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Throwing Load Does Not Impact Musculoskeletal Measures around Competitive Pitching in Adolescent Baseball Pitchers

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Throwing Load Does Not Impact Musculoskeletal Measures around Competitive Pitching in Adolescent Baseball Pitchers

Context: Baseball pitching load is linked to injury in adolescent baseball athletes, however, it is unclear if pitch counts are a good indicator of total upper extremity load during baseball pitching.
Objective: The purpose of this study is to 1) determine the recovery time-course of musculoskeletal variables after a single live pitching bout and 2) determine the association between pitch counts, rating of perceived exertion, and arm-specific session rating of perceived exertion on musculoskeletal changes after live game pitching in adolescent baseball athletes.
Design: Cross Sectional
Setting: Competitive Baseball Games
Participants: 36 adolescent baseball pitchers (16.1±0.9 years, 178.2±10.4 cm, 71.5±10.2 kg)
Main Outcome Measures: Internal (IRROM) and external (ERROM) shoulder range of motion, internal (IRPF) and external (ERPF) shoulder rotation peak force, and infraspinatus cross sectional area (CSA) and echo intensity (EI) were collected prior to pitching (PRE), immediately after pitching (POST), and on days 1 (D1), 3 (D3), and 5 (D5) after pitching. Pitch count and rating of perceived exertion (RPE) was collected during the pitching bout, and an arm-specific session rating of perceived exertion (aRmPE) score was calculated as the product of pitch count and RPE. Linear mixed models were used to determine the recovery time-course on both arms and to determine the association between the load variables (pitching count, RPE, aRmPE) and the change in the musculoskeletal variables on the dominant arm.
Results: IRROM was highest on D3 (mean difference: 3.31, $t=3.12$, $p=0.019$), ERPF decreased at POST(-11.53, $t=3.51$, $p=0.005$) and increased at D5 (14.8, $t=4.52$, $p<0.001$). IRPF was lowest at POST and highest at D5 (19.14, $t=4.18$, $p<0.001$). There was no significant ($p>0.057$) association between load variables and musculoskeletal variables.
Conclusions: Baseball specific pitching load metrics did not predict musculoskeletal changes following live game pitching. Future research should investigate pitching load variables that better predict musculoskeletal changes.

Key Terms: baseball, adolescent, shoulder, workload

Abstract Word Count: 290

Key Points:

1) Pitch counts do not adequately describe the overall load experienced by a baseball pitcher during a competitive baseball game.
2) The addition of an internal load metric, such as Rating of Perceived Exertion does not aid in predicting musculoskeletal changes following live game pitching in adolescent athletes.

Baseball pitchers experience a high rate of injuries that affect the upper extremity,[1] developing from both intrinsic[2,3] and extrinsic risk factors.[4-7] Intrinsic risk factors include altered musculoskeletal factors at the shoulder and elbow, such as decreased shoulder range of motion[2,3] and low shoulder strength,[8] that could predispose throwing athletes to a higher risk of injury. Extrinsic risk factors include participation habits such as throwing volumes and rest intervals. Research indicates that athletes with a high throwing volume (e.g., throw more pitches and/or complete more innings per year)[4,6,7] are more likely to become injured than those who throw less or play positions with lower throwing volume. To aid in injury prevention practices, pitch count guidelines were developed to address extrinsic risk factors, which could indirectly have an impact on the intrinsic risk factor development and recovery.[9]

Acute pitching bouts cause significant changes to the upper extremity musculoskeletal system. Baseball pitchers experience decreases in shoulder rotational range of motion[10-12] and shoulder rotational muscle strength[13] following an acute bout of pitching. Additionally, structural changes to the rotator cuff are evident on the dominant limb when assessed with imaging modalities.[11,14] Specifically, increased infraspinatus cross sectional area (CSA) on ultrasound are present after a pitching bout regardless of the pitch count.[11] A pitcher's decreased range of motion,[10,13] shoulder external rotation strength,[13] and increased infraspinatus CSA[11] are present for up to three days after pitching, before it finally returns to a pre-pitching level. Pitchers who return to pitching prior to three days may not have enough time for recovery, and an additional pitching bout could add more negative changes of strength, range of motion, or muscle size. As negative changes accumulate, range of motion and strength deficits may reach critical levels, predisposing a pitcher to injury.[2,3] By appropriately prescribing pitching load and recovery, the negative changes after pitching could dissipate, which may allow pitchers to reach healthy pre-pitching levels prior to entering each new pitching bout.[11,13]

Pitch count and recovery recommendations are in place to minimize the accumulation of musculoskeletal changes, but previous work[15] has suggested that pitch counts only capture approximately 60% of the load that the arm experiences during a baseball pitching outing. To gain a more robust measure of arm load, clinicians could utilize a rating of perceived exertion (RPE) scale to create an arm-specific session-rating of perceived exertion (aRmPE) for the entire pitching outing.[16] This measurement captures both an exertional and perceptual measure of training load, and these types of loads have been used previously in other sports to aid in performance enhancement and injury risk reduction.[17,18] The RPE as a training load measure has been used in baseball research previously. For example, Pexa et al (2020) demonstrated the RPE could be helpful in identifying the changes to clinical measures of shoulder strength and range of motion over 4 weeks of baseball participation, and Slowik et al (2021) demonstrated that the RPE may impact baseball injury risk when calculated as a 3 week acute-to-chronic workload ratio.[16] However, there is no information if the RPE is related to musculoskeletal changes about the shoulder in a short time frame (e.g. a single baseball pitching bout). If the aRmPE would be beneficial for tracking training load in baseball athletes, we postulate that it would have a significant association with the physical changes that baseball pitchers experience acutely after a single pitching bout. Therefore, the purpose of this study is to 1) determine the recovery time-course of musculoskeletal variables after pitching and 2) determine the association between pitch counts, RPE, and aRmPE on musculoskeletal variables after live game pitching in adolescent baseball athletes.

