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VERTICAL HAND FORCE AND FOREARM EMG DURING A *HIGH-STEP ROCK-ON* CLIMBING MOVE WITH AND WITHOUT ADDED MASS

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Eight experienced climbers completed four trials of a climbing movement known to climbers as a *high-step rock-on* on a vertical indoor wall. Climbers performed 2 trials of each condition of body mass (BM) and body mass plus 4.5 kg of added mass (AM). Two force platforms (FP) were imbedded into the wall flush with the climbing surface and modified to accept artificial climbing holds. During the movement sequence, a point was attained when all weight was supported by the right foot and right hand on the two FP. Vertical ground reaction force (F_V) and forearm EMG were recorded at 500 Hz throughout the movement. Peak F_V was significantly higher for AM vs BM. Also peak F_V was higher than F_V at peak IEMG. There were no differences in IEMG. Added weight increases the support maintained by the hand, but, is not related to in IEMG at the point of peak force.

KEY WORDS: rock climbing, electromyography, contact force

INTRODUCTION: The nature of rock climbing requires the individual to transport 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. It has been suggested that the ability to maintain specific hand-finger configuration against force generated by the effect of gravity on body mass is important in rock climbing performance (Quaine et al., 1995; Watts, 2004; Watts et al. 1996; 1999). In this regard, climbers often attempt to reduce the effect of mass by using lightweight equipment and, in some cases, reducing fat weight of the body. The effects of variations in mass upon vertical ground reaction force at the point of hand contact have not been reported.

Muscle activity during climbing movements has been characterized as a series of isometric contractions of the hand musculature (gripping a handhold), while larger extrinsic muscles move the climber past the hold (Watts, et al., 1999). However, it is unclear to what extent these gripping actions and the attendant muscle activity are important in the vertical movement.

The purpose of this study was to record vertical ground reaction force at the hand during a common rock climbing movement performed with body mass and with 4.5 kg of added mass consisting of equipment commonly used in traditional lead climbing. In addition the muscle activity of the finger flexors was examined during the movement and compared to different points in the generation of vertical force.

METHODS: Eight experienced rock climbers volunteered as subjects (mean ± SD: age = 27.8 ± 13.7 years; height = 172.7 ± 7.8 cm; body mass = 71.5 ± 8.8 kg). The mean climbing ability for the subjects was rated as 5.11b on the Yosemite Decimal System scale, which currently extends from 5.0-5.15a. Subjects completed a Physical Activity Readiness-Questionnaire and signed an informed consent form prior to participating in the study. Approval for the use of Human Subjects was obtained from the institution prior to commencing the study.

Each subject completed four trials of a climbing movement sequence on a vertical indoor wall. The specific movement sequence is known to climbers as a *high-step rock-on*. Climbers performed 2 trials (T1, T2) randomized by conditions of body mass (BM) and body mass plus 4.5 kg of added mass (AM).

Two force platforms (FP) (OR6-5-2000, AMTI, Watertown, MA, USA) were imbedded into the wall flush with the climbing surface (see Figure 1). The FP surfaces were modified to accept artificial climbing holds typical of indoor climbing venues. These holds had a horizontal edge approximately 2 cm deep for hand to hold on to using the distal two phlanges of the four fingers of the right hand. Ground Reaction Force (GRF) data were collected at 1000 Hz, real time displayed and saved with the use of computer software (BioSoft 1.0, AMTI, Watertown, MA, USA) for later analysis. During the movement sequence, a point was attained at which all weight was supported by the right foot on one FP, and the right hand on the second FP. Vertical ground reaction force (F_V) for the hand was recorded at 500 Hz throughout the movement.

Electromyograms were recorded from the anterior forearm via surface electrodes (Blue Sensor; Medicotest A/S, Denmark). One electrode was placed 1/3 of the linear distance from 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 (1992). 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 an MP100 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.).

EMG and force data were acquired simultaneously and matched via a common data signal. The raw EMG was integrated via root mean squared (RMS) across 50 samples.

Statistical treatment of the data was performed using a Two-Way (trial by weighted condition) Repeated Measures ANOVA for peak vertical ground reaction force, peak integrated EMG, peak ground reaction force at Peak EMG, and EMG at peak vertical ground reaction force. A Mixed Factors Three Way ANOVA (Repeated factors of trial by weighted condition and independent measure of when peak was measured) was also performed.

