The Effect of a High Pitch Volume on Musculoskeletal Adaptations in High School Baseball Pitchers

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Background: Shoulder range of motion and strength adaptations occur at an early age in baseball pitchers.

Purpose/Hypothesis: The purpose of this study was to examine the effect of pitch volume on in-season and year-to-year range of motion (ROM) and strength adaptations in high school baseball pitchers. The hypothesis was that a high pitch volume will not affect range of motion asymmetries but will impair supraspinatus strength.

Study Design: Cohort study; Level of evidence, 2.

Methods: Pre- and postseason ROM and strength measures were performed on pitchers from 3 high schools for 4 consecutive seasons, for a total of 95 player-seasons (mean ± SD participant age, 16 ± 1 years). Preseason measures were repeated the next year on players returning to the teams, for a total of 71 consecutive player-seasons. ROM tests included internal-external rotation and posterior shoulder flexibility. Strength tests (hand-held dynamometer) included internal-external rotation, supraspinatus, and scapular retraction. Pitchers were categorized by pitch count for the season (high, >400; moderate, 180-400; low, <180). ROM and strength changes in the dominant versus nondominant arm were assessed by analysis of variance.

Results: Dominant versus nondominant ROM differences did not change from pre- to postseason (P = .36-.99) or from one year to the next (P = .46-.86), with no effect of pitch volume (P = .23-.87). Supraspinatus strength decreased in the dominant arm during the season, with 13% loss in high-volume pitchers ($P < .001$) and insignificant losses in moderate- (6%) and low-volume pitchers (2%). Strength in other tests was unaffected by pitch volume. Consistent with physical development, strength increased bilaterally from one year to the next (supraspinatus, 12%; external rotation, 15%; internal rotation, 14%; scapular retraction, 23%; $P < .001$). Supraspinatus strength gain in the dominant arm was affected by prior pitch volume (P = .02): 24% in low-volume pitchers ($P < .01$), with no significant change in moderate-volume (0%; P = .99) or high-volume (5%; P = .99) pitchers.

Conclusion: Dominant versus nondominant ROM differences did not progress during the season, or from one year to the next, and were unaffected by pitch volume. A high pitch volume was associated with in-season supraspinatus weakness and diminished strength gains from one year to the next. In conclusion, a high pitch volume appeared to have a catabolic effect on supraspinatus strength.

Keywords: hand-held dynamometer; supraspinatus; empty-can test; glenohumeral range of motion; posterior shoulder tightness

Musculoskeletal adaptations to repetitive baseball pitching are well described. With respect to shoulder range of motion (ROM), pitching is associated with a loss of glenohumeral internal rotation (IR) and a gain in external rotation (ER). These adaptations have been demonstrated in professional pitchers,[5,9,14] college pitchers,[1,3,6] and high school pitchers.[10,11] Additionally, loss of IR ROM is associated with increased posterior shoulder (PS) tightness, which has been measured using the Tyler test.[7,13] These ROM adaptations in pitchers appear to be similar across different age groups. For example, loss of IR was 9° to 12° in professional pitchers,[5,9,14] 10° to 13° in college pitchers,[1,3,6] and 12° to 13° in high school pitchers.[10,11] Similarly, ER gain in the dominant arm was not different between professional (14°,[5] 11°,[9] 8°[14]), college (14°,[1] 16°[6]) and high school (11°[11]) players.

With regard to shoulder strength, asymmetries between the dominant and nondominant arm appear to depend on the pitcher's age and level of play. High school pitchers

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(tested in postseason) were stronger on the dominant versus nondominant side in the internal rotator, external rotator, latissimus dorsi, middle trapezius, and lower trapezius muscles, with no difference in the rhomboid and supraspinatus muscles.[11] College pitchers had a tendency for greater strength in the internal rotator muscles, with no apparent side-to-side difference in the external rotator, latissimus dorsi, rhomboid, middle trapezius, or lower trapezius muscles.[6] Notably, the supraspinatus was 12% weaker on the dominant versus nondominant side. Supraspinatus weakness was previously noted in professional pitchers (8% deficit) and was thought to represent subclinical pathologic changes.[5]

Taken together, these studies[1,3,5,9,10,11,14] indicate that ROM adaptations occur at an early age and are not progressive. However, the trend for older pitchers to have supraspinatus weakness suggests that repetitive stress may have a progressive, deleterious effect on supraspinatus strength.

The effect of a season of pitching on ROM and strength adaptations in high school pitchers has not been previously examined. Furthermore, it is not known how these pitching-induced adaptations change from year to year as the high school athlete matures. Therefore, the purpose of this study was to (1) examine the changes in shoulder ROM and strength from the start to the end of a single season and from year to year in high school pitchers and (2) determine whether pitch volume affects ROM and strength adaptations. In line with the previous research, we hypothesized that ROM asymmetries would be apparent but unaffected by pitch volume. With respect to strength, drawing on previously reported supraspinatus weakness in pitchers,[5,6] we hypothesized that a high pitch volume would have a deleterious effect on shoulder strength and that this would be most apparent in the supraspinatus muscle.

