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Communication

Arm EMG during abduction and adduction: hysteresis cycle

J.C. Politti * [1], C.J. Felice [2], M.E. Valentinuzzi [3]

Departamento de Biongeniería (DBI), Facultad de Ciencias Exactas y Tecnología (FACET), Universidad Nacional de Tucumán (UNT), 327 Correo Central, 4000 Tucumán, Argentina

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Abstract

The electromyographic study of the muscles involved in the complex movements of the shoulder, is usually one way to quantifying the static and dynamic joint's behavior. In particular, the deltoid medium EMG produced a phenomenon similar to a hysteresis cycle when its amplitude was plotted as a function of the lateral angular position during a static, step by step, sequential abduction–adduction of the arm. Such a cycle was consistently repeated in 16 subjects (12 males and 4 females). The paired Student *t*-test, after comparing the mean EMG values of the rectified wave for the same arm opening angle between abduction and adduction, produced a highly significant difference ($\alpha < 0.001$) in all subjects. In all likelihood, it manifests the participation of muscles other than the deltoid medium in the overall movement (as for example, the anterior and posterior deltoids), that is, they are collaborating muscles that are different in the opening or lifting of the arm from those involved in its closure or lowering. Thus, it is concluded that a quantifiable and significant deltoid medium EMG difference has been demonstrated when the muscle is either ready to abduction or ready to adduction. The effect is fully reproducible between 0 and 90 degrees of an arm in static position within the scapular plane.

Keywords: Electromyography; Deltoid muscle; Codman paradox

1. Introduction

The surface electromyogram (EMG) is a rather ubiquitous tool used, for example, as a measure of muscular effort in traumatology, as an evaluation parameter in rehabilitation engineering, as the control input to myoelectric prostheses and as another diagnostic piece of information in myopathies many times faced in clinical medicine [1,2]. It can also be used to estimate the muscle action potential propagation velocity [3]. Its analysis permits a better knowledge of the muscle activation sequence, either in lower or upper extremities, during predetermined voluntary movements. This kind of information is essential in functional electrical stimulation (FES) and in the simulation of the human gait [4–7].

Muscle hysteresis is a non linear phenomenon which, by and large, is not taken into account in the analysis of movement and in its modelling. It was measured and theoretically studied by Tal'nov [8] in 1997, and later on, by Kotsyukov [9] in 1998. Both authors underlined the importance of the hysteresis cycle during dynamic and steady-state movements and during slow and fast transition velocity movements between two equilibrium states.

In this paper, we show that in static conditions (i.e., without any movement), there are statistically significant differences between the amplitudes of the average rectified values of two EMGs obtained from the human deltoid, with the arm at the same angular position, after abduction and adduction. The differences detected were reproducible, greater when the arm was at 90°, and were measure, in subjects of both sexes and different age.

* Corresponding author. Tel./Fax.: 54-381-436-4120.
E-mail address: jpolitti@herrera.unt.edu.ar (J.C. Politti).

[1] Also with Instituto Superior de Investigaciones Biológicas (INSIBIO), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) and UNT

[2] Also with Instituto Superior de Investigaciones Biológicas (INSIBIO), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) and UNT

[3] Also with Instituto Superior de Investigaciones Biológicas (INSIBIO), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) and UNT

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2. Materials and methods

In 16 normal subjects (12 males, ages between 20 to 67 years old, and 4 females, 23 to 40 years old), a series of ten electromyographic records was carried out lifting laterally one arm from 0 to 90° (abduction) followed by another series of ten measurements lowering the arm from the latter 90° back to 0 (adduction), that is, returning the limb to its original hanging down resting position.

The subject stood up with his/her shoulder rotated 20° forward with respect to the saggital plane, to make the movements on the scapular plane and so decreasing muscular work, basically for the deltoid medium muscle activity during abduction and adduction [10,11]. Initially, both arms rested hanging laterally down. An angular scale was drawn behind the subject in 10° steps (from 0 to 90°), the latter corresponding to a horizontal extended arm.

EMG records were obtained at each angular static position during 3 s with intervals of 6 s to permit the subject the positioning of the arm at the new angle. A pair of sterile stainless steel acupuncture needles were used as electrodes (0.2 mm in diameter), inserted in the belly of the deltoid medium with a separation of 2 cm. This muscle was preferred because, in the scapular plane, its action can be taken as similar to a string running on a pulley when raising or lowering a weight, say, the arm during the abduction–adduction movements. Besides, this muscle is easily accessible to placing the electrodes.

