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Isometric and Anisometric Contraction Relationships with Surface Electromyography*

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Abstract— **The isometric contraction is the most investigated muscle contraction, however most tasks in daily life involve anisometric contractions. Most hand prostheses studies [1] use sEMG features to directly relate the exerted force as a means of intuitive control. It may thus be expected that similar sEMG-velocity relationships characterizing anisometric contractions may also contribute towards intuitive prosthetic hand control. While different contraction type relationships have been studied separately, in this work anisometric and isometric contraction experiments on the biceps brachii muscle were carried out using the same sEMG electrode system and the motor unit activity was then related to limb velocities and limb forces, to respectively characterize the isometric and anisometric contractions. This muscle was chosen as a simpler alternative to the synergistic hand muscles as an initial test of the general concept.**

Clinical Relevance— **These contraction characterizations with sEMG may be used to afford prosthetic intuitive control and to assist in motor impairment diagnosis and rehabilitation.**

I. INTRODUCTION

The two main types of muscle contractions are isometric and anisometric. Isometric contractions are generated whenever a force is exerted at a constant muscle length. Anisometric, or dynamic, contractions, where a force is generated during muscle length change, can be either isotonic or isokinetic. Isotonic contractions relate to concentric and eccentric contractions whereas isokinetic contractions refer to isotonic contractions performed at constant speeds [2].

In order to understand better how different contraction types are manifested physiologically, surface electromyography (sEMG) [3] is used to measure motor unit responses to activations sent through the nervous system. This makes it possible to obtain relationships between sEMG and kinematic features through the analysis of changes in the sEMG signal characteristics for the different motor program contraction exertions.

The most investigated contraction is the isometric contraction, however most tasks in daily life involve anisometric contractions. Anisometric contractions are more challenging to study since during such dynamic contractions, muscle fibers change length whereas sEMG electrodes remain affixed to the original skin location. Thus, the relationship between the electrode and the muscle fibers is continuously changing, adversely affecting the sEMG signal [4].

In general, sEMG-force relationships for different muscles have been reported to vary due to their recruitment properties, muscle firing rates and other anatomical aspects such that smaller muscles usually result in quasi-linear relationships unlike larger muscles, such as the biceps and triceps muscles, which are known to produce a curvilinear relationship [5]. Meanwhile, quadratic [6], exponential [7] and linear [8] sEMG-velocity relationships have been recorded in the literature for the biceps muscle.

Most works, especially with regard to hand prostheses [1], use the magnitude of the sEMG features to relate directly to the intended exerted force as a means of intuitive control. Thus, since this sEMG-force relationship has been found to be useful, it may be expected that similar sEMG-velocity relationships characterizing anisometric contractions may also contribute towards further intuitive and natural control.

In the literature, different contraction type relationships have been reported separately. In contrast, this work investigates how an electrode system mounted on a specific muscle may be used to characterize the relationship of both force and velocity with respect to the sEMG, with a view to obtaining a sEMG-force relationship and a sEMG-velocity relationship from the same system. This is done to characterize the isometric and anisometric contractions of this muscle to afford intuitive and natural control for a prosthetic hand. Such relationships will also indicate how the motor units react to anisometric and isometric contractions, respectively.

The rest of the paper is organized as follows: in Section II, the two experiments are described, including their separate data acquisition protocols and data processing techniques; in Section III, the obtained results are presented and discussed, whilst Section IV concludes the paper.

II. METHODS

A. Anisometric and Isometric Experiments

In these experiments the sEMG signal was recorded from the biceps brachii muscle of the subjects' dominant hand. The choice of examining this large muscle was to test the general concept using a simple muscle, which could later be applied in the context of forearm muscles used for hand prostheses. The

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experiments were split into the *Anisometric* and *Isometric Contractions*. The *Anisometric Contraction Experiments* were based on the concept of isokinetic movements which consisted of concentric movements of the lower arm, ideally performed at various pre-determined speeds, at a constant rate, without changing the exerted force value. In the *Isometric Contraction Experiments*, the forearm and upper arm muscles were required to be kept at a constant length, at a static 90 ° elbow joint posture, whilst exerting a specific force value at the wrist against an immovable object.

These experiments were performed by two right-hand dominant subjects, a 24-year-old female and a 23-year-old male, S1 and S2, who gave their participation consent in line with the research ethics guidelines of the University of Malta. Both subjects did not do physical training on a regular basis and did not have any history of musculoskeletal pain or injury in their upper limb since these were exclusion criteria which were set to retain subjects within the norm. The Institution's Ethical Review Board approved all experimental procedures involving human subjects.

