Original Article

Upper Extremity Electromyography During Bouldering: Research Report

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Abstract

Background: Despite the growing popularity of bouldering, little is known about the degree and variability of muscle activation that occurs while solving bouldering problems. The purpose of this study was to explore the electromyography of eight upper extremity and trunk muscles during a session of indoor bouldering while completing four different problems.

Methods: Eleven climbers with self-reported ability to climb a V-scale V4 problem grade or higher and regularly boulder at least two days/week for at least six months participated in this study. Electromyography was used to record muscle activity of the flexor digitorum superficialis, extensor carpi radialis longus, biceps brachii, triceps brachii, anterior deltoid, middle deltoid, posterior deltoid, and latissimus dorsi.

Conclusion: The highest average EMG across all four climbs occurred in the flexor digitorum superficialis, latissimus dorsi, and extensor carpi radialis brevis. Significant differences in muscle activity were noted between the anterior deltoid and latissimus dorsi, flexor digitorum superficialis and biceps brachii, triceps brachii and flexor digitorum superficialis, posterior deltoid and latissimus dorsi, and triceps brachii and latissimus dorsi. This information may be useful in developing a strength and conditioning program for climber and to help guide rehabilitation and return to climbing decisions for climbers who have been injured.

Keywords: Bouldering, EMG, Physiotherapy, Upper extremity

Introduction

Competition climbing was recognized as an Olympic sport in 2020 and debuted in the 2021 summer games in Tokyo, increasing its popularity as both a competitive and recreational sport.[1] The competitive discipline of climbing includes bouldering, which involves movement sequences performed on a pre-determined direction of travel, without a rope, and at about 10-20 feet in height, requiring power and strength[2] as compared to endurance. Due to the lack of rope and harness, safety mats are positioned under the climber to protect them in the event of a fall. The increased popularity of bouldering has led to an increase in climbing related injuries.[3] The most frequently injured body parts sustained during

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climbing are the hands and wrists[3], likely due to the strength requirements of the forearm flexors and grip to successfully complete a climb.[4-6]

A bouldering problem is the specific route the climber takes when moving up the bouldering wall. A bouldering route is called a problem because it takes some figuring out before physically starting the climb; the climber studies the route and finds the best way to successfully ascend the wall. The sport of bouldering requires the athlete to move their body mass vertically, with a varying degree of support, through a variety of movements and body positions, to solve a bouldering problem. The ability to produce adequate muscle force when solving a problem may prevent falls, reduce climbing-related injuries, and improve climbing skill.[5]

It has been demonstrated in the climbing population that grip strength and forearm flexorsare associated with climbing ability.[4-6] However, the degree and variability of other muscle activation that are employed while solving bouldering problems is unknown. The purpose of this study was to explore muscle activation through electromyography (EMG) of eight upper extremity and trunk muscles during a session of indoor boulderingwhile completing four different problems. It was hypothesized that the level of muscle activity would vary between muscles. Insight into muscle activity may help climbers focus their trainingefforts to improve climbing ability and to assist with rehabilitation decisions if an injury occurs.

Materials and Methods

Participants

Eleven experienced climbers volunteered to participate in the study. See **Table 1** for descriptive characteristics. To be eligible to participate, all participantshad to be 18-45 years of age, have a self-reported ability to climb a bouldering problem of at least a V-scale V4 (Fontainebleau 6A), and regularly boulder at least 2 days/week for at least 6 months. Additionally, participants were excluded if they had any current upper or lower extremity injuries which may limit ability to climb. Prior to testing, participants were asked to refrain from strenuous activity 24 hours prior and caffeine, nicotine, and pre/post-workout supplements 12 hours prior. Screening for suitability of exercise was determined using a physical activity readiness questionnaire (PAR-Q) and was mandatory prior to beginning exercise. All experimental procedures were approved by the Samford University Institutional Review Board (IRB), andwritten and informed consent was obtained from each participant prior to data collection.

Table 1. Descriptive characteristics of the study participants.