METHODS

Participants were recruited from 12 local travel and high school baseball teams. To be included in the study, participants must have been between the ages of 13-18, be an active member of a baseball team, and pitch first or second in the game that the research team attends. Participants were excluded from the study if they did not pitch in the current game, they self-reported pain or injury in their throwing arm or self-reported a neuromuscular disease. There was no minimum or maximum number of pitches that a participant had to reach to be included in the study. A power analysis was performed from previous research and it was determined that over 32 participants would be needed to power the analysis (effect =.52; alpha=.05; power =.08; sample size = >32).[19,20] After screening all potential participants, 39 participants signed IRB approved consent and assent forms (IRB# 16-2714). If the participants were less than 18, parents also signed approved consent forms. Three participants had pre-pitching data collected, but did not pitch in the game they were scheduled to pitch in. Therefore, 36 participants were included in the final sample (age = 16.1 ± 0.9 years, stature = 178.2 ± 10.4 cm, body mass = 71.5 ± 10.2 kg).

Experimental Design

Participants completed 5 testing sessions around one of their competitive live pitching bouts. The baseline testing session took place on the day of their scheduled pitching bout prior to all baseball activity. All teams and leagues that were tested abided by the USA Baseball Pitch Smart Guidelines, which gave pitch count and rest guidelines to ensure that pitchers are in a healthy state. Following the initial testing session, participants reported to the field for pre-game warm-up activities. Participants were scheduled to pitch either first or second for the game they were to be tested. There was no control for pregame or in-game activities; participants were not restricted to pitching only and were not limited in their pre-pitching or post-pitching activities. Upon completion of the competitive game, the participant performed another testing battery. Follow-up testing sessions were completed on day 1, day 3, and day 5 post-pitching. Between the post-pitching assessment and the day 5 assessment, participants were not limited in their recovery and performed their traditional activities which may have included using recovery modalities (e.g. ice, compression, massage, therapeutic exercise, etc.), attend practice, or perform other training. All testing sessions on follow-up days were completed prior to any baseball activity of the day. During the testing sessions, participants completed a bilateral ultrasound assessment of the infraspinatus, a glenohumeral rotational range of motion assessment, and an isometric glenohumeral internal and external rotation strength assessment.

Infraspinatus Ultrasound Assessment

To obtain infraspinatus CSA and echo intensity (EI), the participant's infraspinatus muscle was imaged using B-mode ultrasonography (LOGIQ, General Electric, Boston, MA) with a 5cm linear array probe (12L-RS; 5–13 MHz; 38.4 mm FOV, General Electric Company, Milwaukee, WI, USA) using consistent settings, such as frequency (12 MHz), gain (56 dB) and depth (5 cm). Participants laid prone on a portable treatment table with their arms at their sides and hands up. To consistently determine the region of interest, a line was made from the trigonum spinae to the acromial angle by the same examiner (BSP) (**Figure 1**). This line was measured, and a second line was made at a right angle one third of the distance down line one from the trigonum spinae. The ultrasound probe was placed longitudinally on this second line and slowly moved along the line inferiorly to produce a short-axis view of the infraspinatus. Three panoramic images were taken on the dominant and non-dominant limbs each to capture the entire muscle cross-sectional area. The ultrasound images were uploaded to ImageJ software (National Institute of Health, Bethesda, MD) and the same investigator perform all analyses. The straight-line function was used to convert each image from pixels to centimeters. To determine CSA, the same technician used the polygon function to trace the outline of the infraspinatus for each participant's scan along the fascia border as close as possible to capture only the muscle. This region was used to determine infraspinatus CSA (cm^2). Echo intensity (EI) was determined as the average grayscale of all pixels within the same region of interest.[21] The average CSA and EI of the three images was averaged for data analysis. The EI values were corrected for subcutaneous fat thickness.[21] Test-retest reliability data from our lab have demonstrated acceptable intraclass correlation coefficients (ICC) and standard error of measurement (SEM) values for infraspinatus CSA ($ICC_{(2,1)}$=0.911, SEM = 0.69 cm^2 [4.25% of grand mean]), and EI ($ICC_{(2,1)}$=0.850, SEM = 2.77 [9.23% of grand mean]). Methods for ultrasound collection and reduction are presented in **Figure 1**.

Glenohumeral Rotational Range of Motion

To determine range of motion, participants laid supine on a padded table with their arm abducted to 90 degrees and elbow flexed 90 degrees. A researcher internally or externally rotated the arm while stabilizing the scapula over the coracoid process while a second researcher used a digital goniometer (Saunders Group, Chaska, MN) to measure the angle of the forearm relative to the true vertical. Three measurements were taken of internal and external rotation on the dominant and non-dominant limbs to the nearest 1 degree. Range of motion outcome scores were averaged across three measurements of internal rotation (IRROM) and external rotation (ERROM) on both the dominant and non-dominant limb. This method has demonstrated acceptable reliability for shoulder rotational range of motion measures.[11]