For both experiments, the subjects were required to be standing up with their dominant arm at a 90 ° shoulder flexion with the wrist in a natural position (i.e. the thumb is upwards). By using a tripod as an elbow rest, the subjects were free to move their forearm in a lateral (external from the chest) and medial (internal towards the chest) manner, by adjusting the elbow joint. These movements shall be referred to as extension and flexion of the elbow joint, respectively.

A straight posture and a lunge posture were required for the anisometric and isometric experiments, respectively. The lunge posture was chosen to enable the subjects to exert their actual maximum force in a steadier posture without risk of toppling over. The participants were also required to minimize unnecessary shoulder and upper arm movements such that the biceps brachii muscle remained the main activator throughout both experiments.

B. Data Acquisition Protocol - Anisometric Experiments

The focus of the anisometric experiments was for the subjects to perform elbow flexions at a constant velocity, to the best of their ability, for five repetitions, at five different reference beats, namely 50, 85, 120, 155 and 190 beats per minute. The speed guidelines were provided to the subject by a metronome, and necessary resting times were indicated clearly whenever required. These flexions were initiated at a 0 ° elbow joint angle (wrist in line with the shoulder) and halted when the hand reached the chest at an approximate elbow joint angle of 120 °.

The tripod was adjusted and levelled according to the subject's height such that the elbow could comfortably and firmly rest on it. A single wireless bipolar electrode module (ZeroWire, Aurion, Italy) was used to record bicep sEMG data with the use of two 8 mm, pre-gelled silver/silver chloride (Ag/AgCl) disposable electrodes. The sEMG module was connected to the UIM100C analogue inputs module (BIOPAC Systems Inc., Goleta, California), which was in turn connected to the MP150 acquisition system (BIOPAC Systems Inc., Goleta, California) for data collection using a sampling rate of 1 kHz. The Vicon Nexus optical motion capture system (Vicon Motion Systems, Oxford, UK) captured motion data at 100 Hz and was used for elbow angle measurement and posture visualization. Ten optical markers were placed on the hips, knees, ankles, shoulders and area between the shoulder and the neck for both sides. This setup is shown in Fig. 1.

Additionally, two optical markers were placed on the dominant elbow and wrist for elbow angle measurement. The angle measurements, θ, were done using (1), where $\overrightarrow{SE}$ and $\overrightarrow{EW}$ are the two-dimensional vectors obtained from the shoulder (S) and elbow (E) markers, and the elbow (E) and wrist (W) markers, respectively.

$$\cos\theta = \frac{\overrightarrow{SE}\cdot\overrightarrow{EW}}{|\overrightarrow{SE}||\overrightarrow{EW}|} \qquad (1)$$

Prior to data collection, the subjects' skin was shaved, abraded and cleaned with alcohol wipes for noise reduction and best quality recordings. The Ag/AgCl disposable electrodes had an 8 mm diameter conductive area and following adjacent electrode placements, the inter-electrode distance was 24 mm. Following the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guideline recommendations [9], the two electrodes were placed in a longitudinal arrangement, ensuring that they remained on the active muscle mass during movements on the most dominant middle portion of the biceps brachii muscle belly.

A minimum five-minute rest time was granted to the subjects between the anisometric and isometric experiments.

C. Data Acquisition Protocol - Isometric Experiments

For the isometric experiments, isometric contractions were exerted at a 90 ° elbow joint angle. Meanwhile, the force was applied at the wrist to ensure that the biceps and triceps muscles were primarily involved. The subjects were required to exert five levels of force for five seconds each. These force levels were determined in accordance to the greatest Maximum Voluntary Contraction (MVC) performed by the subject such that other prescribed sub-maximal forces were exerted at approximately 20%, 40%, 60%, 80% and 100% of the MVC, using the display of a dynamometer as feedback.

All contractions were to be performed in non-fatigued conditions, thus, suitable resting times were provided between trials. The lunge posture used for these experiments as captured by the motion markers is provided in Fig. 2.

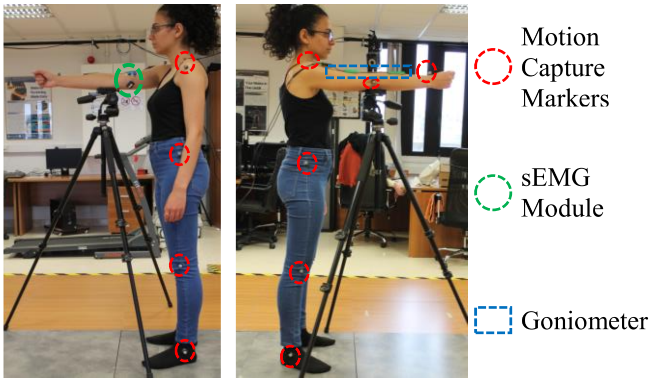

Figure 1. The anisometric experiment setup showing the subject's posture, the elbow resting on the tripod, the motion capture markers, the sEMG module, and the goniometer used for data alignment.

