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TECHNICAL NOTE

Deltoid Electromyography is Reliable During Submaximal Isometric Ramp Contractions

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The EMG and load relationship is commonly measured with multiple submaximal isometric contractions. This method is both time consuming and may introduce fatigue. The purpose of this study was to determine if the electromyography (EMG) amplitude from the middle deltoid was reliable during isometric ramp contractions (IRCs) at different angles of elevation and rates of force application. Surface EMG was measured at 3 shoulder elevation angles during IRCs at 4 submaximal levels of maximum voluntary contraction (MVC). Data were reliable in all conditions except during the rate relative to the subjects' MVC at 90° for 30% and 40% MVC. The main effect for angle on EMG amplitude was found to be significant, $p < .01$. EMG at 90° was greater than at 60° ($p < .017$) and at 30° ($p < .017$). The main effect of force level on EMG amplitude was significant, $p < .01$ and follow-up contrast demonstrated a significant ($p < .001$) linear increase of EMG amplitude with force level. We conclude that EMG amplitude from IRCs are reliable across all shoulder elevation angles and up to 40% MVC. IRCs are a feasible method for recording EMG at the deltoid.

Keywords: EMG, deltoid, shoulder, ramp, contraction, reliability

Electromyography (EMG) is a tool to determine the electrical behavior of muscles during a contraction. EMG can be measured simultaneously with an applied force to determine the relationship of EMG and an external load. This relationship may change depending on the rate of force development,[1] joint angle,[2] muscle fiber properties,[3] and the particular muscle under investigation.[4]

Reliability of EMG variables and measured isometric force has been demonstrated in a multitude of muscles, such as the quadriceps[5] and triceps brachii.[6] Establishing an EMG amplitude and isometric force curve requires repeated isometric contractions at each force level. This procedure is both time consuming and can introduce fatigue which is known to elicit changes in the EMG signal.[7] A potential solution to this problem is to utilize isometric ramp contractions (IRCs), which give a continuous EMG amplitude curve with isometric force. The deltoid is a superficial muscle of the shoulder and is often investigated using EMG.[8,9] It would be important to know if IRCs could be used to reduce overall testing time for this muscle.

The purpose of this study is to determine the reliability of EMG amplitude during IRCs from the middle deltoid. Since the EMG signal may change at different muscle lengths and rate of force increase, possibly affecting reliability, these factors will be included in the analysis. We hypothesize that IRCs will be reliable for submaximal isometric contractions. We further hypothesize that EMG amplitude will increase with load and elevation angle.

Material and Methods

Subjects

Twenty-two subjects between 18 and 35 years old (11 male, 11 female, age: 20.2 ± 1.2 years, 20 right handed, 2 left handed) were tested. Subjects self-reported hand dominance by indicating which hand was used to write. Exclusion criteria included: (1) previous shoulder or neck injuries, (2) current shoulder or neck pain, (3) humeral elevation ROM less than 135°, and (4) pregnancy. The subjects were briefed on the purpose and the experimental procedure prior to the start of the experiment and completed an informed consent form. The experiment received ethical clearance from the internal review board at the University of Oregon.

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Experimental Set Up

The force acting on a wrist cuff was recorded using a uni-axial load cell (Lebow Products, Troy, MI; Model 3397-50). Force data and surface EMG were sampled at 1000 Hz and processed with custom LabVIEW software (LabVIEW v13.0, National Instruments, Austin, TX).

Surface EMG signals from the middle deltoid of the dominant limb were recorded with oval, bipolar Ag/AgCl, conductive solid gel electrode pairs (Bio Protech Inc, Wonju, Korea). The skin surface was cleaned with rubbing alcohol and Nuprep gel (Weaver and Company, Aurora, CO). The electrodes were placed 2 cm below the acromion process on the middle deltoid. The electrodes were positioned along the estimated muscle fiber direction with an inter-electrode distance of 2 cm. The ground electrode was fixed over the acromion process of the ipsilateral scapular. The deltoid EMG was collected with the Myopac Jr unit (Run Technologies, Mission Viejo, CA). This unit provided signal amplification (gain = 1,000 dB), band pass filtering (10-1,000 Hz), and CMMR of 110 dB.

