omplex coordination of numerous muscle contractions is required to effectively throw a baseball. The complexity of the task is heightened during a game, during which the velocity and location of the pitch determine success. The inherent instability of the shoulder makes baseball players highly susceptible to injury, and adolescent players are especially susceptible. Shoulder injuries in baseball range in severity from general tenderness to Little Leaguer’s shoulder, which involves a stress fracture of the proximal humeral epiphysis. Such injuries are often associated with overuse and pitching while fatigued. Previous research has demonstrated that type of pitch, number of pitches thrown per game, and number of pitches thrown during the season can contribute to shoulder pain in youth baseball pitchers. Fleisig et al. reported that fundamental pitching mechanics remain constant during progression through youth, high school, college, and professional levels of competition, but joint forces increase as an athlete matures. Thus, players at high levels of competition possess elevated risk for injury. Fortunately, increasing strength as the body matures can help prevent such injuries.

The incidence rate of injuries requiring medical intervention in adolescent baseball players appears to be increasing, which is believed to be associated with an increase in both the intensity and frequency of competition. Many overuse shoulder injuries do not develop until the mid to late teens (i.e., high school age). Guidelines for injury prevention in baseball have been focused on limitation of the total number of pitches thrown during a game or season and regulation of the types of pitches thrown.

Research has demonstrated that proper preparation and strengthening of the shoulder musculature can prevent injuries in throwing athletes. Many of the training programs developed exclusively for baseball players have focused on strengthening the rotator cuff muscles (i.e., subscapularis, supraspinatus, infraspinatus, and teres minor), which dynamically stabilize the glenohumeral joint. The supraspinatus tendon is especially vulnerable to injury during performance of the throwing motion due to its anatomical proximity to the inferior surface of the acromion. Both overuse tendinosis and also impingement of the supraspinatus tendon between the head of the humerus and the acromion are associated with muscular weakness. Supraspinatus weakness has been related to the incidence of shoulder injury in professional baseball players. Yanagisawa et al. identified increased MRI signal intensity in the supraspinatus muscle after a pitching session. Thus, adequate strength of the supraspinatus muscle appears to be an important factor for prevention of throwing injuries in baseball players.

Plyometric exercises, which involve rapid transitions from eccentric to concentric muscle contractions, have been advocated for rotator cuff strengthening. Rapid transition in contraction mode during the stretch-shortening cycle is believed to enhance muscle reactive capabilities that improve dynamic joint stability. Plyometric training regimens often use medicine balls for performance of exercises that replicate the eccentric and concentric forces associated with pitching.
Despite widespread use of plyometric training, very little research has been done to assess the effectiveness of such programs. The “Ballistic Six” is a sport-specific plyometric training program designed to strengthen the rotator cuff muscles in the throwing athlete. Carter et al. found that this program significantly improved throwing velocity in college baseball players, but the strength increase that resulted was not significantly greater than that observed in players who performed an alternate off-season strengthening program that involved elastic resistance and dumbbells, and they did not specifically assess strength increase in the supraspinatus muscle. We examined the effectiveness of the “Ballistic Six” for strengthening of the supraspinatus musculature in high school baseball players.

Procedures and Findings

Four high school baseball players were recruited from two high schools in Portland, Maine: one catcher, one pitcher, one infielder, and one outfielder (average 16.25 years of age, 174.1 cm height, 71.4 kg weight). Three of the participants played at the varsity level and one was on a freshman baseball team. One participant who was also engaged in a separate off-season program of exercises and baseball pitching was dismissed after shoulder fatigue precluded continued participation in the “Ballistic Six” training program.

