation and increase the stress on the anterior capsule (Glousman et al., 1988). Decreased activity from the serratus anterior may cause the scapula to be abnormally positioned relative to the externally rotating and horizontally adducting humerus, and a deficiency in scapular upward rotation may decrease the subacromial space and increase the risk of impingement and rotator cuff pathology (DeWilde et al., 2003).

Infraspinatus activity was lower in pitchers with chronic anterior shoulder instability compared with healthy pitchers (Gowan et al., 1987). During arm cocking, the infraspinatus not only helps externally rotate and compress the gleno-humeral joint, but also may generate a small posterior force on the humeral head due to a slight posterior orientation of its fibres as they run from the inferior facet of the greater tubercle back to the infraspinous fossa. This posterior force on the humeral head helps resist anterior humeral head translation and unloads strain on the anterior capsule during arm cocking.

Arm Acceleration

Like the arm cocking phase, high to very high activity is generated from the gleno-humeral and scapular muscles during this phase in order to accelerate the arm forward. The gleno-humeral internal rotators (subscapularis, pectoralis major and
latissimus dorsi) have their highest activity during this phase (Table 1) as they contract concentrically to help generate a peak internal rotation angular velocity of approximately 6500°/sec. near ball release (Escamilla et al., 2007). This rapid internal rotation, with a range of motion of approximately 80° from maximum external rotation to ball release, occurs in only 30–50 milliseconds (Pappas et al., 1985; Escamilla et al., 1998). The very high activity from the subscapularis (115% MVIC) occurs in part to help generate this rapid motion, but it also functions as a steering muscle to maintain the humeral head in the glenoid. The teres minor, infraspinatus and supraspinatus also demonstrate moderate to high activity during this phase to help properly position the humeral head within the glenoid.

Werner et al. (1993) reported relatively little triceps EMG during the arm acceleration phase. In addition, elbow extensor torque is very low during this phase compared with the arm cocking phase (Feltner & Dapena, 1986; Werner et al., 1993). It should be re-emphasized that elbow extension initially begins during the arm cocking phase as the shoulder approaches maximum external rotation (Escamilla et al., 2007).

Similar findings were reported by Roberts (1971) who found that subjects who threw with paralyzed triceps could obtain ball velocities >80% of the ball velocities obtained prior to the triceps being paralyzed. Toyoshima et al. (1974) also demonstrated normal throwing using the entire body generated almost twice the elbow extension angular velocity compared with extending the elbow by throwing without any lower extremity, trunk and shoulder movements. These authors concluded that during normal throwing the elbow is swung open like a ‘whip’, primarily due to linear and rotary contributions from the lower extremity, trunk and shoulder, and to a lesser extent from a
concentric contraction of the triceps. However, the triceps do help extend the elbow during this phase, as well as contribute to shoulder stabilization by the triceps long head. Gowan et al. (1987) demonstrated that rotator cuff and biceps brachii activity was 2–3 times higher in amateur pitchers compared with professional pitchers during this phase.

**Arm Deceleration Phase**

The arm deceleration phase begins at ball release and ends at maximum shoulder internal rotation (Figure 1) (Fleisig et al., 1995 & 1996a; Escamilla et al., 1998 & 2002). Large loads are generated at the shoulders to slow down the forward acceleration of the arm. The purpose of this phase is to provide safety to the shoulder by dissipating the excess kinetic energy not transferred to the ball, thereby minimizing the risk of shoulder injury. Posterior shoulder musculature, such as the infraspinatus, teres minor and major, posterior deltoid and latissimus dorsi, contract eccentrically not only to decelerate horizontal adduction and internal rotation of the arm, but also help resist shoulder distraction and anterior subluxation forces. Tillaar & Ettema (2004) determined the force-velocity relationship in overarm throwing using ball weights varying from 0.2 to 0.8 kg. Velocity of joints of the upper extremity and ball together with the force on the ball were derived from the data. A simple model revealed that 67% of ball velocity at ball release was explained by the summation of effects from the velocity of elbow extension and internal rotation of the shoulder. With regard to the upper extremity the internal rotation of the shoulder and elbow extension are two important contributors to the total ball velocity at release.

A shoulder compressive force slightly greater than body weight is generated to resist shoulder distraction, while a posterior shear force of 40–50% bodyweight is
generated to resist shoulder anterior subluxation. Consequently, high activity is generated by posterior shoulder musculature (DiGiovine et al., 1992), in particular the rotator cuff muscles. For example, the teres minor, which is a frequent source of isolated tenderness in pitchers, exhibits its maximum activity (84% MVIC) during this phase (Table I). In addition, scapular muscles also exhibit high activity to control scapular elevation, protraction and rotation during this phase.

Weak or fatigued posterior musculature can lead to multiple injuries, such as tensile overload undersurface cuff tears, labral/biceps pathology, capsule injuries and internal impingement of the infraspinatus and supraspinatus tendons on the posterosuperior glenoid labrum (Meister, 2000).

