

Preseason Upper Extremity Range of Motion and Strength in Relation to In-Season Injuries in NCAA Division I Gymnasts

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Background: Gymnastics is a demanding sport that places unique forces on the upper extremity. The repetitive nature of the sport and the high-impact forces involved may predispose the gymnast to overuse injuries. Risk factors for injuries in gymnastics are not well understood.

Purpose/Hypothesis: The purpose of this study was to ascertain whether preseason upper extremity range of motion (ROM) and strength differ between National Collegiate Athletic Association (NCAA) Division I collegiate gymnasts who sustain an in-season upper extremity injury and those who do not. We hypothesized that gymnasts who sustain an upper extremity injury would demonstrate reduced ROM and strength compared with noninjured gymnasts.

Study Design: Cohort study; Level of evidence, 3.

Methods: Over 4 seasons, from 2014 to 2018, a total of 15 female NCAA Division I collegiate gymnasts underwent preseason upper extremity ROM (shoulder: flexion, internal and external rotation; elbow: extension; wrist: extension) and strength (shoulder: internal and external rotation, and middle and lower trapezius) testing. Overuse upper extremity injuries were tracked in each subsequent season. Gymnasts were dichotomized into injured and noninjured groups, and a 2 × 2 analysis of variance was used to measure differences in preseason measures between the groups as well as within arms (injured vs noninjured arm for the injured group; dominant vs nondominant arm for the noninjured group).

Results: A total of 12 overuse upper extremity injuries (10 shoulders; 2 wrist/forearm) occurred during 31 gymnast-seasons. There were no significant interactions for preseason ROM and strength measurements between groups (injured vs noninjured) or within arms (injured and noninjured arm for the injured group; dominant and nondominant arm for the noninjured group; $P = .07$).

Conclusion: Preseason upper extremity ROM and strength were not different between gymnasts who sustained an in-season upper extremity overuse injury and those who did not. It is possible that ROM and strength measures used to screen other overhead athletes may not capture the unique features and requirements of gymnastics. Further, it may be challenging to discern differences in clinical measures of ROM and strength in gymnastics populations owing to the bilateral nature of the sport.

Keywords: gymnastics; shoulder; elbow; wrist; overuse injury; female athlete

In women's collegiate gymnastics, injuries occur at an average rate of 9.22 injuries per 1000 hours of athlete exposure.¹⁸ Elite gymnasts train 21 to 37 hours per week before attending college; therefore, it is not surprising that they experience more severe injuries than their novice counterparts.^{12,14,27} The greatest incidence of injury occurs in female gymnasts between 18 and 19 years old, an age range that encompasses most collegiate teams.^{12,27} Compared to other sports, gymnastics has the highest overuse injury rate, with up to 44% of injuries being attributed to

overuse.¹⁰ The alarmingly high rate of injury is often overlooked in gymnastics.¹⁰

Gymnasts will encounter 102 to 217 weightbearing impacts on the upper extremity during a single training session.^{7,8} Forces on the wrist and elbow can reach 2 to 5 times body weight per contact.^{7,8} The repetitive nature of the sport and the high impact forces predisposes the gymnast to overuse injuries.³ From 20% to 30% of all injuries occur in the upper extremity, with the wrist accounting for the most injuries and the shoulder having the highest rate of overuse injuries.^{18,27,29} Additionally, it is estimated that up to 85% of gymnasts experience wrist pain and 60% report shoulder pain during their career.^{8,33} Ligament sprains, tendinopathies, and

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musculotendinous strains are the most commonly diagnosed injuries, with 30% to 44% occurring because of overuse.^{10,18,27,29}

Previous studies^{6,11,17,23,28,30} in overhead athletes demonstrated an association between preseason range of motion (ROM) and strength measures and in-season upper extremity injuries. Considering the high forces on the upper extremity, it is possible that impairments in ROM and strength may alter the load distribution within the upper extremity joints, thus predisposing gymnasts to injury,^{8,16} but prospective studies are lacking. Therefore, the purpose of this study was to ascertain whether preseason upper extremity ROM and strength differ between National Collegiate Athletic Association (NCAA) Division I collegiate gymnasts who sustain an in-season upper extremity injury compared with those who do not. Similar to studies in overhead athletes, we hypothesized that gymnasts who sustain an upper extremity injury would demonstrate reduced ROM and strength compared with noninjured gymnasts.

