31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Analysis of Surface EMG-force Relation of the First Dorsal Interosseous Muscle

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***Abstract*—The electromyogram (EMG)-force relation was investigated using 2-dimensional surface electrode arrays. The surface EMG and isometric contraction forces were recorded from the first dorsal interosseous (FDI) muscles in 4 human subjects when they generated different levels of isometric contraction in three radial directions: abduction, flexion, and a linear combination of abduction and flexion. The surface EMG-force relation, fitted by a straight line, was constructed for each tested task direction. We found that the FDI muscle did not activate uniformly across the different directions of isometric contraction, resulting in variations in slope of the surface EMG-force relation. Furthermore, this variation was also sensitive to different channels of the surface electrode array on the muscle.**

I. Introduction

THE relation between isometric force and surface EMG amplitude has been the subject of extensive experimental investigation [1-6]. For small muscles with narrow motor unit recruitment force ranges, such as the first dorsal interosseous (FDI) muscle, the observed relation between force and the average rectified value (ARV) of surface EMG is reported as being approximately linear. For larger muscles with wide motor unit recruitment force ranges, such as proximal leg or arm muscles, the observed relation is reported to be nonlinear, with the surface EMG increasing faster than force.

In this study our goal is to further our understanding of the relationship between surface EMG and force using surface electrode array EMG recordings from the FDI muscles. Specifically, we examined how the slope of the surface EMG-force relation changes with isometric tasks in different directions in the FDI, a multifunctional muscle that is activated in a variety of directions about the metacarpophalangeal (MCP) joint. We also explored the effects of different electrode locations on the FDI, by computing the EMG-force slope from various recording sites from a 64-channel grid electrode that covered the whole muscle.

Manuscript received April 23, 2009.

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II. Materials and Methods

A. Subjects

We examined the FDI muscles of 4 neurologically intact subjects. All participants gave informed consent via protocols approved by the Institutional Review Board under the Office for the Protection of Human Subjects at Northwestern University. The subjects were volunteers from our institute without known (self-reported) neuromuscular diseases (age: 28.25 ± 6.9 years).

B. Experimental Setup

Study participants were seated upright in a Biodex chair and positioned in a standardized posture with the forearm resting comfortably on an arm base. The wrist and forearm were secured to the supporting surface to avoid unwanted movement. The three medial fingers and thumb were comfortably splayed and strapped to the resting surface. The index finger was cast in an extended position and fixated distally to a plastic interface attached to a six degrees-of-freedom load cell (ATI-FT4006, ATI Inc, Garner, NC), which was used to measure the isometric force generated at the MCP (Figure 1).

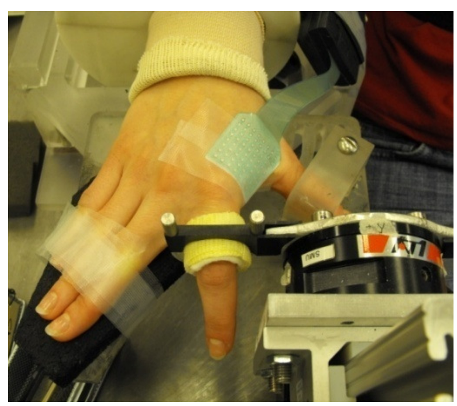

Fig. 1: Experimental setup for surface EMG recording from the FDI muscle

C. Experimental Protocols

Participants were asked to generate a maximum isometric force in three different radial directions: abduction, flexion and a linear combination of abduction and flexion (Figure 2). The maximum voluntary contraction (MVC) for each direction was first measured; after which, the subject was asked to generate different levels of isometric forces (from 5 to 35N in multiples of 5N) in each direction. Each contraction level lasted for 10 seconds, with enough rest time allowed between contractions to avoid muscle fatigue.