2.2 THROWING PERFORMANCE

Although throwing kinematics and kinetics have been well documented in various studies, it is equally important to understand what amounts to good throwing performance. It is well accepted that good throwing performance has properties of greater distance, accuracy and higher velocity. The distance covered in turn has a strong relationship with speed, angle of throw and height of release. This release characteristic is altered by each athlete’s technique during the throwing procedure. Effective technique maximizes the speed of release and optimizes the angle and height of release (Linthorne & Everett, 2006; Leigh & Yu, 2007). Calculations showed that the distance of a throw may be increased by a few meters by launching the ball with a fast backspin, but the ball must be launched at a slightly lower release angle (Linthorne & Everett, 2006). Throwing speed has been measured by many authors using radar gun which can be hand held or fixed depending upon the type of measurements involved (Potteiger et al., 1992).
It has been shown to a reliable technique with an interclass correlation of .953 between repeated measurements on different days using same subjects (Newton & McEvoy, 1994).

In addition to velocity and accuracy of throwing, several authors have also used distance as a tool for objectifying throwing performance (Leigh & Yu, 2006; Vaverka et al., 2011). Negrete, et al. (2011) also conducted a study to identify if relationships exist between tests of upper body strength and power (Single Arm Seated Shot Put, Timed Push-Up, Timed Modified Pull-Up, and The Davies Closed Kinetic Chain Upper Extremity Stability Test, and the softball throw for distance. It is evident that distance of throwing is an important measure that has been used in the past as an objective tool to measure throwing performance.

2.3 ROLE OF STRENGTH IN DYNAMIC ACTIVITIES

Since throwing is a highly coordinated neuromuscular activity, it can be debated whether strength plays a role in sporting activities. But there are many research reports which indicate that strength of muscles does play an important role even in highly skilled coordinated sporting events.

According to Schmitdbleicher (1992), there are two variables of primary importance for most sports: 1) the peak rate of force development (PRFD) and (2) power output. The PRFD is associated with the concept of explosive strength and is directly related to the ability to accelerate objects including body mass. According to Garhammar (1993), Thomas et al.(1997), McBride et al. (1999) & Kauhanen et al.(2000), although the power output is likely to be the more associated with performance in endurance sports, for explosive activities, Peak Power (PP) is typically strongly related to effective
performance. Fleck et al. (1992), Gorostiaga et al. (2005) and Tilaar & Ettema (2007) reported three factors which are essential with regard to the efficiency of throwing: (1) mechanics, (2) coordination of consecutive actions of body segments and (3) the upper and lower extremity muscle strength and power. It can be argued that maximum strength is the basic quality that affects power output. Furthermore, the maximum strength affects power in a hierarchical manner with diminishing influence as the external load decreases to a point at which the other factors such as the rate of force development may become more important (Schmitdbleicher, 1985 & 1992). Therefore, the relationship of strength and sporting performances is not fully understood.

Barker et al. (1993), studied the university football team and found that starters had a higher 1RM squat than non-starters suggesting that maximum strength plays a role in superior football performance. Fry & Kraemer (1991) and Stone et al. (2003) also reported that superior strength especially in relation to the body mass, may enhance the ability to perform other motor skills such as jumping. Ward (1982) compiled data from 1978 to 1981 and concluded that throwing ability was related to maximum strength in the power clean, snatch, squat, and bench press.

Toyoshima et al. (1974), Pedegana et al. (1982) and Bartlet et al. (1989) have reported that increasing dynamic muscle strength in the upper limb will increase the throwing speed. In addition to these muscles concentric shoulder adduction, wrist and elbow extension have been shown to significantly predict throwing speed in adult baseball players by these authors. Toyoshima (1974) in his extensive study also found that 53.1 % of throwing speed can be attributed to upper limb involvement.

Clements et al. (2001) in their review on muscle strength and its correlation with throwing speed in baseball players, reported that elbow extensor and shoulder internal
rotation strength has large influence on throwing speed. Therefore, potential strength training for elbow extension and shoulder internal rotation muscle groups in adolescents without neglecting the antagonist muscle groups is recommended. They also reported that weakness in these muscles should be taken care of in rehabilitation of these sportspersons. Marques et al. (2007) in his study examined the relationship between ball-throwing velocity during a 3-step running throw and dynamic strength, power, and bar velocity during a concentric-only bench-press exercise in team-handball players. Subjects power and bar velocity was measured during a concentric-only bench-press test as well as 1-repetition-maximum Bench Press (1-RMBP) strength. Ball-throwing velocity was evaluated with a standard 3-step running throw using a radar gun. The results of this study indicated that throwing velocity of elite team-handball players is related to maximal dynamic strength, peak power, and peak bar velocity. Thus, a training regimen designed to improve ball-throwing velocity in elite male team-handball players should include exercises that are aimed at increasing both strength and power in the upper body. Pauwels (1978) investigated the relationship of several anthropometric measures and physical skills of 12-19 year old non-experienced boys and with ball velocity and found that strength along with body size were crucial in determining the throwing velocity. Lachowetz et al. (1998) demonstrated that free weight training increased throwing velocity with an eight week dynamic strengthening program.

Byram et al. (2010) measured preseason shoulder strength in professional baseball players over a 5-year period (2001-2005). Prone internal rotation (IR), prone external rotation (PER), seated external rotation (SER), and supraspinatus (SS) strength were tested during spring training before each season. The players were then prospectively
followed throughout the season for incidence of throwing-related injury. Preseason weakness of external rotation and SS strength is associated with in-season throwing-related injury resulting in surgical intervention in professional baseball pitchers. Thus, preseason strength data may help identify players at risk for injury and formulate strengthening plans for prevention.

