ORIGINAL RESEARCH

DIFFERENCES IN STATIC SCAPULAR POSITION BETWEEN ROCK CLIMBERS AND A NON-ROCK CLIMBER POPULATION

Aimee Roseborrough, PT, DPT[a]
Michael Lebec, PT, PhD[b]

ABSTRACT

Background. The increasingly popular sport of rock climbing is an activity which predisposes participants to overuse injuries. The unique physical demands associated with climbing, as well as a reported 33%-51% incidence of shoulder injuries in these athletes is suggestive of abnormalities in scapulohumeral biomechanics.

Objective. To examine the glenohumeral to scapulothoracic (GH:ST) ratio, as represented by end range static positions (ERSP) of the scapula and humerus, in a group of rock climbers and compare it to a group of non-climbers.

Methods. The GH:ST ratio of twenty-one experienced rock climbers was compared with 40 non-climbers using a bubble inclinometer to measure scapular upward rotation at the subjects' maximum glenohumeral elevation.

Results. As represented by ERSP, rock climbers had a significantly greater GH:ST ratio than non-climbers. The mean ratio of climbers was 3.7:1 compared with non-climbers at 2.8:1. Scapulothoracic motion appeared to be the source of this difference.

Discussion and Conclusion. A possible explanation for this difference could be related to the extreme and prolonged positioning associated with rock climbing maneuvers that result in shoulder musculature imbalances in strength and flexibility.

Key Words: rock climbing, shoulder injuries, scapulohumeral dyskinesis

CORRESPONDENCE:
Aimee Roseborrough
780 Hattie Greene
Flagstaff, AZ 86001
eMail: aimeel_3@hotmail.com

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[a]Physical Therapist, Yavapai Regional Medical Center, Prescott, AZ, USA

[b]Assistant Professor, Northern Arizona University, Flagstaff, AZ, USA

INTRODUCTION

Due to a lack of stability with respect to bony articulations, the shoulder complex is highly dependent upon soft tissue relationships to maintain joint congruency.[1] The interactions of these muscular, ligamentous, and capsular structures lead to coordinated movements between the glenohumeral (GH) and scapulothoracic (ST) articulations, known as scapulohumeral rhythm.[2] While, this value varies greatly throughout the literature, normal scapulohumeral rhythm is approximately 2:1 overall,[3] with the scapula elevating 1 degree for every 2 degrees of corresponding humeral movement. Significant deviations from standard ratios, often referred to as abnormal scapulohumeral rhythm, are frequently cited as a predisposition to shoulder impingement and injuries.[3,4]

A possible etiology of abnormal scapulohumeral rhythm is the presence of imbalances in shoulder girdle musculature strength and length.[3] For efficient upward rotation of the scapula, the serratus anterior and lower trapezius must be strong and at their optimum length-tension relationship. Also, the pectoralis minor must be sufficiently flexible otherwise passive insufficiency may occur, restricting full upward rotation of the scapula.[5] When considering how these biomechanical interactions allow normal movement of the shoulder complex, it is possible to envision how impairments affecting any part of this system may result in pathology.

Sports involving sustained overhead and end range movements and extreme positioning, such as rock climbing, place intense demands on the soft tissues surrounding the glenohumeral joint. These circumstances have the potential to result in imbalances in muscle performance and soft tissue length and is a primary reason shoulder injuries are common among rock climbers. Rooks[6] reported a 33% incidence of rotator cuff tendonitis or impingement in a group of recreational rock climbers.

This high incidence of shoulder problems is important to clinicians because rock climbing is no longer a fringe sport. Over the past two decades its popularity has increased dramatically. During this time, the number of indoor rock climbing gyms has exploded and equipment technology has advanced, allowing the activity to be accessible to almost anyone. Rooks[6] proclaimed rock climbing to be "one of the most rapidly growing sports in the world." Sheel[7] estimated there to be approximately 300,000 rock climbers in the U.S. Additionally, the Outdoor Industry Association reports more than 3.4 million young people between the ages of 16-24 tried indoor rock climbing in 2004.[8]

With the continued increase in the number of rock climbers, physical therapists are more likely to provide treatment to these athletes, especially considering the frequency of overuse injuries. Wright et al[9] estimates that 75-90% of climbers can be expected to develop an upper extremity overuse injury, alluding to the fact that climbers may have an abnormal scapulohumeral ratio. The effect that the unique demands associated with this sport may have upon the soft tissues of the shoulder complex provide rationale for the hypothesis that frequent climbers may be predisposed to irregular scapulothoracic mechanics.