METHODS

Shoulder strength and ROM measurements were made before and after the spring baseball season in high school pitchers from 3 different high schools for 4 consecutive seasons from 2008 to 2011. Pitchers currently injured, in rehabilitation, or presenting with shoulder soreness were excluded, as were any pitchers who did not pitch in at least 1 game during the season or who subsequently withdrew from the team during the season. The study was approved by institutional review board, and subjects gave written informed assent with parental or guardian consent.

All pitchers on each team were scheduled for preseason screening, which included the tests for this study. At the end of the season, testing was repeated on all pitchers who had pitched in at least 1 game and who were currently on the team. Because most nonsenior athletes returned to pitch on subsequent seasons, many players were tested during more than 1 season. Of a total of 69 pitchers, 16 were tested for 2 consecutive seasons, 2 were tested for 3 consecutive seasons, and 2 were tested for 4 consecutive seasons (total, 95 player-seasons). Of the 95 player-seasons studied, 12 were freshman pitchers, 22 were junior varsity, and 61 were varsity (mean ± SD age, 16 ± 1 years). Excluding players who graduated from high school or chose not to return to the team the following year, 46 pitchers were tested in the preseason for consecutive seasons. Of these, 26 were tested for 2 consecutive seasons, 15 for 3 consecutive seasons, and 5 for 4 consecutive seasons (total, 71 consecutive player-seasons). Of these 71 consecutive player-seasons, 7 were freshman pitchers, 21 were junior varsity pitchers, and 43 were varsity pitchers in the first year.

The number of games pitched during the season was recorded for each pitcher, including the number of pitches in each game. Depending on the number of games scheduled in a given week, teams practiced between 3 and 5 times per week. Players were involved in a game or practice on 5 or 6 days throughout the season. The volume of pitches thrown in practice was not recorded. In preseason, pitchers reported whether they had participated in baseball during the previous winter, fall, and summer seasons.

ROM Measurements

The IR, ER, and PS ROM measurements were assessed bilaterally by use of a digital level as described previously (Figure 1).[12] Passive IR ROM was measured with the player in the supine position with the shoulder in 90° of abduction and with the elbow in 90° of flexion. The digital level was aligned with the forearm while the shoulder was passively rotated. The ER ROM was measured similarly. PS ROM was measured with the player in the side-lying position, with the shoulder and elbow flexed to 90°. The tester manually stabilized the axillary border of the scapula when the player's arm was placed in 90° of shoulder abduction and 90° of elbow flexion (starting position). This scapular position was maintained as the arm was lowered. The digital level was aligned with the humerus, and the angle relative to the horizontal was recorded (cross-chest abduction angle).

Strength Measurements

Strength in IR, ER, supraspinatus (empty-can test), and scapular retraction was measured bilaterally with a handheld dynamometer (Lafayette Manual Muscle Tester) using the break test as described previously (Figure 2).[12] The IR strength was measured with the player in the supine position with the shoulder in 90° of abduction and the elbow in 90° of flexion. The arm was placed in neutral rotation, and the subject maximally resisted against the dynamometer placed on the volar aspect of the wrist. ER strength was tested in a similar manner, with the dynamometer placed on the dorsal aspect of the wrist. Supraspinatus strength was measured with the player in the sitting position with the shoulder flexed 90° in the scapular plane, the elbow in full extension, and the shoulder fully internally rotated (thumb down; ie, empty-can test). The dynamometer was placed on the ulnar aspect of the wrist, and the subject maximally resisted a downward force. Scapular retraction strength was measured with the player in the prone position with the shoulder abducted 90° and the elbow in 90° of flexion. The arm was held at 20° horizontal abduction (20° above the horizontal) with the dynamometer placed

Figure 1. Passive range of motion measurements for (A) internal rotation and (B) external rotation. (C) Passive posterior shoulder flexibility measurement.

