

Influence of Body Position on Shoulder and Trunk Muscle Activation During Resisted Isometric Shoulder External Rotation

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Background: External rotation (ER) strengthening of the shoulder is an integral component of rehabilitative and preventative programs for overhead athletes. A variety of shoulder ER strengthening exercises are reported, including those intended to integrate the core musculature. The purpose of this study was to examine ER torque and electromyographic (EMG) activation of shoulder and trunk muscles while performing resisted isometric shoulder ER in 3 positions (standing, side lying, and side plank).

Hypothesis: Significantly greater force and shoulder muscle activation would be generated while side lying given the inherent stability of the position, and greater trunk muscle activation would be generated in the less stable plank position.

Study Design: Quasi-experimental repeated-measures study.

Level of Evidence: Level 5.

Methods: A convenience sample of 25 healthy overhead recreational athletes (9 men, 16 women) participated in this study. EMG electrodes were placed on the infraspinatus, posterior deltoid, middle trapezius, multifidi, internal obliques, and external obliques. EMG signals were normalized to a maximal isometric contraction. Participants performed resisted isometric ER in standing, side-lying, and side plank positions. Results were analyzed using a repeated-measures analysis of variance with post hoc Bonferroni corrections ($\alpha = 0.05$).

Results: There was no significant difference in ER torque between positions ($\alpha = 0.05$). A significant difference in EMG activity of shoulder and trunk musculature between positions was found in 7 of the 8 muscles monitored. Significantly greater EMG activity in the infraspinatus, middle trapezius, and the nondominant external and internal obliques was found in the side plank position as compared with standing and side lying.

Conclusion: While there was no difference in ER torque between the 3 exercise positions, EMG activity of the shoulder and trunk muscles was dependent on body position.

Clinical Relevance: If a clinician is seeking to integrate trunk muscle activation while performing shoulder ER strengthening, the side plank position is preferred as compared with standing or side lying.

Keywords: electromyography; shoulder; strengthening

A variety of preventative and rehabilitative programs have been proposed for shoulder strengthening given the demands of throwing and overhead sports.^{3,14,16} Wilk et al¹⁶ described a program of progressive external rotation (ER) exercises performed while standing, seated, on a stability ball, and in a side plank position. It was postulated that less stable positions would pose a greater challenge to trunk musculature to

maintain the body in proper alignment. The overall goal of this and similar programs is to equip the athlete with greater strength, dynamic stability, and endurance of the glenohumeral and trunk musculature to diminish the likelihood of sustaining injury from the repetitive, high-stress nature of overhead sports.^{4,12,13,16}

Integrating shoulder and core exercises is advocated during the transition phase of rehabilitation for the throwing athlete

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Table 1. Participant demographics^a

	Men	Women	Overall
Age, y	24.2 ± 2.8	23.4 ± 0.8	23.7 ± 1.8
Height, cm	181.9 ± 9.4	169.9 ± 6.1	174.1 ± 9.3
Weight, kg	80.1 ± 10.3	64.1 ± 6.7	69.8 ± 11.2
Body mass index, kg/m ²	24.2 ± 1.8	22.2 ± 1.9	22.9 ± 2.1

^aData presented as mean ± SD.

prior to return to play.³ The core, which includes the hip, pelvis, and abdominal muscles, works to stabilize the spine and pelvis to allow efficient function of the limbs during sporting activities.^{9,11} Literature describing electromyographic (EMG) activation of shoulder and core musculature while performing ER exercises in various body positions is limited. Further understanding of the influence of body position on muscle recruitment will help clinicians select shoulder ER strengthening exercises that effectively integrate shoulder and core musculature for the overhead athlete.

The aim of this research was to examine shoulder girdle and select “core” trunk muscle EMG activity while performing resisted isometric shoulder ER in 3 positions. The positions examined included standing, side lying, and side plank. We hypothesized that there would be significantly greater torque and EMG shoulder muscle activation while side lying as compared with the other positions as we felt the more stable body position would result in an ability to generate greater ER torque. We also hypothesized that there would be greater trunk muscle activation in the side plank position as the trunk muscles function to maintain the suspended position against gravity.