2.4 RELATIONSHIP BETWEEN ISOMETRIC STRENGTH AND DYNAMIC PERFORMANCE

Muscle contraction can be either dynamic or static. The dynamic muscle strength can be measured isotonically and isokinetically while static strength is quantified as Isometric muscle strength. As evident from the review of literature, considerable amount of work has been done on the relationship between dynamic strength and sports performance; there are conflicting reports on the relationship between Isometric strength and dynamic performance. Very few studies have been to evaluate Isometric strength and their relationship to dynamic performance specially throwing. In many studies that we found, group actions have been measured to see their relationship with dynamic actions (Barker et al., 1993; Clements, 2001; Khamoui et al., 2011).

Isometric tests are generally performed to quantify the maximal force (or torque) and/or the maximal rate of force development (RFD). The RFD presents the rate of rise in contractile force at the onset of contraction within the early phase of rising muscle force (Hakkinen & Komi, 1986), and it has been one of the most frequently applied tests for Explosive Force Production (Mirkov et al., 2004). In isolated muscle preparations, contractile RFD is obtained from the slope of the force time curve (force/time), whereas, for intact joint actions, RFD is calculated as the slope of the joint moment-time curve.
(moment/time). The maximal RFD is typically quantified as the greatest slope of the force time curve over some time interval (Wilson et al., 1993; Aagaard et al., 2002; Rajic et al., 2004). Other methods include determining the time needed to reach a certain level of absolute force, or the time needed to achieve a relative force level such as 30% (Hakkinen et al., 1985). Another important strength parameter is the total contractile impulse that can be produced within a given contraction time (Baker et al., 1994), or alternatively, the time interval between two relative force levels (Bobbert & Zandwijk, 1999; Gorostiaga et al., 1999; Mirkov & Nedeljkovic, 2002; Mirkov et al., 2004).

Khamoui et al. (2011) in his recent study investigated relationships between velocity-time characteristics (high pull and vertical jump peak velocity and rate of velocity development, high pull peak force (HPPF), high pull peak force relative to body mass (HPPF/BM), and high-pull maximum rate of force development (HPRFDMax). force-time characteristics, isometric peak force, body mass adjusted isometric peak force, isometric rate of force development at different millisecond windows, body mass adjusted dynamic peak force, and vertical jump height (VJ) Height. The correlations suggested that explosive isometric force production within 50 to 100 milliseconds may influence the ability to accelerate an implement or body and attain high velocity. In addition, body mass adjusted strength may positively influence vertical jump parameters. Kraska et al. (2009) investigated the relationship between maximum strength and differences in jump height during weighted and unweighted (body weight) static (SJ) and countermovement jumps (CMJ), Isometric Peak Force (IPF), Isometric Rate of Force Development (IRFD), IPF and IRFD showed moderate strong correlations with SJ and CMJ. The results of this study suggested that the ability to produce higher peak and
instantaneous forces and IRFD is related to Jump height (JH) which indicates that Isometric measures have a relationship with dynamic activities.

McGuigan & Winchester (2008) examined the relationships between measures of isometric force peak force (PF), RFD, jump performance and strength in collegiate football athletes. The subjects were tested for PF using the isometric mid thigh pull exercise. Explosive strength was measured as RFD from the isometric force-time curve. The one repetition maximum (1RM) for the squat, bench press and power clean exercises were determined as measures of dynamic strength. The two repetition maximum (2RM) for the split jerk was also determined. Vertical jump height and broad jump was measured to provide an indication of explosive muscular power. There were strong to very strong correlations between measures of PF and 1RM. The correlations were very strong between the power clean 1RM and squat 1RM. There were very strong correlations between 2RM split jerk and clean 1RM squat 1RM bench 1RM and PF There were no significant correlations with RFD. The isometric mid thigh pull test in this study does correlated well with 1RM testing.

In another study by McGuigan et al., (2010), the author examined the relationships between measures of maximal isometric force peak force (PF), rate of force development (RFD), vertical jump (VJ) performance and 1-repetition maximum (1RM) strength in recreationally trained men. The subjects were tested for PF using the isometric midthigh pull exercise. The 1RM for the squat and bench press exercise were determined as a measure of dynamic strength. Explosive strength was measured as RFD from the isometric force–time curve. There was a nearly perfect correlation between measures of PF and 1RM squat and 1RM bench press. The correlations were very strong between VJ
and PF and 1RM bench. There were also strong correlations between VJ and 1RM squat. There were no significant correlations with RFD. The results showed that isometric maximum strength determined during the isometric mid-thigh pull test correlated well with 1RM and VJ testing. The authors suggested that isometric mid-thigh pull was an efficient method for assessing strength in recreationally trained individuals.