Glenohumeral Rotational Strength

Glenohumeral internal rotation peak force (IRPF) and external rotation peak force (ERPF) was measured with the participant in the prone position. Participants had their arms abducted to 90 degrees and elbows bent to 90 degrees. Participants held a handle connected to a non-yielding chain, which held in series with a tension dynamometer (TSD121C Hand Dynamometer, Biopac Systems Inc., Goleta, CA, USA) that was fixed to a stationary object. Participants were instructed to remove the slack, and then, when instructed, would pull superiorly for external rotation and inferiorly for internal rotation as hard and fast as possible for 3 – 4 seconds. Three trials of internal and external rotation strength were collected on the dominant and non-dominant limbs with 60 seconds of rest between each trial. Peak isometric strength (Newtons) was recorded as the highest 50 ms epoch across all three trials and filtered with a fourth order butterworth filter low passed at 50 Hz using custom designed software (LabVIEW, National Instruments Corp., Austin, TX). Test-retest reliability form our lab demonstrated acceptable reliability for peak strength measures ($ICC_{2,k}$ = 0.936, SEM = 11.52 N [7.4% of grand mean]) and range of motion $ICC_{2,k}$ = 0.868, SEM = 4.55º (2.5% of grand mean)).

Load Tracking

When the pitcher started their pitching bout, the research team recorded the number of pitches thrown in the game. This number did not include warm-up pitches or field throws. Upon completion of the game, the research team asked the participant to rate the difficulty of their pitching bout on their throwing arm using a Borg RPE scale from 6-20. Throwing load variables consisted of pitch count, RPE, and the product of the two (pitch count * RPE = aRmPE). This aRmPE was used as a total load measurement to quantify both the physical activity and perceptual difficulty of the baseball pitching bout similar to previous research.[16]

Statistical Analysis

All analyses were performed in R (R Core Team, 2021).[22] Descriptive statistics were calculated and reported for all participants. Load data and musculoskeletal outcomes are reported as averages and standard deviations. To determine the recovery time-course of musculoskeletal variables after pitch, we ran separate linear mixed models with the raw scores of CSA, EI, IRROM, ERROM, IRPF, and ERPF as dependent variables. Recovery could be interpreted as the musculoskeletal variables reaching pre-pitching levels (PRE). Fixed factors were time (PRE, POST, D1, D3, D5) and side (dominant and non-dominant) and the interaction between them (side*time). If the interaction term was not significant, we reduced the data to only analyze the dominant limb, as this was what sustained the baseball specific load. Subject ID was used as a random factor, and age was used as a covariate. Estimated marginal means were calculated and used for post-hoc testing on significant interactions and main effects. Post-hoc testing was performed with Bonferroni adjustments, and data was considered significant at $p<0.05$.

To determine the association between pitch counts, RPE, and aRmPE on musculoskeletal variables after live game pitching, we ran separate linear mixed models with the percent change scores from baseline (100*[PRE-Current Value]/PRE) of the dominant limb musculoskeletal outcomes as the dependent variables. The fixed factors were pitch count, RPE, aRmPE, Time, and the interaction of Time with each loading variable to assess if there was a relationship between the musculoskeletal outcomes and load at any single time point. Subject ID was used as a random intercept, and age was used as a covariate. Only the dominant limb was used in the correlation analysis to determine if the loading variables specifically impacted the dominant limb. Insignificant interactions and main effects were dropped from all models to create the simplest model possible.

RESULTS

The average pitch count was 58.2 ± 25.8 pitches (range: 16 -120 pitches, median: 60, Interquartile range: quartile 1 = 38.75, quartile 3 = 75.5), the average RPE was 10.6 ± 2.14 (range: 6-14), and the average aRmPE was 662.2 ± 333.4 (range: 108 – 1320 AUs). Descriptive data for all dependent variables across days is presented in **Table 1**.

Time-Course Recovery of Pitching

When assessing the time-course recovery of the musculoskeletal outcomes (see Figure 2), there was no significant interaction between side and time, indicating that the changes occurred to both the dominant and non-dominant limbs. When assessing main effects, there was a main effect of time on IRROM (F = 4.11, p = 0.002), ERPF (F = 6.73, p <0.001), and IRPF (F = 5.36, p <0.001). Post-hoc testing for IRROM demonstrated a significant increase on D3 when compared to PRE (mean difference: 3.31, t = 3.12, p = 0.019) and POST (3.66, t = 3.42, p = 0.006). Post-hoc testing for ERPF demonstrated a significant decrease in ERPF POST when compared to PRE (-11.53, t = 3.51, p = 0.005). The ERPF measures at POST were also significantly decreased when compared to D1 (9.97, t = 3.00, p = 0.028), D3 (14.3, t = 4.3, p <0.001), and D5 (14.8, t = 4.52, p<0.001). Post-hoc testing for IRPF demonstrated a significant increase in IRPF at D5 when compared to POST (19.14, t = 4.18, p < 0.001) and D1 (14.51, t = 3.11, p = 0.020). There were significant effects of side for CSA (F = 25.43, p <0.001), IRROM (F = 325.44, p<0.001), ERROM (F = 55.39, p<0.001), and IRPF (F = 6.86, PP-0.009). Post-hoc testing revealed CSA (8.23, t = 2.82, p = 0.005), ERROM (4.66, t = 6.12, p<0.001), and IRPF (8.23 N, t = 2.82, p = 0.005) where higher for the dominant limb, while the non-dominant limb was significantly higher than the dominant limb for IRROM (12.3, t = 18.1, $p < 0.001$). There was no effect of time or side on EI ($p > 0.05$).

