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ORIGINAL RESEARCH

# IMPACT SHOULDER ANGLES CORRELATE WITH IMPACT WRIST ANGLES IN STANDING BACK HANDSPRINGS IN PREADOLESCENT AND ADOLESCENT FEMALE GYMNASTS

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## ABSTRACT

***Background and Purpose:*** In gymnastics, the wrist is exposed to many different stresses including increased extension, especially during back handsprings. Currently a wrist extension angle during impact that places the wrist in danger has not been established. The purpose of this study was to: (1) determine the mean impact wrist angle during a standing back handspring in female preadolescent and adolescent gymnasts and (2) determine which factors predict impact wrist angles.

***Methods:*** Fifty female gymnasts from six facilities, ages 8-15 were included in this study. Each gymnast completed a questionnaire about gymnastics participation and history of wrist pain. Active range of motion of the shoulder, elbow, wrist, hip, and ankle was measured. Each gymnast was asked to perform a standard back handspring, which was videotaped. The wrist and shoulder flexion angles, at maximum impact, were recorded and measured using motion analysis software. Two-sample t-test was used to assess the relationship between impact wrist angle and wrist pain. Multiple linear regression was used to determine the association between related variables and impact wrist angle.

***Results:*** The mean back handspring impact wrist angle was 95°. Fifteen subjects (30%) reported wrist pain. Years of participation ($p = 0.02$) and impact shoulder angle ($p = 0.04$) were predictive of impact wrist angles.

***Conclusion:*** Shoulder angles and years of participation correlate with impact wrist angles during the performance of a standing back handspring. Future studies are necessary to determine if addressing these factors can affect the impact wrist angles.

***Keywords:*** Back handspring, gymnastics, wrist

***Level of Evidence:*** 3

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## INTRODUCTION

USA Gymnastics reports that over 90,000 athletes are currently registered participants in competitive gymnastics in the United States.[1] Gymnasts are unique in that they weight-bear on their upper extremities. This often results in joint injuries due to increased loads at the shoulder, elbow, and wrist, and these injuries often result in missed time from sport and accumulated healthcare costs.[2,3,4] The wrist is the most frequently injured upper extremity joint in female gymnasts,[2] yet the body of research examining wrist angles during common impact gymnastic skills and factors that affect the impact wrist angle during dynamic gymnastic skills is limited.

It is theorized that development of correct technique and attention to mechnaics are important early in a gymnast's career in order to minimize excessive forces experienced through the wrist and subsequently lower the potential for wrist injury. Gymnasts will build on basic movements and positions as they progress in skill level. In order to understand forces at the wrist, it is important to examine a gymnast's wrist angles during activity. A hyperextended wrist angle during impact centralizes and intensifies weight-bearing forces over the distal radius and ulna.[4] Hyperextension of the wrist may result from decreased shoulder flexion and increased elbow flexion at impact during a dynamic skill, or failure of the shoulders to reach the fully open, or fully flexed, position at time of impact. (Figures 1 & 2)