METHODS

Participants

This institutional review board–approved study included a prospective cohort of athletes from the 2014 to 2018 University of Florida women's gymnastics team (NCAA Division I). At the time of recruitment, athletes had to be healthy and free of injuries that precluded full participation in gymnastics-related activities. Athletes were excluded if they (1) were unwilling to have strength and ROM measured and (2) reported any recent injury or surgery before the start of testing.

Procedure

All athletes were tested preseason before the start of the subsequent collegiate competitive season. If a gymnast participated in multiple years of preseason testing, each season was considered a separate player-season. Baseline characteristics, including age, height, weight, position/event, and arm/hand dominance, were obtained for each gymnast. Preseason screening tests were chosen based on relevance to overhead requirements in gymnastics

tumbling and swinging skills, as well as previous utilization in preseason screening of overhead athletes. As further described later, upper extremity ROM was measured bilaterally through a single passive goniometric measurement. Passive ROM was recorded at the point in which tissue resistance (ie, end feel) was first felt but normal joint arthrokinematics was still maintained. Upper extremity strength was measured bilaterally using an electromechanical (Biodex System 3; Biodex Medical Systems Inc) or a handheld dynamometer (Hoggan Scientific LLC). Participants were asked to perform 1 maximal muscle contraction.

Range of Motion

Shoulder flexion was measured using a goniometer with participants lying supine. One tester stabilized the scapula and passively moved the shoulder joint to the end of the available glenohumeral joint ROM. A second tester placed the stationary arm of the goniometer parallel to the table and the moving arm parallel to the shaft of the humerus toward the lateral epicondyle. The axis of rotation was inferior and lateral to the acromion process. This method has an excellent intraclass correlation coefficient (ICC) of 0.87.^{24,25}

Shoulder external rotation and internal rotation were measured using a goniometer with participants lying supine, with the testing shoulder abducted to 90° and the elbow flexed to 90°. One tester used a C-shaped grasp with fingers around the posterior scapula and coracoid anteriorly to stabilize the scapula. The shoulder was then passively moved to the end range of glenohumeral joint external and internal rotation. The second tester placed the stationary arm of the goniometer perpendicular to the table and the moving arm parallel to the posterior shaft of the ulna toward the ulnar styloid. The axis of rotation was through the olecranon. This method has a good ICC of 0.88 and 0.43 for external and internal rotation, respectively.^{24,25}

Elbow extension was measured using a goniometer with the athletes lying supine. A rolled towel was placed underneath the distal humerus; the forearm was fully supinated with the palm facing the ceiling. One tester stabilized the anterior shoulder while passively extending the elbow until the end feel was perceived. A second tester placed the stationary arm of the goniometer parallel to the humeral shaft and the moving arm parallel to the posterior shaft of the

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ulna toward the ulnar styloid. The axis of rotation was through the lateral epicondyle of the elbow. This method has an excellent ICC of 0.92.^{24,26}

Wrist extension was measured using a goniometer with the athletes lying supine. A rolled towel was placed underneath the distal humerus; the forearm was fully supinated with the palm facing the ceiling. One tester stabilized the distal forearm while passively extending the wrist until the end of wrist joint extension ROM (the point where end feel is perceived). A second tester placed the stationary arm of the goniometer parallel to the ulnar shaft toward the medial epicondyle and the moving arm parallel to the shaft of the fifth metacarpal. The axis of rotation was through the lateral triquetrum. This method has a good ICC of 0.80.^{19,24}

Strength Testing

Shoulder internal and external rotation strength was measured using the isokinetic dynamometer. Athletes were positioned according to manufacturer recommendation with the arm slightly abducted. The height of the isokinetic device was adjusted between each gymnast to achieve a neutral anatomic resting position of the shoulder. The forearm was secured in neutral rotation with a Velcro strap. The tester instructed the gymnast to perform 5 maximum-effort repetitions in a row of shoulder external and internal rotation at a speed of 120 deg/s. Shoulder internal and external rotation strength was measured. These testing methods have an ICC of 0.60 to 0.95.²⁰