Relationship between Load and Musculoskeletal Outcomes in Dominant Limb

When assessing the relationships between load and time on the musculoskeletal changes within the dominant limb, there were no significant interactions between time (POST, D1, D3, and D5) and the throwing load variables (pitch count, RPE, aRmPE) on the musculoskeletal changes ($F<2.6$, $p\geq0.057$, $R^2 < 2.8\%$). This indicated that the relationship did not vary based on the time post pitching. Therefore, time was removed from the models as an interaction effect. When assessing the relationships between load and the musculoskeletal outcomes without time, there was no significant relationships between the load variables (pitch count, RPE, and aRmPE) and the musculoskeletal changes (CSA, EI, IRROM, ERROM, IRPF, and ERPF) (F = 3.1 – 1.4, p = 0.837 - 0.059, R^2 = 13.5 – 1.4%).

DISCUSSION

Our results indicate that ERPF decreases immediately following pitching but returns to baseline by day 1. Additionally, we found significant side-to-side differences in IRROM and ERROM, consistent with other research in baseball athletes.[11] Interestingly, we did not find a significant relationship between pitch count, RPE or aRmPE and any changes in the musculoskeletal variables. High pitch counts may increase injury risk,[4,5,23] but the evidence presented in this study indicates that pitch counts either independently or in conjunction with RPE may not explain musculoskeletal changes after pitching. This supports more recent literature indicating that pitch counts may be a poor measure of shoulder load during baseball participation.[15] Future research should investigate total arm loads from pitching, throwing, and other arm actions (i.e. batting and fielding demands) that may cause changes to musculoskeletal variables about the shoulder.

Baseball pitching is one of the fastest movements in sport utilizing high speed concentric and eccentric muscle contractions about the shoulder. Previous studies have utilized repetitive eccentric muscle actions in laboratory settings to examine exercise-induced muscle damage,[24,25] resulting in reductions in muscle strength and[26,27] range of motion,[19] and increased muscle size (i.e. increases in muscle CSA). [19,25,27] However, these targeted muscle actions to induce muscle damage fail to account for the whole-body aspect of baseball pitching, so baseball pitchers may be able to dissipate forces at the shoulder and elbow by using their whole kinetic chain. When researchers use simulated games[13,28,29] to measure the time course recovery of musculoskeletal outcomes after pitching, there is still a significant change in range of motion, strength, and/or muscle architecture for up to 3 days post-pitching. However, the studies also create strict recovery protocols. The current study utilized live game pitching and did not limit the participant to playing other positions or utilizing recovery techniques. This difference in methods may explain the difference in the outcomes, with the current study better replicating real-life scenarios for adolescent pitchers. It appears healthy adolescent baseball pitchers may effectively manage the pitching load and demonstrate limited musculoskeletal changes from pre-pitching to post-pitching for up to 5 days after their pitching outing. However, recovery methods have been left unaccounted for, as are previous pitching history, which may have impacted how these participants recover following pitching. Future research should investigate how different recovery methods and/or previous pitching history plays a role in time-course recovery.

Baseball pitchers demonstrate decreases in range of motion immediately following baseball pitching,[10,12] and these changes may be present for up to three days.[10,11] Additionally, collegiate baseball pitchers show increased dominant limb infraspinatus CSA that can last for up to 2 days post-pitching.[11] The current study investigated adolescent baseball pitchers who pitched in competitive games. There was no change in IRROM, ERROM, or infraspinatus CSA and EI from PRE to POST. However, there was a significant decrease in ERPF immediately after pitching, but these changes returned to PRE levels by D1 post-pitching. Interestingly, as the time from pitching increased, there were additional changes, including increased IRPF, ERPF, and IRROM on D3 and D5 compared to POST. Overall, the immediate decrease in external rotation strength matches previous research in baseball pitchers,[13] but the lack of range of motion changes is interesting. Previous research on time-course recovery after pitching has been in college[11,13] and professional pitchers,[12] with the only study on high school athletes occurring in a game or practice.[10] College and professional pitchers are primarily pitchers only, so the load they experience is all pitching related. Athletes in this study only played live competitive games, were not limited to only pitching, and had no restrictions on recovery or training activities across the week when assessing the time-course of recovery. The additional activities, such as playing another position or using recovery modalities, could have impacted the changes, but these activities are common in pitchers after pitching. Future research should continue to investigate the time course recovery of adolescent baseball pitchers, with special attention on positions played, the impact of pitching, hitting, and playing the field, timing of the season, previous experience as a pitcher, and additional training and recovery activities.

Pitch count limitations and regulations have been implemented to ensure youth and adolescent baseball pitchers do not overexert themselves for the sake of performance. Previous evidence indicates that high pitch counts will lead to injury.[5,6] Recent rule and regulations also implement age-specific recovery guidelines to prevent pitchers from returning to pitching prior to full recovery.[30] There is a lack of information regarding the relationship between pitching related load, assessed as pitch count, and changes in musculoskeletal variables. The results suggest there does not appear to be a relationship between pitch counts, RPE, and aRmPE for any variable between PRE, POST, and D1 post-pitching. A potential explanation for this outcome is that pitch counts and RPE do not adequately reflect the load experienced by adolescent baseball pitchers around a single acute bout. There is a clear need to better measure baseball specific training loads, as pitch counts only track approximately 60% of all throws made in a day.[15] If a pitcher plays other positions over the course of a game or tournament, then they will acquire more load that may impact musculoskeletal variables about the shoulder. The current study did not control the ability of the participants to play other positions, so this is a limitation. Instead of pitch counts, clinicians and coaches may want to track total shoulder movements, such as field throws, warm-up pitches, game pitches, and even batting swings to better capture the load experienced by the shoulder during baseball participation. Future research should investigate more comprehensive methods to track arm-specific load to better understand the impact of extrinsic risk factors on baseball pitching injury. One such method to better track total shoulder movements would be to implement wearable technology. The emergence of wearable technology for baseball athletes could be beneficial in the future, although the current validity and accuracy of metrics such as arm slot, arm stress, and shoulder rotation is poor.[31] However, the sensors could be repurposed to only collect throw count and used as an upper body ergometer. Current research on upper extremity throwing sensors used as a throw counter are promising[32] but require further investigation. If a wearable sensor could provide a more accurate reflection of the total work performed during baseball pitching and playing, the wearable sensors could project changes better than just a pen and paper recording of pitch count. Additionally, to supplant RPE, wearable sensors could capture heart rates as an internal load measure that could aid in understanding total body load experienced during baseball participation in adolescents.

