
FOREARM EMG DURING ROCK CLIMBING DIFFERS FROM EMG DURING HANDGRIP DYNAMOMETRY

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ABSTRACT

Int J Exerc Sci 1(1): 4-13, 2008 Handgrip dynamometry is often given importance in the study of rock climbing performance. Whether handgrip dynamometry produces a degree of muscle activation comparable to actual climbing has not been reported. Furthermore, the degree and variability of muscle activation for various hand configurations during climbing are unknown. The purpose of this study was to record forearm EMG responses for six hand configurations during climbing and to compare these responses to a maximum handgrip test. Five experienced climbers performed four moves up (UP) and down (DN) on an overhanging 45-deg. climbing wall with each of six hand configurations: crimp (C), pinch (P), three 2-finger combinations (2F1, 2F2, 2F3) and an open-hand grip (O). Forearm EMG was recorded via surface electrodes. Data were recorded for the second UP and second DN moves. Prior to climbing, maximum handgrip force (HG) and simultaneous EMG were obtained. Mean HG force was 526.6 ± 33.3 N. Times to complete the climbing movements with each hand configuration varied between 3.1 ± 0.5 and 4.8 ± 0.9 sec with no significant differences. Peak EMG's during climbing were higher than HG EMG ($p < .05$). Mean EMG amplitudes for UP, as percentages of HG EMG, were 198 ± 55 , 169 ± 22 , 222 ± 72 , 181 ± 39 , 126 ± 32 , and $143 \pm 47\%$ for C, P, 2F1, 2F2, 2F3, and O respectively. Significant differences were found for O versus 2F1 and for 2F3 versus 2F1 and C ($p < .05$). EMG amplitudes were lower for DN than UP ($p < .05$). Since all climbing EMGs exceeded HG EMG, it was concluded that handgrip dynamometry lacks specificity to actual rock climbing.

KEY WORDS: Electromyography, handgrip, strength

INTRODUCTION

The development of indoor climbing structures has made the activity of rock climbing available to a wide audience and promoted climbing as a competitive activity. The physiological aspects of difficult rock climbing have been recently reviewed by Watts (13).

The nature of rock climbing requires the individual to transport the body mass vertically, with varying degrees of support, through a series of complex movements and body positions. Since the resistance load for this task primarily involves lifting and supporting body weight, often via relatively small muscle groups of the upper

body, high upper body strength and low body mass would be expected in high-level rock climbers. The balance between strength and body mass in climbers has been expressed as strength/mass ratio. Previous studies have found elite rock climbers to be relatively small in stature with low body mass and low body fat percentage and to possess high handgrip strength to body mass ratio (15, 16).

Failure to produce adequate force for maintaining finger and hand contact with specific rock features is often cited by climbers as the primary cause of falls. Various devices that involve squeezing actions with the hand and fingers are advertised as and used by climbers as specific training modes. These perceptions, and reports by active climbers, have encouraged the assessment of maximum handgrip force in the study of rock climbing performance. Typically, handgrip force is measured with a handgrip dynamometer and involves an isometric squeeze action between the fingers and the base of the thumb. Several studies have reported mean maximum handgrip forces that range from 506.0 ± 62.8 to 581.5 ± 69.6 N for male rock climbers of high ability (2, 4, 5, 14, 15, 16). Although maximal handgrip force is often correlated with climbing ability in these studies, the reported values for elite climbers are not unusually high when compared with sex- and age-matched population norms (15). It remains unclear whether fatigue of handgrip strength is a direct cause of falls in climbing. Watts et al. have found handgrip endurance, expressed as holding time at 70% of maximum handgrip force, to decrease to a greater degree than maximum handgrip strength

as a result of sustained climbing to the point of a fall (11, 16).

In practice, climbing requires production of hand-to-rock contact forces in a wide variety of hand and finger configurations. It has been suggested that the hand position commonly used for handgrip dynamometry may not occur often in climbing (13). Furthermore, the degree and variability of muscle activation for common, though different, hand positions employed in rock climbing are unknown. The purpose of this study was to compare the electromyogram (EMG) response to maximum handgrip dynamometry with the EMG responses recorded for six different hand configurations during concentric and eccentric phases of a rock climbing movement.