METHODS

This study was approved by the institutional review board at the Mayo Clinic, Rochester, Minnesota. Maximal isometric shoulder ER force was recorded via a handheld dynamometer. EMG activity from dominant upper extremity infraspinatus, posterior deltoid, middle trapezius, multifidi, bilateral external obliques, and bilateral internal obliques was collected via surface electrodes. The independent variable was exercise position. Dependent variables were ER torque and EMG activity of the tested muscles in each of the 3 test positions (standing, side lying, and side plank).

Participants

Twenty-five healthy participants (9 men, 16 women) aged 22 to 31 years volunteered to participate (Table 1). All participants were active in a recreational overhead sport within 6 months of the study. Inclusion criteria consisted of individuals between 20 and 45 years of age who were free of shoulder girdle or upper extremity pathology. Participants were excluded if they reported

a previous shoulder surgery or a current condition that limited the ability to perform resisted shoulder ER. Based on an a priori power analysis, 22 or more participants were needed to provide 80% power at $\alpha = 0.05$ to detect differences in recruitment of 5% or greater maximal voluntary isometric muscle contraction (MVIC) (effect size = 0.20) among the 3 testing positions, assuming correlations among repeated measures of 0.75 or greater.

Procedures

Prior to collection of ER exercise EMG activity, EMG activity for each muscle of interest was recorded during a 5-second MVIC. These data were used to normalize EMG data recorded during the ER exercises. The protocol for obtaining MVIC data was in accordance with procedures described previously (Figure 1).^{5,7,8,10}

A within-participant design was used with each participant performing isometric ER of the shoulder in standing, side-lying, and side plank positions (Figure 2). Prior to the muscle test, the forearm length was measured from the lateral epicondyle to the radial styloid. This measurement was used with ER force output to calculate torque. The order of exercises was randomized for each participant. Participants performed 3 trials in each position with both force and EMG recorded for each trial. A 5-second manual muscle test (make test) was administered at the dorsal aspect of the forearm just proximal to the wrist joint. Force was recorded using a MicroFET 2 handheld dynamometer (Hoggan Health Industries Inc). A 20-second rest period was provided between each trial, with a 2-minute rest between positions to minimize the effects of fatigue. The shoulder was positioned in neutral rotation with the elbow flexed to 90°. The arm was positioned in slight shoulder abduction by placing a rolled towel between the arm and trunk to enhance posterior cuff EMG signal.¹⁴ De Mey et al⁶ found that correction of scapular orientation during extension and side-lying ER exercises increased activation in the 3 sections of the trapezius. Therefore, we provided consistent verbal and tactile cueing to keep the scapula in proper orientation, as assessed by observation. Standardized verbal encouragement was provided during all 3 trials. Of the 3 trials, the trial with the greatest force recorded on the dynamometer was used for analysis.

Raw EMG signals were collected using Bagnoli DE-3.1 double-differential bipolar surface electrodes and a Bagnoli-16 amplifier (Delsys Inc). The electrodes were made of 99.9% pure