This study is not without limitations. First, previous playing experience and recovery modalities were not measured throughout the study. These factors could have played a role in how adolescent pitchers recovered. Additionally, the pitch count was only in-game pitches and not all throws. A full throw count measure might be more useful in the future to gain the total accumulation of all shoulder and elbow activities. Additionally, this pitch count did not account for different types of pitches or pitch speed, but future studies should add these variables. Next, there was no control for playing pitcher only, so participants may have played additional positions before and/or after their pitching bout. Additionally, the testing times corresponded with larger tournaments and other games throughout the season, so players could be playing other positions during their required rest time, thus altering the internal validity between throwing volume and the musculoskeletal changes. However, there were no additional games between the end of the pitching bout and day 1 post-pitching, as all measures were prior to baseball activity for the day. Therefore, we expected to see a relationship between pitch count and the musculoskeletal changes immediately post-pitching and on day 1 post-pitching which did not occur. The sample size could be improved to aid in generalizability and further power the analysis, especially if performed across a broad population of adolescent throwers, pubertal stages, and experience levels. We did not record any information about the most recent pitching bout the participants experienced before the baseline testing. If the participants had pitched immediately prior to the baseline time, there could be some residual effects from that pitching bout. However, all participants adhered to the USA Baseball Pitch Smart Guidelines, which requires rest after pitching bouts to ensure that participants are in a healthy state before pitching again.

CONCLUSIONS

Overall, the results of this study indicate that there were significant changes in IRPF and ERPF as pitchers recovered from the pitching bout. There was no significant association between any arm-specific pitching load measure and any musculoskeletal changes in the dominant limb. Pitch count, RPE, and aRmPE may not reflect the musculoskeletal changes experience by baseball pitchers in a single pitching bout. Future research should utilize these measures in a within-subjects design to gain better insight into their predictive capabilities on musculoskeletal changes after pitching. Additionally, research should find ways to quantify all movements that may impart shoulder specific training loads, including warm-up throws, pitch counts, fielding throws, and other baseball-related shoulder movements, to determine the relationship between baseball specific training loads and shoulder specific musculoskeletal outcomes.

REFERENCES

1. Boltz AJ, Powell JR, Robison HJ, Morris SN, Collins CL, Chandran A. Epidemiology of Injuries in National Collegiate Athletic Association Men's Baseball: 2014-2015 Through 2018-2019. *J Athl Train*. Jul 1 2021;56(7):742-749. doi:10.4085/1062-6050-432-20

2. Wilk KE, Macrina LC, Fleisig GS, et al. Deficits in Glenohumeral Passive Range of Motion Increase Risk of Shoulder Injury in Professional Baseball Pitchers: A Prospective Study. *Am J Sports Med*. Oct 2015;43(10):2379-85. doi:10.1177/0363546515594380

3. Wilk KE, Macrina LC, Fleisig GS, et al. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. *Am J Sports Med*. Sep 2014;42(9):2075-81. doi:10.1177/0363546514538391

4. Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc*. Nov 2001;33(11):1803-10. doi:10.1097/00005768-200111000-00002

5. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med*. Jul-Aug 2002;30(4):463-8. doi:10.1177/03635465020300040201

6. Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med*. Feb 2011;39(2):253-7. doi:10.1177/0363546510384224

7. Hibberd EE, Oyama S, Myers JB. Rate of Upper Extremity Injury in High School Baseball Pitchers Who Played Catcher as a Secondary Position. *J Athl Train*. May 2018;53(5):510-513. doi:10.4085/1062-6050-322-16

8. Garrison JC, Johnston C, Conway JE. Baseball Players with Ulnar Collateral Ligament Tears Demonstrate Decreased Rotator Cuff Strength Compared to Healthy Controls. *Int J Sports Phys Ther*. Aug 2015;10(4):476-81.

9. Baseball U. Guidelines for Youth and Adolescent Pitchers. Updated January 2024. https://www.mlb.com/pitch-smart/pitching-guidelines

10. Reuther KE, Larsen R, Kuhn PD, Kelly JDt, Thomas SJ. Sleeper stretch accelerates recovery of glenohumeral internal rotation after pitching. *J Shoulder Elbow Surg*. Dec 2016;25(12):1925-1929. doi:10.1016/j.jse.2016.07.075

11. Pexa BS, Ryan ED, Hibberd EE, Teel E, Rucinski TJ, Myers JB. Infraspinatus Cross-Sectional Area and Shoulder Range of Motion Change Following Live-Game Baseball Pitching. *J Sport Rehabil*. Mar 1 2019;28(3):236-242. doi:10.1123/jsr.2017-0158

12. Reinold MM, Wilk KE, Macrina LC, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *Am J Sports Med*. Mar 2008;36(3):523-7. doi:10.1177/0363546507308935

13. Mirabito NS, Topley M, Thomas SJ. Acute Effect of Pitching on Range of Motion, Strength, and Muscle Architecture. *Am J Sports Med*. Apr 2022;50(5):1382-1388. doi:10.1177/03635465221083325

14. Yanagisawa O, Niitsu M, Takahashi H, Itai Y. Magnetic resonance imaging of the rotator cuff muscles after baseball pitching. *J Sports Med Phys Fitness*. Dec 2003;43(4):493-9. doi:10.1053/sroe.