Amidst some encouraging reports on relationship between isometric strength evaluations and dynamic performance, some authors reported poor or no correlations between the two. Murphy & Wilson (1996) conducted isometric tests at two joint angles and examined their relationship to dynamic performance. In addition, electromyography data were collected from the triceps brachii and pectoralis major muscles to compare underlying neural characteristics between the isometric tests and dynamic movement. The subjects performed two isometric tests in a bench press position, at elbow angles of 90° and 120°. In addition, each subject performed a seated medicine ball throw as a measure of dynamic upper body performance. Correlations showed that isometric measurements of force (r = 0.47-0.55) and rate of force development (r = 0.08-0.31) were poor predictors of dynamic performance. The angle of isometric assessment had little effect on the relationship between the tests and measurements of performance. Aleksander et al. (2009) investigated the relationship between different muscle strength assessments in bench press action and reported contradictory findings. In their study subjects were tested in the isometric bench press machine in two different positions. All of the subjects were also tested in the classical bench press action. The performance measure of dynamic performance was 1RM in classical bench press action. The relationship between isometric and dynamic strength test was assessed by Pearson's
correlation coefficients. They failed to demonstrate a high correlation between the isometric testing and the performance task.

Nuzzo et al. (2008) determined the relationship between countermovement vertical jump (CMJ) performance and various methods used to assess isometric and dynamic multi-joint strength. The first session involved 1 repetition maximum (1RM) (kg) testing in the squat and power clean. During the second session, peak force (PF), relative peak force, peak power (PP), relative peak power, peak velocity, and jump height (meters) in a CMJ, and peak force and rate of force development (RFD) in a maximal isometric squat and maximal isometric mid-thigh pull were assessed. The results of this study indicated that multijoint dynamic tests of strength (squat 1RM and power clean 1RM), expressed relative to body mass were most closely correlated with CMJ performance.

Kuhlman et al. (1992) evaluated the strength of active external rotation and of abduction of the shoulder when the humerus was in the plane of the scapula (30° of horizontal flexion anterior to the coronal plane) isokinetically and isometrically. There were highly significant differences in strength, measured isokinetically and isometrically, between younger and older men and between older men and older women. The variability of normal values for torque was similar in each group. Repeated testing demonstrated a high reliability of isokinetic measurements and of isometric measurements at angles within the range of the production of peak torque.

In contrast to many studies cited which suggest that Isometric testing may be useful to predict dynamic functions, Requenna et al. (2009) determined muscle strength and power output characteristics in a group of professional soccer players and concluded
that isometric and isokinetic muscle strength assessed in an open kinetic chain were not movement-specific enough to predict performance during a more complex movement, such as jump or sprint. The results of Requenna et al. (2009) were in accordance with those of Murphy and Wilson (1996), Nuzzo et al. (2008) & Aleksander et al. (2009), who reported that isometric strength and its testing does not correlate well with dynamic activities and that dynamic strength assessment were more closely associated with dynamic sporting actions.

It has been suggested that there might be differences in the neural activation of muscles between isometric and dynamic activation. Furthermore, the isometric rate of force development test was found to be an ineffective tool to monitor training induced changes in performance of the triceps brachii and pectoralis major of 24 male subjects (Murphy & Wilson, 1996). Such a result supports the suggestions that specific recruitment patterns are developed for dynamic contractions and that these patterns differ to motor unit recruitment during isometric activity (Baker et al., 1994). These findings appear to be due to the large neuronal and mechanical differences between dynamic and isometric muscular actions. These authors recommended that isometric assessment of dynamic performance should be avoided and dynamic forms of muscle assessment should be employed which is in contrast to many studies that we found.

In the review of the literature we found that, in spite of the contradictory reports, a number of authors have reported good to strong relationships between the two. In addition to the various studies that reported good relationship between the two, an interesting study by Stone et al. (2004), investigated the relationship of whole-body maximum strength to variables potentially associated with track sprint-cycling success.
These variables included body composition, power measures, coach’s rank, and sprint-cycling times. Maximum strength was measured using an isometric mid thigh pull (IPF). Explosive strength was measured as the peak rate-of-force development (PRFD) from the isometric force-time curve. Peak power was estimated from countermovement Jump Peak Power (CMJPP) and static vertical jumps peak power (SJPP) and measured by modified Wingate tests. Maximum strength (both absolute and body mass corrected) and explosive strength were shown to be strongly correlated with jump and Wingate power. Additionally, maximum strength was strongly correlated with both coach’s rank and sprint cycling times. The results suggest that larger, stronger sprint cyclists have an advantage in producing power and are generally faster sprint cyclists. Stone et al. (2003) in their research report on Maximum strength–power performance relationships in collegiate throwers reported that IPF is strongly related to dynamic PF and PP. Results of this study suggested that maximum strength (i.e., Isometric Peak Force) is strongly associated with dynamic PF. In addition, maximum strength is strongly associated with PP even at relatively light loads such as those associated with sport-specific dynamic explosiveness.