METHOD

Participants

Five experienced male rock climbers volunteered to participate as subjects in the study. All subjects were experienced with indoor climbing on terrain similar to that employed in the study and with outdoor climbing on real rock. The mean climbing ability for the subjects was rated according to the most difficult ascent made by each specific subject according to the Yosemite Decimal System (YDS) scale. The YDS scale uses the numeral 5 to indicate "free" climbing, where no artificial means are employed to aid progress, followed by a "decimal" and a second numeral to indicate the overall difficulty of the route. This scale currently extends from 5.0 (easiest) to 5.15 (most difficult). Letter subdivisions of a, b, c and d are used from the 5.10 level upward to indicate further gradients of difficulty.

Thus, a route rated 5.11b would be more difficult than a route rated 5.11a for most climbers. The YDS scale currently extends from 5.0-5.15a. The mean climbing ability for the subjects was rated as 5.11b on the YDS scale.

Protocol

Prior to testing, height, total body mass, and skinfold thickness from seven anatomical sites were measured. The sum of the seven skinfold measurements was calculated and percent body fat was estimated according to the method of Jackson and Pollock (7). All procedures were approved by the University Institutional Review Board for Human Subjects Research and each subject read and signed written informed consent prior to participation.

Subjects performed a series of repeated climbing movements on an overhanging climbing board set at a constant angle of 45-degrees from horizontal. The climbing board was fitted with five sets of identical molded features, or holds (HIT Strips, Nicros Inc.), positioned 45.7 cm linear-distance apart. The HIT Strip system is designed to force climbing-specific hand positions that may be repeated in multiple efforts. The hand positions tested in this study were: crimp(C) with four fingers on a 1 cm edge; pinch (P) with thumb in opposition to four fingers; three 2-Finger combinations with digits V+IV (2F1), IV+III (2F2), and III+II (2F3); and with an open hand (O) on a four cm edge (Figure 1). The movement sequence, often termed a *twist-lock* movement by climbers, involved grasping a handhold with one hand and, with the opposite foot on a lower hold, twisting the trunk to face toward the

handhold side, and reaching for the next higher hold with the opposite hand. The movement was then repeated with the twist to the opposite side and a reach with the opposite hand (Figure 2). For each climbing trial, two full moves for each side were made upward (UP) at which point the climber matched hands on the same hold then reversed the movements downward (DN) until the starting position was reached. A ten-minute rest period was imposed following each trial with the different hand positions for each subject. All subjects were experienced with use of the climbing board and HIT Strip hold system.

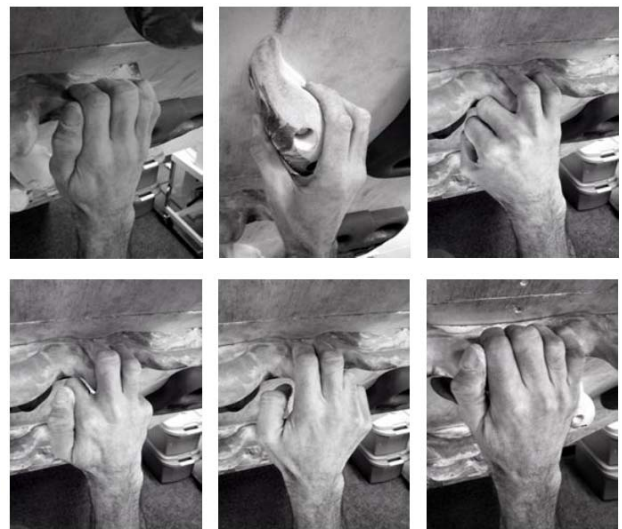


Figure 1. The six hand configurations employed, where C = crimp, P = pinch, 2F1 = digits V+IV, 2F2 = digits IV+III, 2F3 = digits III+II, and O = open.

Electromyograms were recorded from the anterior forearm via surface electrodes (Blue Sensor; Medicotest A/S, Denmark). Previous study by Koukoubis, et al. has indicated immediate and sustained EMG activity in the anterior forearm during a climbing-type movement (8). One electrode was placed 1/3 of the linear distance from



Figure 2. The 45-degree HITTM Strip climbing board and the primary move used in this study.

the medial epicondyle of the humerus to the styloid process of the radius and a second electrode two cm distal along the same line according to Davies (3). A ground electrode was affixed at the olecranon process. Impedance between electrodes was tested and verified at below 5000Ω . All raw EMG data were recorded at 500 Hz using a Tel-100 system (Biopac Systems, Inc.) and laptop microcomputer. The raw EMG signals were integrated via root mean squared (RMS) over 50 samples and peak values subsequently determined via Acqknowledge version 3.5.6 software (Biopac Systems, Inc.).