15. Zaremski JL, Zeppieri G, Jr., Jones DL, et al. Unaccounted Workload Factor: Game-Day Pitch Counts in High School Baseball Pitchers-An Observational Study. *Orthop J Sports Med*. Apr 2018;6(4):2325967118765255. doi:10.1177/2325967118765255

16. Pexa B, Ryan ED, Blackburn JT, Padua DA, Garrison JC, Myers JB. Influence of Baseball Training Load on Clinical Reach Tests and Grip Strength in Collegiate Baseball Players. *J Athl Train*. Sep 1 2020;55(9):984-993. doi:10.4085/1062-6050-0456.19

17. Impellizzeri FM, Rampinini E, Coutts AJ, Sassi A, Marcora SM. Use of RPE-based training load in soccer. *Med Sci Sports Exerc*. Jun 2004;36(6):1042-7. doi:10.1249/01.mss.0000128199.23901.2f

18. Haddad M, Stylianides G, Djaoui L, Dellal A, Chamari K. Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Front Neurosci*. 2017/11// 2017;11:612. doi:10.3389/fnins.2017.00612

19. Oyama S, Myers JB, Blackburn JT, Colman EC. Changes in infraspinatus cross-sectional area and shoulder range of motion with repetitive eccentric external rotator contraction. *Clin Biomech (Bristol)*. Feb 2011;26(2):130-5. doi:10.1016/j.clinbiomech.2010.09.018

20. Neuharth B. *Relationship Between Pitch Count and Infraspinatus Cross-Sectional Area and Shoulder Range of Motion*. Dissertation. University of North Carolina at Chapel Hill; 2014. Accessed 2019-03-20.

21. Ryan ED, Shea NW, Gerstner GR, Barnette TJ, Tweedell AJ, Kleinberg CR. The influence of subcutaneous fat on the relationship between body composition and ultrasound-derived muscle quality. *Appl Physiol Nutr Metab*. Oct 2016;41(10):1104-1107. doi:10.1139/apnm-2016-0238

22. Team RC. R: A language and environment for statistical computing. 2022;

23. Erickson BJ, Chalmers PN, Axe MJ, Romeo AA. Exceeding Pitch Count Recommendations in Little League Baseball Increases the Chance of Requiring Tommy John Surgery as a Professional Baseball Pitcher. *Orthop J Sports Med*. Mar 2017;5(3):2325967117695085. doi:10.1177/2325967117695085

24. Chen TC, Lin KY, Chen HL, Lin MJ, Nosaka K. Comparison in eccentric exercise-induced muscle damage among four limb muscles. *Eur J Appl Physiol*. Feb 2011;111(2):211-23. doi:10.1007/s00421-010-1648-7

25. Ochi E, Tsuchiya Y, Nosaka K. Differences in post-exercise T2 relaxation time changes between eccentric and concentric contractions of the elbow flexors. *Eur J Appl Physiol*. Dec 2016;116(11-12):2145-2154. doi:10.1007/s00421-016-3462-3

26. Hicks KM, Onambele GL, Winwood K, Morse CI. Muscle Damage following Maximal Eccentric Knee Extensions in Males and Females. *PLoS One*. 2016;11(3):e0150848. doi:10.1371/journal.pone.0150848

27. Lauritzen F, Paulsen G, Raastad T, Bergersen LH, Owe SG. Gross ultrastructural changes and necrotic fiber segments in elbow flexor muscles after maximal voluntary eccentric action in humans. *J Appl Physiol (1985)*. Dec 2009;107(6):1923-34. doi:10.1152/japplphysiol.00148.2009

28. Yanagisawa O, Taniguchi H. Changes in lower extremity function and pitching performance with increasing numbers of pitches in baseball pitchers. *J Exerc Rehabil*. Jun 2018;14(3):430-435. doi:10.12965/jer.1836196.098

29. Warren CD, Szymanski DJ, Landers MR. *Effects of three recovery protocols on range of motion, heart rate, rating of perceived exertion, and blood lactate in baseball pitchers during a simulated game*. vol 29. Journal of Strength and Conditioning Research. 2015:3016-3025.

