

[Physical Therapy]

Muscular Activation During Plyometric Exercises in 90° of Glenohumeral Joint Abduction

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Background: Plyometric exercises are frequently used to increase posterior rotator cuff and periscapular muscle strength and simulate demands and positional stresses in overhead athletes. The purpose of this study was to provide descriptive data on posterior rotator cuff and scapular muscle activation during upper extremity plyometric exercises in 90° of glenohumeral joint abduction.

Hypothesis: Levels of muscular activity in the posterior rotator cuff and scapular stabilizers will be high during plyometric shoulder exercises similar to previously reported electromyographic (EMG) levels of shoulder rehabilitation exercises.

Study Design: Descriptive laboratory study.

Methods: Twenty healthy subjects were tested using surface EMG during the performance of 2 plyometric shoulder exercises: prone external rotation (PERP) and reverse catch external rotation (RCP) using a handheld medicine ball. Electrode application included the upper and lower trapezius (UT and LT, respectively), serratus anterior (SA), infraspinatus (IN), and the middle and posterior deltoid (MD and PD, respectively) muscles. A 10-second interval of repetitive plyometric exercise (PERP) and 3 repetitions of RCP were sampled. Peak and average normalized EMG data were generated.

Results: Normalized peak and average IN activity ranged between 73% and 102% and between 28% and 52% during the plyometric exercises, respectively, with peak and average LT activity measured between 79% and 131% and between 31% and 61%. SA activity ranged between 76% and 86% for peak and between 35% and 37% for average activity. Muscular activity levels in the MD and PD ranged between 49% and 72% and between 12% and 33% for peak and average, respectively.

Conclusion: Moderate to high levels of muscular activity were measured in the rotator cuff and scapular stabilizers during these plyometric exercises with the glenohumeral joint abducted 90°.

Keywords: shoulder; plyometrics; EMG

Clinical rehabilitation of the injured overhead athlete often includes exercises performed with the glenohumeral joint at 90° of abduction.^{12,13,26,31,32}

Progression to exercises with 90° of glenohumeral joint abduction prepares the athlete for a return to the demands of overhead function.^{4,14,24} Specific levels of muscular activity

during many exercises used in shoulder rehabilitation are known in normal subjects^{6,20,21,25,26,29} as well as in certain types of pathology.² These studies allow the clinician to select specific exercises to normalize muscle balance and improve muscular strength and local muscle endurance for rehabilitation, prevention, and performance enhancement programs.

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Medicine ball plyometric exercise in the 90° of glenohumeral abducted position results in improvements in internal and external rotation strength and in throwing velocity after 8 weeks of training in college baseball players.⁷ Proprioception, kinesthesia, and selected muscular strength have improved after a 6-week plyometric training program in swimmers.²⁹ Despite these favorable results, little objective information is available regarding the muscular activity in plyometric shoulder exercises used in rehabilitation. The normalized muscular activity of the scapular stabilizers and glenohumeral musculature during a 2-hand plyometric chest pass exercise using a medicine ball shows moderate levels in the rotator cuff and scapular musculature.⁹

MATERIALS AND METHODS

Participants

Subjects read and signed an informed consent prior to participation. This study was approved by the Institutional Review Board of Physiotherapy Associates, Exton, PA. Twenty subjects (13 men, 7 women) between 18 and 50 years of age and no history of shoulder or spinal injury in the past year prior to data collection volunteered to participate in this investigation. Subjects were free from any history of shoulder or spinal surgery. Subjects were active in recreational sports and demonstrated competence in the performance of the exercises, including catching and throwing ability.

Equipment and Procedures

A Noraxon Myotrace Model 1400A (Noraxon) electromyography (EMG) unit was used to measure muscular activity on the subjects' dominant upper extremity using standardized surface electrode application and technique (infraspinatus, upper trapezius, lower trapezius, serratus anterior, middle deltoid, and posterior deltoid). The application of surface electrodes followed standardized methodology.