Hand-held dynamometry was used to obtain two pretraining assessments of the supraspinatus strength that were at least seven days apart (Figure 1). Kelly et al. demonstrated that isolated activation of the supraspinatus muscle is best achieved in a position of 90 degrees of scapular elevation and 45 degrees of glenohumeral external rotation, and hand-held dynamometry is an accepted method for determination of upper extremity strength. The two pretraining strength assessments were averaged to establish baseline strength level, after which participants completed a 10-week training program (Table 1). The “Ballistic Six” program consists of six plyometric exercises that are performed two times per week (Figure 2). Each exercise session was supervised by the principal investigators to ensure program completion and to monitor participant safety. A single post-training strength assessment was performed within one week of completion of the 10-week training program. All three of the athletes demonstrated an increase in supraspinatus strength (Table 2), which averaged 4.28 kg of increased force output.

Discussion

Numerous studies have documented that high school baseball players are at high risk for the occurrence of a shoulder injury, which is primarily due to the ballistic nature of the throwing motion. The supraspinatus muscle is particularly susceptible to injury.
Table 2. Athletes Demonstrating an Increase in Supraspinatus Strength

<table>
<thead>
<tr>
<th>Player</th>
<th>Pretraining Strength Trial 1</th>
<th>Pretraining Strength Trial 2</th>
<th>Pretraining Strength Mean of Trials 1 &amp; 2</th>
<th>Posttraining Strength</th>
<th>Pre- to Post-training Strength Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.85</td>
<td>8.05</td>
<td>9.45</td>
<td>13.40</td>
<td>3.95</td>
</tr>
<tr>
<td>S2</td>
<td>6.10</td>
<td>7.10</td>
<td>6.60</td>
<td>12.95</td>
<td>6.35</td>
</tr>
<tr>
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<td>10.05</td>
<td>10.30</td>
<td>13.15</td>
<td>2.85</td>
</tr>
</tbody>
</table>

Figure 2 Components of the “Ballistic Six” exercise program: (a) external rotation in adducted position against elastic resistance, (b) external rotation exercise in abducted position against elastic resistance, (c) overhead weighted-ball toss, (d) externally rotating weighted-ball toss, (e) deceleration catch of weighted-ball toss, (f) acceleration toss of weighted-ball.
Trakis et al.\textsuperscript{12} reported that adolescent baseball pitchers with shoulder pain demonstrated less supraspinatus strength compared to those without pain and suggested that it might result from repetitive eccentric loading. They also suggested that prophylactic strengthening of the rotator cuff muscles might prevent injury in adolescent baseball players. Weakness of the supraspinatus in professional baseball players has been associated with elevated risk for in-season throwing-related shoulder injuries that require surgical intervention.\textsuperscript{30}

Several studies have assessed the effectiveness of different exercises for strengthening of the supraspinatus muscle,\textsuperscript{31-33} but none of them involved multidirectional functional movement patterns that replicate components of the baseball throwing action. The “Ballistic Six” program was designed to replicate the stresses imposed by throwing a baseball through plyometric exercises, which have been shown to be very effective for realization of strength gains.\textsuperscript{34} Carter et al.\textsuperscript{22} examined the effect of an 8-week “Ballistic Six” exercise program on pitch velocity, as well as internal and external rotation strength, in collegiate baseball players, but the strength measurements did not isolate the force output of the supraspinatus muscle.

The exercise program we administered closely followed the progression described by Pretz.\textsuperscript{21} The players were encouraged to perform both single-arm and double-arm throwing exercises with the greatest amount of force possible, without compromising form. Each athlete was closely monitored during each training session to ensure compliance with proper exercise performance technique, with verbal cues provided when necessary to correct improper form.

An advantage of this program is the minimal amount of equipment that is required. The entire program can be completed with resistive elastic tubing material and four weighted balls (2.2-lb, 6-lb, 8-lb, and 10-lb). The exercises can be performed by pairs of athletes, with one player throwing the weighted ball while the second player monitors form and tosses the weighted ball back to the exercise partner.

Conclusion

The results of this pilot study suggests that supraspinatus muscle strength can be improved through a 10-week, sport-specific, plyometric training program, which may reduce the risk of shoulder injuries in male high school baseball players.


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