Overhead throwing performance requires an intricate balance between static and dynamic structures of the shoulder in order to maintain functional stability. Such integration requires muscular strength, endurance, flexibility and neuromuscular control. If any one of these factors is compromised functional and performance deficits are likely to occur. During adolescence due to rapid bony growth and effects of overhead sports, muscle imbalances have the potential to affect the throwing performance. Because of the critical role of shoulder rotators in throwing activities and the fact that antagonist muscle strength balance is fundamental, their evaluation becomes crucial.

This study was conducted with the primary goals of identifying the relationship of Isometric and isotonic strength of shoulder external and internal rotators with throwing performance in children. The results of our study clearly suggest that a relationship exists between Isometric and Isotonic strength and strength ratios of External rotators and Internal rotators of the shoulder joint. During throwing motions the arm velocity may reach very high internal rotation velocities and external rotators of the shoulder work to control this high speed action. But role of the external rotator muscles is not limited to deceleration of the arm but also to maintain dynamic stabilization of the gleno-humeral joint in overhead activities.

Many investigators using isokinetic devices have calculated a ratio of external-to-internal rotator muscle strength for concentric strength in an attempt to identify imbalances (Aldenrink & Kuck, 1986; Cook et al., 1987; Brown et al., 1988; Ellenbecker, 1991; Codine et al., 1997). But during the overhead motion, humeral rotation occurs at speeds which exceed Isokinetic testing capabilities. For example, the angular velocity of
the arm of a baseball pitcher has been estimated to reach approximately 6000°/sec (Pappas et al., 1985). No existing Isokinetic testing apparatus can attain even 1/10th of this speed. But still the Isokinetics have been used in various studies and the test speeds have been inconsistent in the literature. In fact many recent studies have reported that there is a poor correlation between functional activities and Isokinetic measurements (Yildiz et al., 2003; Goharpey et al., 2007; Jones et al., 2010).

In our study, Isometric and Isotonic External and Internal Rotator strength and strength ratios were calculated and their relationship with throwing strength was examined. Although Isometric measurements are reliable and valid means of muscle strength assessments, Isometric strength ratios of shoulder rotators have hardly been studied before and there was paucity of work done on the relationship of Isometric ratios of External and Internal rotators of the shoulder joint and their relationship to throwing performance. Even the dynamic measurements in the form of iso-inertial evaluations have not been utilized to observe their relationship with performance in throwing sports. In spite of the Isometric methods being static methods of testing, there is evidence of strong correlations between Isometric and isokinetic measurements (Reed et al., 1993).

The study also attempted to find out the effects of Isometric training near the end ranges to improve the ratios of External rotator(ER) to Internal Rotators(IR) strength and observe its effects on the Throwing performance (measured as distance of throw using a cricket ball of standard weight). The major finding of this study were the significant correlations between Strength ratios of ER: IR measured isometrically and isotonically and throwing distance.
5.1 ISOMETRIC STRENGTH AND STRENGTH RATIOS OF SHOULDER ROTATORS AND THROWING

In our study, we found significant differences between Isometric strength of External and Internal rotators strength when measured at both 70° and 90° of gleno-humeral External Rotation. The measurements performed at 90° of abduction and external rotation in our study revealed a ratio of ER: IR strength as 0.67 when measured at 70° of external rotation and 0.59 when measured at 90° of external rotation which are partly in accordance with the work of Donatelli et al., (2002). Although there is limited literature available on Isometric Strength of Shoulder rotators, our results are in accordance with some of the previously available data on the differences between External and Internal Rotator strength measured isometrically. Donatelli et al., (2000) in their study, reported that the mean strength of the external rotators in the dominant arm was 68% of the strength of the internal rotators when tested in the POS (Plane of Scapula) and 83% of the internal rotators when tested at 90° of abduction. In this study, the Shoulder rotator strength was measured at 0° of external rotation which is not a functional position of throwing. Some studies which measured the strength ratios using dynamic measures reported shoulder strength ratios of around 0.66 in young subjects specially overhead athletes (McMaster 1986; Allegrucci et al., 1994; Fowler, 1995). Magnusson et al. (1994) reported significant weakness in external rotator muscles of professional baseball pitchers. This was a very interesting finding in view of the fact that the subjects of this study were professionals. The author reported that throwing activity imposes tremendous demands on the external rotators which can lead to overuse and thus weakness. Wang et al. (2000) measured concentric strength ratios (external rotation – internal rotation in concentric contraction ratio) and reported a strength concentric ratio of $0.67 \pm 0.16$ for the dominant side and $0.98 \pm 0.22$ for the non-dominant side. However,
Isometric ratios of shoulder rotators have been reported by very few authors and literature on their relationship with overhead activities is extremely limited.