Precise locations of each surface electrode followed previous guidelines.^{3,23}

The average and peak muscle activity was recorded for each exercise and was normalized to the maximum voluntary isometric contraction (MVIC) of each muscle tested. The muscular activity classification used in this study included 0% to 15% as absent to minimal, 16% to 30% as low, 31% to 60% as moderate, and greater than 60% as high.²⁷ Two repetitions were used for each muscle with 1-minute rest given between muscles. Positions used for determination of MVIC are as follows: infraspinatus—0° of abduction with the glenohumeral joint in 45° of internal rotation with resistance applied just proximal to the wrist with force application into internal rotation,¹⁶ upper trapezius—seated position shoulder girdle shrug with resistance applied over the acromion and resistance applied in a caudal direction,¹⁷ lower trapezius—prone positioning with 135° of abduction in the coronal plane with thumb up position using an anteriorly directed force just proximal to the wrist,¹⁷ serratus anterior—standing position

with 120° of flexion with force application posterior and inferior,³ middle deltoid—resisted abduction in the coronal plane in 90° of neutral humeral rotation (palm down) with force application straight downward into adduction,¹⁷ and posterior deltoid—shoulder abduction 90° in neutral rotation with resistance applied just proximal to the elbow in an anterior direction (horizontal adduction).¹⁷ Sampling occurred at 1000 HZ, with all signals bandpass filtered between 10 and 500 HZ and then full-wave rectified using the Myoresearch 1.04 version software (Noraxon Inc).

The order of testing for the 2 exercises was randomized as was the load (Thera-Band Soft Weight; Hygenic Corporation): 0.5 kg and 1 kg for each subject. The MVIC and exercise data were collected in the same testing session. Electrodes were applied once and not moved between the MVIC and exercise data sampling. Subjects were allowed 5 minutes of rest between MVIC testing and performance of the exercise conditions and 2 minutes of rest between exercise conditions. Prior to application of the electrodes, subjects who were unfamiliar with the exercises were allowed time to practice with the metronome to ensure proper form, speed, and consistent performance during data collection.

Medicine Ball Plyometric Exercises

Prone 90/90 External Rotation Plyometric

The subjects were positioned prone on a standard treatment table with 90° of external rotation and 90° of glenohumeral joint abduction in the coronal plane (90/90 position). A 0.5-kg (tan) and a 1-kg (yellow) Thera-Band Soft Weight were used to alternately catch and drop during a 10-second interval while muscular activity was sampled from the targeted muscles (Figure 1). An internal metronome at 160 bpm was set to regulate the speed of the exercise to allow for standardization between trials and between subjects tested. Sampling was performed for 10 seconds, with the first and last 4 seconds discarded. A 2-second central interval was analyzed using full-wave rectification and root mean square smoothing with a window of 50 ms for data analysis. This central window selected for analysis was chosen to represent several movements of the exercise and to characterize the muscular performance during this repetitive exercise.

Reverse Catch External Rotation Plyometric

Subjects were tested in an upright position with their dominant side (ipsilateral) knee flexed onto a foam pad and contralateral lower extremity in 90° of hip and knee flexion directly in front of them for stabilization (Figure 2). From a distance of 3 feet behind the subject, 1 examiner used an underhand toss to propel the medicine ball toward the subject who caught the ball in the 90/90 position, decelerated the ball, and then rapidly tossed the ball back to the examiner maintaining the arm in 90° of abduction and 90° of elbow flexion. This was repeated for 3 trials, with the middle trial used for data collection.



Figure 1. Prone 90/90 external rotation plyometric exercise.

Data Analysis

SPSS (SPSS Inc) was used to generate the descriptive statistics from a Microsoft Excel spreadsheet that had transferred the peak and average normalized muscular activity data from the sampling windows from the Noraxon EMG software.

RESULTS

The muscular activity results are presented in Tables 1 and 2.

DISCUSSION

The 2 plyometric exercises resulted in moderate to high levels of muscular activity of the infraspinatus and scapular stabilizing musculature (lower trapezius and serratus anterior) using relatively low loads of 0.5 and 1 kg. While direct comparisons between EMG studies outlining rotator cuff and scapular muscle activity are difficult because of methodologic differences, it is worth noting that the muscular activity levels in the infraspinatus measured during these 2 exercises are similar to percentage MVIC reported for more traditional exercises such as side-lying and prone external rotation.^{26,30} Similarly, muscular activity in the trapezius and serratus anterior force couple¹ are again comparable with previously reported values for the serratus punch, push up with a plus, and resisted scapular retraction exercises such as rowing variations used in many shoulder rehabilitation programs.^{10,11,18,21}

In a series of plyometric training investigations of upper extremity movement patterns, small increases in rotator cuff and upper extremity strength and functional improvement were encountered particularly among experienced, coordinated subjects who could optimally perform the movement patterns.^{15,27,28} One of the key components of the plyometric sequence is the use of the eccentric contraction and overload applied to the exercising muscle tendon unit.^{8,13,19,22,33}



Figure 2. Reverse catch external rotation plyometric exercise.