The EMG signal was amplified by means of a BIOPAC EMG100B Electromyogram amplifier module with a high pass filter (10 Hz) and a low-pass filter (dc-500 Hz). The accepted range is from 2 to 500 Hz [12]. Data were acquired at a rate of 2 kHz by a BIOPAC MP100WSW system with a 16 bits A/D resolution.

The digital signal processing of the raw data was accomplished with MATHCAD® 7 software for each 3 s recorded strip derived from each static angular position. Any linear drift was removed along with the dc component calculating also the mean value of the rectified EMG signal amplitude.

The well-known equation [13], published by Challis and Kitney in 1990 and by Merletti and Conte [14] in 1995, describes this parameter, i.e.,

$$ARV = \sqrt{\frac{\sum_{k=0}^{N-1} |a_k|}{N}} \qquad (1)$$

where N=number of samples in each strip and a_k=value of the k-th sample.

From each 3 s, the average value of the 6000 samples within it was calculated. A typical full cycle consisted of 10 such segments for abduction and another 10 for adduction (that is, a total of 20 average values). For the proposed significance level of $\alpha = 0.001$ (or 0.1%), the cutting t-value is 3.09 when there are infinite degrees of freedom, which is precisely the case with a sample above 30 data points (in our case there were 6000).

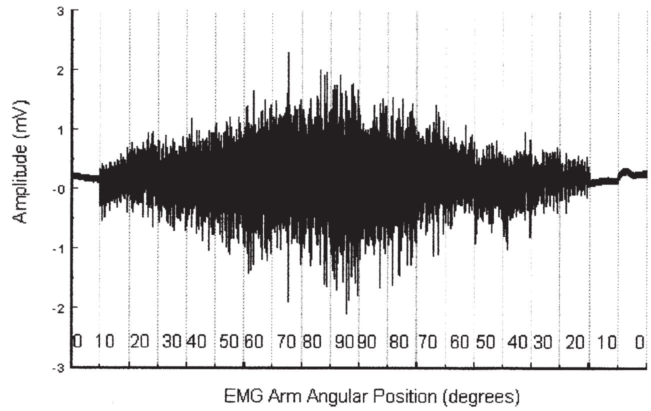

Fig. 1. Typical unprocessed EMG recorded from a 66 yr old male. Abduction corresponds to the first left half and adduction to the second portion. Sampling frequency was 2 kHz, measuring 3 s segments on each angular position, between 0 and 90°. The vertical axis (amplitude) is calibrated in mV while the horizontal axis corresponds to angles.

3. Results

Fig. 1 displays the raw data of a sequence of measurements obtained from 0 to 90° and back to 0°. This EMG was partitioned in the lifting and lowering sections (Fig. 2), where drifts and dc components were removed, folding over the first section in order to better compare amplitudes for the same angular position. The amplitude of the signal increases with abduction and decreases with adduction. For the same angle, such amplitudes are smaller when the arm was returning to its resting position than when it was being lifted.

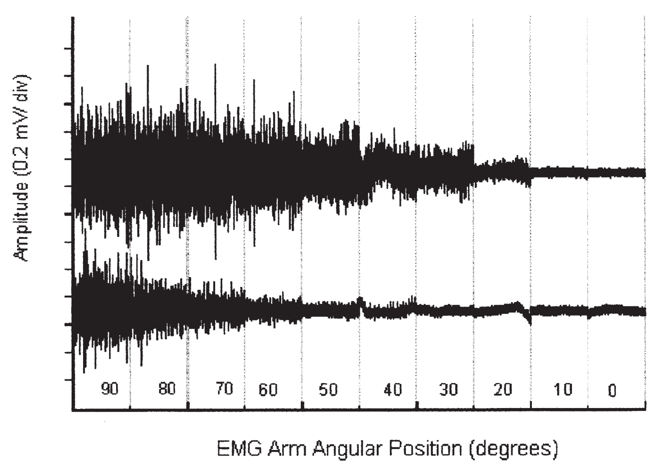

Fig. 2. The same EMG of Fig. 1 after processing it. Drifts were removed. The upper record corresponds to abduction. It was obtained by folding over the first section of the EMG. In this way it is easier to compare the amplitudes for the same angular positions.