30. Myers JB, DeFreese JD, DiStefano L, et al. Long-Term Athlete Development Plan. *USA Baseball*. 2018:1-21.

31. Camp CL, Loushin S, Nezlek S, Fiegen AP, Christoffer D, Kaufman K. Are Wearable Sensors Valid and Reliable for Studying the Baseball Pitching Motion? An Independent Comparison With Marker-Based Motion Capture. *Am J Sports Med*. Sep 2021;49(11):3094-3101. doi:10.1177/03635465211029017

32. Freehill MT, Rose MJ, McCollum KA, Agresta C, Cain SM. Game-Day Pitch and Throw Count Feasibility Using a Single Sensor to Quantify Workload in Youth Baseball Players. *Orthop J Sports Med*. Mar 2023;11(3):23259671231151450. doi:10.1177/23259671231151450

LEGEND TO FIGURES AND TABLES

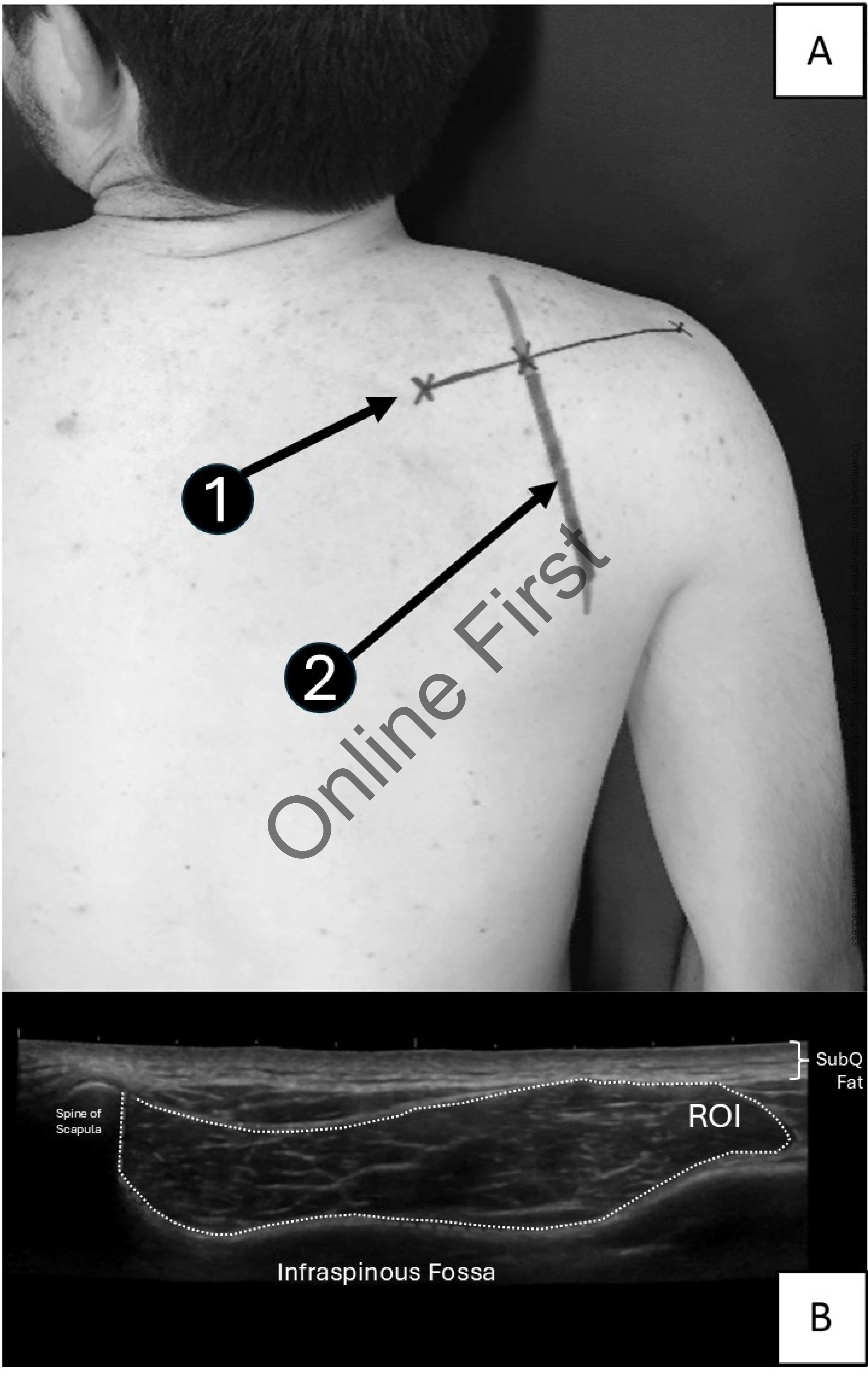
Figure 1. Figure 1.A demonstrates the two lines used to image the infraspinatus. Arrow 1 is a line from the trigonum spinae to the posterior aspect of the acromion, and Arrow 2 indicates the path that the ultrasound head will move to create the longitudinal panoramic image. Figure 1.B is the infraspinatus panoramic image, with the muscle outlined to attain the infraspinatus CSA and EI. SubQ Fat = subcutaneous fat layer, ROI = Region of interest.