Middle and lower trapezius strength was measured using the handheld dynamometer (microFET 2) with athletes lying prone. The testing arm was positioned off the table with the elbow extended. For middle trapezius testing, the shoulder was abducted to 90° and in neutral rotation. For lower trapezius testing, the shoulder was flexed in the scapular plane with slight external rotation. The tester first palpated the muscle to ensure the presence of voluntary activation. The handheld dynamometer was then placed just proximal to the distal radioulnar joint. Gymnasts were asked to push against the device as hard as they could for 3 seconds. This method has an excellent ICC of 0.93 to 0.98.²

Elevation in the scapular plane (ie, scaption) strength was measured using the handheld dynamometer with gymnasts seated and feet flat on the floor. The testing shoulder was flexed to 90° in the scapular plane. The handheld dynamometer was placed just proximal to the distal humerus. Athletes were asked to push against the device as hard as they could for 3 seconds. This method has an excellent ICC of 0.93.^{2,4}

Injury Tracking

The University of Florida athletic training staff tracked injury data throughout each competitive season using a secure electronic system (Presagia Sports Pro; Presagia Sports). A reportable injury was defined as an injury that (1) restricted the gymnast from at least 1 full practice participation; (2) occurred as a result of participation in an organized collegiate practice or competition; and (3)

TABLE 1
Descriptive Statistics for the Study Participants (N = 15)^a

| | Mean ± SD or No. |
|------------------------|------------------|
| Age, y | 20.5 ± 0.9 |
| Weight, kg | 62.1 ± 8.6 |
| Height, m | 1.6 ± 0.06 |
| BMI, kg/m ² | 24.27 ± 3.5 |
| Hand dominance | |
| Right | 11 |
| Left | 4 |

^aBMI, body mass index.

required attention from an athletic trainer, physician, or physical therapist.¹³ The following descriptive measures were collected to track injuries: region injured (shoulder, elbow, wrist), side (dominant, nondominant), medical diagnosis, and type (overuse, traumatic). Traumatic injuries (fractures, dislocations, ligament tears, etc) were excluded from the analysis because they were less likely to have occurred as a result of preseason strength or ROM imbalances. Preseason ROM and strength measures were linked to injuries sustained during that same competitive season.

Data Analysis

Gymnasts were dichotomized into 2 groups based on upper extremity injury history. Gymnastics performance requires bilateral contribution of the upper extremity. Therefore, both noninjured (dominant and nondominant) and injured (injured and noninjured) sides were considered in the analysis. In the injured group, the side of preseason screening was matched with the side of the injury. A 2 × 2 analysis of variance (ANOVA) was used to measure differences in preseason measures between groups (injured vs noninjured) and within arms (injured vs noninjured arm for the injured group; dominant vs nondominant arm for the noninjured group). The ANOVA model included a repeated measure on the within-factor (arms). Results in the ANOVA model were considered significant if the *P* value of the interaction reached .05. Between- and within-group differences were described using mean differences, 95% CI, and effect sizes (Cohen *d*). Only between- and within-group differences associated with at least moderate (0.5) effect size were considered for discussion.

RESULTS

Over 4 competitive seasons, 31 gymnasts were approached for participating in the study. Sixteen gymnasts consented to participate, but 1 gymnast quit the team during the season. Injury data for this participant were not available and was therefore excluded from the analysis. Table 1 shows the characteristic information for the 15 study participants. A total of 31 gymnast-seasons were included in the analysis (Figure 1). These gymnasts sustained 18 injuries to the

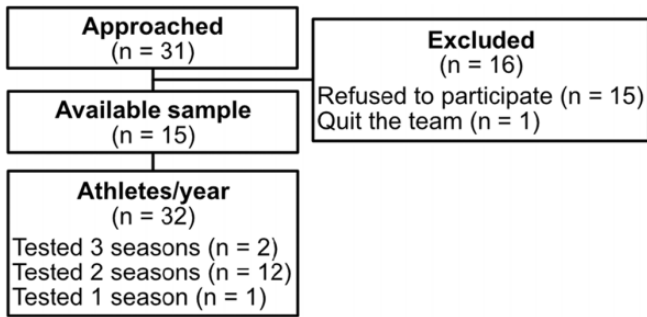


Figure 1. Participant flowchart.