Characteristic	Value*
Age, years	26.65±7.41(20-44)
Mass, kilograms	69.91±13.05(48.3-92.5)
Height, centimeters	173.91±11.41(153-188)
Arm span, centimeters	176.59±12.80(156.5-197)
Climbing experience, years	10.26±11.18(1.67-40)

*mean±SD(range)

Electromyography

Wired, surface EMG sensors (SX230) connected to a Bluetooth EMG System (PS900) (Biometrics Ltd., Newport, UK) was used to detect muscle activity of eight upper extremity and trunk muscles, including flexor digitorum superficialis (FDS), extensor carpi radialis longus(ECRL), biceps brachii (BB), triceps brachii (TB), anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), and latissimus dorsi (LD). For all conditions, sensors were placed unilaterally on the right-side upper extremities and trunk. Prior to senor placement, the skin was cleaned with alcohol. Plastic adhesive strips were attached to each sensor and pressed firmly onto the skin. Athletic pre-wrap and sports tape was used to ensure adequate skin connection during activity and to reduce signal noise (**Figure 1**). The ground reference strap was placed on the right-sideulnar styloid. All electrodes were placed according to the surface EMG for noninvasive assessment of muscles (SENIAM) recommendations (**Table 2**).[7] Electrode placement was verified by having the participant perform submaximal contracts of each muscle using the standardized testing procedures described by Kendall et al.[8]

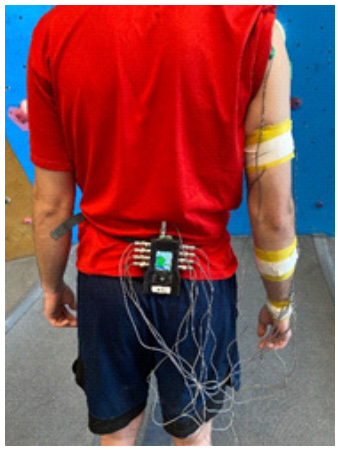

Figure 1. EMG set up for participants.

Table 2. EMG sensor placement for each of the muscles collected.

Muscle	Sensor Placement
Flexor digitorum superficialis	¾ of the forearm length from elbow, between radius and ulna; participant actively flexed fingers to confirm location
Extensor carpi radialis longus	1/3 of forearm length from elbow; participant actively extended and radially deviated wrist to confirm location
Biceps brachii	1/3 of arm length from acromion to fossa cubit; participant actively flexed and supinated elbow to confirm location
Triceps brachii	½ of arm between acromion and olecranon; participant actively extended elbow to confirm location
Anterior deltoid	1 finger width distal and anterior to acromion; participant flexed shoulder to confirm location
Middle deltoid	Greatest bulge of muscle from acromion to lateral epicondyle; participant abducted shoulder to confirm location
Posterior deltoid	In area 2 fingerbreadths posterior to acromion; patient abducted and extended shoulder to confirm location
Latissimus dorsi	4 cm below inferior angle of scapula, halfway between the lateral edge of torso and the spine; patient extended shoulder and depressed scapular to confirm location

Experimental Protocol

Data was collected at an indoor bouldering gym in Birmingham, Alabama. Data was collected on each participant in one visit, lasting approximately 30-minutes. Prior to testing, age, height, total body mass, arm span, and climbing experience were measured. EMG sensors were then placed on the participant and electrode placement was verified. Each participant completed four pre-set bouldering problems, each featuring different kinds of holds and moves common to bouldering. These problems were completed in the order self-selected by the participant andparticipants rested as needed between each problem. Participants were allowed to use climbing chalk for their hands and wear their own climbing shoes. Participants were given time to observe and feel the climbing holds on the route before climbing and were instructed to climb each problem how they would normally climb.