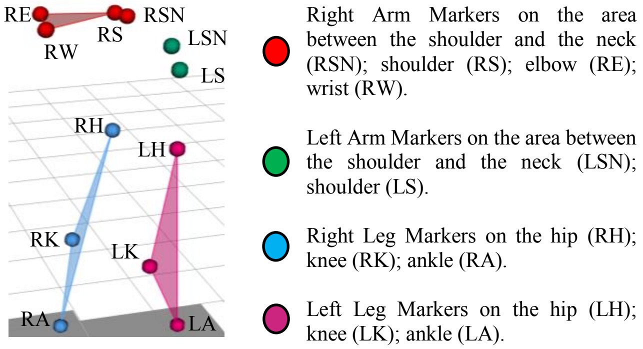

Figure 2. A subject in the lunge posture during an isometric experiment as recorded from the 12 motion capture markers.

An M5-500 Force Gauge Model dynamometer (MARK-10, New York, USA) was mounted to a brick wall in a manner to allow a horizontal rope to be attached to the subject's wrist in a perpendicular manner, adjustable to the subject's height. The rope was attached to a Velcro band which could be easily strapped to the subject's wrist. A set square was used in order to ensure that the rope and the subject's forearm were perpendicular to each other while a twin-axis goniometer (TSD 130B, BIOPAC Systems Inc., Goleta, California) was used to ensure a 90 ° elbow joint angle during force exertion. The dynamometer and goniometer were both connected to the MP150 for synchronized data collection and the joint angle was provided to the experimenter in real-time. This was done by using the UIM100C and DA100C (BIOPAC Systems Inc., Goleta, California) modules.

The subject was instructed to follow the procedure indicated by a Graphical User Interface (GUI) projected on a screen. This clearly indicated the actions required from the subject as well as the required force levels to be exerted. Through the GUI, the subject and experimenter were notified when the subject was to get ready for the next contraction, the instant when the contraction was to start and when the subject was to release the contraction and rest.

D. Data Processing - Anisometric Experiments

For every subject's anisometric experiment, 25 different flexion trials were analyzed to obtain the final relationships. Since the Vicon and BIOPAC systems were not hardware synchronized, the joint angle motion data was manually aligned to the sEMG data using the goniometer data since the latter two are hardware synchronized through the BIOPAC system. The goniometer was not used for motion data analysis due to unreliability at higher velocities.

For every flexion trial the sEMG onsets were determined using the single-threshold method [10]. In this method the resting mean, μ_{rest}, and standard deviation, σ_{rest}, were estimated and a suitable value for c was chosen manually to ensure proper onset detection. The threshold, T, was set using:

$$T = \mu_{rest} + (c*\sigma_{rest}). \tag{2}$$

The movement period was defined as that interval where the calculated velocity exceeded 5% of the peak velocity of that specific flexion. The average velocity of each flexion was calculated by dividing the change in the joint angle during this interval by its duration.

The raw sEMG signal was detrended and filtered using a 4th order Butterworth filter, having cut-off frequencies at 10 Hz and 450 Hz. Since the RMS feature is related to the power of the signal, this feature was chosen to be used in this analysis. Thus, an average RMS value was estimated for each flexion trial starting from the sEMG signal onset up till the end of the movement period as illustrated in Fig. 3.

E. Data Processing - Isometric Experiments

The force data recorded by the MP150 data acquisition system was smoothened using a 300 ms averaging window with a 50% overlap.

The single thresholding method was applied to the force signal to detect those segments where the prescribed force levels were reached and remained stable for at least three seconds. For each isometric contraction level, sEMG RMS features and average force levels were computed from 20 consecutive non-overlapping windows having a duration of 150 ms, each yielding 100 sEMG RMS values and their corresponding average force values.

III. RESULTS AND DISCUSSION

Matlab's built-in *Curve Fitting application* was used to find a suitable parametric curve fit for each subject's isometric and anisometric measurements based on visual observation, the square of correlation (R^2), the adjusted R^2 and the Root Mean Squared Error (RMSE) resulting from every fit.

For ease of comparison, curve fitting was performed on the normalized data for both experiments. Force values were normalized during the experiments based on the subject-specific MVC. Specifically, the average sEMG RMS value of the 20 measurements obtained at 100% MVC was used to normalize the sEMG RMS features obtained from both the isometric and anisometric sessions of this subject. For the velocity measurements there was no subject-specific maximum value, therefore the largest velocity measured across all trials and subjects was found and an upper bound of 240 °/s was used for velocity normalization.