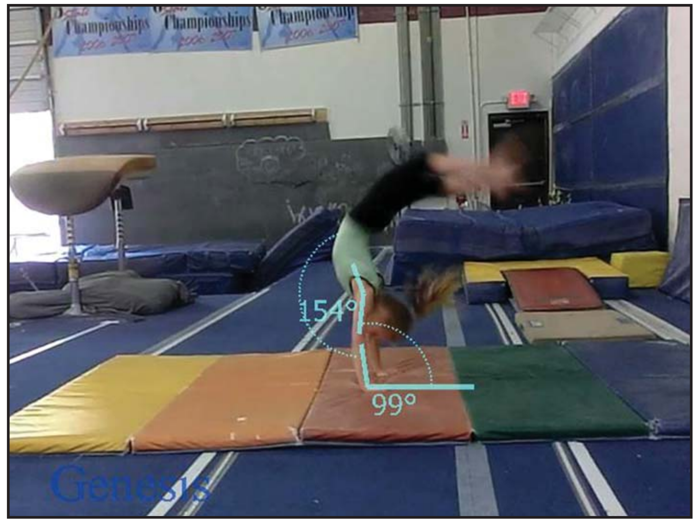


**Figure 1.** *Greater shoulder flexion angle with less acute angle of wrist extension.*

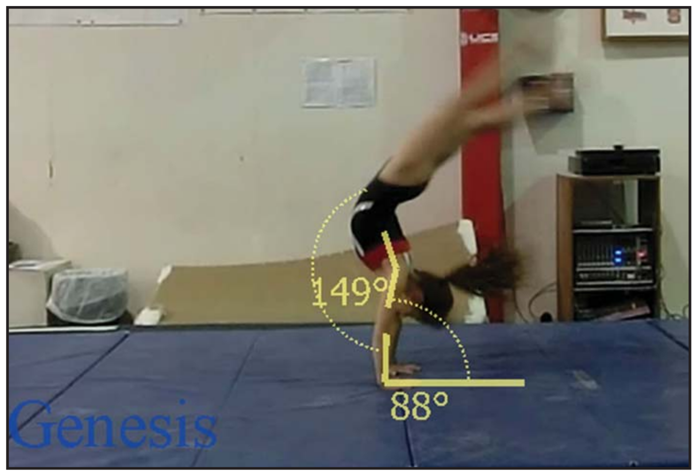


**Figure 2.** *Decreased shoulder angle with greater angle of wrist extension. (less optimal).*

The back handspring, a basic skill that a gymnast will build on throughout their career, is an excellent representation of a dynamic skill that requires wrist motion and will essentially pass through the basic handstand position. The purpose of this study is to: (1) determine the mean wrist angle during a standing back handspring in female preadolescent and adolescent gymnasts; and (2) determine if other factors, such as impact shoulder angle, affect the impact wrist angle. For the purpose of this study, glenohumeral shoulder flexion will be measured in each gymnast. Discussion will consist of addressing the shoulder complex as a whole as impact during a back handspring is dynamic and is affected by both the glenohumeral joint and the shoulder complex.

## METHODS

This study was Institutional Review Board approved. Between March 2013 and May 2013, participants were prospectively recruited from six gymnastics facilities in the metropolitan Atlanta area via phone calls to the facilities. High-level female gymnasts USAG level 6 or higher, USAG Platinum or higher, or AAU Prep Op 3 who were between the ages of 8 to 15 years were invited to participate. Each level listed is the minimum level in which a skilled back handspring is required of the athlete, therefore the inclusion competition levels were chosen to ensure that the back handspring was not a novice skill for the participant. Exclusion criteria were a history of injury to the neck, shoulder, elbow, or wrist, a diagnosis of wrist pathology by a physician with or without radiographs, and male sex.

Following consent to participate in the study from the guardian and the athlete, each participant filled out a self-administered subjective questionnaire about her competition level, gymnastics experience, and history of wrist pain developed by the researchers. If the participant reported current or previous wrist pain, she was asked the duration of symptoms and any treatment she received. Next, range of motion measurements were taken by two experienced clinicians using clinical standards of gonionmetric measurements with a standard size goniometer. Motions recorded included active shoulder flexion and extension, elbow flexion, extension and carrying angle, wrist flexion and extension, hip extension and ankle dorsiflexion.[5]

Biomechanical analysis was performed using a Casio Ex-ZR200 camera for gathering video data, and shoulder and wrist angles measured, documented, and analyzed using Genesis motion analysis software (EquineTec, Monroe, GA). Each gymnast was allowed time to stretch and warm up with one back handspring performed individually prior to performing the recorded back handspring. Each gymnast was asked to perform one back handspring without wrist guards or braces on a standard 1-inch (depth) eight-panel mat. The gymnast was verbally cued to "perform one back handspring." A single investigator recorded each back handspring and measured shoulder and wrist angles during the point of impact for each back handspring. Impact angles were measured using standard goniometric landmarks. The impact wrist and shoulder angle are defined as the moment in time when a gymnast's hands make contact with the floor and the body absorbs its weight. These measurements were captured simultaneously and were measured using the Genesis software. Each wrist impact angle was measured with the x-axis parallel to the floor and the y- axis through the center of the wrist following the forearm. (Refer to Figures 1 & 2) All angles were measured in the right wrist. Angles that were measured to be less than 90 degrees indicate closer proximity of the fingers to the forearm and a greater (more severe) extension angle at impact. Angles that are measured to be greater than 90 degrees indicate a lesser (less severe) extension angle at impact.

Statistical analyses were performed using SAS 9.3 (Cary, NC). A two-sample t-test was used to assess the relationship between impact wrist angle and wrist pain. Linear regression was used to identify variables associated with impact wrist angle. Variables entered into the initial model included years of participation, use of extension limiting wrist braces, impact shoulder angle, age, and active range of motion including shoulder flexion, shoulder extension, elbow flexion, elbow extension, elbow valgus, wrist flexion, wrist extension, hip extension, and ankle dorsiflexion each measured separately. Backwards elimination and forward selection were used to identify the best model and to determine which variables should remain in the model for analysis (Table 1). The final model was analyzed using linear regression to determine the association between related variables and impact wrist angle. All statistics were analyzed at the 95% level, and $p < 0.05$ was considered statistically significant.