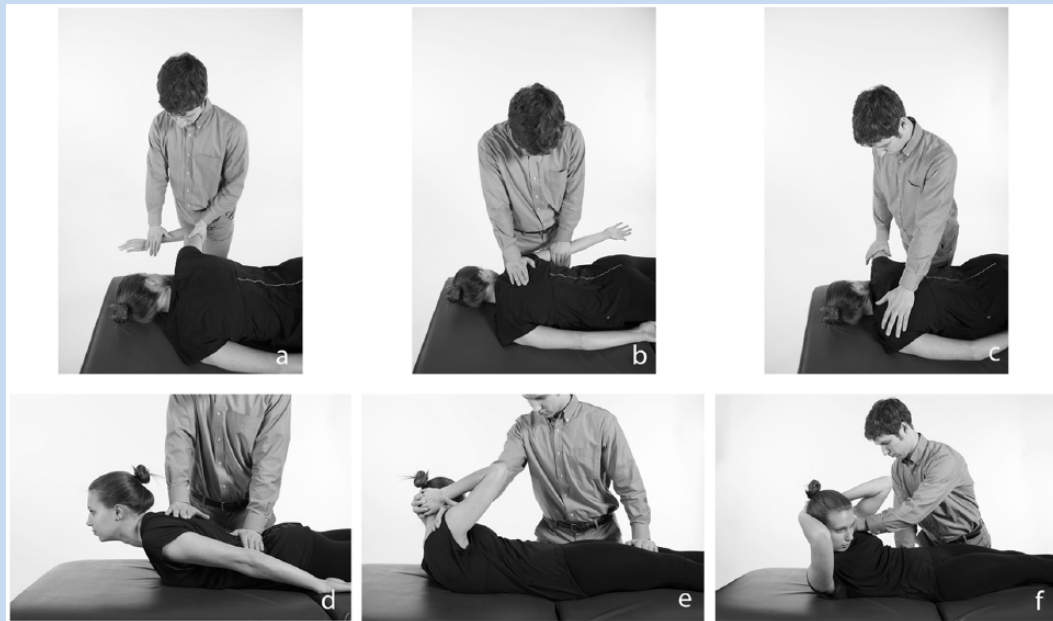


Figure 1. Testing procedures to establish maximal voluntary isometric muscle contraction: (a) infraspinalus, (b) posterior deltoid, (c) middle trapezius, (d) lumbar multifidi, (e) right external oblique and left internal oblique, and (f) left external oblique and right internal oblique (examiner positioned on the left side for purposes of picture).

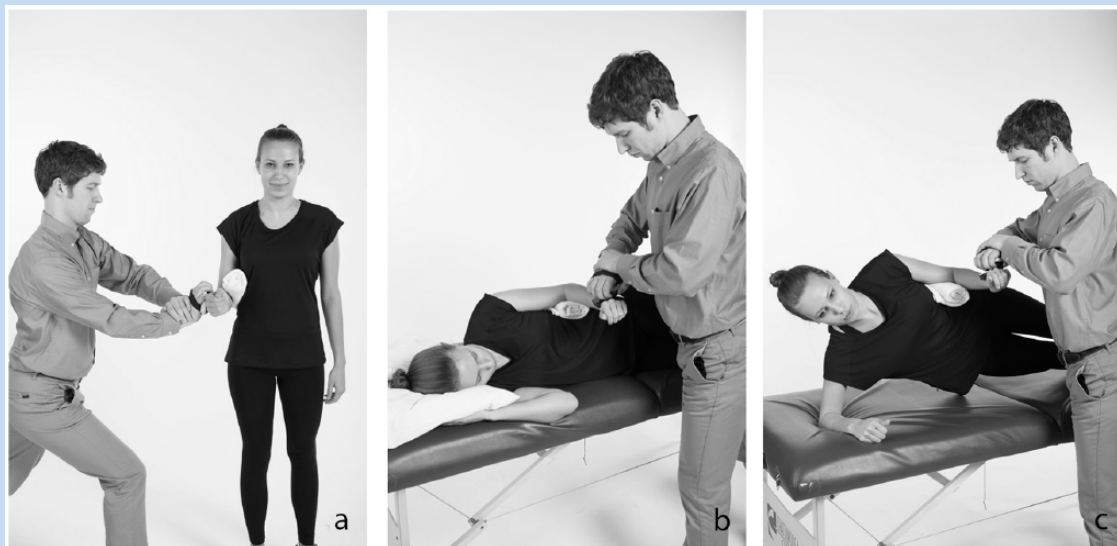


Figure 2. Shoulder external rotation in (a) standing, (b) side-lying, and (c) side plank positions.

silver bars. Each bar was 10 mm long and 1 mm wide, spaced 10 mm apart, and encased within preamplifier assemblies measuring $41 \times 20 \times 5$ mm. The preamplifiers had a gain of 10 V/V. The combined preamplifier and main amplifier system permitted overall amplification of 100 to 10,000 V/V. The common mode rejection ratio was 92 dB at 60 Hz, input impedance exceeded 10^{15} ohm, and estimated noise was $\leq 1.2 \mu\text{V}$.