There are inherent difficulties in clinically testing the strength of the shoulder rotator muscles. These problems are related to position and mode of testing. The measurements in most studies were done at 0° of external rotation and in some at 90° of abduction but in our study we performed end range measurements in accordance with the recommendation of Scoville et al. (1997) who measured dynamic strength near the functional positions of throwing. Scoville et al. (1997) tested the subjects in with the shoulder in 90° of abduction and the elbow flexed to 90° (parallel to the horizontal plane). This position defined neutral rotation (0°). To more closely approximate functional dynamics of the shoulder, evaluation of the concentric and eccentric forces for both medial and lateral rotation were determined over the terminal 30° of motion tested in this study. These values were described as the end range forces and were performed to simulate the muscle forces that occur in the cocking phase of throwing, and the deceleration or follow-through phase. The ratio of concentric lateral rotation to concentric medial rotators measured isokinetically was reported to be 2:3 which is very close to our findings at 70° of external rotation. However, the results of eccentric measurements of strength and their ratios reported by Scoville et al. (1997) cannot be compared with our results as the Isometric and isotonic measurements utilised in our study do not evaluate the eccentric muscle work. Because many of the symptoms of instability or impingement are also reported in end range position, in addition to throwing performance other significant information can be obtained using this position.

Another very important finding of our study was a poor correlation between absolute Isometric strength of Internal rotators of the shoulder and Throwing performance and significant correlation between the ER: IR ratios and throwing
performance. This again indicates that absolute strengths may not be the best way of predicting throwing performance and it is the ratios, which may be a better indicator of the efficiency in overhead activities. Some of the studies which have measured the ratio for the lateral rotators firing eccentrically (antagonist) to the medial rotators firing concentrically (agonist) was 1.08:1 for the dominant shoulder and 1.05:1 for the non-dominant shoulder. Thus, it is apparent that despite the high correlations, there is remaining variability of isometric muscle strength with Isokinetic strength measurements at some levels.

It seems logical that the strength of external rotators would be less as it approaches end range external rotation due to the length tension relationship of muscles which affects the ratios as in externally rotated positions the muscles would be working in shortened positions which led to a decreased ER:IR ratio. In addition to the External rotators working in the shortened position, it is also noteworthy that the Internal rotators at 90° of externally rotated position would be working in a lengthened position although in our study, we did not find an increase in Internal rotator strength at 90°. Significant differences between muscle force at 70° and 90° was seen in both External and Internal rotator muscle groups (p<0.05).

The results of our study revealed a significant correlation between isometric ER:IR ratios and throwing performance measured as throwing distance. Although both the ratios i.e. at 70° and 90° showed a correlation with both types of throws used in our study, ER:IR ratios showed a stronger correlation with Standing Throw (ST) (Table 4.8 - Table 4.13) in comparison to Step Throw (SPT). An interesting finding was a stronger correlation of ER:IR ratio at 90° in comparison to that at 70° which corroborates well with the findings of Scoville et al. (1997) who reported that end range measurements may provide more relevant information in overhead athletes. Our results are also in
accordance with results of some studies which have studied the speed of ball throw and the muscle strength of specific upper limb muscles (Lachowetz et al., 1998; Clements, 2001). The speed of ball throw has a direct relationship with throwing distance and therefore has been considered as an outcome measure of throwing performance in various studies. Wooden et al. (1992), Lachowetz et al., (1998) and Clements (2001) have reported increased throwing speeds with increasing strength of shoulder muscles. It is evident that throwing performance increases with increasing strength but our study focused on Isometric and Isotonic type of measurements and throwing distance as a performance marker.

In the observational part of our study, we found that the average isometric ratios of ER:IR were 0.67 at 70° and 0.59 at 90° of external rotation which can be useful normative data for measuring muscle imbalances at end ranges of dominant shoulders of physically active individuals in this age group. Although, it can be expected that the ratio of ER: IR should be better in professional overhead sportspersons, conflicting reports which actually reported a decrease in ER strength in professionals (Magnusson, 1994) were also found during the literature search. Donatelli et al., (2000) measured the shoulder musculature strength isometrically and reported significant deficit of the gleno-humeral external rotator muscles and significantly stronger internal rotator muscles at 90° of abduction.