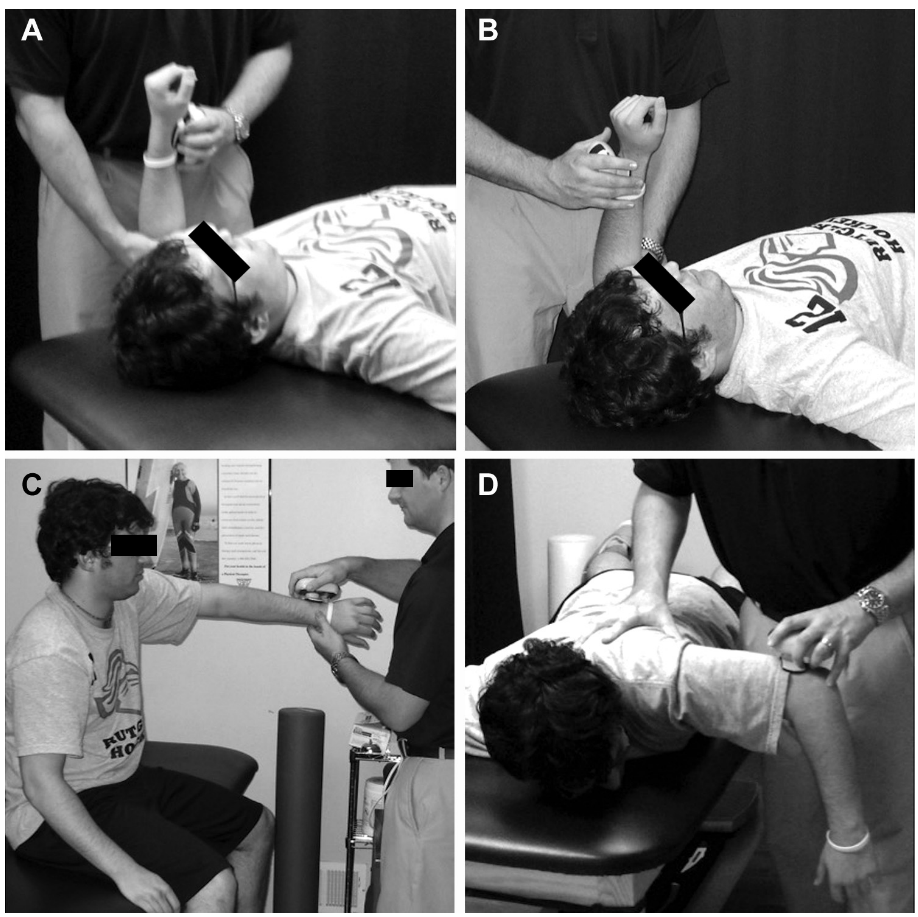

Figure 2. Strength measurement for (A) internal rotation, (B) external rotation, (C) supraspinatus, and (D) scapular retractor.

at the elbow, and the subject maximally resisted a downward-directed force until the arm reached a horizontal position. The average of 3 repetitions was recorded for each arm in each strength test. Tests were deemed invalid if pitchers reported pain during strength testing, and the data were not included in the dataset. Orthopaedic screening occurred before strength testing, and symptomatic pitchers were not cleared to participate in strength testing. Consequently, no pitchers reported pain during any of the strength tests.

Data Analysis

No specific references are available to indicate what represents a high volume of pitches in a season for high school pitchers. Therefore, for pre- to postseason analyses, we categorized pitchers by pitch count for the season by separating them into 3 equal groups: high volume (>400 pitches; n = 32), moderate volume (180-400 pitches; n = 32), and low volume (<180 pitches; n = 31). Mixed-model analysis of variance (ANOVA) was used to assess the effects of time (preseason to postseason or year to year), pitch volume (high, moderate, low), and side (dominant vs nondominant) on ROM and strength changes. Bonferroni corrections were applied to pairwise comparisons. Assuming equal division of 95 player-seasons between groups, we estimated that the sample had 80% power to detect a 4° difference in between-group ROM changes from pre- to postseason at $P < .05$. For strength measures, we estimated that the sample had 80% power to detect a 5% to 12% between-group difference in strength from pre- to postseason at $P < .05$. These estimates were based on a standard deviation of 8° for the variability in repeated measures of IR and ER ROM in pitchers and a standard deviation of 10% to 24% for the variability in changes in strength.[6]

Analysis of changes in strength and ROM from one year to the next was performed on the preseason data recorded in consecutive years. Since many of the high-volume pitchers were seniors and were therefore not available for testing the following year, it was necessary to recategorize the groups to have equal numbers in each group (high volume, >330 pitches [n = 24]; moderate volume, 151-330 pitches [n = 23]; and low volume, <151 pitches [n = 24]). For the effect of pitch volume on year-to-year changes (71 consecutive player-seasons), the estimated detectable effects were 5° for ROM and 6% to 14% for strength.

Comparison of strength changes between the 4 tests was performed by calculating the percentage change in strength from pre- to postseason and comparing this value between the dominant and nondominant arms and between each of the 4 tests (side × muscle group ANOVA). Since the lever arm for the supraspinatus test was twice the lever arm for the other tests (distance from dynamometer to center of joint rotation), it was not valid to compare actual force value between muscle groups. In this preseason test setting, it was not practical to measure lever arms for the tests to enable a torque calculation. Thus, percentage changes in strength were used to compare changes between muscle groups.

RESULTS

Pitchers participated in a mean (±SD) of 6 ± 4 games, throwing 54 ± 26 pitches per game. High-volume pitchers (566 ± 153 pitches) participated in more games (9 ± 4) than did low-volume pitchers (105 ± 45 pitches, 4 ± 3 games; $P < .001$) and moderate-volume pitchers (288 ± 71 pitches, 5 ± 2 games; $P < .001$). High-volume pitchers threw more pitches per game than did low-volume pitchers (71 ± 20 vs 30 ± 17; $P < .001$) and had a tendency for more pitches per game compared with moderate-volume pitchers (60 ± 20; $P = .06$). Sixteen pitchers participated in winter, fall, and summer baseball in addition to the spring season being studied. Thirty-seven pitchers participated in baseball in 2 other seasons (32 fall and summer, 3 summer and winter, 2 fall and winter). Twenty-five pitchers participated in baseball in 1 of the other seasons (20 summer, 5 fall). Seventeen pitchers did not participate in baseball in the previous winter, fall, or summer seasons. Participation rates in baseball in the previous winter, fall, and summer were not different between high-, moderate-, and low-volume pitchers (chi-square linear association, $P = .66$).