Despite the high incidence of reported shoulder injuries among rock climbers, the relationship between participation in this sport and scapular mechanics has not been investigated. It is the opinion of the investigators that rock climbers possess a significantly different glenohumeral:scapulothoracic (GH:ST) ratio in comparison to those not participating in the sport.

Since this GH:ST ratio is a function of the available glenohumeral and scapular motion during upper extremity elevation,[3] the ranges through which these segments move to achieve their end range positions may be compared to produce a representation of the GH:ST ratio. For the purpose of this investigation, the term ERSP (End Range Static Position) is used to represent the degrees of active movement in the scapulothoracic or glenohumeral joints at maximum shoulder elevation. The ERSP measures of the humerus and scapula are then used to calculate an "end range" representation of the GH:ST ratio. Considering these principles, it was the purpose of this study to analyze and compare GH:ST ratios, as represented by ERSP's of the scapula and humerus, in climbing and non-climbing individuals.

METHODS

Subjects

A convenience sample of 21 rock climbers volunteered for the study at a rock climbing trade show and competition near Phoenix, Arizona. The group included 17 males and 4 females, with a mean age of 25.8 years (SD = 6.8) and a mean of 8.4 (SD = 7.2) years of rock-climbing experience. Forty non-climbing (11 male, 29 female, mean age = 25.7 years old, SD = 4.7 years) physical therapy students at Northern Arizona University served as the comparison group. Exclusion criteria for the non-climbers included a history of shoulder macro-trauma and rock climbing experience of greater than 1 year. Approval for the study was obtained from the Institutional Review Board at Northern Arizona University. All subjects were informed of the nature and details of the study and signed an informed consent form before participation. A power analysis confirmed that the sample was appropriate for detecting differences and minimizing statistical error.

Equipment

A Baseline® bubble inclinometer was used to assess ERSP associated with scapular upward rotation and glenohumeral elevation. This fluid filled instrument was calibrated on the basis of its position in space against gravity. This approach allows for fixation of the starting position of the inclinometer and minimizes the placement error.[10] The use of such measurement devices is well described in the literature. Similar fluid filled inclinometers have been shown to have "acceptable" intra-rater reliability in measuring glenohumeral joint motion.[11-15] Johnson et al[16] established "good to excellent" intra-rater reliability (ICC = 0.89 – 0.96; 95% CI) using an inclinometer with a digital readout to measure scapular upward rotation.

The measurement protocol utilized in this study was based on the method of assessing scapular upward rotation described by Johnson et al.[13] To measure glenohumeral elevation, a vertical guide pole was secured to a plinth. Standing position for subjects was standardized by lines marked on the floor. This position was established so that when the subject elevated his or her arm, their arm would be raised in the scapular plane (40 degrees anterior to the frontal plane) while maintaining contact with the guide pole. Subjects were instructed to keep their elbow straight and thumb pointing upward during elevation. The bubble inclinometer was aligned over the mid-shaft of the humerus while the subject elevated their arm as far as possible. At end range, maximum glenohumeral motion was recorded. Motion in the right upper extremity of all subjects was measured regardless of hand dominance.

Figure 1. Measuring scapular upward rotation with the Baseline® bubble inclinometer

Subjects then rested while the root of the right scapular spine was identified and marked in preparation for measuring upward rotation of the scapula. The left edge of the bubble inclinometer was placed on this mark and another mark was placed where the right edge of the inclinometer rested on the scapula *(Figure 1)*. These marks ensured that the bubble inclinometer rested on the same location on the scapula in repeated measures. The subject then returned to their maximum GH elevation and the angle of upward rotation of the scapula, as measured by the inclinometer, was recorded. The investigator recorded both measures three times for each subject. These measurements were performed in both the climber group and the comparison group of non-climbers.

Prior to data collection, the investigators assessed measurement consistency of the bubble inclinometer using the procedures just described. Intratester reliability for the measurement of glenohumeral elevation and scapular upward rotation was examined using a test-retest design on 40 subjects. The intraclass correlation coefficient (ICC-2,1) was 0.88 for glenohumeral elevation and 0.89 for scapular upward rotation.[17]

Data Analysis

Mean scores derived from the three range of motion measurements at maximum glenohumeral elevation and scapular upward rotation were used for calculation of the end range GH:ST ratio. An independent, two-tailed t-test was used to compare the ratios, maximum glenohumeral range of motion, and maximum scapular upward rotation of the rock climbers and the non-climbing population. Using a Boneferroni correction due to the use of three separate tests, significance was set at $p < .017$.