Protocol

The subjects stood so that their arm was elevated in the scapular plane and that the styloid process of the ulna was placed on the far edge of the load cell surface in the 'thumbs up' position and the elbow fully extended (Figure 1). Three angles of humeral elevation

Figure 1 — Experimental setup. (1) Bracket and load cell set flush with forearm at 60° humeral elevation. (2) Middle deltoid electrodes. (3) Floor taping. Tape was placed at 60° from the coronal plane. The subject's feet and pelvis were placed parallel to these lines with the shoulder in line with the bracket. This placed the subject's arm in the scapular plane, approximately 30° anterior to the coronal plane.

selected for testing were: 30°, 60°, and 90°. The angle and height of the load cell was adjusted for each testing angle so that the forearm was flush with the surface of the load cell. A single 5-second maximal voluntary contraction (MVC) for each humeral elevation angle was recorded prior to the first session of testing. Following the MVCs, IRCs were recorded.

The IRC protocol was repeated twice at 2 rates of loading: absolute and loading rates relative to the subject's MVC. The absolute loading rate was set at 15 N/s and relative loading was set at 14.3% MVC/s. This level was based on pilot subjects MVC and set so that the loading rates were unlikely to exceed 30 N/s.

The subjects performed 3 IRC trials at each angle of shoulder elevation. The order that the angles were tested was block randomized. Each loading rate was tested completely before repeating the same angle testing order for the second rate of loading (18 contractions total). The loading rate conditions order was also block randomized. After the trials at all contractions were completed in the first session, subjects waited 15 minutes and the protocol was repeated.

An LCD monitor presented visual feedback of force output that consisted of 3 lines. Biofeedback of the subject's force output was represented with a dynamic pink line across the width of the graph, and required loading rate was presented by 2 limit green lines across the width of the graph. The limit lines were separated by a space representing 10 N. The limit lines would move up the graph at either the absolute rate of 15 N/s or the relative rate at the onset of the trial from a point representing −40 N. Fifty percent force MVC for each humeral elevation angle (30°, 60°, and 90°) was represented with a static red line across the width of the graph.

Subjects were instructed to relax the arm at the beginning of each trial and to increase the force applied on the load cell to keep the dynamic force line between the 2 moving limit lines. The limit lines were set to increase at either the relative or absolute rate. If the dynamic force line left the boundaries set by the limit lines, the trial was repeated. Each trial was separated by a 1-minute rest period and a 2-minute rest period was given between angle changes.

Normalization

EMG amplitude data and force data for each subject at each angle were normalized with respect to their maximum values obtained during a maximal voluntary contraction performed at 30°, 60°, and 90° of humeral elevation.[10] The 5-second MVC contraction was smoothed using a 300-ms root mean square (RMS) window. The first 2.5 seconds and the last 1 second was trimmed. The mean of the remaining 1.5 seconds was used for normalization.

Data Analysis

EMG amplitude was smoothed using a running 300-ms RMS window. After normalization, the program would search the data for the first instance that the subject reached one of the predetermined force level values (10%, 20%, 30%, and 40% MVC). The associated smoothed and normalized EMG amplitude value was extracted for each force level from every trial. Three EMG amplitude values were obtained for each force level from the 3 trials and were averaged for each angle and loading rate.

Statistical Analysis

Statistical analysis was performed using SPSS version 22.0 (SPSS Inc., Chicago, IL). Reliability for EMG amplitude at 30°, 60°, and 90° elevation and for absolute and relative rates were assessed at 10%, 20%, 30%, and 40% of max force between the first and second testing sessions via a 2-way mixed effects ICC(2,3) model. A 2-way repeated measures ANOVA was used to assess the effect of elevation angle and force level on EMG amplitude using the first session's data. Follow-up comparisons were performed using a Bonferroni adjustment.

Results

ICC values (Table 1) were higher than 0.8 for all angles and rates except for 90° elevation during relative rate. Due to the drop in reliability for the relative rate at 90° elevation, we utilized the first

Table 1 ICC values for EMG at different %MVC force levels for each rate of force application

	Angle	10%	20%	30%	40%
Absolute Rate	30°	0.94	0.93	0.93	0.85
	60°	0.92	0.89	0.87	0.89
	90°	0.96	0.93	0.95	0.95
Relative Rate	30°	0.94	0.94	0.84	0.85
	60°	0.93	0.90	0.86	0.83
	90°	0.93	0.89	0.69	0.67