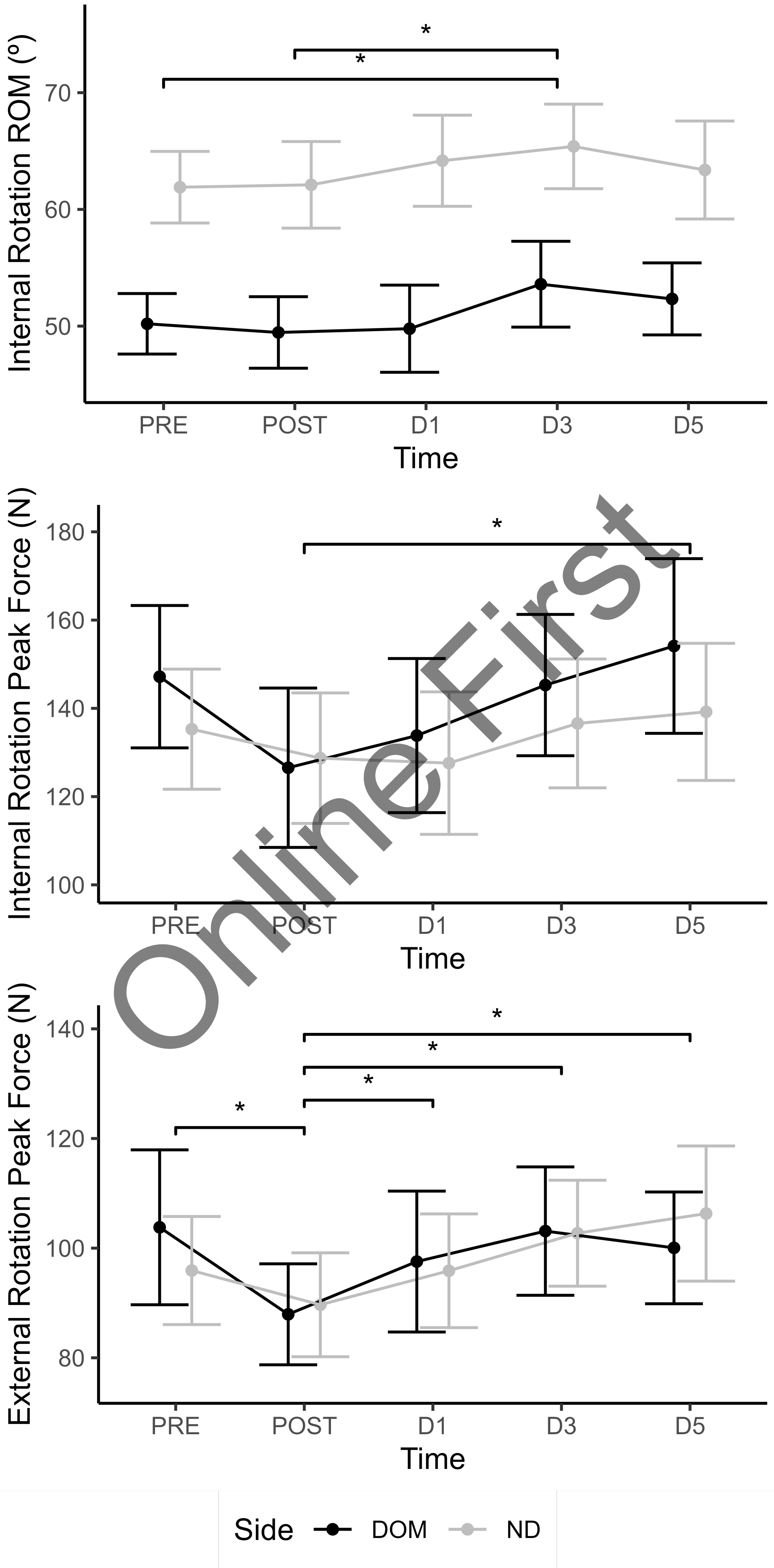
Figure 2. Time course recovery of internal rotation range of motion (IRROM) internal rotation peak force (IRPF), and external rotation peak force (ERPF). Data is presented as means and associated confidence intervals. Asterisk indicates significant difference between time.

Table 1. Descriptive (mean ± sd) statistics of all physical measures across time. DOM = Dominant Limb, ND = Non-dominant Limb, CSA = Infraspinatus Cross Sectional Area, EI = Infraspinatus Echo Intensity, ERROM = External Rotation Range of Motion, IRROM = Internal Rotation Range of Motion

Limb	Variable	Pretest			Posttest			Day 1			Day 3			Day 5		
DOM	CSA	14.13	±	3.19	14.01	±	2.88	14.17	±	2.88	14.34	±	3.00	14.14	±	2.59
	EI	34.39	±	9.91	32.70	±	8.19	32.54	±	7.06	32.02	±	7.17	33.02	±	7.27
	ERROM	128.44	±	11.74	127.63	±	11.34	126.38	±	10.01	126.32	±	12.09	127.24	±	12.54
	IRROM	50.20	±	7.94	49.46	±	9.25	49.78	±	11.11	53.59	±	11.10	52.33	±	8.90
ND	CSA	13.65	±	2.81	13.52	±	2.83	13.66	±	2.58	13.54	±	2.74	13.41	±	2.01
	EI	33.20	±	7.83	34.36	±	7.91	33.58	±	6.51	33.53	±	7.90	34.64	±	7.33
	ERROM	121.79	±	10.21	122.03	±	11.75	121.54	±	11.32	122.15	±	12.97	121.44	±	11.59
	IRROM	61.90	±	9.39	62.11	±	11.20	64.17	±	11.61	65.40	±	10.93	63.38	±	12.12

Table 1. Descriptive (mean ± sd) statistics of all physical measures across time. DOM = Dominant Limb, ND = Non-dominant Limb, CSA = Infraspinatus Cross Sectional Area, EI = Infraspinatus Echo Intensity, ERROM = External Rotation Range of Motion, IRROM = Internal Rotation Range of Motion


A
1
2
Spine of Scapula
SubQ Fat
ROI
Infraspinous Fossa
B



Internal Rotation ROM (°)
70
60
50
*
*
PRE
POST
D1
D3
D5
Time
Internal Rotation Peak Force (N)
180
160
140
120
100
*
PRE
POST
D1
D3
D5
Time
External Rotation Peak Force (N)
140
120
100
80
*
*
*
*
PRE
POST
D1
D3
D5
Time
Side
DOM
ND