TABLE 2
Incidence of Upper Extremity Injury by Region^a

| | n (%) | Injury Side (D/ND) |
|-------------------------|---------|--------------------|
| Overuse injuries | 12 (67) | 5/7 |
| Shoulder | | |
| Instability | 5 (28) | 3/2 |
| Biceps tendinitis | 3 (17) | 1/2 |
| Rotator cuff tendinitis | 2 (11) | 0/2 |
| Forearm/wrist | | |
| Flexor tendinitis | 1 (6) | 0/1 |
| Sprain | 1 (6) | 1/0 |

^aD, dominant; ND, nondominant.

upper extremity: 12 were overuse injuries (10 at the shoulder, 2 at the forearm/wrist) (Table 2).

There was no significant group-by-arm interaction for preseason ROM and strength measurements ($P = .07$) (Tables 3 and 4). The between-group differences between the dominant and injured side that reached at least a moderate effect size were wrist extension ROM (mean difference [MD] = -8.6 [95% CI, -17.5 to 0.3]; effect size [ES] = 0.7), shoulder external rotation ROM (MD = 6.8 [95% CI, -3.2 to 16.7]; ES = 0.5), and the ratio of shoulder external rotation to internal rotation strength (MD = -0.06 [95% CI, -0.14 to 0.03]; ES = 0.5). In the noninjured group, the only within-arm difference between the dominant and nondominant sides that reached at least a moderate effect size was shoulder external rotation ROM (mean difference = 8.7 [95% CI, 0.7 - 16.7]; effect size = 0.6) (Tables 3 and 4).

DISCUSSION

We hypothesized that gymnasts who sustained an upper extremity injury during a competitive season would demonstrate reduced preseason ROM and strength measures. Our findings did not confirm this hypothesis. It is possible that ROM and strength measures used to screen overhead athletes may not capture the unique features and requirements of gymnastics. Despite gymnasts having a dominant side for performing pirouetting and tumbling skills, a large majority of skills are executed with the use of both sides in order to develop sufficient power and

rotation.^{8,16} For this reason, it may be challenging to discern differences in clinical measures of ROM and strength in gymnastics populations. Owing to a lack of prospective studies in gymnastics, several potential differences between and within groups merit further discussion.

Overhead athletes (baseball, handball, tennis) demonstrate increased shoulder external rotation ROM in the dominant shoulder compared with the nondominant,^{1,9,15,22,31,32} which is advantageous for throwing and serving performance. In our study, noninjured gymnasts demonstrated greater shoulder external rotation ROM (MD = 8.7 [95% CI, 0.7 - 16.7]; ES = 0.6) in the dominant compared with the nondominant side. No study has previously reported ROM features of elite, collegiate, or youth gymnasts. Despite gymnastics being a bilateral sport, it is possible that the increased shoulder external rotation in the dominant side may provide an advantage when performing skills. Reduced shoulder external rotation ROM in the throwing arm has also been found in injured cohorts of professional overhead athletes. Shoulder external rotation deficit of at least 5° in the throwing shoulder is associated with a higher risk of injury in professional baseball pitchers.²³ Our results show a similar trend: gymnasts who sustained an in-season injury had reduced preseason shoulder external rotation ROM on the injured side (MD = 6.8 [95% CI, -3.2 to 16.7]; ES = 0.5) compared with the dominant side of noninjured gymnasts. The small sample size generated a wide confidence interval and prevented the performing of a risk analysis. Therefore, future research is necessary to determine the usefulness of screening shoulder external rotation ROM in collegiate gymnasts.

A notable finding was the increase in wrist extension ROM on the injured side of the injured group compared with the dominant side of the noninjured group (MD = -8.6 [95% CI, -17.5 to 0.3]; ES = 0.7). McLaren et al²¹ measured wrist extension in a weightbearing position in a group of gymnasts with and without a history of wrist pain. They found that gymnasts who impacted with greater wrist extension during a back handspring reported a higher incidence of wrist pain.²¹ The hyperextended wrist position during impact may centralize and increase the forces through the wrist joint.²¹ Greater wrist extension during a back handspring is also related to decreased shoulder flexion upon impact, indicating potential disruption of energy absorption in the kinetic chain.²¹ With long training hours and high repetition over time, this could potentially contribute to overuse injuries of the upper extremity.^{5,33} Future studies should investigate whether a weightbearing measure of wrist ROM can better discriminate between injured and noninjured gymnasts.