**Table 1.** *Results of multivariate linear regression using backward elimination*

| Variable | p-value |
|---|---|
| Age (years) | p=0.35 |
| Years of Participation | *p=0.02 |
| Impact Shoulder Angle (degrees) | *p=0.04 |
| Wrist Flexion Limiting Brace Use | p=0.95 |
| Wrist Flexion ROM (degrees) | p=0.53 |
| Wrist Extension ROM (degrees) | p=0.95 |
| Elbow Flexion ROM (degrees) | p=0.08 |
| Elbow Extension ROM (degrees) | p=0.37 |
| Elbow Valgus ROM (degrees) | p=0.70 |
| Shoulder Flexion ROM (degrees) | p=0.80 |
| Shoulder Extension ROM (degrees) | p=0.27 |
| Hip Extension ROM (degrees) | p=0.67 |
| Ankle Dorsiflexion ROM (degrees) | p=0.19 |

## RESULTS

Fifty-seven female gymnasts from six gymnastics facilities were examined. Participants were excluded due to systemic pathology affecting joint mobility, previous wrist, elbow, or shoulder surgery or previous wrist injury that required immobilization. Self reported generalized wrist pain was not within exclusion criteria. Fifty participants met the criteria for this study and were included in the analysis. Mean age of participants was 12.7 years (range: 8.1 to 15.0 years). Mean number of years of participation in gymnastics was 8 (range: 3 to 15). Twenty-two (44%) reported current usage of a wrist extension limiting brace bilaterally.

Mean back handspring wrist angle was 95 degrees (range: 77.0 to 119.0 degrees). Mean back handspring glenohumeral shoulder flexion angle was 154 degrees (range: 126 to 174 degrees). There was a significant difference between the mean impact wrist angle and the measured active range of motion (95 degrees vs. 67 degrees; $p = < 0.001$). Fifteen (30%) reported current or recent history of wrist pain for an average duration of 10.95 months (range: 0.25 to 24.00 months). Gymnasts with wrist pain had a slightly different impact wrist angle compared to those without wrist pain (97.8 degrees and 94.3 degrees, respectively; $p = 0.06$), which approached statistical significance. Multivariate linear regression analysis indicated that increased years of participation decreases the amount of wrist extension at impact ($p = 0.02$), and that impact shoulder angle ($p = 0.04$) correlated with impact wrist angles. Backwards elimination and forward selection revealed a final model where for every one degree increase in impact shoulder angle (increased shoulder flexion or a more open shoulder position), impact wrist angle increases by 0.18 degrees (more wrist flexion or less wrist hyperextension), after controlling for the other variables in the model.

## DISCUSSION

The mean impact wrist angle during a standing back handspring was 95 degrees. While there was a difference in impact wrist angles for gymnasts with wrist pain compared to gymnasts without wrist pain, this difference was not significant due to sample size. The results of the current study also indicate that there is a relationship between impact wrist angle and impact glenohumeral shoulder flexion angle during a gymnast's standing back handspring where a decreased glenohumeral shoulder flexion angle at impact results in an increased wrist extension angle. A limitation in glenohumeral shoulder flexion during impact results in an increase in elbow flexion, creating excessive extension through the wrist. The above summarizes what is described as a collapse through the shoulders at impact. The results suggest the development of strategies that increase the angle of glenohumeral shoulder flexion during a back handspring in gymnasts, possibly shoulder strengthening and flexibility strategies in the shoulder complex could reduce increased wrist extension during impact. This could be useful for guiding the clinical treatment of gymnasts and educating coaches in prevention of wrist injuries.

A few studies have examined the shoulder complex and wrist mechanics of a back handspring. Kampschroeder et al[7] and Penitente, Merni et al[8] made comparisons between "skilled" and "unskilled" gymnasts performance of back handsprings and reported that a skilled gymnast performing a back handspring had less ground reaction forces at the wrist and less vertical displacement at the shoulders during the back handspring.[7] Henrichs reported that a back handspring caused significantly more wrist extension than the gymnasts were able to obtain during the active range of motion (AROM) measurement.[9] This is in agreement with the findings of this study (95 degrees during performance, versus 67 degrees during AROM measurment; $p = < 0.001$). In addition, Henrichs found that maximum wrist hyperextension and maximum vertical force occur almost simultaneously in the back handspring during impact. The authors of the current study believe that this requirement of a large increase in extension of the wrist at the time of maximum vertical force is one factor that may lead to injury of the wrist during a back handspring.