The best fitting relationship between sEMG RMS and average velocities for these two subjects was found to be a first order exponential as in (3) whilst the best fitting relationship between sEMG RMS and the exerted forces was found to be a second order polynomial as shown in (4).

$$f(x) = ae^{bx} \tag{3}$$

$$f(x) = ax^2+bx+c \tag{4}$$

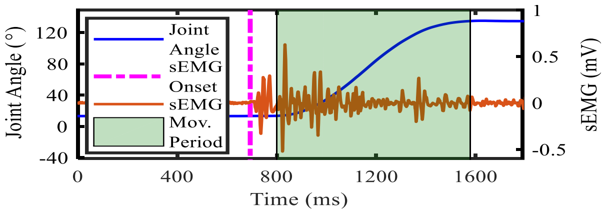

Figure 3. The recorded elbow joint angle and sEMG signal from a flexion during an anisometric experiment, as well as the determined sEMG onset instance and the movement period. The average RMS value was estimated from the sEMG onset up till the end of the movement period whilst the average velocity was calculated by dividing the change in joint angle of the movement period by its duration.

where,

$f(x)$ is the sEMG RMS amplitude;

x is the velocity or force value in (3) and (4), respectively;

a, b and c are constant coefficients.

The coefficient values as well as the square of correlation (R^2), the adjusted R^2 and the Root Mean Squared Error (RMSE), for the separately fitted curves are provided in Table I and Table II for both subjects' anisometric and isometric fits, respectively.

TABLE I. CONSTANTS AND GOODNESS OF FIT PARAMETERS FOR THE TWO SUBJECTS' ANISOMETRIC FITS

Subject	a	b	R^2	Adj R^2	RMSE
1	0.053	1.882	0.803	0.793	0.033
2	0.033	1.706	0.670	0.656	0.016

TABLE II. CONSTANTS AND GOODNESS OF FIT PARAMETERS FOR THE TWO SUBJECTS' ISOMETRIC FITS

Subject	a	b	c	R^2	Adj R^2	RMSE
1	1.246	-0.484	0.211	0.919	0.917	0.090
2	1.149	-0.350	0.190	0.899	0.897	0.102

In the context of a prosthesis application which makes use of the sEMG feature to determine a prosthesis velocity or force value, normalized results are plotted in Fig. 4 with the sEMG RMS feature on the horizontal axis common to both the velocity and the force parameters. When the prosthesis is in a mode that is free to move, the subject's sEMG activation will be mapped to a specific velocity and the prosthesis will be moved at this velocity; conversely, when the prosthesis is making contact with a fixed object, the subject's sEMG activation will be mapped to a specific force and the prosthesis will apply this force to the object.

From Fig. 4, it may be observed that while the normalized sEMG RMS values range across the full-scale to cover all the force values, the full-scale of velocity values only requires normalized sEMG RMS values in the lower end of the scale.

IV. CONCLUSION

Whilst the deduced relationships were discussed in terms of intuitive prosthesis control, the importance of such relationships is also very beneficial in motor disability diagnosis, providing useful insights with regard to the most effective personalized rehabilitation treatment [11]. Such motor disabilities may include stroke, osteoarthritis and cerebral palsy induced disabilities. A suitable assessment of a patient's motor control deficiencies cannot be done unless both isometric, as well as anisometric contractions are studied, especially since one uses a hybrid of the two to perform most activities of daily living. Thus, by integrating the two relationships, motor impairment diagnosis and rehabilitation could be more reliable.

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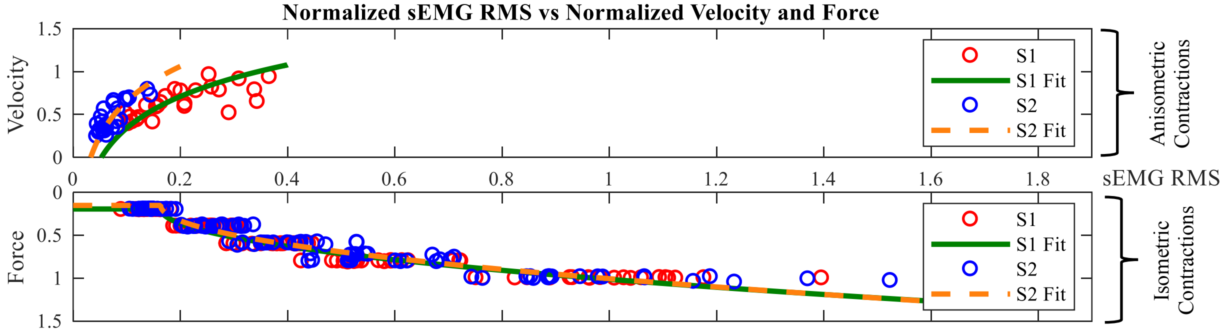

Figure 4. Normalized sEMG RMS against normalized velocity and normalized force data points and relationship fits for S1 and S2.