One of the reasons for the disparity in the research findings may be the large variation in angles used in the isometric assessments (Murphy & Wilson, 1995). For example, isometric leg extension tests have been performed at knee angles ranging from 90° to 140° throughout the literature (Viitasalo et al., 1981; Hakkinen, 1987; Ryushi et al., 1988; Sale et al., 1992). Sale (1991) recommended that isometric testing be performed at a joint angle that corresponded to the peak of the strength curve for that particular muscle group to reduce the variability associated with small errors in the
determination of joint angle. However, the use of such an angle may not necessarily be optimal in terms of relationship to dynamic performance. For example, in their study, the 120° angle involved a significantly greater isometric force than the 90° position, but its relationship to performance was substantially worse. Furthermore, the correlations between the isometric tests of muscular function and performance clearly showed that changing the joint angle from 120 to 90° improved the relationship of most of the tests by more than 100%. The results of the their study strongly support the notion that the joint angle at which isometric testing takes place should not be arbitrary because the relationship between the isometric tests themselves, and between the isometric tests and performance, varies substantially as a function of angle. Such a finding is not surprising given that previous research has shown differences in motor unit recruitment patterns within isometric tasks with changes in the direction of force application (Romeny et al., 1982) or the performance of different tasks of the same muscle (Romeny et al., 1984). Further, and particularly relevant to multi-joint tests, researchers have shown that the relationship between EMG activation level of synergistic muscle groups varies as a function of joint angle (Hasan & Enoka, 1985, Howard et al., 1986). Although these correlation coefficients are statistically significant, they are smaller than what may have been expected. It is apparent that when an identical isometric movement is changed by 30°, the magnitudes of the change in both force and RFD are subject to large individual variations. Therefore, if isometric tests are to be used to infer the functional capacity of the musculature in dynamic activities, it is likely that the best angle to perform isometric tests may be the joint angle at which peak force is developed in the performance of interest.
2.5 MEASUREMENT OF ISOMETRIC STRENGTH

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. According to Aleksander et al. (2009) tests of isometric strength are easy to perform as they require only a single maximal contraction due to several reasons:

- They are easily standardized and hence reproducible. Indeed, a number of studies have reported high levels of reliability with the use of isometric procedures (Bemben et al., 1991; Hortobagyi & Lambert, 1992).
- They are simple tests that require training with untrained and trained subjects.
- They are straightforward to administer and safe for subjects to perform.
- They use relatively inexpensive equipment.

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. Isometric strength of some shoulder muscles have also been studied by several authors using the strain gauge or hand held dynamometers.

2.6 USE OF STRAIN GAUGE FOR MUSCULAR EVALUATION

Strain Gauge which is used to measure muscular performance vary greatly in their methods of applications and design. However, basic principle remains the same. Load applied (in
the form of tension, compression or shear) to the materials causes a change in the geometric configuration of the material. Deformation in the material caused by a load is known as strain that is measurable.

When the load is applied to the strain gauge, a fine metal ring or rod or the circular spring deforms and a strain created can be measured. Strain gauge devices are used for muscle evaluation by attaching it to an object that a limb segment can either pull or push against the device in the same way (in the same line) that the calibration weights are applied to the instrument. The application during different tests must be identical. Stabilization of the limbs can be maintained so that force measurements reflect only those muscles being tested. In addition, the interface i.e. the place where the patient makes contact with the device must be comfortable, so that can pull or push maximally.

2.6.1 Reliability of Strain Gauge

Many Strain Gauge devices have been used and described in research literature. Investigators believe that since the instrument has a sound theoretical basis, reliability between sessions and examiners can be assumed. Some of the early studies were done by Asmusson et al. (1959) who demonstrated that the force measurements obtained with a variety of strain gauge devices were replicable. They constructed five different strain gauge dynamometers; each designed for a different part of body and assessed four of these for reliability. Six muscle groups in 50 normal young men were tested twice. Reliability coefficients ranged from 0.91 to 0.96. Clarke (1953) compared the reliability of cable tensiometer and the Wakim Porter strain gauge for the measurements of six muscle groups (finger flexion, wrist dorsiflexion, shoulder outward rotation, neck extension, knee extension, ankle plantarflexion) in 64 non-disabled male college students.
and reported that test retest correlations ranged from 0.81 to 0.94 and were very similar to those he obtained with cable tensiometer. The two studies described above show that under controlled condition, strain gauge devices could reliably measure force generated by muscles.

Bohannon & Andrews (1987) conducted a study to examine the inter-rater reliability of hand held dynamometer which is essentially a strain gauge device. Two raters performed hand-held dynamometer testing of six muscle groups of 30 patients to determine the interrater reliability of the procedure. Six muscle groups were tested - shoulder external rotators, elbow flexors, wrist extensors, hip flexors, knee extensors, and ankle dorsiflexors. The inter-rater reliability of the procedure was found to be good to high in the six muscle groups tested. Andrews et al. (1996) attempted to establish normative values for isometric muscle force measurements obtained with strain gauge based hand held dynamometers. Malerba et al. (1993) also conducted a study to determine the test-retest reliability of concentric, eccentric, and isometric muscle performance measurements of shoulder external and internal rotation in the scapular plane test position and to compare this reliability between the involved and uninvolved limb of subjects with a history of unilateral shoulder pathology. Intraclass correlation coefficients (ICCs) were used to determine test-retest reliability. Isometric tests were generally most reliable (ICC = .81-.93), followed by concentric (ICC = .60-.95) and eccentric tests (ICC = .44-.92). Isokinetic and isometric reliability were usually higher for involved than uninvolved shoulders.
2.6.2 Validity of Strain Gauge

The comparisons with loads (Khalil & Jerome, 1950) and tensiometers have been used to justify the use of strain gauge devices to measure muscle performance. Another rationale offered is that the strain gauge can be applied in manner of manual muscle testing (MMT) and can therefore objectify an otherwise subjective test.