Gymnastics requires a delicate balance between upper extremity strength and mobility. The gymnast is required to achieve high levels of strength to land on and take off repetitively from the hands.⁸ From a biomechanical standpoint, lack of strength may generate maladaptive techniques, which can increase stresses on local, proximal, and distal tissues, as well as joints.^{8,12,16} The association between shoulder strength and injury has been reported across multiple upper extremity sports. Edouard et al¹¹

TABLE 3
Range of Motion Results for the Noninjured and Injured Groups^a

| Range of Motion | Noninjured Group (n = 19) | Injured Group (n = 12) | Mean Difference (95% CI) ^b | P ^c |
|---------------------------------|---------------------------------|---------------------------------|--|----------------|
| Wrist extension, deg | | | | .22 |
| Dominant/injured arm | 62.5 ± 12.0 | 71.1 ± 11.5 | -8.6 (-17.5 to 0.3) ES = 0.7 | |
| Nondominant/noninjured arm | 65.6 ± 16.7 | 67.8 ± 13.5 | 2.2 (-13.9 to 9.5) ES = 0.1 | |
| Mean difference (95% CI) | -3.2 (-10.7 to 4.4) ES = 0.2 | 3.3 (-3.4 to 9.9) ES = 0.3 | | |
| Elbow extension, deg | | | | .89 |
| Dominant/injured arm | -7.4 ± 6.5 | -8.3 ± 6.3 | 0.9 (-3.9 to 5.6) ES = 0.1 | |
| Nondominant/noninjured arm | -7.8 ± 8.8 | -9.3 ± 7.6 | 1.5 (-4.9 to 7.8) ES = 0.2 | |
| Mean difference (95% CI) | 0.4 (-2.7 to 3.4) ES < 0.1 | 0.9 (-2.7 to 4.5) ES = 0.1 | | |
| Shoulder external rotation, deg | | | | .07 |
| Dominant/injured arm | 111.1 ± 13.7 | 102.4 ± 14.5 | 6.8 (-3.2 to 16.7) ES = 0.5 | |
| Nondominant/noninjured arm | 104.3 ± 12.4 | 107.5 ± 17.8 | -5.1 (-17.0 to 6.8) ES = 0.3 | |
| Mean difference (95% CI) | 8.7 (0.7 to 16.7) ES = 0.6 | -3.2 (-14.5 to 8.2) ES = 0.2 | | |
| Shoulder internal rotation, deg | | | | .80 |
| Dominant/injured arm | 30.9 ± 5.4 | 29.0 ± 8.9 | 1.9 (-3.3 to 7.2) ES = 0.3 | |
| Nondominant/noninjured arm | 32.0 ± 5.7 | 30.6 ± 8.1 | 1.4 (-3.7 to 6.5) ES = 0.2 | |
| Mean difference (95% CI) | -1.1 (-4.0 to 1.9) ES = 0.2 | -1.6 (-4.7 to 1.5) ES = 0.2 | | |
| Shoulder flexion, deg | | | | .79 |
| Dominant/injured arm | 170.5 ± 12.0 | 166.6 ± 16.1 | 3.8 (-6.5 to 14.1) ES = 0.3 | |
| Nondominant/noninjured arm | 171.7 ± 9.3 | 167.2 ± 11.4 | 4.5 (-3.2 to 12.2) ES = 0.4 | |
| Mean difference (95% CI) | -1.2 (-4.3 to 2.0) ES = 0.1 | -0.5 (-5.4 to 4.5) ES < 0.1 | | |

^aData are reported as mean ± SD unless otherwise indicated. ES, effect size (Cohen *d*).

^bBetween-group difference calculated as (*noninjured group* - *injured group*) for each arm.