Lower exercise intensities facilitate the relative activation of the rotator cuff compared with the deltoid musculature supporting the use of the lighter exercise intensities during plyometric exercises.⁵

Several limitations exist in this study that must be taken into account. With the present instrumentation and methods, analysis of the specific phases of the exercises was not possible, and the data for each exercise are meant to summarize both the average and peak muscular activity which characterizes these exercises. Additionally, there can be surface EMG cross talk between electrodes, which can compromise the measurement of activity of individual muscles. Every attempt was made to standardize electrode placement and sample carefully representative data from each of the exercise trials to capture optimal windows of muscle performance. Cross talk secondary to movement artifact during these exercises may further affect the data collection from surface electrodes during scapulothoracic and glenohumeral joint movements. Finally, as the primary purpose of this study was descriptive, neither a formal analysis was performed to determine sample size nor were repeated measures performed to evaluate the reproducibility of the standardized methodology used during this investigation.

Table 1. Muscular activity during the prone 90/90 external rotation plyometric exercise^a

Muscle/Load	0.5 Kilogram		1 Kilogram	
	Peak	Average	Peak	Average
Infraspinatus	85 ± 23	43 ± 13	103 ± 26	52 ± 14
Upper trapezius	54 ± 33	27 ± 13	71 ± 40	35 ± 16
Lower trapezius	118 ± 35	61 ± 19	131 ± 37	61 ± 21
Serratus anterior	96 ± 91	36 ± 31	76 ± 50	35 ± 23
Middle deltoid	42 ± 23	21 ± 10	54 ± 23	26 ± 13
Posterior deltoid	55 ± 25	27 ± 11	73 ± 24	33 ± 12

^aData are expressed as percentage maximum voluntary isometric contraction (% MVIC) and presented as mean ± standard deviation.

Table 2. Muscular activity during the reverse catch plyometric exercise^a

Muscle/Load	0.5 Kilogram		1.0 Kilogram	
	Peak	Average	Peak	Average
Infraspinatus	71 ± 24	27 ± 8	73 ± 22	29 ± 9
Upper trapezius	56 ± 36	17 ± 10	53 ± 25	18 ± 12
Lower trapezius	81 ± 53	31 ± 16	79 ± 44	31 ± 13
Serratus anterior	98 ± 43	39 ± 22	87 ± 40	37 ± 19
Middle deltoid	58 ± 33	17 ± 9	62 ± 31	18 ± 9
Posterior deltoid	41 ± 25	11 ± 6	49 ± 24	12 ± 6

^aData are expressed as percentage maximum voluntary isometric contraction (% MVIC) and presented as mean ± standard deviation.

CONCLUSION

Moderate to high levels of muscular activity were measured in the rotator cuff and scapular stabilizers during the prone 90/90 external rotation and reverse catch plyometric exercises with the glenohumeral joint abducted 90°.²⁷

REFERENCES

1. Bagg SD, Forrest WJ. A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. *Arch Phys Med Rehabil.* 1988;67:238-245.
2. Ballantyne BT, O'Hare SJ, Paschall JL, et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. *Phys Ther.* 1993;73:668-682.
3. Basmajian JV, DeLuca CJ. *Muscles Alive: Their Functions Revealed.* 5th ed. Baltimore, MD: Williams & Wilkins; 1985.
4. Basset RW, Browne AO, Morrey BF, An KN. Glenohumeral muscle force and moment mechanics in a position of shoulder instability. *J Biomech.* 1994;23:405-415.
5. Bitter NL, Clisby EF, Jones MA, Magarey ME, Jaberzadeh S, Sandow MJ. Relative contributions of infraspinatus and deltoid during external rotation in healthy shoulders. *J Shoulder Elbow Surg.* 2007;16:563-568.
6. Blackburn TA, McLeod WD, White B, Wofford L. EMG analysis of posterior rotator cuff exercises. *J Athl Train.* 1990;25:40-45.
7. Carter AB, Kaminsky TW, Douex AT, Knight CA, Richards JG. Effects of high volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players. *J Strength Cond Res.* 2007;21:208-215.
8. Chu DA. *Jumping into Plyometrics.* Champaign, IL: Human Kinetics Publishers; 1998.
9. Cordasco FA, Wolf IN, Wooten ME, Bigliani LU. An electromyographic analysis of the shoulder during a medicine ball rehabilitation program. *Am J Sports Med.* 1996;24:386-392.
10. Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. *Am J Sports Med.* 1999;27:784-791.
11. Donatelli RA, Ekstrom RA. Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles. *J Orthop Sports Phys Ther.* 2003;33:247-258.
12. Ellenbecker TS. *Shoulder Rehabilitation: Non-Operative Treatment.* New York, NY: Thieme; 2006.
13. Ellenbecker TS, Davies GJ, Rowinski MJ. Concentric versus eccentric isokinetic strengthening of the rotator cuff: objective data versus functional test. *Am J Sports Med.* 1988;16:64-69.
14. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med.* 1995;23:233-239.