Prior to climbing, maximum handgrip force (HG) and simultaneous EMG were recorded for the best of two trials using a

standard handgrip dynamometer (Lafayette Instruments). The handgrip test was administered with the subject standing and the arm extended at the elbow. The extended elbow position was utilized since the specific climbing task primarily involved support from the arms with the elbows extended (see Figure 2). Each handgrip contraction was held for five seconds and the highest value attained recorded from the dynamometer gauge. The handgrip dynamometer was also interfaced with the computer data acquisition system to provide a non-calibrated force curve to match the contraction timing and the point of highest force with the EMG data. The peak IEMG for handgrip was determined from within an interval between the start of the contraction to a point 0.5 sec beyond the peak level of the force curve. Since this IEMG amplitude corresponds to the point at which the maximum handgrip force was observed, it will be referred to hereafter as maximum handgrip IEMG (HG IEMG). Unpublished pilot study in our laboratory has found IEMG amplitude to have a linear relationship with handgrip force recorded via dynamometer ($r^2 = 0.99$, $SE = 0.05$).

Statistical Analysis

Integrated EMG amplitudes recorded during climbing were normalized as percentages of HG IEMG (%max). Reported data are peak values for the second UP move and second DN move per trial. Repeated measures ANOVA (SPSS, 2000) was employed for data analyses with a $p < .05$ level of confidence accepted as significant for all tests.

Table 1. Descriptive characteristics of subjects.

Subject	Age	Height (cm)	Mass (kg)	$\Sigma 7$ Skinfoldds (mm)	%Fat	HG (N)	HG:Mass Ratio
1	47	190.4	79.3	45.0	8.34	529.8	0.68
2	21	167.6	56.0	40.0	4.37	500.3	0.91
3	19	174.0	75.8	61.0	7.47	490.5	0.66
4	40	174.0	70.3	70.0	11.45	539.6	0.78
5	21	174.0	63.7	44.0	5.10	573.9	0.92
Mean	29.6	176.0	69.0	52.0	7.3	526.8	0.79
std. dev.	± 13.0	± 8.5	± 9.4	± 12.9	± 2.8	± 33.2	± 0.12

RESULTS

Descriptive characteristics of the subjects are presented in Table 1. Mean (\pm std.dev.) maximum handgrip force was 526.8 ± 33.2 N and handgrip force to body mass ratio was 0.79 ± 0.12 .

Movement times for each hand configuration ranged from 3.1 ± 0.5 (O) to 4.8 ± 0.9 (P) seconds. No significant differences were found for time to complete the movement among hand configurations or between UP and DN conditions. For all hand configurations, the absolute peak IEMG for climbing was significantly greater than the HG IEMG. Table 2 presents IEMG data for all hand configurations as %max HG IEMG. Significant differences were found for O versus 2F1 and for 2F3 versus 2F1 and C for the UP movement. All IEMG amplitudes were significantly lower for DN than UP, however no significant differences were found among hand configurations for DN.

DISCUSSION

The subjects in this study were taller, heavier, and had higher percent fat values

than elite climbers previously studied by Watts, et al (15). The mean handgrip to body mass ratio of 0.79 ± 0.12 was comparable to previously reported values for elite and expert-level rock climbers (2, 15). Although the anthropometry of the experienced climbers in this study differs from previously reported data, the comparable strength to mass ratio supports application of our results to difficult rock climbing tasks.

This study represents the first reported attempt to record EMG data from the forearm musculature during an actual repeated rock climbing movement. Mean IEMG amplitudes exceeded 160% of maximum handgrip IEMG amplitudes for four of the hand configurations during upward movement. We were surprised to observe these large differences between the climbing IEMG amplitude and the IEMG during maximum handgrip dynamometry.

Koukoubis et al. (8) reported that forearm IEMGs, recorded during fingertip hanging and pull-up movements, attained average amplitudes of only 69% of maximal voluntary contraction (MVC) IEMGs.

Table 2. Means (\pm s.d.) for movement time and IEMG amplitude (as percent of maximum handgrip IEMG) for six had configurations during climbing. There were no significant differences among hand configurations for the DN movement.