^cInteraction effect.

found that handball players with a shoulder external rotation/internal rotation strength imbalance were 2.5 times more likely to sustain a shoulder injury. Stickley et al²⁸ showed that volleyball players with a history of shoulder pathology exhibited decreased eccentric internal rotation and concentric external rotation strength. Additionally, Wang and Cochrane³⁰ found that a decrease in shoulder external rotation strength compared with internal rotation strength in the dominant arm was associated with shoulder injuries and pain in elite volleyball players. Similarly, our current study found increased shoulder external to internal rotation ratio on the injured side of injured compared with the dominant side of noninjured gymnasts (MD = -6% [95% CI, -14% to 3%]; ES = 0.5). Although the finding was not statistically significant, monitoring shoulder external and internal rotation strength may be important in gymnasts with a history of upper extremity injury.

Limitations of this study include the small sample size. A high percentage of gymnasts did not consent to participate in this study, which is critical considering that college gymnastics teams are small (typically 12-15 athletes). Furthermore, an a priori sample size estimate was not performed. Standardized and reliable clinical measures of ROM and strength were used by an experienced investigator [G.Z.]; however, investigator reliability was not measured. Joint laxity, which is common in gymnasts, was not measured. Last, the results are limited to NCAA Division I college female gymnasts and cannot be generalized to other age groups or to male gymnasts.

Future research is needed to determine whether preseason screening can identify collegiate gymnasts at risk of injury. Additionally, this research should be expanded to include younger age groups and skill levels to determine how changes in clinical measures vary across the life span. Some

TABLE 4
Strength Testing Results for the Noninjured and Injured Groups^a

| Strength | Noninjured Group (n = 19) | Injured Group (n = 12) | Mean Difference (95% CI) ^b | P ^c |
|--|-----------------------------------|----------------------------------|--|----------------|
| Shoulder external rotation, N·m | | | | .89 |
| Dominant/injured arm | 10.2 ± 2.9 | 10.9 ± 3.9 | -0.7 (-3.3 to 1.9) ES = 0.2 | |
| Nondominant/noninjured arm | 9.8 ± 2.2 | 10.2 ± 3.5 | -0.4 (-2.4 to 1.8) ES = 0.1 | |
| Mean difference (95% CI) | 0.3 (-1.1 to 1.6) ES = 0.1 | 0.4 (-0.5 to 1.5) ES = 0.1 | | |
| Shoulder internal rotation, N·m | | | | .85 |
| Dominant/injured arm | 17.0 ± 4.4 | 16.6 ± 4.9 | 0.3 (-3.3 to 3.8) ES = 0.1 | |
| Nondominant/noninjured arm | 16.2 ± 4.8 | 17.3 ± 5.2 | -1.1 (-4.8 to 2.6) ES = 0.2 | |
| Mean difference (95% CI) | 0.8 (-0.5 to 2.0) ES = 0.2 | -0.5 (-2.0 to 1.0) ES = 0.1 | | |
| Shoulder scaption, kg | | | | .08 |
| Dominant/injured arm | 4.7 ± 2.1 | 4.6 ± 1.7 | 0.1 (-1.4 to 1.6) ES = 0.1 | |
| Nondominant/noninjured arm | 4.7 ± 2.2 | 5.0 ± 1.8 | -0.4 (-1.9 to 1.2) ES = 0.2 | |
| Mean difference (95% CI) | 0.1 (-0.2 to 0.4) ES < 0.1 | -0.4 (-1.0 to 0.2) ES = 0.2 | | |
| Lower trapezius, kg | | | | .57 |
| Dominant/injured arm | 2.2 ± 1.2 | 2.2 ± 0.9 | -0.3 (-0.9 to 0.8) ES < 0.1 | |
| Nondominant/noninjured arm | 2.3 ± 1.2 | 2.2 ± 0.8 | 0.1 (-0.8 to 0.9) ES = 0.1 | |
| Mean difference (95% CI) | -0.1 (-0.3 to 0.1) ES = 0.1 | <0.1 (-0.3 to 0.3) ES < 0.1 | | |
| Middle trapezius, kg | | | | .34 |
| Dominant/injured arm | 2.4 ± 1.1 | 2.3 ± 0.9 | 0.1 (-0.7 to 0.9) ES = 0.1 | |
| Nondominant/noninjured arm | 2.3 ± 1.2 | 2.5 ± 0.8 | -0.2 (-1.0 to 0.6) ES = 0.2 | |
| Mean difference (95% CI) | 0.1 (-0.3 to 0.4) ES < 0.1 | -0.2 (-0.7 to 0.3) ES = 0.2 | | |
| Shoulder external to internal rotation ratio, % ^d | | | | .25 |
| Dominant/injured arm | 0.60 ± 0.10 | 0.66 ± 0.12 | -0.06 (-0.14 to 0.03) ES = 0.5 | |
| Nondominant/noninjured arm | 0.63 ± 0.11 | 0.61 ± 0.14 | 0.02 (-0.07 to 0.11) ES = 0.2 | |
| Mean difference (95% CI) | -0.02 (-0.94 to 0.05) ES = 0.2 | 0.04 (-0.06 to 0.14) ES = 0.3 | | |