Clarke (1953) compared the following equipment: a cable tensiometer, a Wakim Porter Strain Gauge, a spring scale and a Newman Myometer. Comparisons were made on basis of which instruments were the most reliable and whether the measurements obtained with the different devices were equivalent. Finger flexion, wrist dorsal flexion, shoulder outward rotation, neck extension, knee extension, ankle plantar flexion were examined. Clarke categorized these actions as being strong or weak, with knee flexion and ankle plantar flexion constituting the strong category. The weak motions correlated poorly between the tensiometer and the strain gauge (coefficients ranged from 0.14 to 0.43), while for the strong motions of knee extension and plantar flexion the values were 0.89 to 0.9.

Kennedy (1965) using a strain gauge and cable tensiometer, examined measurements of knee flexion and extension bilaterally. The measurements were found to be interchangeable and lead Kennedy to conclude that the devices were equally good. He also stated that both the strain gauge and cable tensiometer measurements were highly correlated with the maximum weight that a subject could lift. Reed et al.(1993) compared hand-held isometric muscle strength measurement to an isokinetic muscle strength measurement in a healthy elderly population. Hand-held dynamometry for strength measurement correlated strongly with measurement of strength using isokinetic dynamometry. These reports are very interesting from the point of view that some of the
researches have proposed that Isokinetics should be used for muscular evaluations in sportspersons.

The studies described above attempted to compare strain gauge measurements with those taken by means of other devices. They discussed whether strain gauge measurements correlated with other measurements and found that it is highly correlated with measurements obtained with cable tensiometers and maximal loads lifted. This can be considered a form of criterion-related validity, i.e. does one type of measurement has the ability to predict another. Some studies stated that the instrument has a sound theoretical basis to reflect muscle tension, which is a form of construct validity.

We also found few studies in which isometric strength of specifically shoulder muscles was studied. Bohannon (1986), measured the isometric strength of 10 upper extremity muscle groups bilaterally in 31 young women to get an estimate of the strength of the muscle groups and the relationship between the strength of the muscle groups using a strain gauge hand-held dynamometer. Inferential statistics revealed a significant difference in strength between the left and right side for only three muscle groups. The only antagonistic muscle groups that differed significantly on both the left and right side were the elbow flexor and extensor muscles. The strength of each muscle group was significantly related to the strength of every other muscle group on each side.

Kolber et al., (2007) determined the test-retest reliability of a hand-held dynamometer with the use of a portable stabilization device while testing the shoulder internal and external rotator musculature. Intra-class correlation coefficients (ICC’s) were high, ranging from ICC (3,1) = 0.971-0.972 for the test-retest trials of internal and external rotation. There was no significant difference between sessions one and two for maximum internal rotation (p = 0.431) and maximum external rotation strength (p =
The results indicate that the testing protocol with stabilization device is a reliable method for measuring strength of the internal and external rotator shoulder musculature.

2.7 EFFECT OF JOINT ANGLE IN ISOMETRIC ASSESSMENTS

It has been well documented that the Isometric force producing capabilities of the musculature fluctuate as a function of joint angle. (Doss & Karpovich, 1965 & 1966; Singh & Karpovich, 1966; Murphy et al., 1995). However, there is limited research which has examined the effect of joint angle on the relationship between isometric assessment and athletic performance. When examining the relationship between dynamic performance and Isometric assessment, most researchers have only assessed muscle function at only one joint angle in the movement range. (Hakkinen, 1987; Ryushi et al., 1988; Hakinnen & Keskinen, 1989; Sale et al., 1992; Wilson et al., 1993; Murphy et al., 1995). Clarke (1953) and more recently Sale (1992) recommended that the Isometric testing be performed at the joint angle which corresponded to the peak of the strength curve for that particular muscle group to reduce the variability in force output associated with small errors in the determination of the angle. Murphy et al. (1995) in their study reported that the relationship of Isometric testing and dynamic performance of Bench press could improve as much as 100% by changing the angle of measurement due to motor unit recruitment patterns and differing muscle mechanics at varying joint angles. Therefore, they suggested that the best angle at which to assess isometric function may be the joint angle at which peak force is developed in the performance of interest.

As shown in Table 1, the peak force of Internal rotators develops around the arm cocking and the arm acceleration phase while the peak force of External rotators is around the stride phase and the arm deceleration phase. Based on the reports of Murphy...
et al. (1995), in our study we used 70° and 90° of external rotation as angles for measurement of isometric strength of external and internal rotator muscles.

Donatelli et al. (2000) measured the Shoulder internal and external rotation strength with subjects in the supine position, with the humerus placed on a wedge at 30° anterior to the frontal plane and elevated to 45°, and in the frontal plane with 90° of abduction. The elbow was flexed to 90° in both positions and the hand-held dynamometer was placed on the ulnar styloid process. In a study by Greenfield et al. (1990) external rotator muscle strength was shown to be markedly greater in the plane of the scapula (30° anterior to the frontal plane) than in the frontal plane. Kuhlman et al. (1992) evaluated the strength of active external rotation and of abduction of the shoulder when the humerus was in the plane of the scapula (30° of horizontal flexion anterior to the coronal plane) isokinetically and isometrically in 39 normal volunteers, who were stratified by age and sex. The angles at which peak torque was produced were similar when tested isokinetically and isometrically.