5.2 ISOTONIC STRENGTH (1 RM) RATIOS OF SHOULDER ROTATORS

In our study we used the Brzycki (1993) 1 RM prediction equation for evaluating the 1 RM of External and Internal rotators for dominant shoulder and examined the relationship between Isotonic strength and Throwing distance. In addition to Isokinetic methods, dynamic evaluations for strength training exercises is also performed based on a percentage of the one-repetition maximum (1-RM). One-RM strength is the greatest
amount of weight that an individual can lift only one time for a specific exercise (Fleck and Kramer, 1997). For exercise prescription, assessment, and goal setting it is helpful to know the 1-RM. Several studies have generated regression equations for predicting 1-RM strength using either a generalized prediction equation (Bryzcki, 1993; Lander, 1985) or prediction equations for specific exercises (Kuramoto and Payne, 1995; Dohoney et al., 2002). Other studies developed regression equations for the prediction of 1-RM bench press strength using the YMCA bench press test (Rose and Ball, 1992; Kim et al., 2002). Regression equations typically include the number of repetitions completed and the resistance used (Kim et al., 2002), although some equations include body weight (Rose and Ball, 1992). There is no doubt that 1 RM method of evaluating strength in sportspersons is a valid and reliable tool of assessment (Barrow & McGee, 1979; Sale & Mac Dougall, 1981; Enoka, 1988; Jones et al., 1988). Taylor and Bandy (2005) determined intra-rater reliability of the 1 repetition maximum (1RM) estimation for shoulder internal rotation.

In our study, the 1 RM of Internal rotators was found to be significantly higher than the External rotators which were in accordance with the results of isokinetic evaluations used in some of the previous studies. The ratios of Isotonic (1RM) and Isometric ER:IR (both at 70° and at 90°) were also found to be strongly correlated to each other. Statistically there was no significant difference in the Isometric ratios measured at 70° and between 1RM ER:IR ratios and Isometric ER:IR (at 90°) and 1 RM ER: IR. These findings are crucial in view of the fact that static strength ratios and dynamic ratios were quite similar.

Dynamic ER:IR ratios were mostly done as isokinetic measurements in previous researches (Bak and Magnusson 1997; Noffal 2003; Stickley et al., 2008; Andrade et al., 2011). These researchers studied functional ratios using the Isokinetic devices as
Eccentric External Rotator (ER): Concentric Internal Rotators (IR) and reported these ratios to be greater than 1. In addition to these many of these studies also investigated concentric ER: eccentric MR depending on the phasic activity of these muscles in the entire throwing action.

Shoulder internal rotation 1RM estimation appears to be reliable and accurate. In our study, we found the that 1 RM ER: IR ratios were strongly correlated to the Standing Throw (ST) \((r = 0.476)\) whereas the correlation was weak to moderate with the Step Throw (SPT) \((r = 0.360)\) which were similar to the observations in Isometric mode of muscle function in our study. Interestingly the Isometric ER: IR at 90° had a higher correlation \((r= .550)\) with Standing Throw (ST) in comparison to 1 RM ER: IR and ST, in spite of the fact that the latter is a dynamic measurement and the former a static measure. These findings of our study suggest that in addition to end range Isometric muscle evaluations isotonic assessment of external and internal rotators of the shoulder can provide very useful clinical information regarding shoulder function in overhead sporting activities such as throwing.

5.3 DIFFERENCE BETWEEN STANDING THROW (ST) AND STEP THROW (SPT)

In our study we used two types of throwing patterns- a Standing Throw (ST) in which the feet were stable and the front foot was not allowed to lift, and Step Throw (SPT) in which the front foot was allowed to move forward and a step could be taken to gain momentum while throwing. The standing throw was performed to increase the contribution of the shoulder muscles while throwing, as in a normal throw other body components are likely to contribute significantly. We found a significant difference in the distance attained by the subjects in the two types of throws. The mean distance thrown in the Standing Throw was only \(26.17 \pm 7.19 \, \text{m}\) in comparison to \(38.54 \pm 7.19 \, \text{m}\) in Step
Throw. This was expected as the momentum of the body in a step throw helps the thrower to attain more speed and thus distance. It is noteworthy that the mean throwing distance of subjects with least isometric ER: IR ratios in the experimental part of the study of our study was $21.22 \pm 0.66$ Kg for standing throw and $36.43 \pm 0.75$ for step throw which was lesser than means of all subjects.

Tillaar & Ettema (2004) reported that in such a Standing throw about $67\% (\pm 9\%)$ of total ball velocity at ball release was contributed by the internal rotation of the shoulder and extension of the elbow. The author reported that although $67\%$ contribution of the internal rotation of the shoulder and extension of the elbow to the total ball velocity at release is likely overestimated, but still remains extremely high. Other significant contributions could come from maximal angular velocity of shoulder horizontal adduction, shoulder abduction, forearm supination, upper torso rotation, forward trunk tilt and pelvis rotation (Matsuo et. al., 2001). However, in this position the torso rotation, forward trunk tilt and pelvis rotation contributed very little ($6\%)$ since the ratio of the modelled velocity and the ball velocity relative to the shoulder marker only increases $6\%$ compared with the total ball velocity at ball release. This was to be expected as the subjects had to throw from the spot without lifting their front foot, which is normal for handball players when they have to take a penalty throw. Thus, the other $27\%$ could come from maximal angular velocity of shoulder horizontal adduction, shoulder abduction, forearm supination and wrist flexion.