Variable	C	P	2F1	2F2	2F3	O
Time (sec)	3.8 \pm 0.6	4.8 \pm 0.9	4.7 \pm 0.7	3.6 \pm 0.4	3.7 \pm 0.4	3.1 \pm 0.5
IEMG _{UP} (%HG-IEMG _{max})	208 \pm 38#	169 \pm 22	222 \pm 72#	181 \pm 39	126 \pm 32	143 \pm 77*
IEMG _{DN} (%HG-IEMG _{max})	128 \pm 42	160 \pm 33	176 \pm 33	162 \pm 38	123 \pm 45	122 \pm 28

*Indicates $p < .05$ versus 2F1.

#Indicates $p < .05$ versus 2F3.

Although the subjects for the study were rock climbers, Koukoubis et al. did not report how the MVC was produced. Also, the movements described in their study appear to be pull-up movements performed on a horizontal bar. Thus, the nature of the task and the hand position may have differed significantly from actual rock climbing.

A linear relationship between EMG amplitude and isometric tension in muscle has long been established (9). If one assumes this relationship to exist for our data, then the climbing movement would demand a considerably higher generation of force by the forearm musculature than that elicited by maximum handgrip effort against a dynamometer. A conservative estimate of the muscle tension developed during climbing could be more than double the tension during the handgrip dynamometer test. This would lead to an estimated exerted force of over 980 N, which would be greater than the mass of the heaviest subject. We were unable to record the actual force exerted onto the HIT Strip features and cannot verify these magnitudes of force for our subjects. It

would seem unlikely that force demands alone account for the high EMG amplitudes observed during climbing since the resistance forces were always less than a subject's body mass due to partial support from the feet.

Very limited work has been done in the area of force measurement during actual rock climbing. Quaine et al.(10) have measured single hand contact forces of 95.8 \pm 31.4 N during three-limb support on an instrumented climbing frame. These forces appear to be quite low relative to expected MVC force. The climbing position employed by Quaine et al. (10) was essentially vertical (90o), with two-foot support, thus, it would be expected that the contact force would be less than maximum handgrip strength. It is also expected that contact forces on vertical terrain, where more of the body mass may be supported by the legs, are less than those required on overhanging terrain. The 45-degree overhanging terrain employed in our study would significantly limit, but not completely eliminate, the amount of body mass supported by the feet. Thus, there would be more resistance force demands on

the hands for our climbing task relative to the task of Quaine et al. (10). Still, the expected force, even with one-hand support, would be less than body mass for our subjects.

It may be possible that the hand configuration during handgrip dynamometry does not enable maximum force development for finger flexion, however this is not supported by other data. Grant et al. (4) employed a special climbing-specific dynamometer to measure finger strength for hand configurations common to rock climbing. With four-finger contact without thumb opposition, similar to the open hand configuration used by our subjects during climbing, maximum exerted forces were 446.2 ± 20.6 N. This mean climbing-specific finger force was about 84% of maximum handgrip strength for their subjects. Grant et al. did not record electromyograms during these tests. Thus, we are unable to verify any shift in the force-EMG relationship between conditions.

The method employed by Grant et al. (4) to measure finger force may not be as climbing-specific as it first appears. Their data reflect forces that were produced via finger flexion against a strain gauge. In actual climbing, the force for contact with most holds is generated by the effect of body mass along the gravital line. Thus, the external force pulls the hand onto the hold with muscular force serving the role of maintaining the specific hand position against the external force. Since body mass exceeded maximum handgrip force for all of our subjects, it seems possible that, with one arm support, the muscles controlling hand position may be called upon to

generate forces higher than that attained during handgrip dynamometry. Assuming a linear force-EMG relationship, this would still not account for all of the increase in EMG amplitude observed during climbing. There are some factors that have been reported to change the shape or slope of the force-EMG relationship and one or more of these could be operative during rock climbing.