RESULTS

As presented in Table 1, the end range GH:ST ratio of the rock climber group

Table. Glenohumeral motion, scapulothoracic motion, and GH:ST ratio of climbers and non-climbers

	Rock climbers (n = 21)	Non-Rock climbers (n = 40)
GH:ST ratio mean (SD)	3.7:1 (1.0)*	2.8:1 (0.62)*
GH max mean (SD)	160.0 (8.7)	154.4 (9.2)
Scapular upward rotation mean (SD)	35.3 (7.5)*	41.1 (6.7)*

*denotes significant differences

(3.7:1; SD = 1.0) was greater than that of the non-climber comparison group (2.8:1; SD = 0.62). Also, rock climbers demonstrated greater glenohumeral range of motion (160.0 degrees; SD = 8.7) in comparison to non-rock climbers (154.4 degrees; SD = 9.2), while demonstrating less scapular upward rotation (35.3 degrees; SD = 7.5) than non-climbers (41.1 degrees; SD = 6.7). The end range GH:ST ratio ($t = 4.7$, $p < 0.017$) and scapular upward rotation values ($t = 3.8$, $p < 0.017$) were found to be significantly different via a two tailed, independent t-test. The maximum glenohumeral range of motion was not found to be significantly different between rock climbers and the non-climbing population ($t = 2.2$, $p > 0.017$).

The means for glenohumeral range appear to be lower than expected norms, due to the manner in which the inclinometer records motion. Prior to measurement, the instrument is set at zero with the subject's arm at his or her side.[10] In this position, the humerus is situated approximately 10 – 20 degrees away from the vertical axis. Therefore, the end range measures in these subjects are reflective of movement of the humerus through the available range rather than its resulting angle from the vertical as is the case in traditional goniometry. Considering this measurement technique, it is concluded that these subjects were within normative values for humeral elevation.

DISCUSSION

The group of rock climbers participating in this study were found to have a higher end range GH:ST ratio than the studied control population. A higher end range ratio may result from decreased upward rotation of the scapula, excess humeral elevation, or a combination of both events during overhead movements. In this group of climbers, the data demonstrate the greatest differences with respect to scapular upward rotation, with the climbers having significantly less mobility in this plane. One etiology of decreased upward scapular rotation is the presence of imbalances in shoulder girdle musculature strength and length.[3] For efficient upward rotation of the scapula, the serratus anterior and lower trapezius must be strong and at their optimum length-tension relationship. Also, pectoralis minor must be sufficiently flexible otherwise passive insufficiency may occur, restricting full upward scapular movement.[5]

The authors offer the following hypotheses for altered scapular mechanics in the climber group. Decreased upward rotation of the scapula in rock climbers may occur due to muscle imbalances in strength and flexibility secondary to the intense tissue stresses associated with frequent participation in this sport. As stated by Rooks,[6] rock climbers are "chronically gripping and pulling without stretching the tight muscles or exercising the antagonist muscles" which often leads to overdevelopment and contractures of the pectoral muscles. Tightness in these muscles may inhibit the scapular upward rotators from fully rotating the scapula. Furthermore, strength is developed in a position of scapular protraction *(Figure 2)*, where the pectoral muscles are in a shortened position. This scenario enhances the potential for adaptive shortening of the pectoralis minor, which as previously discussed may result in abnormal scapulohumeral rhythm by not allowing full upward rotation of the scapula.[5] Borstad and Ludewig[5] confirmed this idea by demonstrating that shortening of the pectoralis minor leads to increased downward rotation of the scapula and, therefore, impingement.

The roles of the lower trapezius and serratus anterior muscles during rock climbing are also worthy of discussion. While these muscles may be active during rock climbing maneuvers, the extent to which the muscles are trained is likely within limited ranges and static positions. Bourdin et al[18] demonstrated that under highly challenging circumstances, climbers tended to increase the velocity of upper extremity movements and decrease the "free motion" portion of reaching maneuvers. Therefore, movements through a range were minimized in an attempt to re-establish stability, supporting the idea that the majority of upper limb muscle activity during climbing occurs in static fashion.

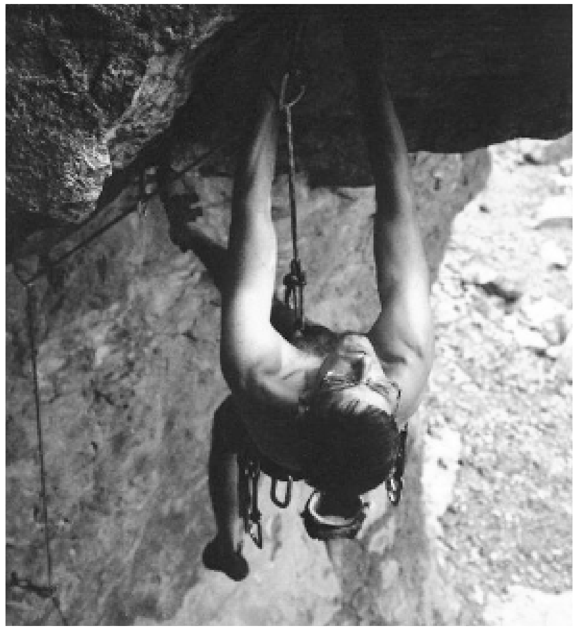
Figure 2. Rock climber in sustained protraction