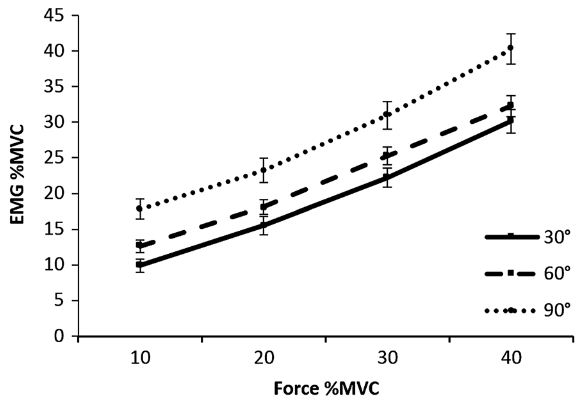

Figure 2 — Electromyography (EMG) and isometric force curve for 30°, 60°, and 90° humeral elevation at a rate of 15 N/s. Error bars are standard error of the mean. The main effect for force on EMG amplitude was significant ($p < .01$), demonstrating a linear increase with increased force levels. The main effect for elevation angle was significant ($p < .01$). Follow-up tests found EMG amplitude was higher at 90° than at 60° ($p < .017$) and 30° ($p < .017$) elevation; 60° and 30° elevation were not significantly different ($p = .0171$). MVC = maximal voluntary contraction.

session's absolute rate data for further analysis. The main effect for force level on EMG amplitude was significant, $p < .01$ (Greenhouse Geisser adjustment) with a follow-up contrast demonstrating a significant ($p < .001$) linear increase in EMG amplitude with force level. The main effect for elevation angles on EMG amplitude was significant, $p < .01$. Follow-up pairwise comparisons were performed with a Bonferroni adjustment ($\alpha = .017$). Deltoid EMG amplitude was found to significantly different between 30° and 90° ($p < .017$) elevation and 60° and 90° ($p < .017$) but not between 30° and 60° ($p = .0171$) (Figure 2).

Discussion

The purpose of this study was to assess the reliability of deltoid EMG amplitude during isometric ramp contractions and determine if EMG amplitude and isometric force relationship was affected by shoulder elevation angle and rate. We found that reliability was better during the absolute rate of force application (15 N/s) and did not drop below an ICC value of 0.87. This is comparable to reliability during isometric contractions at the triceps brachii and quadricepts.[5,6] We selected to further examine the absolute rate of force application because it was more reliable (or as reliable) as the relative rate in 9 of the 12 conditions and because ICC values below 0.70 were found at 90° elevation for the relative rate. Subjects reported that 90° of elevation was the most uncomfortable position from which to apply a force.

Although we found an effect for both shoulder angle and force level, neither was associated with a drop in reliability. The change in EMG amplitude and isometric force curve with increased elevation angles reflects an effect of the change in muscle length or the need to overcome a greater amount of baseline torque at higher angles of elevation.[11] The effect of increasing EMG amplitude with increased force is consistent with previous research.[4,12]

Using the IRC method, 3 data points for each force level can be obtained in about 5 minutes using a 2-minute rest period and the same elevation angle. Another methodology using isometric contractions combined with a regression analysis is able to strongly predict EMG at loads above 60% in the quadriceps muscles.[13] This method would take an estimated 11 minutes and records a single isometric contraction data point at intervals of 10% MVC up to 60% MVC. These time estimates do not include the measurements of MVCs.

Researchers should consider EMG variables of interest when selecting a contraction type. A frequency analysis cannot be performed with a Fourier transform algorithm during an IRC due to the nonstationarity of the signal. However this can be solved by using a wavelet and principle component analysis.[14] In the case of a frequency domain investigation, an isometric contraction type protocol may be less complex.

Conclusion

A set rate of 15 N/s for all subjects was reliable across all angles while the reliability for the rate based on MVC had reduced reliability at 90° elevation but was still reliable overall. We concluded that EMG amplitude during isometric ramp contractions are reliable up to 40% MVC and that either a set rate or a rate relative to a subject's MVC can be used. This provides an additional tool for researchers to obtain a continuous EMG amplitude and isometric force curve without the use of regression, increased time efficiency, multiple data points, and reduced fatigue-induced signal alterations.

Limitations

This study utilized a single MVC at each humeral elevation angle to normalize the force and EMG data. While subjects were given practice MVC attempts, it is possible that the recorded MVC may underestimate actual MVC. The effect of angle and load should be interpreted with this in mind. The position of the subjects in this study was controlled and the results are not necessarily applicable to movements occurring outside the scapular plane or at higher rates of load application.

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