Preseason Strength and ROM

All pitchers completed strength testing without pain. In preseason, the pitchers had no side-to-side differences in supraspinatus strength (1% ± 19%), scapular retractor strength (0% ± 17%), or external rotator strength (0% ± 20%). The internal rotators were 5% ± 19% stronger on the dominant versus nondominant side ($P < .01$). Pitchers had 9° ± 10° less IR ROM, 9° ± 11° greater ER ROM, and 8° ± 14° less PS ROM on the dominant versus nondominant side (all $P < .001$).

In-Season Changes in Strength

During the season, supraspinatus strength decreased in the dominant arm (main effect of time, 7%; $P < .001$) but not in the nondominant arm (main effect of time, 3%; $P = .13$; side × time, $P < .05$) (Figure 3A). Supraspinatus strength loss in the dominant arm was affected by pitch volume (time × pitch volume, $P < .05$), with 13% strength loss in high-volume pitchers ($P < .001$), 6% loss in moderate-volume pitchers ($P = .072$), and 2% in low-volume pitchers ($P = .50$). Strength was not different between the dominant and nondominant side for any of the pitch volume groups in preseason or postseason. However, for the high-volume pitchers, supraspinatus strength was 2% higher on the dominant versus nondominant side in preseason but 5% weaker in postseason (time × side, $P < .01$).

External rotator strength decreased during the season (time effect, 7%; $P < .001$) (Figure 3B), but this effect was not different between the dominant (8%) and nondominant (6%) arms (time × side, $P = .28$) and was unaffected by pitch volume (6% high volume, 6% moderate volume, 8% low volume; time × pitch volume, $P = .39$).

Internal rotator strength also decreased during the season (6%; $P < .01$) (Figure 3C), but this effect was also not different between the dominant (7%) and nondominant (4%) arms (time × side, $P = .07$) and was unaffected by pitch volume (6% high volume, 5% moderate volume, 5% low volume; time × pitch volume, $P = .48$).

Similarly, scapular retractor strength decreased during the season (4%; $P < .05$) (Figure 3D), an effect that was not significantly different between the dominant (5%) and nondominant (3%) arms (time × side, $P = .28$) and was unaffected by pitch volume (2% high volume, 2% moderate volume, 6% low volume; time × pitch volume, $P = .92$).

When we compared percentage strength loss from pre- to postseason between muscle groups, it was apparent that overall strength loss was greater on the dominant versus nondominant sides (5% ± 12% vs 2% ± 13%; $P < .001$), but this effect was not different between the different muscle groups (side × muscle group, $P = .71$).

