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Relationship between grasping force and features of single-channel intramuscular EMG signals

Ernest Nlandu Kamavuako[a,*], Dario Farina[a], Ken Yoshida[a,b], Winnie Jensen[a]

[a] Center for Sensory-Motor Interaction (SMI), Department of Health Science and Technology, Aalborg University, Fredrik Bajers Vej 7 D, DK-9220 Aalborg, Denmark
[b] Biomedical Engineering Department, IUPUI, Indianapolis, IN, USA

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ABSTRACT

The surface electromyographic (sEMG) signal can be used for force prediction and control in prosthetic devices. Because of technological advances on implantable sensors, the use of intramuscular EMG (iEMG) is becoming a potential alternative to sEMG for the control of multiple degrees-of-freedom (DOF). An invasive system is not affected by crosstalk, typical of sEMG, and provides more stable and independent control sites. However, intramuscular recordings provide more local information because of their high selectivity, and may thus be less representative of the global muscle activity with respect to sEMG. This study investigates the capacity of selective single-channel iEMG recordings to represent the grasping force with respect to the use of sEMG with the aim of assessing if iEMG can be an effective method for proportional myoelectric control. sEMG and iEMG were recorded concurrently from 10 subjects who exerted six grasping force profiles from 0 to 25/50 N. The linear correlation coefficient between features extracted from iEMG and force was ~0.9 and was not significantly different from the degree of correlation between sEMG and force. This result indicates that a selective iEMG recording is representative of the applied grasping force and can be used for proportional control.

1. Introduction

Electromyographic (EMG) signals are widely used for the control of prosthetic devices (myoelectric control, e.g. Otto Bock DMC Plus®). The EMG signal features are typically used for predicting either the intended limb movement (Hargrove et al., 2007; Farrell and Weir, 2008) or the amount of force required to execute a task (Duque et al., 1995; Hoozemans and Van Dieën, 2005). The main advantage of myoelectric prosthesis over other systems, e.g. body-powered prostheses, is that myoelectric control is close to the physiological experience of limb control. Non-invasive EMG recordings (surface EMG, sEMG) are most commonly used for this purpose. For example, grasping force can be predicted from sEMG because of the monotonic relationship between sEMG amplitude and force, which can be linear (Inman et al., 1952; Hoozemans and Van Dieën, 2005) or non-linear (Zuniga et al., 1970; Herzog et al., 1998; Liu et al., 1999).

The use of intramuscular EMG (iEMG) for myoelectric control has been less explored due to technical difficulties. However, reliable, implantable electrodes have been proposed recently (Weir et al., 2005; Farina et al., 2008b). Thus iEMG interfaces for myoelectric control may be chronically implanted and may provide more stable and more selective recordings than sEMG. Furthermore, the use of iEMG will not require appropriate control signal sites to be on superficial muscles. Though, the greater selectivity of iEMG with respect to sEMG may be a disadvantage for the control since the signal may provide local, rather than global information on the intensity of muscle activity.

Grasping force is one of the main functions to investigate for applications in myoelectric prosthesis because of the highly important functional value of this task. When the number of DOFs is limited, a control command is typically predicted as the onset of muscle activity, and the amount of grip force and speed of the prosthetic device is estimated from the intensity of the EMG signal (e.g. Otto Bock DMC Plus® prosthesis). Nevertheless the capacity of iEMG to predict the power grasping force, in particular its linear relationship with force for proportional control, has not been investigated. In this study we investigated whether a highly selective recording (at the single motor unit level) was sufficient to estimate the grip force accurately.

The relationship between EMG features and force has been investigated since several decades (Inman et al., 1952; Bigland and Lippold, 1954; Perry and Bekey, 1981; Hof, 1997). The information on the intensity of muscle activity is usually extracted based on the smoothed integrated EMG (SIEMG) (Inman et al., 1952; Bouisset and Maton, 1972; Onishi et al., 2000) or a count of action potentials (Close et al., 1960; Bouisset and Maton, 1972). Due the high selectivity of the recording interface in this study, iEMG signals were

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[*] Corresponding author. Tel.: +45 9940 2414.
E-mail addresses: enk@hst.aau.dk, ernest@bilutel.com (E.N. Kamavuako).