Bouldering Problems

The owner, head setter, and head team coach of the indoor bouldering gym, with over 30 years of combined setting experience,pre-set four bouldering problems that were completed by each participant, each with different holds and moves, as described below, to capture data on a variety of bouldering skills. All problems are a V2/V3 rating.The Biometrics EMG recording began at the start of the climb which was defined as the point where the climber leaves the ground with every part of the body and both hands are on the marked starting holdsand the completion of the attempt and ending of the EMG recording occurredwhen the finishing hold was gripped with both hands, as per IFSC-rules.[9]

Problem A: Purple problem (**Figure 2**)

This is a traverse style problem on a mild angle that progresses to a steeper angle at the top. The holds featured on this problem are midway between a "jug" and a "crimp" hold and with a smooth, small positive in-cut. The feet are large chip-style feet. This problem required some sequencing of hand holds and foot movement and was meant to capture a more endurance focused problem.

Figure 2. Problem A

Problem B: Black problem (**Figure 3**)

This problem is on the corner of two walls and is focused on body positioning and technique. The intent was to capture moves that involved "stemming," or pressing of an arm into a hold to create tension. This problem required some technical footwork and hip movement depending on the height of the climber, with taller climbers being able to stand and skip some holds while shorter climbers had to use each hold. Most climbers involved in this study skipped the diagonally angled slope hold on the tan wall and instead opted to go straight up from the large sloper style, which featured a prominent ridge in the middle, hold into the undercling above it.

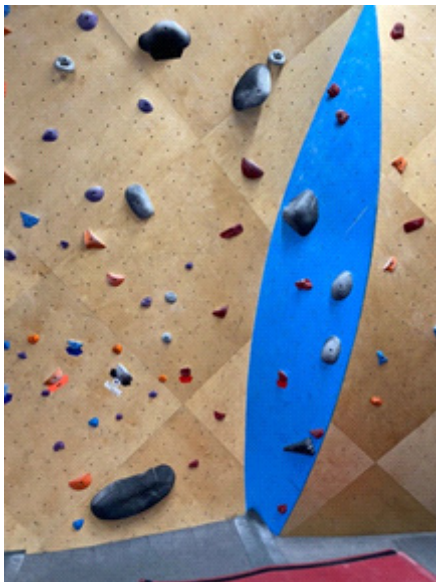

Figure 3. Problem B

Problem C: Blue problem (**Figure 4**)

This problem was considered to be the hardest problem by the routesetters and by the consensus of the participants and featured a mixture of slope and large flat holds. This problem attempted to capture the pulling power required for certain problems. The start involves a low hang in a squat position into a left hand gentle sloper, to capture a common start move. The moves are "reachier" for the average height or shorter climber and thus needed some footwork and pulling power.

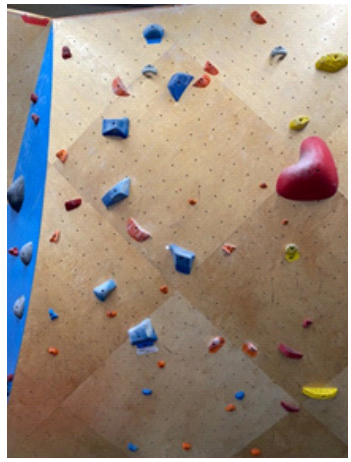

Figure 4. Problem C

Problem D: Green problem (**Figure 5**)

The fourth problem is a crimp problem with smaller footholds on a convex wall. The second move of the problem is considered the crux and involves comfort on mid-small sized feet and pulling from a pinch, (or crimp depending on how it was used) while standing into a further right crimp and then controlling the body's momentum.

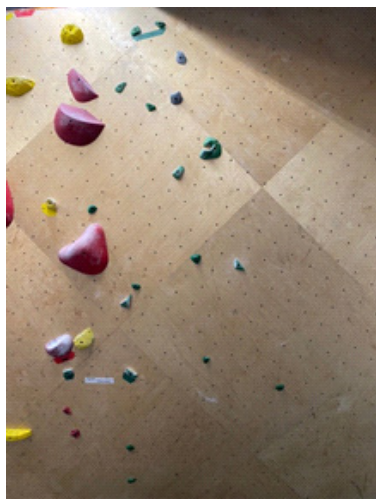

Figure 5. Problem D

Data Analysis

Reported data are mean values for each bouldering climb. All data was analyzed using Jamovi software (Version 0.9). The normalized mean EMG for each of the eight muscles was compared using repeated measures ANOVA with a $p<0.05$ level of confidence accepted as significant for all tests. For data showing a difference in the repeated measures ANOVA analysis, a tukey post hoc analysis was performed.