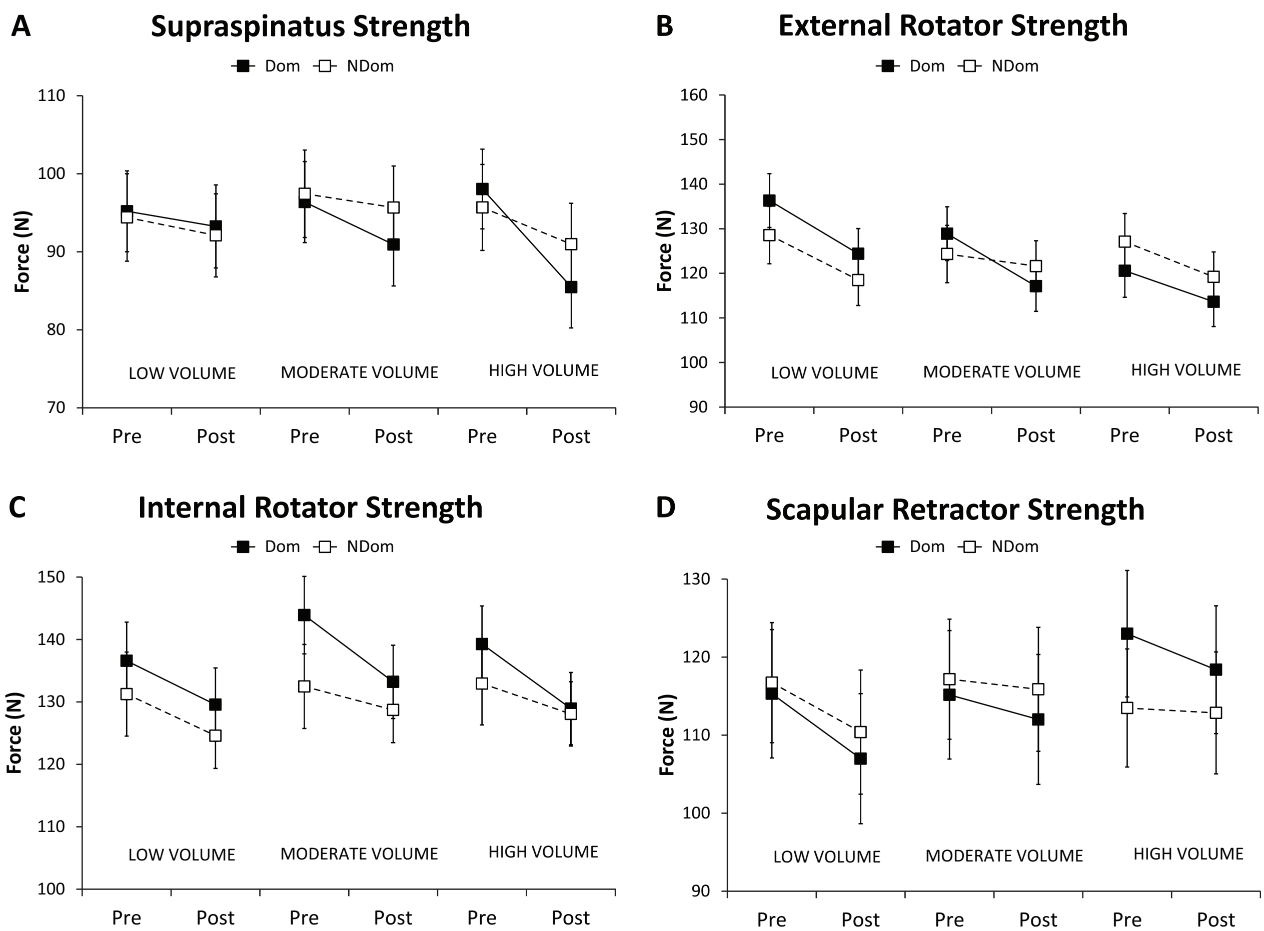

Figure 3. Strength changes in the (A) supraspinatus, (B) external rotators, (C) internal rotators, and (D) scapular retractors from preseason (Pre) to postseason (Post) in the dominant (Dom) and nondominant (NDom) arms of low-, moderate-, and high-volume pitchers. See the Results section for effects of time, dominance, and pitch volume. Mean ± standard error displayed.

In-Season Changes in ROM

The loss of IR ROM in the dominant versus nondominant arm did not change during the season (P = .53) and was unaffected by pitch volume (P = .23) (Figure 4A). Similarly, the gain in ER ROM in the dominant versus nondominant arm did not change during the season (P = .87) and was unaffected by pitch volume (P = .48) (Figure 4B). PS ROM loss was also unchanged during the season (P = .46) and was unaffected by pitch volume (P = .41) (Figure 4C).

Year-to-Year Changes in Strength

Consistent with physical development, strength increased bilaterally from one year to the next in all 4 muscle groups tested (supraspinatus 12%, external rotation 15%, internal rotation 14%, scapular retraction 23%; $P < .001$) (Figure 5). However, supraspinatus strength changes in the dominant versus nondominant arm were affected by pitch volume in the prior season (side × time × pitch volume, P = .02) (Figure 5A). In the dominant arm, supraspinatus strength increased by 24% in low-volume pitchers ($P < .01$) but had no significant changes in moderate-volume pitchers (0%; P = .99) and high-volume pitchers (5%; P = .99).

External rotator, internal rotator and scapular retractor strength increases from year to year were unaffected by pitch volume (side × time × pitch volume: P = .72 [external rotator], P = .66 [internal rotator], P = .58 [scapular retractor]) (Figure 5, B-D).

Year-to-Year Changes in ROM

The loss of IR ROM in the dominant versus nondominant arm did not change from one season to the next (P = .83) and was unaffected by pitch volume (P = .95) (Figure 6A). Similarly, the gain in ER ROM in the dominant versus nondominant arm did not change from one season to the next (P = .51) and was unaffected by pitch volume (P = .49) (Figure 6B). PS ROM loss was also unchanged from one season to the next (P = .65) and unaffected by pitch volume (P = .55) (Figure 6C).