Data were collected at a sampling frequency of 1000 Hz through a 16-bit NI-DAQ PCI-6220 analog-to-digital acquisition card (National Instruments Corp). EMG signals were processed using EMGworks 3.7.2.0 acquisition and analysis software. EMG signals were band-pass filtered between 20 and 450 Hz with a fourth-order Butterworth filter and processed using a root mean square algorithm with 0.2-second time constants and normalized

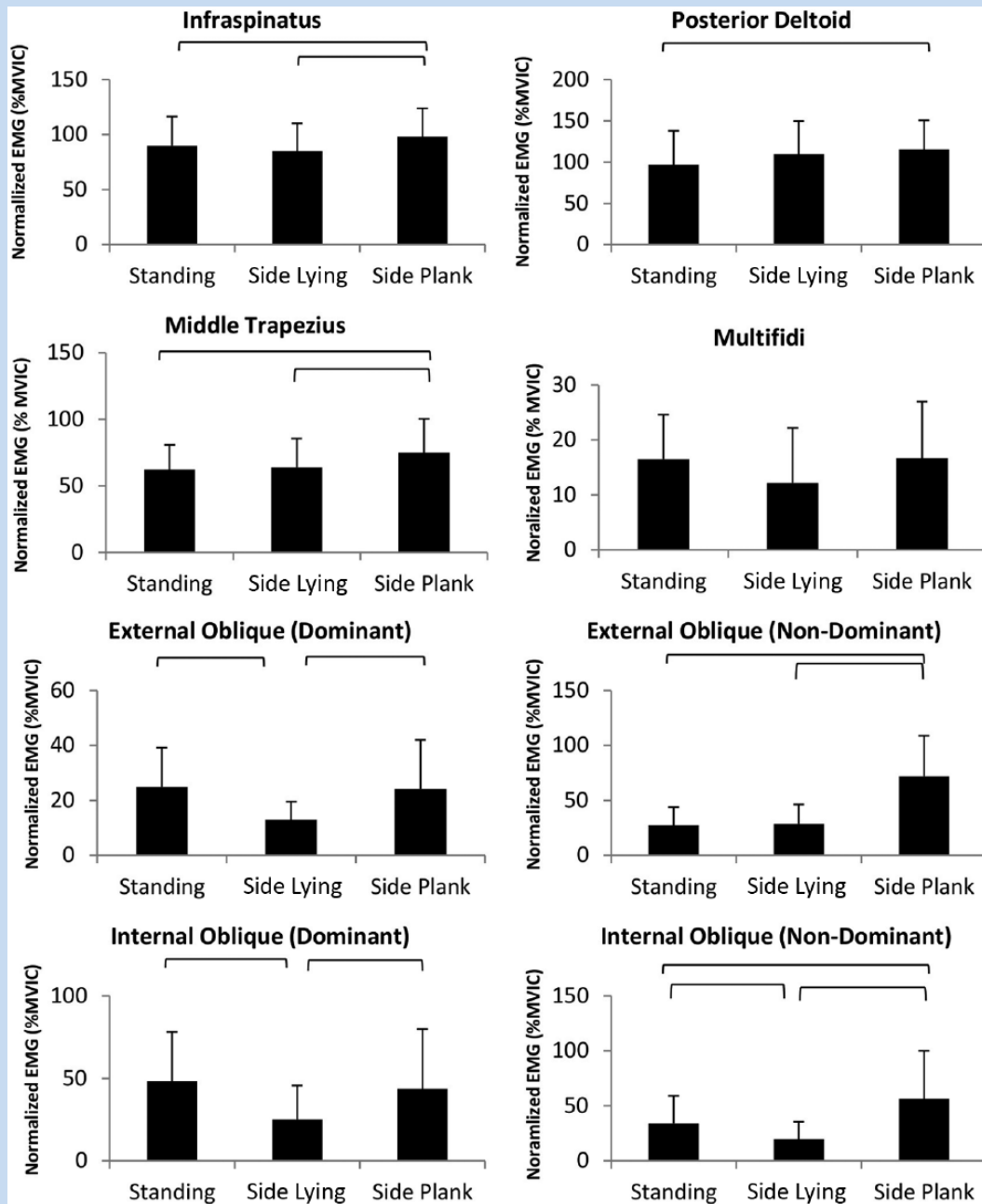


Figure 3. Normalized electromyographic (EMG) muscle activation values for the 3 test positions. Brackets indicate significant differences between EMG values. MVIC, maximal voluntary isometric muscle contraction.

to the MVIC. EMG data were normalized to the MVIC in the analysis. A 100-ms window about the peak was used to establish peak activation.