Results

A significant difference was found ($p<0.001$) with the repeated measures ANOVA. A tukey post hoc analysis showed significant differences in muscle activation between the anterior deltoid and flexor digitorum superficialis ($p=0.038$), anterior deltoid and latissimus dorsi ($p=0.017$), flexor digitorum superficialis and biceps brachii ($p=0.022$), triceps brachii and flexor digitorum superficialis ($p=0.046$), posterior deltoid and latissimus dorsi ($p=0.029$), and triceps brachii and latissimus dorsi ($p=0.034$). **Table 3** shows tukeypost hoc comparisons.

Table 3. Post hoc comparisons.

Comparison			
RM Factor 1	**RM Factor 1**	**Mean Difference**	**P_{tukey}**
AD	BB	-1.7725	0.397
	ECRL	-4.4425	0.305
	FDS	-7.2825	0.038*
	LD	-6.1075	0.017*
	MD	-1.0825	0.619
	PD	-2.3050	0.105
	TB	-1.0125	0.179
BB	ECRL	-2.6700	0.575
	FDS	-5.5100	0.022*
	LD	-4.3350	0.170
	MD	0.6900	0.996
	PD	-0.5325	0.994
	TB	0.7600	0.943
ECRL	FDS	-2.8400	0.201
	LD	-1.6650	0.841
	MD	3.3600	0.695
	PD	2.1375	0.615
	TB	3.4300	0.442
FDS	LD	1.1750	0.949
	MD	6.2000	0.172
	PD	4.9775	0.058
	TB	6.2700	0.046*
LD	MD	5.0250	0.058
	PD	3.8025	0.029*
	TB	5.0950	0.034*
MD	PD	-1.2225	0.863
	TB	0.0700	1.000
PD	TB	1.2925	0.190

Abbreviations: Flexor digitorum superficialis (FDS), extensor carpi radialis longus (ECRL), biceps brachii (BB), triceps brachii (TB), anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), latissimus dorsi (LD).

*indicates <0.05

Muscle Activity (EMG) During Indoor Bouldering

Across the four bouldering problems, the activity of the examined muscles varied considerably (**Table 4**). This highest average EMG amplitude across all four climbs occurred in the flexor digitorum superficialis, latissimus dorsi, and extensor carpi radialis brevis.

Table 4. Mean EMG during four bouldering problems.

	Ant Delt	Bicep LH	ECR	FDS	Lat	MidDelt	PostDelt	Tricep
Climb A	3.73	5.62	11.40	12.08	11.61	4.67	6.82	4.58
Climb B	4.95	5.90	5.45	9.51	10.38	7.55	5.92	5.35
Climb C	5.07	8.74	10.52	14.49	9.87	4.91	7.25	6.19
Climb D	4.58	5.16	8.73	11.38	10.90	5.53	7.56	6.26
Average Muscle Activation	4.58	6.35	9.03	11.86	10.69	5.66	6.89	5.59
st dev	0.52	1.40	2.28	1.78	0.64	1.13	0.62	0.69

Discussion

As hypothesized, upper extremity and trunk muscle activity varied across the four bouldering problems. Certain muscles demonstrated low level of activity, while others demonstrated greater activity. Muscle activity also varied based on the bouldering problem (**Table 4**).