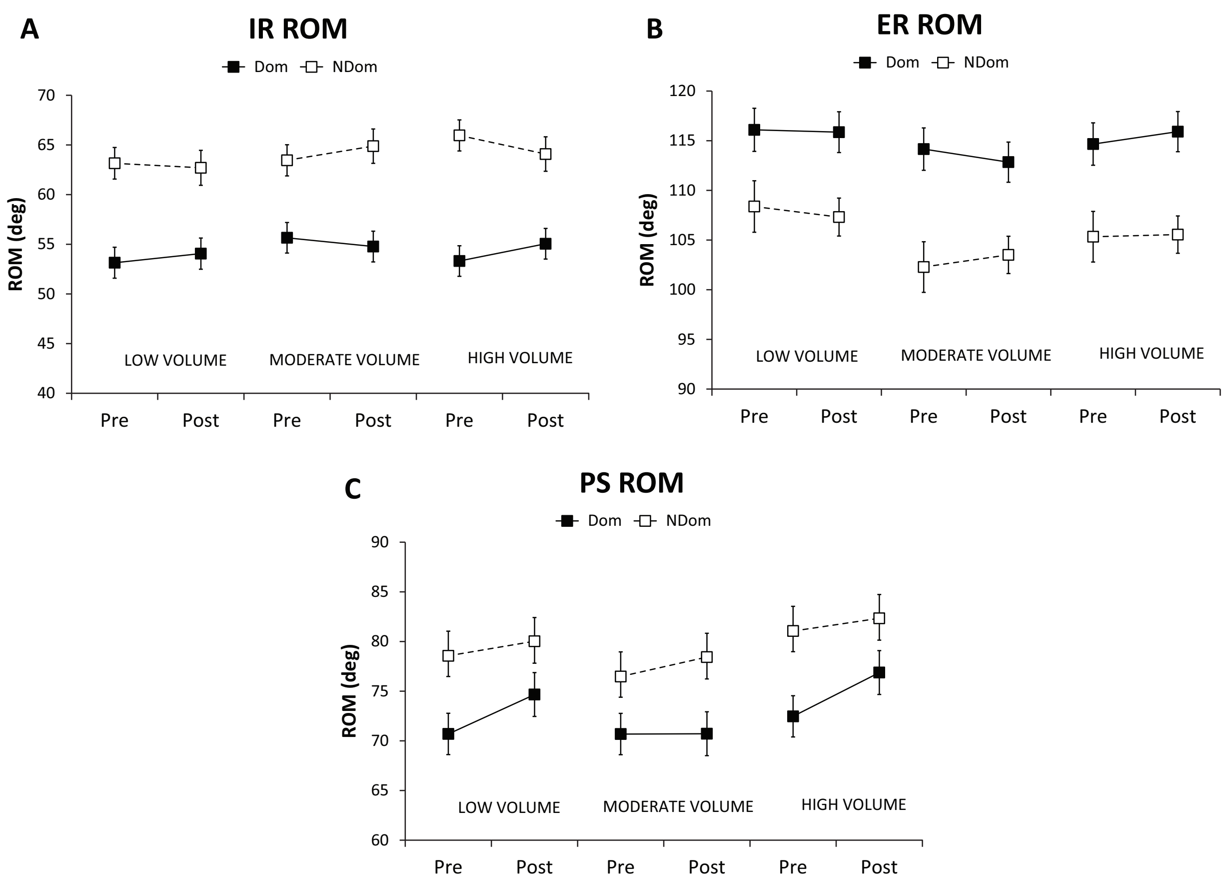

Figure 4. Changes in (A) internal rotation (IR), (B) external rotation (ER), and (C) posterior shoulder (PS) range of motion (ROM) from preseason (Pre) to postseason (Post) in the dominant (Dom) and nondominant (NDom) arms of low-, moderate-, and high-volume pitchers. See the Results section for effects of time, dominance, and pitch volume. Mean ± standard error displayed.

DISCUSSION

In this study, musculoskeletal adaptations in high school pitchers were examined with respect to changes from the start to the end of the season and from the start of one spring season to the start of the next spring season. With respect to shoulder strength, in general there was significant bilateral strength loss in the external rotators, internal rotators, and scapular retractors during the season, with strength loss only on the dominant side for the supraspinatus. Over the subsequent 9 months, strength increased in all 4 muscle groups such that there was an overall strength gain from one year to the next. These strength gains were bilateral and consistent with physical maturation. Shoulder ROM showed a different pattern. In preseason, pitchers had the typical loss of IR ROM in the dominant versus nondominant arm, with associated PS tightness, and gain in ER ROM in the dominant versus nondominant arm. However, these adaptations did not progress during the season or change from one year to the next.

Strength loss from pre- to postseason in the nondominant arm may be attributed to a crossover effect due to central fatigue.[2] Bilateral strength loss has been demonstrated in high school softball pitchers immediately after a pitching performance. This was attributed to acute central fatigue. It is possible that with repetitive pitching over a season, central activation becomes impaired such that both the dominant and nondominant arms exhibit weakness.

The volume of pitches thrown during the season affected the strength changes in the supraspinatus. A high pitch volume was associated with a greater loss of supraspinatus strength during the season and a failure to gain strength from one year to the next.

The impairment in supraspinatus strength seen in these high school pitchers with a high pitch volume is consistent with observations of supraspinatus strength in adult pitchers. In the present study, baseline supraspinatus strength was not different between the dominant and nondominant arms (1% difference). However, preseason supraspinatus strength the following year, for pitchers who had a high pitch volume during the previous season, was 10% lower in the dominant versus nondominant arm. This supraspinatus weakness (10%) is in line with supraspinatus weakness reported by Mullaney et al[6] for college pitchers (12%) and by Magnusson et al[5] for professional pitchers (8%). Together, these findings suggest that the supraspinatus weakness seen in adult pitchers may be related to the chronic effects of high-volume pitching during physical development. Magnusson et al[5] referred