Statistical Analysis

All statistical analyses were performed using SPSS 21.0 software (IBM Corp). Group means and standard deviations were calculated for normalized EMG signal amplitudes for each muscle group in the 3 test positions. Repeated-measures analyses

of variance ($\alpha = 0.05$) with post hoc Bonferroni corrections for multiple comparisons were used to analyze differences in ER torque and EMG recruitment among the testing positions.

RESULTS

Torque

There was no significant difference in ER torque generated between positions. Mean torque values were 29.5 ± 10.0 N·m

Table 2. Position comparisons of electromyographic findings with significant differences

Muscle	Position Comparison	Mean Difference (%MVIC)	95% Confidence Interval	P Value
Infraspinatus	Side plank > Standing	8.12	0.95-15.41	0.02
	Side plank > Side lying	13.11	2.15-24.07	0.02
Posterior deltoid	Side plank > Standing	18.18	3.56-32.79	0.01
Middle trapezius	Side plank > Standing	12.64	2.92-22.35	0.01
	Side plank > Side lying	11.09	2.48-19.70	0.01
External oblique dominant	Standing > Side lying	11.96	6.12-17.81	<0.01
	Side plank > Side lying	11.19	2.48-19.90	0.01
External oblique nondominant	Side plank > Standing	44.85	24.77-64.92	<0.01
	Side plank > Side lying	43.39	29.50-57.27	<0.01
Internal oblique dominant	Standing > Side lying	23.11	10.33-35.89	<0.01
	Side plank > Side lying	18.67	1.32-36.02	0.03
Internal oblique nondominant	Standing > Side lying	13.97	2.09-25.85	0.02
	Side plank > Standing	22.46	1.91-43.01	0.03
	Side plank > Side lying	36.43	18.24-54.62	<0.01

MVIC, maximal voluntary isometric muscle contraction.

while standing, 29.3 ± 11.7 N·m while side lying, and 29.3 ± 10.0 N·m while in the side plank position.

Electromyography

EMG values for the infraspinatus were greatest in the side plank position. In general, EMG values for the trunk muscles were also greatest in the side plank position (Figure 3 and Table 2).

DISCUSSION

The more stable position did not result in the ability to generate greater ER force, as positioning had little effect on ER torque production. An EMG signal of 50% or greater is required to produce a stimulus for strength gains.^{1,2} Using 50% as a minimum threshold, all positions of resisted ER resulted in a sufficient stimulus for the shoulder girdle muscles monitored (infraspinatus, posterior deltoid, middle trapezius). No position resulted in a sufficient stimulus for the multifidi. For the trunk muscles, only the side plank position produced EMG signal greater than 50%. Both the external and internal obliques on the nondominant or “down” side had values sufficient for strengthening given the 50% threshold. Thus, if the shoulder girdle is the primary focus with an ER strengthening program, any of the 3 positions tested can be used to generate a sufficient strength stimulus.

Coordinated activation of glenohumeral and trunk musculature is required to perform many overhead sport-specific tasks. During activities ranging from running to throwing, trunk stability is pivotal for efficient biomechanical function to maximize force generation and minimize joint loads.¹¹ Findings from our study would support ER in side plank as an integrated shoulder and core exercise.

A limitation of this study was the finding of significantly greater EMG values of the infraspinatus and posterior deltoid in the side plank position without a concomitant increase in ER torque. While we cannot explain this finding, recruitment patterns and cross-talk from the teres minor, which is difficult to differentiate with surface electrodes, may be a contributing factor.¹⁵ Another limitation is the use of a young, athletic, asymptomatic population, which affects generalizability. How the elderly, postoperative, or injured patient would respond to these exercises is unknown.

CONCLUSION

If the purpose of a rehabilitation program is to strengthen the rotator cuff, in particular the infraspinatus, the side plank is preferred over standing or side lying. If the goal is to simultaneously strengthen both the rotator cuff and trunk muscles, the side plank position again is preferred.

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