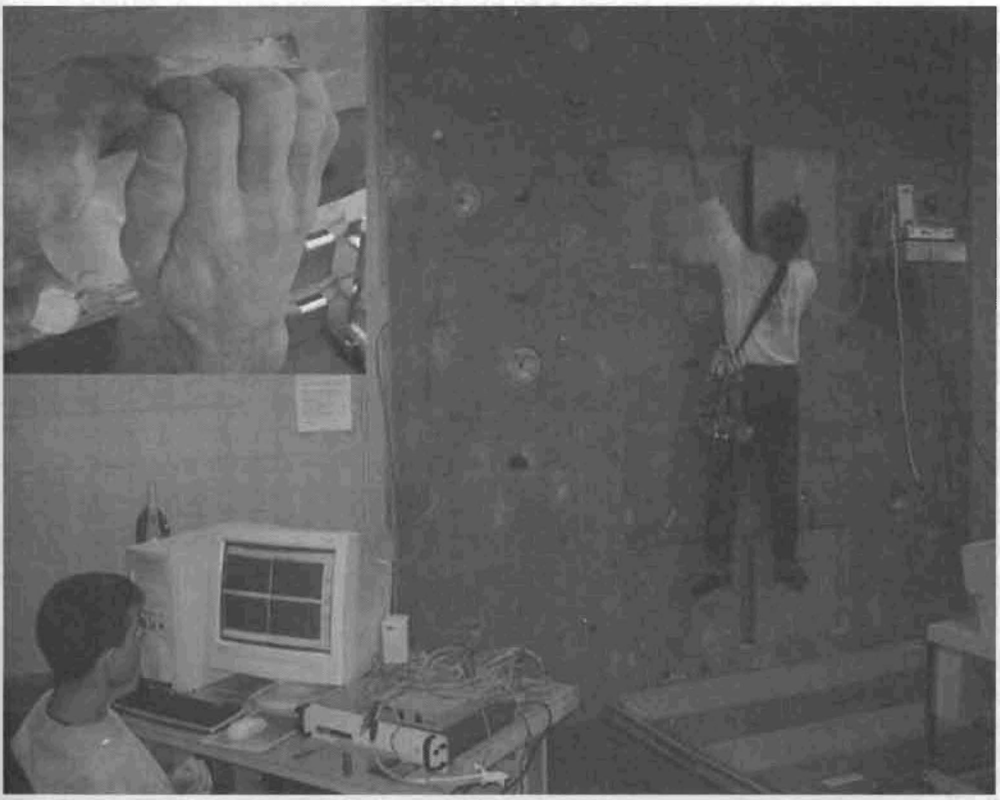

Figure 1 Subject performing the *high-step rock-on* climbing move with 4.5 kg added weight, inset illustrates hand position.

RESULTS: As shown in Table 1, there were no differences in peak F_V between T1 and T2 under either mass condition, however, peak F_V was significantly higher ($p < 0.05$) for AM compared to BM. Peak IEMG at Peak F_V did not differ between trials or between mass conditions ($p > 0.05$). Vertical hand force was lower at the point of peak IEMG than at peak F_V ($p > 0.05$), but did not differ between AM and BM or across trials ($p > 0.05$). There were no interactions for any of the dependent variables or conditions ($p > 0.05$).

Table 1 Peak vertical ground reaction force and IEMG for the hand (mean ± SD) with and without added weight (n=8).

	Body Mass		Added Mass	
	Trial 1	Trial 2	Trial 1	Trial 2
Peak Force (kg) [a]	55.42 ±11.45	53.37 ±11.12	57.38 ±10.11	58.41 ±9.82
Peak IEMG (volts)	0.427 ±0.274	0.414 ±0.254	0.364 ±0.126	0.434 ±0.251
Force @ Peak IEMG (kg) [b]	43.50 ±8.88	39.57 ±8.28	42.10 ±8.22	46.29 ±10.81
IEMG @ Peak Force (volts)	0.232 ±0.108	0.229 ±0.100	0.239 ±0.100	0.260 ±0.146

[a] Significant difference between body weight and added weight conditions ($p < 0.05$).
[b] Significantly different than Peak Force ($p < 0.05$).

DISCUSSION: As expected, added weight increases the required vertical force support of the hand during climbing, as there is a greater mass pulling the body downwards. However, this increased force required by the hand is not reflected by a change in motor unit recruitment in the forearm as indicated by peak IEMG. Furthermore, the EMG amplitude does not reflect the point of peak force at the hand. In other words peak force, as indicated by F_V does not coincide with the peak IEMG. Moreover, the F_V that occurs at peak IEMG was less than the peak F_V during the climbing movement.

The discrepancy between the peak force and muscle activity is puzzling, as they would be expected to occur at similar although possibly not identical times. Factors such as electromechanical delay and that the movement involves both an isometric component (gripping the hold) and a dynamic component (moving upward) could be the cause of the discrepancy. Electromechanical delay seems less likely, as the peak IEMG occurred after peak F_V (see Figure 3). Indeed the first and higher of the two peaks in F_V appears related to contacting the hold, while the secondary, later, peak is more likely related to actual movement. In addition, the later peak was closely related to the peak IEMG.