^aData are reported as mean ± SD unless otherwise indicated. ES, effect size (Cohen *d*).

^bBetween-group difference calculated as *noninjured group* - *injured group* for each arm.

^cInteraction effect.

^dCalculated as *external rotation strength* / *internal rotation strength* for each upper extremity.

gymnasts may be able to compensate for joint laxity with strength and motor control. However, testing of this hypothesis would require a dedicated research study. Further studies on the effects of lower extremity ROM and strength on lower extremity injury are also warranted. With the high injury rates observed in women's gymnastics, this information may provide insight into injury patterns, training regimes, and sport-specific adaptations that may affect the performance and longevity of the gymnast.

CONCLUSION

Preseason ROM and strength are not different between gymnasts who sustain an in-season upper extremity overuse injury and those who do not. It is possible that ROM and strength measures used to screen other overhead athletes may not capture the unique features and requirements of gymnastics. Further, it may be challenging to discern differences in clinical measures of ROM and

strength in gymnastics populations due to the bilateral nature of the sport.

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REFERENCES

- Agresta CE, Krieg K, Freehill MT. Risk factors for baseball-related arm injuries: a systematic review. *Orthop J Sports Med.* 2019;7(2):2325967119825557.
- Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther.* 1996;76(3):248-259.
- Bradshaw EJ, Hume PA. Biomechanical approaches to identify and quantify injury mechanisms and risk factors in women's artistic gymnastics. *Sports Biomech.* 2012;11(3):324-341.
- Brookham RL, McLean L, Dickerson CR. Construct validity of muscle force tests of the rotator cuff muscles: an electromyographic investigation. *Phys Ther.* 2010;90(4):572-580.
- Brüggemann GP. Biomechanical and biological limits in artistic gymnastics. In: International Symposium on Biomechanics in Sports (2005). International Society of Biomechanics in Sports; 2005. <https://ojs.ub.uni-konstanz.de/cpa/article/view/647>
- Bullock GS, Faherty MS, Ledbetter L, Thigpen CA, Sell TC. Shoulder range of motion and baseball arm injuries: a systematic review and meta-analysis. *J Athl Train.* 2018;53(12):1190-1199.
- Burt L, Naughton G, Higham D, Landeo R. Training load in pre-pubertal female artistic gymnastics. *Sci Gymnast J.* 2008;2(3):5-14.
- Caine D, Russell K, Lim L, eds. *Handbook of Sports Medicine and Science: Gymnastics.* 1st ed. Wiley-Blackwell; 2013.
- Camp CL, Zajac JM, Pearson DB, et al. Decreased shoulder external rotation and flexion are greater predictors of injury than internal rotation deficits: analysis of 132 pitcher-seasons in professional baseball. *Arthroscopy.* 2017;33(9):1629-1636.
- Campbell RA, Bradshaw EJ, Ball NB, Pease DL, Spratford W. Injury epidemiology and risk factors in competitive artistic gymnasts: a systematic review. *Br J Sports Med.* 2019;53(17):1056-1069.
- Edouard P, Degache F, Oullion R, Plessis JY, Gleizes-Cervera S, Calmels P. Shoulder strength imbalances as injury risk in handball. *Int J Sports Med.* 2013;34(7):654-660.
- Edouard P, Steffen K, Junge A, Leglise M, Soligard T, Engebretsen L. Gymnastics injury incidence during the 2008, 2012 and 2016 Olympic Games: analysis of prospectively collected surveillance data from 963 registered gymnasts during Olympic Games. *Br J Sports Med.* 2018;52(7):475-481.