### 5.4 ISOMETRIC STRENGTH TRAINING AND THROWING PERFORMANCE

Only 60 subjects with the least ER: IR ratios out of a total of 209 were chosen for this part of the study and the External rotators were subjected to isometric strengthening for a period of 8 weeks in order to improve the ratios. A period of 8 weeks was chosen
because hypertrophy undoubtedly plays a dominant role in the course of strength and contribution by hypertrophy has been documented only after 3-5 weeks of resistance training (Elizabeth et al., 1986; Sale, 1988). Lachowetz et al. (1998) also used an 8 week training program for various upper body muscles in baseball throwers. Although there was significant improvement in the ratios, but pairwise comparisons revealed that there was very little improvement (statistically insignificant) between 0-4 weeks of Isometric training. Staron et al. (1994) reported that maximal strength gains in men significantly increase only after 4 weeks of strength training. In our study between 4-8 weeks there was significant improvement in the ER:IR ratios and accordingly a change was observed in the throwing distances both in Standing Throw(ST) as well as in Step Throw(SPT).

The Isometric training at 90° of External rotation which led to an increase in throwing distance clearly indicates that the ER:IR strength near end ranges may be an important contributor to throwing performance as this functional position imposes specific demands on the shoulder stability. It is possible that when ER: IR ratios are poor, greater demands of stability and lack of posterior muscle activity reduces the overall force production of IR also leading to the decrease in throwing performance. It appears logical to say that if an antagonist is not functioning optimally, the agonist may also produce less force to avoid injury to the joint, thereby decreasing performance. We propose that the ER:IR ratios improved with the end range isometric training in our study which led to this enhanced performance.

5.5 RELATIONSHIP OF TRICEPS AND WRIST FLEXORS WITH THROWING

Although our hypothesis testing did not require Triceps and wrist flexor evaluation, we measured their Isometric strength to observe their relationship to throwing. For the elbow extensors, our results suggest a significant correlation between
Isometric Strength of triceps and both types of throwing actions. Although Tillar & Ettema (2004) used ball velocity in their study, our results are partly in accordance with their findings that in the Standing Throw about 67% (± 9%) of total ball velocity at ball release is contributed by the internal rotation of the shoulder and extension of the elbow. Other significant contributions could come from maximal angular velocity of shoulder horizontal adduction, shoulder abduction, forearm supination, upper torso rotation, forward trunk tilt and pelvis rotation (Matsuo et. al., 2001). Very few studies have examined the relationship of triceps muscle strength and throwing performance. Terzis et al. (2003) measured the triceps strength and found its relationship to overhead sports activity. Lin et al. (2010) studied the ratio of biceps concentric to triceps concentric functional strength and reported that the ratio strongly predicts elbow-injury status in baseball players.

We found a poor correlation between the wrist flexor strength and throwing performance in both methods of throwing (Pearson coefficient of less than 0.1). It appears that the wrist flexors can only contribute to minor extent (given the leverage of the hand and maximal wrist flexion speed). Adams et al. (1988) also conducted a study involving wrist strengthening in sportspersons and reported a poor relationship between strengthening wrist flexors and throwing velocity. The findings of Tatsuyuki et al. (2003) also support our findings of insignificant correlation between the two. They reported that the wrist contributes more towards the accuracy of throwing rather than the force delivered to the ball and thereby the speed.

Our literature search did yield a lot of relevant information on the imbalances between shoulder external and internal rotators but the previous studies have not determined whether these imbalances are a byproduct of the demands imposed by the sport and therefore are needed for optimal performance. The results of our study strongly
suggest that Isometric strength ratios of the gleno-humeral External Rotators to Internal Rotators have a strong relationship with throwing distance and isometric training to correct these ratios can lead to better performance. Isometric strength measurements of shoulder rotators to assess imbalances can be used as an effective tool in addition to the functional tests for predicting throwing performance.

In addition to Isometric strength ratios, the results of Isotonic muscle evaluations also suggest that 1 RM measurements of shoulder rotators can also provide useful information for predicting performance in overhead throwing.
CONCLUSION

Based on our results and analysis, we would like to suggest the following clinically relevant inferences of our study:

1) Shoulder External and Internal Rotators are important components of the kinetic chain involved in throwing and muscle imbalances between the two are common. Therefore the shoulder rotators should be assessed to evaluate muscle imbalances which could be limiting throwing performance.

2) Isometric strength and strength ratios of Shoulder Rotators should be measured near end ranges of external rotation to predict overhead shoulder function in sports.

3) The 1 RM assessment using prediction equation is a safe and reliable method of measuring shoulder muscle imbalances and can be used effectively to quantify the same in addition to isometric methods.

4) Improving Shoulder imbalances using isometric strengthening has the potential to increase throwing performance.