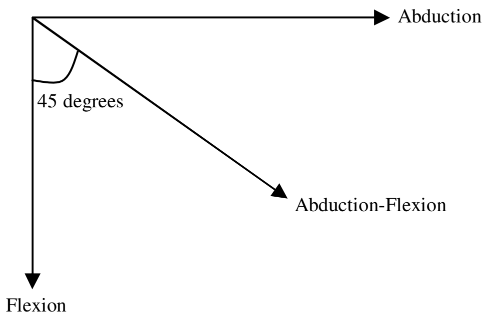

Fig. 2: Radial directions of FDI isometric contractions

D. EMG and Force Recordings

During the experiment, the isometric contraction force was measured using a six degree-of-freedom load cell (ATI-FT4006, ATI Inc, Garner, NC). Specially designed finger vises were attached to the load cell to ensure maximal isolation of the FDI muscle. The ATI is a dual calibrated load cell, which has the capacity to measure maximal voluntary contractile forces in all of the participants (maximum load**:** 65 N, 14 N; resolution: 6.5 mN, 1.4 mN). The surface EMG signals from the FDI muscle was recorded using a 2-dimensional surface electrode array (Figure 1). The electrode array is designed using the flexprint technique [7] and it facilitates recording from an uneven surface of a muscle due to its flexibility. The array contains 64 recording electrodes arranged in an 8×8 square matrix with a small electrode-skin contact area (diameter 1.2 mm) and inter-electrode (center to center) distance (4 mm). Compared with rigid electrode arrays, it is more suitable for recording from small muscles such as human hand muscles (e.g., FDI). The recording channel on the right-upper corner of the electrode array shown in Figure 1 represents channel 1, the right-bottom corner channel represents channel 8, i.e., the first column on the most right represents channels 1-8. Similarly, the second column from the right represents channels 9-16; the column on the most left represents channels 57-64 (the recording channel on the left-bottom corner of the electrode array shown in the figure represents channel 64, the left-upper corner channel represents channel 57). Surface EMG signals were amplified by Refa128 EMG/EEG recording system (TMS International, Amsterdam, Netherlands), with a sampling rate at 2000 Hz per channel. All the experimental data were stored in a computer for offline analysis.

E. Data Analysis

The data analysis was performed using Matlab (the MathWorks, Inc, Natick, MA). The average force and the ARV of the surface EMG signal were computed over the stable range for each contraction level. This was performed for all the valid electrode array channels with clear EMG activity; electrode channels that were not overlying the FDI were excluded from the analysis. Then, the ARV of the EMG was plotted as a function of the force for all contraction levels. The EMG and force measurements were fitted by a straight line with the least square error to build the EMG-force relation. This was performed with both the monopolar and bipolar electrode configurations. In the interest of clarity and brevity we have selectively reported signals from three of the grid electrodes with relatively large EMG amplitude and two of the grid electrodes in which relatively lower EMG amplitude was recorded.

III. Results

Figure 3 shows an example of the EMG-force relation for different task directions for a given electrode channel. For all four study participants, we observed that the FDI muscle EMG did not activate uniformly across the three different task directions. In Table 1, each row demonstrates the direction dependence of the EMG-force slope at a given electrode location. Note that the differences in the surface EMG-force relation slope as a function of task direction was also subject-dependent. For example, in subject 1, the slopes calculated from the selected five grid channels, were uniformly greater in the pure abduction and pure flexion directions as compared with the abduction/flexion direction. On the other hand in subject 4, in 2 of the 5 selected electrode channels, the EMG-force slope was greater in the flexion direction than in the abduction and abduction/flexion direction. No consistent outcome amongst the four tested subjects can be observed.

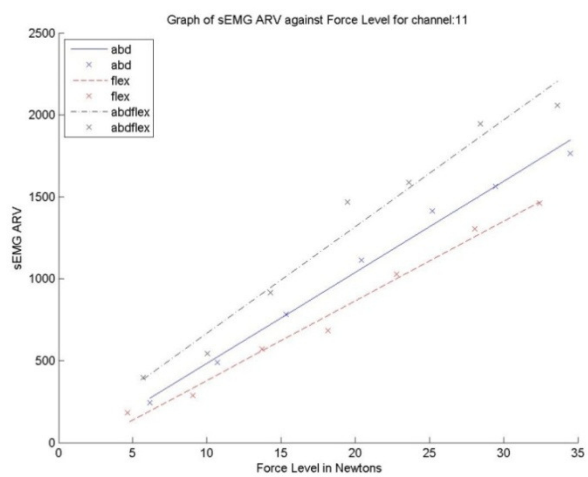

Fig. 3: Surface EMG-force relation for different task directions for a given bipolar electrode configuration. The 3 lines of best fit from the top are for the directions of abduction-flexion, abduction, and flexion.