- Fuller C, Bahr R, Dick RMW. A framework for recording recurrences, reinjuries, and exacerbations in injury surveillance. *Clin J Sport Med.* 2007;17(3):197-200.
- Gil JA, Goodman AD, DeFroda SF, Owens BD. Characteristics of operative shoulder injuries in the National Collegiate Athletic Association, 2009-2010 Through 2013-2014. *Orthop J Sports Med.* 2018;6(8):2325967118790764.
- Gillet B, Begon M, Sevez V, Berger-Vachon C, Rogowski I. Adaptive alterations in shoulder range of motion and strength in young tennis players. *J Athl Train.* 2017;52(2):137-144.
- Jemni M, ed. *The Science of Gymnastics.* Second Edition. Routledge; 2018.
- Keller RA, De Giacomo AF, Neumann JA, Limpisvasti O, Tibone JE. Glenohumeral internal rotation deficit and risk of upper extremity injury in overhead athletes: a meta-analysis and systematic review. *Sports Health.* 2018;10(2):125-132.
- Kerr ZY, Hayden R, Barr M, Klossner DA, Dompier TP. Epidemiology of National Collegiate Athletic Association women's gymnastics injuries, 2009-2010 through 2013-2014. *J Athl Train.* 2015;50(8):870-878.
- LaStayo PC, Wheeler DL. Reliability of passive wrist flexion and extension goniometric measurements: a multicenter study. *Phys Ther.* 1994;74(2):162-174.
- Malerba JL, Adam ML, Harris BA, Krebs DE. Reliability of dynamic and isometric testing of shoulder external and internal rotators. *J Orthop Sports Phys Ther.* 1993;18(4):543-552.
- McLaren K, Byrd E, Herzog M, Polikandriotis JA, Willimon SC. Impact shoulder angles correlate with impact wrist angles in standing back handsprings in preadolescent and adolescent female gymnasts. *Int J Sports Phys Ther.* 2015;10(3):341-346.
- Moreno-Pérez V, Elvira J, Fernandez-Fernandez J, Vera-Garcia F. A comparative study of passive shoulder rotation range of motion, isometric rotation strength and serve speed between elite tennis players with and without history of shoulder pain. *Int J Sports Phys Ther.* 2018;13(1):39-49.
- Pozzi F, Plummer HA, Shanley E, et al. Preseason shoulder range of motion screening and season risk of shoulder and elbow injuries in overhead athletes: systematic review and meta-analysis. *Br J Sports Med.* 2020;54(17):1019-1027.
- Reese N, Bandy W. *Joint Range of Motion and Muscle Length Testing.* Saunders/Elsevier; 2002.
- Riddle DL, Rothstein JM, Lamb RL. Goniometric reliability in a clinical setting: shoulder measurements. *Phys Ther.* 1987;67(5):668-673.
- Rothstein JM, Miller PJ, Roettger RF. Goniometric reliability in a clinical setting. Elbow and knee measurements. *Phys Ther.* 1983;63(10):1611-1615.
- Saluan P, Styron J, Freeland Ackley J, Prinzbach A, Billow D. Injury types and incidence rates in precollegiate female gymnasts: a 21-year experience at a single training facility. *Orthop J Sports Med.* 2015;3(4):2325967115577596.
- Stickley CD, Hetzler RK, Freemyer BG, Kimura IF. Isokinetic peak torque ratios and shoulder injury history in adolescent female volleyball athletes. *J Athl Train.* 2008;43(6):571-577.
- Thomas RE, Thomas BC. A systematic review of injuries in gymnastics. *Phys Sportsmed.* 2019;47(1):96-121.
- Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *J Sports Med Phys Fitness.* 2001;41(3):403-410.
- Wilk KE, Macrina LC, Fleisig GS, et al. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers. *Am J Sports Med.* 2015;43(10):2379-2385.
- Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med.* 2011;39(2):329-335.
- Wolf MR, Avery D, Wolf JM. Upper extremity injuries in gymnasts. *Hand Clin.* 2017;33(1):187-197.