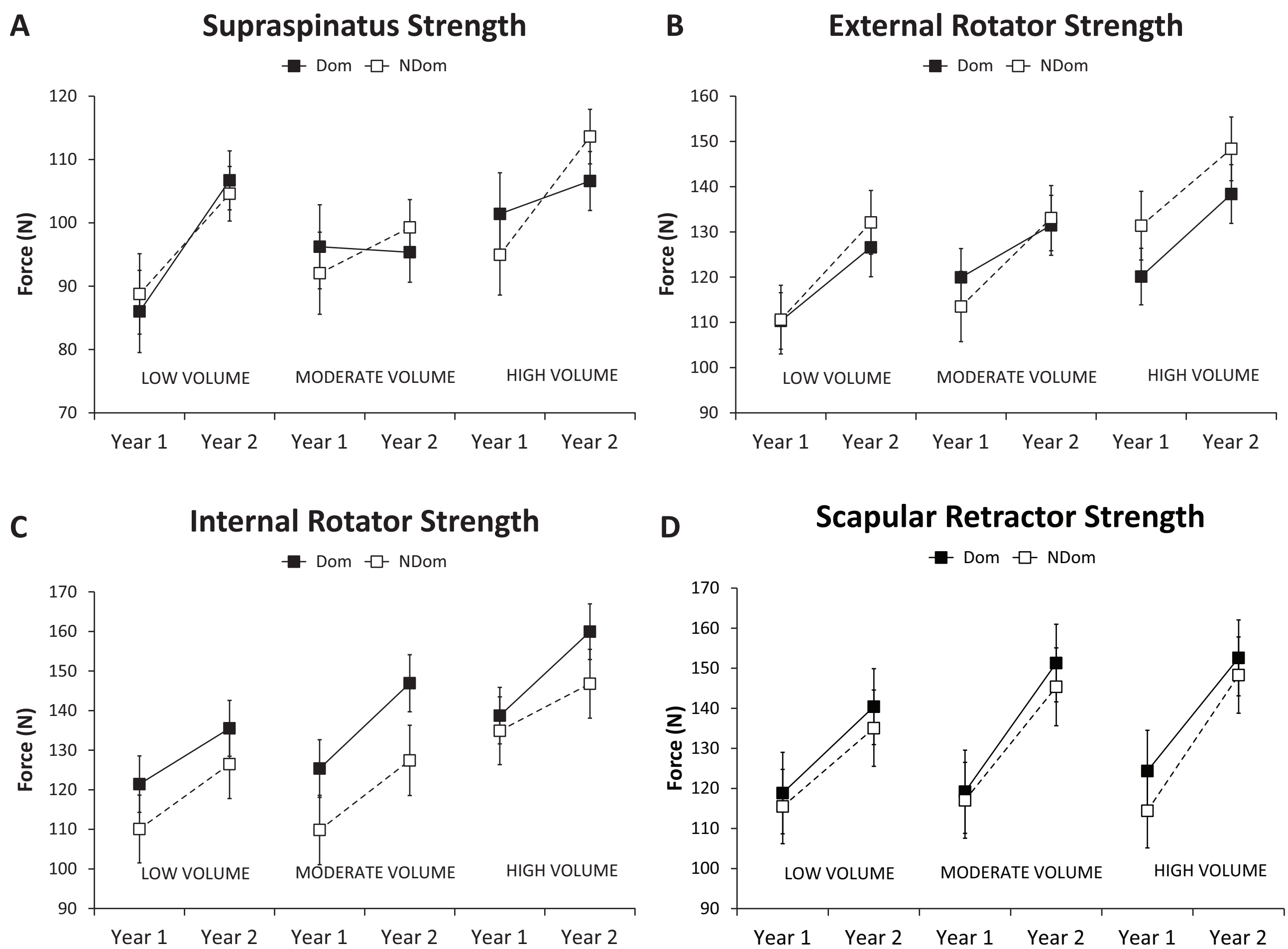

Figure 5. Changes in preseason strength from one year to the next in the (A) supraspinatus, (B) external rotators, (C) internal rotators, and (D) scapular retractors in the dominant (Dom) and nondominant (NDom) arms of low-, moderate-, and high-volume pitchers. See the Results section for effects of time, dominance, and pitch volume. Mean ± standard error displayed.

to supraspinatus weakness as "subclinical pathologic changes." In support of this conclusion, Tyler et al[12] reported that for this cohort of high school pitchers (the same cohort as in the current study), preseason supraspinatus weakness increased the risk of a major shoulder or elbow injury (>3 missed games). In the present study, none of the pitchers were injured at the time of testing. The loss of supraspinatus strength in high-volume pitchers during the season and the failure to gain supraspinatus strength from one season to the next further support the need for in-season and off-season supraspinatus strengthening in high school pitchers. However, it is important to note that the volume of pitches thrown by the pitchers in the seasons that were studied was quite low. The players averaged 275 pitches per season, with only one-third throwing more than 400. Whether these results are generalizable to higher-demand high school pitchers remains to be determined.

With respect to ROM adaptations, the literature indicates that IR loss, ER gain, and PS tightness, in pitchers' dominant versus nondominant arms, are similar between high school,[10,11] college,[1,3,6] and professional pitchers.[5,9,14] In the present study, the finding that these ROM adaptations did not progress from the start to the end of the season or from one season to the next indicates that these adaptations are established early in the career of a pitcher and do not progress with physical maturity and increased pitching demands. Some studies have shown acute losses in IR ROM immediately after a game,[4,8] although one study did not.[6] Any acute loss in IR ROM after a pitching performance does not appear to contribute to a progressively greater chronic IR ROM loss. These acute adaptations are presumably due to soft tissue changes. However, the extent to which chronic ROM adaptations in pitchers are due to soft tissue adaptation (eg, posterior shoulder tightness) or bony adaptation (eg, humeral torsion) cannot be determined from the present study. This remains an area for future research.