15. Heiderscheit BC, Palmer-McLean Karen, Davies GJ. The effects of isokinetic vs. plyometric training of the shoulder internal rotators. *J Orthop Sports Phys Ther.* 1996;23:125-133.
16. Kelley BT, Kadmas WR, Speer KP. The manual muscle examination for shoulder rotator cuff strength. An electromyographic investigation. *Am J Sports Med.* 1996;24:581-588.
17. Kendall FP, McCreary EK, Provance PG. *Muscles: Testing and Function.* Baltimore, MD: Williams & Wilkins; 1993.
18. Kibler WB, Sascia A, Uhl T, Tambay N, Cunningham T. Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation. *Am J Sports Med.* 2008;36:1789-1798.
19. Kovacs M, Roetert EP, Ellenbecker TS. Efficient deceleration: the forgotten factor in tennis-specific training. *Strength Cond J.* 2008;30(6):58-69.
20. Malanga GA, Jenp YN, Growney ES, An KN. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. *Med Sci Sports Exerc.* 1996;28:661-664.
21. Moesley JB Jr, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. *Am J Sports Med.* 1992;20:128-134.
22. Mont MA, Cohen DB, Campbell KR, Gravare K, Mathur S. Isokinetic concentric versus eccentric training of the shoulder rotators with functional evaluation of performance enhancement in elite tennis players. *Am J Sports Med.* 1994;22:513-517.
23. Perotto AO. *Anatomical Guide for the Electromyographer: The Limbs and Trunk.* Springfield, IL: Charles C. Thomas; 1994.
24. Reid M, Elliott B, Alderson J. Shoulder joint loading in the high performance flat and kick tennis serves. *Br J Sports Med.* 2007;41:884-889.
25. Reinold MM, Macrina LC, Wilk KE, et al. Electromyographic analysis of the supraspinatus and deltoid muscles during common rehabilitation exercises. *J Athl Train.* 2007;42:464-469.
26. Reinold MM, Wilk KE, Fleisig GS, Zheng N, Barrentine SW, Chmielewski T. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. *J Orthop Sports Phys Ther.* 2004;34:385-394.
27. Ryu KN, McCormick FW, Jobe FW, Moynes DR, Antonelli DJ. An electromyographic analysis of shoulder function in tennis players. *Am J Sports Med.* 1988;16:481-485.
28. Schulte-Edelmann JA, Davies GJ, Kernozek TW, Gerberding ED. The effects of plyometric training of the posterior shoulder and elbow. *J Strength Cond Res.* 2005;19:129-134.
29. Swanik KA, Lephart SM, Swanik B, Lephart SP, Stone DA, Fu FH. The effects of shoulder plyometric training on proprioception and selected muscle performance. *J Shoulder Elbow Surg.* 2002;11:579-586.
30. Townsend H, Jobe FW, Pink M, Perry J. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. *Am J Sports Med.* 1991;19:264-272.
31. Trieber FA, Lott J, Duncan J, Slavens G, Davis H. Effects of Thera-band and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. *Am J Sports Med.* 1998;26:510-515.
32. Wilk KE, Obama P, Simpson CD, Cain EL, Dugas J, Andrews JR. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther.* 2009;39:38-54.
33. Wilk KE, Voight ML, Keirns MA, Gambetta V, Dillman CJ, Andrews JR. Stretch-shortening drills for the upper extremities: theory and clinical application. *J Orthop Sports Phys Ther.* 1993;17:225-239.

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