Because impairment of the lower trapezius is common in many overhead athletes,[19,20] it is logical to suspect that rock climbers may have a similar problem. Intuitively, it might seem that having one's arms positioned overhead for prolonged periods of time would increase strength in the lower trapezius. However, climbers typically support their body weight through the limbs, using the bony articulations and ligaments of the upper extremity in order to rest the muscles *(Figure 3).* In this resting position, the passive restraints of the upper extremity are supporting the rock climber, rather than the contractile tissues. Thus when active, the lower trapezius functions primarily in an isometric fashion, rather than as contractile tissue which facilitates coordinated scapular movement. This concept is supported by Watts[21] stating that "rock climbing is characterized by repeated bouts of isometric contractions."

The constant need for postural stability and associated isometric muscle demands also suggest that the serratus anterior is not trained in a manner which facilitates upward rotation. During climbing maneuvers, the emphasis appears to be on shoulder protraction rather than elevation. Therefore, the degree to which the serratus anterior actively functions as a scapular upward rotator during this activity is questionable. It may be argued that the recruitment of serratus motor units and, thus, the training effect in climbers may occur in a manner which overemphasizes protraction and minimizes facilitation of upward scapular rotation. Therefore, with respect to both of the lower trapezius and serratus anterior muscles, the lack of dynamic contractions elicited may lead one to conclude that when strengthening and motor learning do occur, it is specific to static and isometric positions rather than throughout the available range of motion.[21]

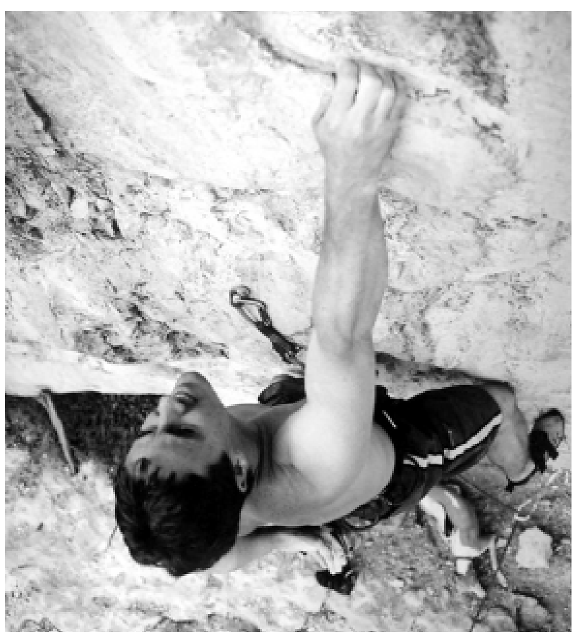
Figure 3. Rock climber using passive restraints of upper extremity to support body weight

If valid, these hypotheses support the argument for relative weakness and inefficient function of scapular rotators in these individuals. This occurrence, combined with overtraining of anterior groups may result in inefficient force coupling during humeral elevation.[22] The resulting imbalances and decrease in upward scapular rotation have the potential to further increase the risk for impingement syndrome in frequent rock climbers who, as a group, already demonstrate a high incidence of shoulder injuries.[6] Additional research is necessary, however, to substantiate these conclusions and identify actual mechanisms of altered scapular mechanics in rock climbers.

The potential for altered scapular mechanics and shoulder injury in rock climbers is relevant to clinicians due to the nature and increasing popularity of the sport.[6,8] Over the past two decades, indoor rock climbing gyms have proliferated and equipment technology has advanced, allowing the activity to be accessible to almost anyone. Sheel[7] estimated there to be approximately 300,000 rock climbers in the U.S. Furthermore, many of these individuals increase their risk for injury by overtraining. While strenuous workouts require as much as 48 hours of recovery,[6] rock climbers frequently travel for the sole purpose of climbing during which they engage in high intensity activity for multiple days to weeks at a time. Indoor climbing gyms also promote overtraining by allowing climbers to conveniently participate in their sport and permitting multiple bouts of climbing in short periods of time. These types of extended activities may overfatigue rotator cuff and scapular musculature, inhibit their actions during sustained, overhead maneuvers and be further reason these athletes are susceptible to impingement syndromes.