It is possible that the more dynamic nature of climbing movement relative to handgrip dynamometry affects the EMG. It has been demonstrated that EMG amplitude is higher when a muscle is short and becomes less as the muscle is stretched relative to the tension level (6). This is thought to be attributable to decreased excitability of motor units as a function of golgi tendon organ afferents with stretched muscle (12). This could result in different EMG amplitudes when the degree of finger flexion is not standardized between handgrip dynamometry and actual climbing. Although we did not measure finger angle in our study, observation of the finger positions involved in the six climbing-specific grips and for the handgrip dynamometer does not reveal extreme differences (Figure 1). The data of Inman, et al. were for larger muscle groups (triceps) associated with a large joint range of motion, and considerable shortening capacity (6). Whether this would be a factor with EMG of the forearm musculature is not known.

From a different perspective, Bigland and Lippold (1) have found increased EMG amplitude in relation to velocity of shortening during concentric muscle contractions. This increase in EMG

occurred although tension was the same. It could be that this was a factor in our observations. Although the handgrip test and the climbing movement had similar time frames, from 3.1 to 4.8 seconds, the handgrip test was probably static for a higher proportion of the performance time. Any differences in the rate of change in flexion between handgrip dynamometry and contact with a HIT Strip feature would be too subtle to detect without precise goniometry or film analysis. Such data await further study.

One of the most obvious differences between handgrip dynamometry and common hand configurations used in rock climbing is the lack of opposition of the thumb against the palm and/or fingers. The pinch hand position of our study involved some opposition from the thumb similar to that with handgrip dynamometry (Figure 1). Although the pinch grip yielded the third lowest IEMG amplitude, the mean value was still significantly higher than the handgrip IEMG ($169 \pm 22\%$). A qualitative comparison of the resistance force between handgrip dynamometry and the pinch grip employed during the climbing task reveals differences. The primary resistance forces during handgrip dynamometry are directed against flexion of the fingers and the base of the thumb. With the pinch grip there would be a resistance force, generated by the effect of gravity, acting as a shear force against the finger-hold interface. This shear force, in effect, attempts to pull the rock feature from the hand. This could demand an additional muscular force to maintain flexion of the fingers and generation of friction to oppose the shear force.

Although limitations of our study prevent closer determination of the nature of handgrip dynamometry versus the use of the hand during climbing, it appears that significant differences exist. The suggestion that handgrip dynamometry may not be specific to the force requirements for climbing is supported indirectly by reported handgrip strength data for rock climbers. Previous studies have not found handgrip strength to be unusually high in expert and elite climbers (13). Watts, et al. (15) found handgrip strength in elite male and female climbers to score at the 50th and 75th percentiles, respectively, for age-matched North American norms. Furthermore absolute handgrip strength was not found to be a significant predictor of climbing performance in elite competitive rock climbers (15). Newer strength measurement instruments such as that employed by Grant, et al. (4, 5) may prove useful in future study. Measurement of applied force and impulse of hold contact and release during actual climbing awaits exploration.

There were limited significant differences among the different hand positions for the upward movement (Table 1). The highest IEMG amplitudes during upward movement were observed for the crimp (C) position and the smaller 2-finger (2F1) position. Climbers would consider these two grips as the most difficult positions of the six in the HIT Strip system. Likewise, the lowest IEMG amplitudes were observed for the open (O) and the larger 2-finger (2F3) configurations. These two grip positions would be rated as the least difficult of the six. Although no significant differences were found among hand positions for the downward movement, a

similar ranking, with the exception of C, was observed. Observation of responses for a larger sample of subjects may reveal more diversity among the hand positions. Still, it seems clear that, during climbing-specific training, the use of body weight alone will result in varying magnitudes of stress on the musculature dependent upon which specific grips and hand positions are employed.

The results of this study indicate that the activation of forearm musculature differs between classic handgrip dynamometry and maintenance of hand to rock contact during climbing. These considerations may have implications for the design of research and climbing-specific muscle training strategies. More specific test modalities should be developed for assessment of hand strength in rock climbers. This has implications in clinical studies of climbing-related injury and in research on climbing performance and specific fatigue where handgrip dynamometry has been the traditional test methodology of choice.

Applications of our results are important for coaches and climbers who plan and participate in training programs for increasing performance. Devices that mimic the squeezing action of hand dynamometry may lack specificity as training modes for improving rock climbing performance. The indication that variability in muscle activation exists among different hand positions suggests that consideration of different resistance loads may be important in the design of exercises to improve climbing-specific strength. The possibility that high contraction velocity and rate of force development are important for attaining and maintaining contact with

holds in difficult climbing calls for study in the area of neural adaptations and associated training strategies.

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