Variations in the relationship of finger flexor EMG to force production in climbing moves have been noted previously. Watts and coworkers (1999) found that EMG during a variety of climbing moves ranged from 126 to 222% of EMG attained during hand grip MVC. Indeed in the current study the EMG during the climbing move was higher than that of hand grip MVC (113-135%) for similar force measures (55.1±9.2 kg). Although climbing EMG was less than that for finger force MVC (78-92%), the force was also much lower (18.0±4.8 kg). These variations in muscle activity and force production indicate that forearm/hand EMG in climbing does not match those during common strength measures. With the large combination of muscles and movements of the hand present in climbing it is likely that studies using different EMG placements are necessary to investigate muscle activity during climbing moves.

The increase in F_V at hand contact during the AM condition indicates that the added weight does require the body to increase the force provided at the hand. However, despite the effect of increased vertical force, it is unclear whether this presents a significant challenge to the climber. Muscle activity as represented by EMG was not greater in the added weight condition, thus it is debatable whether this "overload" would be great enough to provide a training effect.

Furthermore, the peak F_V occurred at contact of the hand hold (see Figure 2) suggesting that maximal strength may be more important for making contact with the rock than for sustaining contact during the move. This appears to be the case even when a move upward is initiated, since the last force spike is of lower amplitude than the initial spike. If this is true, then specific training should likely involve multiple initial contacts with holds, rather than sustained contacts, in order to improve the climber's ability to catch onto the hold.

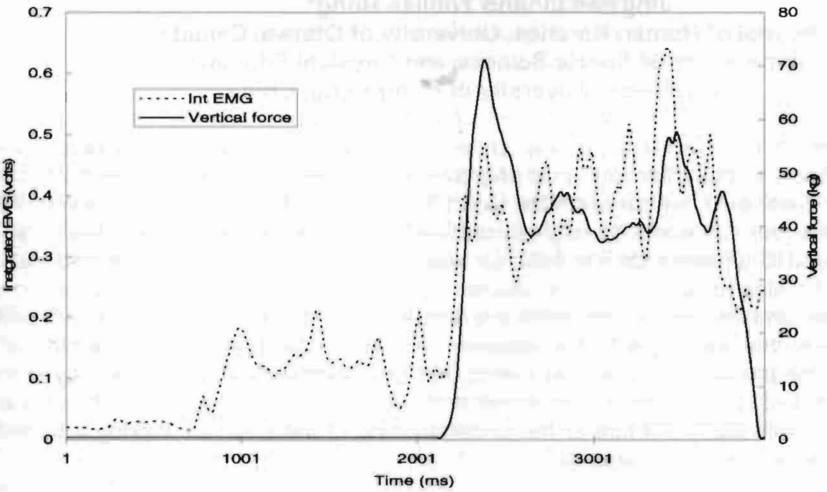

Figure 2 Subject 6 hand force and EMG response to *high-step rock-on* climbing move.

CONCLUSION: A climber using added weight as a training overload may not experience a significantly higher degree of motor unit activation; at least for the muscle(s) monitored in the current study. Perhaps the effect of the added weight would be primarily limited to the initial "catch" of the rock feature (the hold) – similar to a sticking-point principle. Thus, if the climber cannot successfully make the initial catch, he/she cannot finish the move.

REFERENCES:

Davies JF (1992). Manual of surface electromyography. WDAC Technical Report #59-184, 1959. In *Selective Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives*. U.S. Department of Health and Human Services.
Koukoubis TD, Cooper LW, Glisson RR, Seaber AV, and Feagin Jr JA (1995). An electromyographic study of arm muscles during climbing. *Knee Surgery, Sports Traumatology, Arthroscopy*, 3, 121-124.
Quaine F, Martin L, and Blanchi J-P (1995). The effect of body position and number of supports on wall reaction forces in rock climbing. *J of Appl Biomech*, 13, 14-23.
Watts, PB (2004). Physiology of difficult rock climbing. *Eur J Applied Physiol*, 96, 361-372.
Watts, P.B., E. Gannon, R. Kobeinia, J. Maynard, J. Sansom, R.L. Jensen. (1999). EMG responses in rock climbing using six hand positions. *Med Sci Sports Exerc*, 31, S169.
Watts PB, Newbury V, and Sulentic J. (1996). Acute changes in handgrip strength, endurance, and blood lactate with sustained sport rock climbing. *J Sports Med Phys Fit*, 36, 255-260.

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