Limitations

The homogeneity and size of the samples is a limitation to the study. The non-climbing group consisted of healthy, young adults of mixed sex, while the majority of the rock climbing population were male, young adults. The non-climbing group also demonstrated a higher ratio (2.8:1) than what is considered "normal" (2:1).

Other limitations concern the measurement approach and consideration that the study only addressed the upward rotation aspect of scapular motion. Since scapular motion occurs in three planes, it would be useful to examine motion within the two planes not addressed in this study.

CONCLUSIONS

This investigation suggests that the sample of rock climbers had a significantly higher GH:ST ratio as represented by ERSP than the studied non-climbing population. The stresses associated with rock climbing may have the potential to create such a change. While future research is necessary to substantiate these ideas, knowledge of such potential differences may be of value to clinicians who are likely to be involved with the evaluation and treatment of individuals participating in this sport due to its recent rise in popularity.

REFERENCES

1. Kibler BW. Role of the scapula in the overhead throwing motion. *Contp Orthop.* 1991;22:525-532.
2. Inman VT, Saunders M, Abbott LC. Observations on the function of the shoulder joint. *J Bone Joint Surg Am.* 1944;26:1-30.
3. Poppen NK, Walker PS. Normal and abnormal motion of the shoulder. *J Bone Joint Surg Am.* 1976;58:195-201.
4. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther.* 2000;80:276-291.
5. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *J Orthop Sports Phys Ther.* 2005;35:227-238.
6. Rooks MD. Rock climbing injuries. *Sports Med.* 1997;23:261-270.
7. Sheel AW. Physiology of sport rock climbing. *Br J Sports Med.* 2004;38:355-359.
8. Regenold S. Kids scale the walls, and the principal approves. *The New York Times.* March 9, 2006.
9. Wright DM, Royle TJ, Marshall T. Indoor rock climbing: Who gets injured? *Br J Sports Med.* 2001; 35:181-185.
10. Watson L, Balster SM, Finch C, Dalziel R. Measurement of scapula upward rotation: A reliable clinical procedure. *Br J Sports Med.* 2005;39:599-603.
11. Riddle D, Rothstein J, Lamb R. Goniometric reliability in a clinical setting: Shoulder measurements. *Phys Ther.* 1987;76:668-673.
12. Sabari J, Maltzev I, Lubarsky D, et al. Goniometric assessment of shoulder range of motion: Comparison of testing in supine and sitting positions. *Arch Phys Med Rehabil.* 1998;79:647-651.
13. Macdermid J, Chesworth B, Patterson S, Roth J. Intratester and intertester reliability of goniometric measurement of passive lateral shoulder rotation. *J Hand Ther.* 1999;12:187-192.
14. Youdas J, Carey J, Garrett T, Suman V. Reliability of goniometric measurements of active arm elevation in the scapular plane obtained in the clinical setting. *Arch Phys Med Rehabil.* 1994;75:1137-1144.
15. Mitsch J, Casey J, McKinnis R, et al. Investigation of a consistent pattern of motion restriction in patients with adhesive capsulitis. *J of Manual and Manipulative Ther.* 2004;12:153-159.
16. Johnson MP, McClure PW, Karduna AR. New method to assess scapular upward rotation in subjects with shoulder pathology. *J Orthop Sports Phys Ther.* 2001;31:81-89.
17. Roseborrough AE, Lebec M. Inter- and intra-rater reliability of a bubble inclinometer to measure scapular motion during glenohumeral elevation. Abstract in: *J Orthop Sports Phys Ther*. 2005;35:A4.
18. Bourdin C, Teasdale N, Nougier V, et al. Postural contraints modify the organization of grasping movements. *Human Movement Science.* 1999; 18:87-102.
19. Kelley MJ. Anatomic and biomechanical rationale for rehabilitation of the athlete's shoulder. *J Sports Rehab.* 1995;4:122-154.

20. Kelley MJ, Clark WA. *Orthopedic Therapy of the Shoulder*. Philadelphia (PA): J.B. Lippincott; 1995.

21. Watts, PB, Physiological Aspects of Difficult Sport Rock Climbing. In: Messenger N, Patterson WD, Brook D (eds). *The Science of Climbing and Mountaineering* [book on CD-ROM]. Champaign, IL: Human Kinetics Software; 2000.

22. Porterfield JA, DeRosa C. *Mechanical Shoulder Disorders: Perspectives in Functional Anatomy.* St. Louis, MO: Elsevier Science; 2004:80-83.