However, Scoville et al. (1997) in an interesting research commented that, the analysis of strength, most applicable to functions should be done in the range where the antagonist is functioning as a decelerator of the shoulder which is the end range. They studied the medial rotation strength in a range from 90° of lateral rotation to 20° of medial rotation and lateral rotation strength from 20° of medial rotation to 90° of lateral rotation.

2.8 DYNAMIC STRENGTH MEASUREMENTS USING 1 REPETITION MAXIMUM (1RM) AND PREDICTION EQUATIONS

Dynamic contraction involves movement, either concentric, in which the muscle shortens, or eccentric, in which the muscle lengthens. For the assessment of dynamic
strength, the repetition maximum (RM) is widely used. The RM is the maximum number of repetitions per set that can be performed with proper lifting technique, using the given resistance. Thus, a set of a certain RM implies that that the set is performed to momentary voluntary fatigue. The heaviest resistance that can be used for one complete repetition of an exercise is 1 RM. A lighter resistance that allows completion of 10 but not 11 repetitions with proper exercise technique is 10 RM. Some researchers have extrapolated dynamic strength from isometric strength (Sale & Norman, 1982; Young & Bilby, 1993). In addition, questions about the relationship between isometric strength and dynamic strength have been raised.

McDonagh and Davies (1984) stated that under isotonnic conditions involving the lifting of weights, a rough estimate of strength is the weight which can be lifted by a particular muscle group once only without a rest.

Going by its traditional approach, the most popular way to assess dynamic strength has been to determine how much weight an individual can lift for one repetition. Such exercises are usually performed using three or four exercises that are representative of the body’s major muscle groups. However, safety becomes a major concern when the lifter performs with a maximal weight for one repetition. Attempting a 1 RM with heavy weights can place an inordinate and unreasonable amount of stress on muscles, bones and connective tissues. Further 1 RM tends to increase blood pressure beyond that which is normally encountered while using sub maximal weights. Until few years back, it was through hit and trial that 1 RM used to be measured. Brzycki(1993) came out with his work on “Strength Testing-Predicting a One Rep Max from Reps to fatigue” which utilized multiple repetitions and lesser weight to predict 1 RM and was relatively safer. Calculating 1RM has been considered the most reliable and valid method to represent dynamic strength.
There is a direct relationship between reps-to-fatigue and percentage of maximal load: as the percentage of maximal weight increased, number of repetitions decreased in an almost linear fashion. It was also clearly stated that 10 repetitions could be performed with a weight that was equal to approximately 75 % of maximal load (Bryzcki, 1993; Hixon et al. 1994; Folland et al. 2002).

Going by the previous literature of Sale & MacDougall (1981), Brzycki (1993) calculated a mathematical equation for predicting a 1 RM based on reps-to-fatigue. It should be remembered that formula is only valid for predicting a 1 RM when the number of reps-to-fatigue is less than 10.

\[
\text{Predicted 1 RM} = \frac{\text{weight lifted}}{1.0278 - 0.0278 \times \text{no. of rep.} \ (\text{less than 9})}
\]

2.8.1 Validity

The validity of above-mentioned formula has been clearly proved in the following published works of Barrow & McGee (1979), Sale & Dougall (1981), Enoka (1988) and Jones (1988).

Taylor and Bandy (2005) in their study examined the Intrarater reliability of 1 repetition maximum estimation in determining shoulder internal rotation muscle strength performance. The accuracy of the estimated 1RM was determined by establishing the actual 1RM. A 1RM estimation equation was used to estimate shoulder internal rotation strength. After 1 week, procedures were repeated and intrarater reliability was calculated. One week after 1RM estimation procedures were completed, the accuracy of an estimated 1RM was determined by establishing an actual 1RM. The results indicated excellent intrarater reliability and suggested that shoulder internal rotation 1RM estimation appears
to be reliable and accurate. They further supported the reports of Bryzcki (1993) that clinicians may use submaximal loads to estimate the 1RM and decrease the possibility of injury during actual 1RM strength testing.

2.9 STRENGTH RATIOS OF EXTERNAL ROTATORS (ER): INTERNAL ROTATORS (IR)

A ratio of the concentric agonist strength to the concentric antagonist strength has been used frequently to describe force production in the shoulder muscles. Recently, the ratio of eccentric lateral rotation: eccentric medial rotation was also reported to describe eccentric shoulder strength (Hageman et al., 1989; Tata et al., 1993). Electromyographic and kinesiological studies have described the role of the antagonist muscle as that of a muscle firing in an eccentric manner to decelerate the motion of the agonist (Glousman, 1988; Bradley and Tibone, 1991). For lateral rotation, this refers to the medial rotators firing eccentrically (as the antagonists to the lateral rotators) to decelerate the lateral rotators firing concentrically (as the agonists). Conversely, for medial rotation, this refers to the lateral rotators firing eccentrically (antagonists) to decelerate the concentrically firing medial rotators (agonists). In the overhead athlete, a proper ratio of the eccentric antagonist to the concentric agonist muscles is critical for dynamic stability and optimal function.