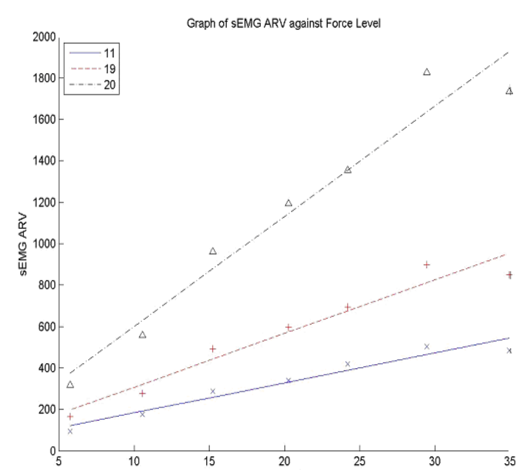

Figure 4: Surface EMG-force relation in the abduction direction for different electrode array channels for subject 4. The lines of best fit from the top are for electrode channels 20, 19, and 11.

Figure 4 shows surface EMG-force relation in a single direction for three different grid channels for subject 4. The strength of the signal changes with the position of the electrode. Thus over a fixed force range, the different electrode positions exhibit different surface EMG force slopes. In Table 1, each column displays all the slope coefficients for a given direction with varying electrode location for all the 4 subjects.

TABLE 1
A summary of EMG-force relation slopes (μV/N) for 4 subjects in 3 radial directions at different electrode array channels. The channels in bold numbers have relatively strong EMG activity while the rest channels have relatively low EMG activity.

		Directions		
Subject	**Channel**	**Abduction**	**Flexion**	**Abd-flexion**
1	**20**	**62.0**	**57.5**	**52.1**
	27	**59.3**	**50.9**	**48.9**
	28	**59.3**	**56.7**	**46.6**
	37	33.9	34.7	26.0
	44	32.7	34.5	24.1
2	**11**	**55.5**	**48.6**	**65.1**
	20	**59.8**	**56.5**	**68.8**
	27	**55.2**	**37.7**	**59.3**
	37	39.1	31.2	38.1
	44	45.1	29.9	41.9
3	**3**	**69.0**	**37.4**	**42.0**
	10	**61.7**	**39.8**	**43.4**
	11	**71.6**	**45.4**	**47.8**
	37	31.4	25.4	22.6
	44	26.5	24.5	24.2
4	**11**	**14.5**	**37.1**	**13.9**
	19	**25.9**	**27.1**	**40.2**
	20	**53.2**	**46.7**	**68.0**
	37	12.8	12.3	24.0
	44	10.3	13.5	11.6

IV. Discussion

The relation between the muscular contraction force and myographic response of the muscle has been extensively investigated in the past [1-6, 8, 9]. Surface EMG-force relation depends on many factors, such as motor unit firing rate, recruitment, muscle length and velocity, etc. [1-6, 9]. In this study, we investigated several new factors taking advantage of a surface electrode array recording on the FDI muscle. We found that the EMG-force relation, quantified by the slope of the ARV of the EMG against force level, varied as a function of isometric task direction. In addition, for the same direction, the EMG-force relation may also vary as a function of recording site of the electrode array.

In this study, we only reported signals from several selected grid electrodes based on different EMG amplitude levels. This selection may induce great variability among subjects resulting in a complex interpretation of the EMG-force relation. With selected small number of channels, the multi-channel nature of the recording was not fully exploited. It is worth noting that our high density grid electrode covers all of the subject's FDI muscle and this allows us to examine all the muscle regions in the FDI during isometric contractions. Our hypothesis is that different muscle regions are activated within the FDI for contractions in different directions. Our data has some evidence supporting this theory but there are other factors that need to be considered in order to support this hypothesis. For example, we suspect that cross talk exists between the adjacent channels. It is also necessary to develop a protocol which specifies how to position the grid electrode on the FDI so that every subject's FDI can be covered in a uniform manner. In such a situation, we can systematically map the location of the EMG electrode array over the muscle region. This will be examined in future experiment. In addition, with high density surface EMG recording, it is also possible to investigate the dependence of EMG-force relation on different (e.g., double differential, laplacian, etc.) electrode configurations [10].

Finally, it is noted that in comparisons with previous work in characterizing the surface EMG-force relation of the FDI using a conventional bipolar surface electrode [2, 3, 6] , our results are consistent with the linear nature of the relationship, in our case to approximately 60% MVC. However, our data also show that the muscle region over which the electrode is placed can greatly alter the slope values. Moreover, the same electrode region may show large differences in slopes of EMG-force relations that are direction task dependent. All of these factors should be taken into consideration when comparing results across studies, and when using the EMG-force relation to infer muscle firing characteristics or muscle properties.

Acknowledgment

We thank Janina Madoff for her coding the force display program and assistance during data collection.

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