Some limitations of the present study should be considered when interpreting the data. (1) The volume of pitching during practices was not recorded. Thus, the effect of pitch volume on strength and ROM changes during the season is based on only the pitches thrown in games. (2) The volume of baseball pitching in the previous winter, fall, and summer seasons was not recorded. In practical

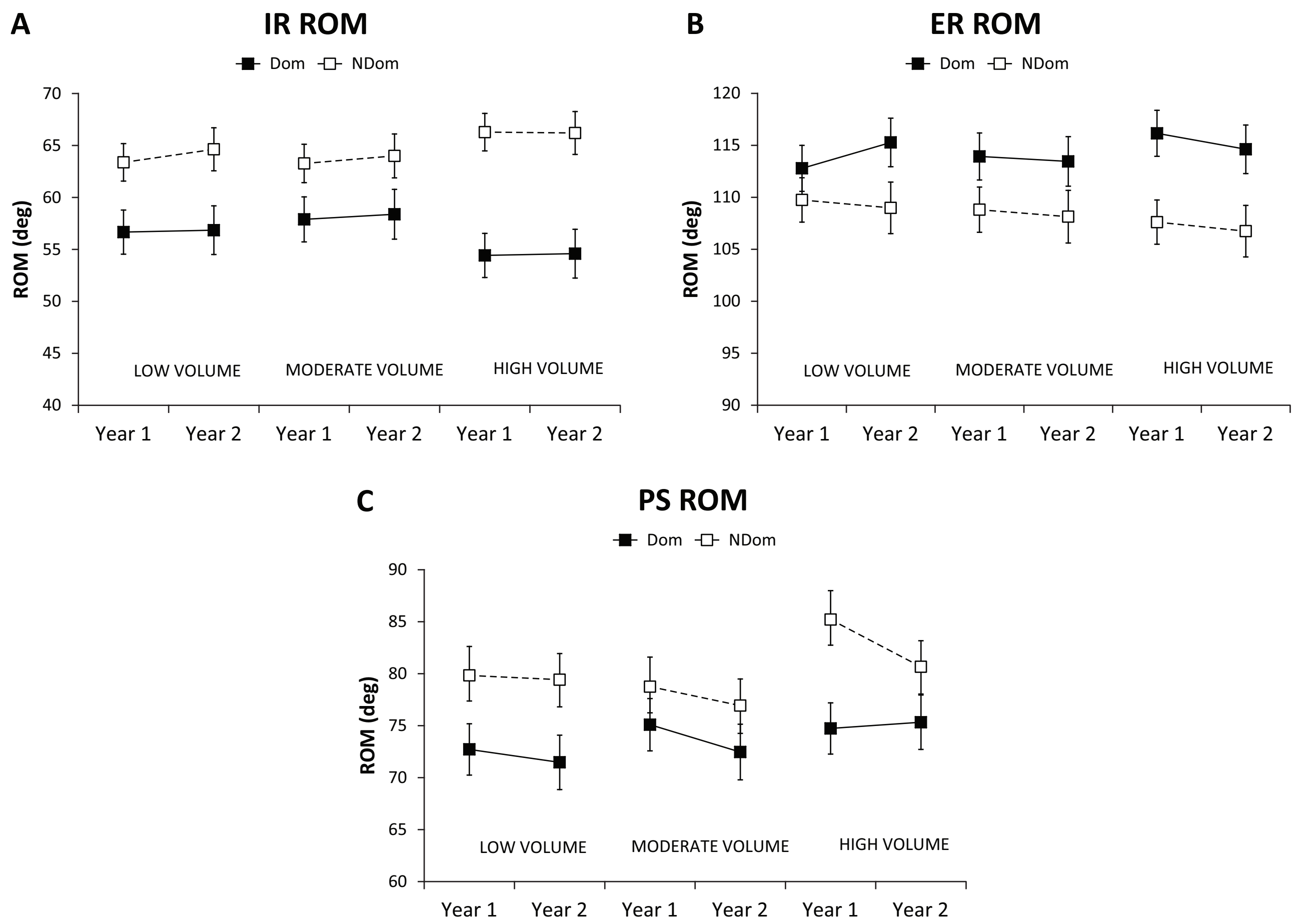

Figure 6. Changes in (A) internal rotation (IR), (B) external rotation (ER), and (C) posterior shoulder (PS) range of motion (ROM) from one preseason to the next in the dominant (Dom) and nondominant (NDom) arms of low-, moderate-, and high-volume pitchers. See the Results section for effects of time, dominance, and pitch volume. Mean ± standard error displayed.

terms, these data were difficult to attain accurately. Pitchers' participation in baseball in these seasons was recorded but without specifics on volume. (3) Participation in other sports or physical activities besides baseball was not recorded. Thus, the effect of pitch volume on year-to-year strength changes was not well controlled. However, since a high pitch volume was associated with supraspinatus strength loss within a season, and a high pitch volume seemed to limit supraspinatus strength gains from one year to the next, it is likely that this latter effect was attributable to baseball pitching. (4) The empty-can test position was chosen as a test of supraspinatus function because it has been used in previous studies on baseball pitchers.[5,6,11,12] However, this may not be the best test of supraspinatus strength.

CONCLUSION

In high school pitchers, a high pitch volume appeared to have a catabolic effect on supraspinatus strength. These data provide further support for in-season and off-season supraspinatus strengthening for baseball pitchers.

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