Knowledge of specific muscle activity during bouldering may help identify exercises that target specific muscles in people looking to improve their bouldering skills. Muscle activity can also help guide return to climbing decisions and best rehabilitation practices for an injured climber. It is challenging to compare the muscle activity produced during bouldering in the current investigation with other studies, as the intensity level and dynamic nature of bouldering differs based on the climbing task. MacLean et al.[10] examined the EMGof 12 upper extremity and trunk muscles of experienced and inexperienced climbers during a horizontal bimanual climbing activity and found the EMG amplitudes were higher in the inexperienced climbers. Thereduced muscle activityin experienced climbers is likely due to the increased efficiency experienced climbers demonstrate when climbing. This difference in muscle activity between climbers with different level of experience would need to be considered when recovering from a muscle injury or determining when it is safe to return to climbing after an injury. Since grip strength and forearm flexor strengthis associated with climbing ability, Watts et al.[11] compared forearm EMG response to maximum handgrip dynamometry with forearm EMG response to six different hand configurations during climbing. Surprisingly, there was a large difference in EMG activity of the forearm musculature during climbing and maximal effort dynamometry with the absolute peak forearm EMG for climbing being significantly greater than for maximal effort hand grip dynamometry. This suggests that the activation of forearm musculature differs between classic handgrip dynamometry and maintenance of hand grip during climbing, which may have implications for climbing specific training, rehabilitation, and safety consideration when returning to climbing after an injury. If grip dynamometry activates forearm musculature less than gripping during climbing, then climbing may be more effective at activating other muscles than classic rehabilitation exercises such as the latissimus pull down or a biceps curl. Future research is needed to test these theories. Nevertheless, the muscle activity levels during bouldering in the current study suggest bouldering may be a beneficial activity to developing strength of upper extremity and trunk musculature.

In our current study, the highest average EMG across all four climbs occurred in the flexor digitorum superficialis, latissimus dorsi, and extensor carpi radialis brevis. The importance of the forearm

musculature in climbing is supported by a study by Deyhle et al.[12] which found prefatiguingthe forearm musculature reduced climbing ability, supporting the importance of the forearm musculature in climbing ability. However, prefatiguing the shoulder adductors (*i.e.* latissimus dorsi) had no significant impact on climbing performance, suggesting the latissimus dorsi may not be as important to climbing success as the forearm musculature.[12]

Study limitations should be considered when interpreting the results presented. The main limitation of this study was the low study sample size. One could speculate that differences in the EMG activity between muscles would be more prominent with a greater statistical power. This research did not include all possible bouldering skills, holds, and moves. Also, this study only included climbers with a self-reported ability of at least a V-scale V4 (Fontainebleu 6A), and regularly boulder at least 2 days/week. EMG amplitude data may differ on less skilled climbers or climbers completing bouldering problems closer to their self-reported ability. In addition, while protocols were in place to standardize procedures, there are limitations associated with the collection and processing of EMG data, such as discrepancies in electrode placement and the ability of participants to reach their voluntary maximum during the test contractions used for normalization purposes. Furthermore, the current study only considered unilateral muscles from healthy participants. Importantly, the findings from this study should not be generalized to other populations or bouldering facilities.

The findings of the present study provide a foundation for designing a muscle conditioning program for climbers. There has been a steady rise in the popularity of climbing, and conditioning specific muscles may be useful at improving the climbers' ability and preventing injuries associated with climbing.

Prior to implementing bouldering problems into a rehabilitation program after an injury, the influence of various climbing problems on muscle activity in people with pain or injury should be investigated. Future research should be conducted to explore whether the prescription of climbing to treat pain is effective in terms of improving symptoms and not furthering injury progression.

Conclusion

The current study identified the activity of eight upper extremity and trunk muscles across four bouldering problems. The activity of the eight muscles varied greatly. The highest average EMG across all four climbs occurred in the flexor digitorum superficialis, latissimus dorsi, and extensor carpi radialis brevis. Significant differences in muscle activity were noted between the anterior deltoid and latissimus dorsi, flexor digitorum superficialis and biceps brachii, triceps brachii and flexor digitorum superficialis, posterior deltoid and latissimus dorsi, and triceps brachii and latissimus dorsi. This information may be useful in developing a strength and conditioning program for climbers, and to help guide the return to climbing criteria for climbers who have been injured. However, prior to recommending climbing as part of a rehabilitation program, the muscle activity requirements should be studied in an injured population.

Ethical Clearance: This research involving human subjects was approved by Samford University's Institute Review Board, approval number EXPD-HP-22-S-23.

Conflict of Interest: Nil

Source of Funding: Self

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