Sahrmann (1987) and Caillet (1977) defined muscle imbalance as a failure of the agonist antagonist relation, when agonistic/antagonistic muscle groups function cooperatively to control the joints. Therefore, the term balance refers to the balance between the torque ratio of agonistic and antagonistic muscle groups (Brostrom et al., 1992; Beneka et al., 2002). Information on shoulder strength has been obtained by isokinetic testing performed on sportspersons at the high school, collegiate, and
professional levels of throwing. The external rotators of the dominant side were found in various studies to be weak in relation to those of the non-dominant side (Sirota and Wilhite, 1992; Ellenbecker & Mattalino, 1997; Meister, 2000).

Isokinetic strength ratios were used as shoulder strength variables in various studies. Andrade et al. (2010) studied the isokinetic profile of shoulder rotator muscles strength in female handball players and tested internal and external rotator muscles peak torque in concentric and eccentric mode. They reported that concentric strength for internal and external rotation was significantly greater for the dominant than for the non-dominant limb for all speeds. For eccentric actions, internal rotator muscles were stronger in the dominant than the non-dominant limb at both speeds. Similarly, Stickley et al. (2008) measured concentric and eccentric peak torque of the medial and lateral rotators of the shoulder and calculated resultant cocking and spiking ratios based on peak torque values in volleyball players. The results of their study indicated that differences in medial and lateral shoulder rotator strength ratios appear to be related more to injury prevalence than to absolute strength.

Bak and Magnusson (1997) in their study also reported that functional ratios of the shoulder measured isokinetically in swimmers were greater in painful shoulders when compared to normal counterparts. Noffal (2003) in their study suggested one of the possible mechanisms leading to shoulder injury may be a strength imbalance between those muscles that accelerate the upper limb and those responsible for deceleration. Functional external eccentric-to-internal concentric ratio may be a better identifier of muscular imbalance in dominant and non-dominant shoulders of throwers and non-throwers. The author reported that throwers exhibited significantly lower ratios than non-
throwers in their dominant limb but there was no difference between groups for the non-dominant limb.

It is apparent that a lot of authors have compared the strength of external rotators to the Internal rotators of the shoulder but majority of them used only Isokinetic methods of evaluation. Isometric strength measurements were either done as isolated muscles of upper limb or were used as secondary measures but Isometric ratios were not calculated to observe the differences between the two groups of muscles. Also there was marked variations in the position of the shoulder in these studies. Wilhite et al. (1992) and Mikeksy et al. (1995) suggested that testing the shoulder rotators at 90° of abduction appeared to be the most sensitive way of detecting differences compared to other shoulder testing positions.

2.10 EFFECT OF STRENGTH TRAINING ON THROWING

Most of the research articles that we found, attempted to observe the effects of dynamic strengthening in the form of isotonic or isokinetic strengthening on throwing velocity. Wooden (1992) compared the effects of isokinetic (IKN) and accommodative isotonic training in the individualized, dynamic, variable resistance (IDVR) mode. The authors reported statistically significant increases in throwing velocity and external rotator torque in the IDVR group but not the IKN group. External rotator power improved in both groups. Internal rotator torque and power were not improved in either group. Results suggested that IDVR may be more effective than IKN training in improving throwing velocity and external rotator torque production. These results are quite contrary to the popular belief that isokinetic training is beneficial for sportspersons. Similarly, Escamilla et al. (2010) studied the effects of a 4-week youth baseball conditioning program on throwing velocity and reported that after 4-weeks of the
program, throwing velocity increased significantly in the training group but did not significantly increase in the control group. Malliou (2004) showed that isokinetic training was most effective in altering the strength ratios of the shoulder rotators. Lachowetz et al. (1998) examined the effect of upper body strength training on the velocity of a thrown baseball. The treatment group received 8 weeks of strength training while the control group received no training. Throwing velocity was measured using a radar gun. A significantly higher mean throwing velocity for the training group following 8 weeks of strength training was reported by the authors. The results of these studies indicate that dynamic training is effective in increasing throwing velocity. Increased throwing velocity may be helpful in various sports where throwing skill is of utmost importance.

With regard to the type of training that is most effective in strengthening the rotator cuff muscles, Brostrom et al. (1992) recommended “isolated” types of exercise, which better emphasize recruitment of the muscles in question. This means that after evaluation of muscular performance and detection of possible imbalances in strength, an exercise programme with isolated movements is applied focusing on the weak muscles which is similar to the procedure used in our study.

A recent meta-analysis by Behringer (2011) reported that resistance training in children and adolescents is effective and safe. Their analysis suggested that younger subjects and non-athletes showed higher gains in motor performance following resistance training than their counterparts and that specific resistance training regimes were not advantageous over traditional resistance training programs. These results emphasize that resistance training provides an effective way for enhancing motor performance in children and adolescents.
Folland et al. (2005) reported that 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. After 9 weeks of training, the increase in isokinetic strength was similar in both legs (pooled data from three velocities: dynamically trained leg, 10.7%; isometrically trained leg, 10.5%). Isometric strength increases were significantly greater for the isometrically trained leg (pooled data from four angles: dynamically trained leg, 13.1%; isometrically trained leg, 18%). This may have been due to the greater absolute torque involved with isometric training or a residual angle specificity effect despite the isometric training being divided over four angles. This is indicative of the fact that Isometric training has the potential to improve dynamic performance as well in contrast to researches which report that isometric contractions cannot predict dynamic performance.