Fig. 3 was drawn using the mean value of the rectified signal for every 3 s EMG segment and the corresponding angular position of the arm. A clear hysteresis is manifested, that is, the returning limb does not coincide with the ascending limb. For the sake of clarity, only the results of three subjects are shown. The other 13 yielded a similar behavior. At 90°, a marked difference is observed when the subject finished his/her abduction and was instructed to prepare for the returning adduction. The mere intention of changing the direction of movement produced a lower electromyographic amplitude. Inverting the sequence, that is, first adduction and thereafter abduction, led to a similar loop.

Most of the actual values of *t* lied always well above the cutting value (3.09) mentioned above, ranging from 5 to 30. Thus, it can be stated that the differences between the average values of the medium deltoid EMG during abduction were significantly different from the values obtained during adduction, for the same angular position of the arm. In other words, the probability of finding a not significant difference is lower than 0.1% for most of the values.

4. Discussion

A hysteresis cycle was detected during a full process of abduction–adduction of any arm in static conditions, that is, when the arm stops momentarily at prescribed angular positions. The main acting muscle during this movement (but admittedly not the only one) is the deltoid medium. At equal angles, the EMG amplitude differences were statistically significant ($\alpha < 0.001$), in all subjects and for all positions.

This phenomenon could be expected in dynamic situations (moving arm) because during abduction and, especially when lifting a weight, the latter opposes the upward movement and during adduction the weight helps in lowering the arm. As a consequence, the muscular effort is greater when the arms goes up than when it moves downward.

Herzog, Guimaraes et al. [15] have described hysteresis cycles for force versus EMG amplitude in dynamic conditions. Even when our results refer to angular position, a comparison is possible if a force is associated to each static angle. We mean dynamic conditions when the arm moves continuously from the initial to the final position, with or without a weight, as opposed to a step by step movement from one angle to another, resting for a while at each position, also with or without a weight.

Tal'nov and Kotsyuko [7,8] also showed hysteresis cycles in *biceps brachii*, *brachioradialis* and *triceps* during transition between two equilibrium states, either with slow or with fast movements. Thus, it was a dynamic condition, different from our tests.

This cycle would agree with the well-known abduction-adduction movement in which the deltoid muscle works as agonist during lifting of the arm losing protagonism when lowering it [16] (of course, this means that other muscles increase their protagonism). Thus, changes in EMG amplitude would be accounted for by the latter at the same angular position when going up as compared to the opposite returning movement.

Another possibility might be attributable to changes in the arm's rotation center as the angle changes. However, Perkel and Gerstein [17], in 1967, and Clancy and Hogan [18], in 1998, claimed that modifications in the electromyographic amplitude cannot be due to the angle.

The marked difference in EMG amplitude may originate in the different relative contribution of the number of activated deltoid muscle fibers, depending on 'getting ready' to abduction or adduction. One question to be investigated is if the effect can be seen in other muscles. Something to underline is that, when studying the dynamics of any movement, very rarely if ever, the latter is the result of a single muscle action. Most of the time the movement is the combined and coordinated action of several muscles.

In conclusion: A quantifiable and significant deltoid medium EMG difference has been clearly demonstrated when the muscle is either ready to abduction or ready to adduction. The effect is fully reproducible between 0 and 90° of an arm in static position within the scapular plane. This findings represent a contribution to the knowledge of muscle mechanics and may be helpful in the design of orthotic devices and in rehabilitation programs after muscular injuries.

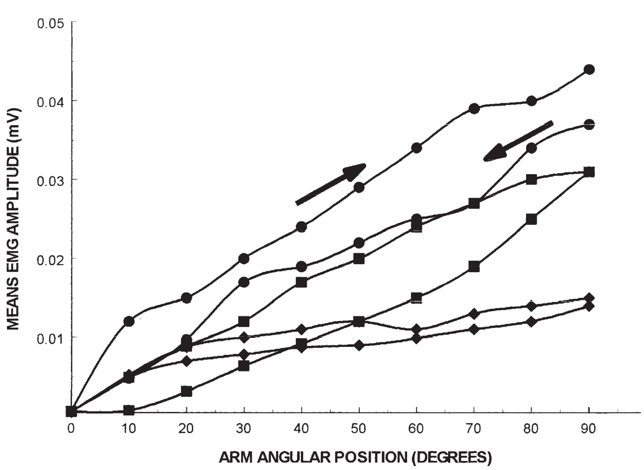

Fig. 3. Three full hysteresis abduction–adduction cycles are shown (from two males, ages ä 24, í 26, and one female, age ë 42). The arrows indicate the direction of rotation of the loops.

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