The current results indicate that increased years of particpation in gymnastics is correlated to decreased wrist extension during impact. Upper extremity weight-bearing in the skeletally immature gymnast often leads to increased stress on the distal radial physis and carpals, causing the wrist to be more vulnerable to overuse injury.[3,4,7,10] Overuse injuries may include scaphoid impaction syndrome, dorsal impingement syndrome[3,4,7,10, 11] and arrest of growth of the radius.[8] The radius absorbs the majority (roughly 80%) [4] of the stress during upper extremity weight bearing, which can be up to two times the gymnast's body weight during impact while performing dynamic skills such as tumbling or vaulting. With repeated stress to the distal radius, a condition known as positive ulnar variance, where the ulna is no longer 2.5mm shorter than the radius, can occur.[3] Positive ulnar variance, caused by growth arrest at the radial physis, can also lead to other complex wrist injuries that may require surgical intervention such as triangular fibrocartilage complex (TFCC) repairs and ulnar shortening procedures. Conversely, after the closure of the growth plates, the injuries experienced by gymnasts differ. From repeated impact forces, skeletally mature gymnasts are more likely to present with TFCC tears, ulnar impaction syndrome, and lunotriquetral impingement.[3] Correction of wrist biomechanics in the skeletally immature gymnast may lead to decreased chronic wrist conditions that occur after skeletal maturity is reached.

Cools et al[12] have described the characteristic presentation of elite female gymnasts as having greater shoulder complex protraction than retraction, when expressed as a ratio. This can alter the ability of the serratus and trapezius to work together as a force couple to stabilize the scapula during upward rotation, and create an imbalance between bilateral scapulae during upward rotation in order to accommodate the upper extremities in a weight bearing position. Biomechanically, with insufficient scapular stabilizers and increased protraction force, it is reasonable to conclude that the shoulders could collapse at contact resulting in the inability to "block", or push off the hands and back on to the feet.[13] The blocking motion is a combination of simultaneous shoulder complex protraction, elevation, and shoulder flexion. Addressing the strength and neuromuscular control in the shoulder complex including the scapular stabilizers could potentially improve the shoulder angle and therefore improve the wrist angle at initial contact. When treating gymnasts with wrist pain the function of the proximal kinetic chain is important to consider as this population bears weight through the upper extremities. Developing a gymnast's strength and neuromuscular control proximally can affect the elbow and wrist in a closed kinetic chain position.

A limitation of the current study is the small sample size; however, this study adds to the literature by determining effect sizes, associations, and variability in order to calculate sample size for a future studies on this topic. Additionally, this study only included youth and adolescent female gymnasts, and consequently can only be generalized to the female gymnast population in this age range. Male gymnasts were excluded from this study due to differences in training, body structure and age of puberty. Recruitment of female gymnasts within the ages of 8-15 who had no history of upper extremity fracture requiring immobilization or surgery proved to be a challenge. Finally, the measurements derived using the motion analysis software quantify glenohumeral motion only in the sagittal plane. The blocking motion, which takes place in multiple planes, as described above, is a key component to a successful back handspring. This complex, multi-planar blocking mechanism was not analyzed. Strengths of this study include recruiting gymnasts from multiple gymnastics facilities in order to minimize the coaching effect and the control of recruiting gymnasts who were not in the process of learning a back handspring. Participants in this study had competed a back handspring in a tumbling pass for at least a year based on the level of participation described in the inclusion criteria. In addition, this study provides important groundwork for future injury prevention studies among female adolescent gymnasts.

## CONCLUSION

To understand forces at the wrist, it is important to examine a gymnast's wrist angles and factors that affect or predict these angles during dynamic activity. Mean impact wrist angle during the back handspring was determined to be 95 degrees in this sample. This number provides a foundation for future studies to examine what factors could possibly change this average impact wrist angle, and establish a "dangerous" impact wrist angle. There is a relationship between years of participation and impact wrist angles and between shoulder angles and impact wrist angles. These results indicate that the longer a gymnast has been participating in gymnastics, the more practiced a back handspring will become, resulting in less extension at the wrist during impact. The results of the current study yield valuable information that may relate to future injury prevention efforts. These results suggest that addressing any lack of shoulder flexion that exists may be a strategy to decrease wrist hyperextension during a back handspring, thereby reducing stress on the wrist. Further avenues of study include examining the effects of strengthening proximally in order to change wrist angle distally.

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