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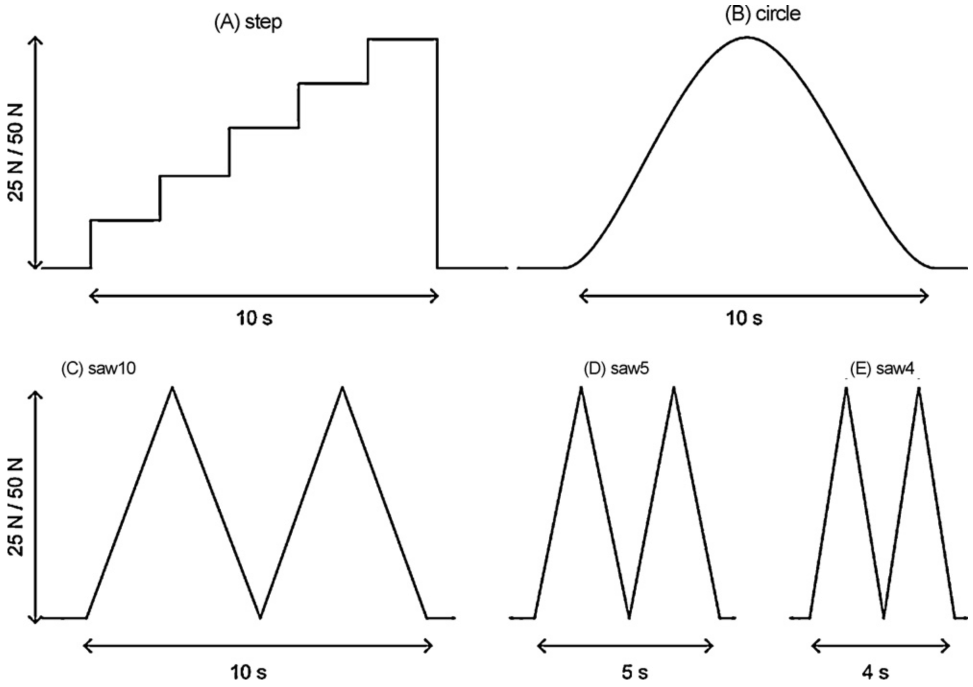

Fig. 1. The five target force profiles presented to the subject with online feedback on the generated force. (A) *Step*, (B) *circle*, (C) *saw10*, (D) *saw5*, and (E) *saw4*.

processed in order to rely only on the modulation of the discharge rate, rather than the signal amplitude.

The multi-unit characteristics of iEMG has been investigated during single muscle isometric contraction mainly for understanding basic physiological processes, where, e.g. the recruitment strategies have been shown to relate to force (Freund et al., 1975; DeLuca et al., 1982). At a given time instant, the level of force is related to the total number of active motor units, from which a global discharge rate (GDR) can be estimated (total number of motor unit action potentials per unit time). With an intramuscular detection system, only few motor units are sampled and it is not known if these units are representative for the applied power grip force. Therefore the aim of this study was to quantify the linear correlation between grasping force and features of the iEMG and sEMG. We did not predict the force based on EMG signal; rather, we investigated whether power grip force was better described by a global measure of intensity (sEMG) or by a GDR in a local muscle area (iEMG), using linear correlation coefficients as measures.

2. Methods

2.1. Experiments

2.1.1. Subjects

The experiments were conducted on 10 able-bodied human subjects (7 w/3 m; age range, 21–37 years, mean 26.9 years). The procedures were in accordance with the Declaration of Helsinki and approved by the Danish local ethical committee (approval no.: N-20080045). Subjects gave written informed consent prior to the experimental procedures. The subjects had no history of upper extremity or other musculoskeletal disorders.

2.1.2. Tasks and procedures

Subjects exerted handgrip forces with their right hand while seated comfortably with both arms placed on a table in front of them. The subject's elbow was flexed at approximately 90° and the forearms were mechanically supported by a brace. First the subjects were asked to produce a maximum grip force (MGF) by increasing force to the maximum in 3 s and maintaining the maximum for 3 s. MGF was applied on a hand dynamometer as described later. MGF was performed twice with 3 min of rest after each trial. Next, the subjects were asked to follow six force profiles randomly assigned. The six force profiles were defined as follows:

1. A step increase in static grip force with 5 increments of 10-s duration of either 10 or 5 N (*step*; Fig. 1A).
2. A gradual increase in grip force ranging from 0 to 25 N or 0 to 50 N in 10 s (*circle*; Fig. 1B).
3. Two linear ramps of 10 s (*saw10*; Fig. 1C).
4. Two linear ramps of 5 s (*saw5*; Fig. 1D).
5. Two linear ramps of 4 s (*saw4*; Fig. 1E).
6. A freely varying grip force for 15 s with the only constraint to keep the force within 25 or 50 N (*vol*).

The three ramp profiles were selected to investigate the effect of the contraction speed.

Two force levels were investigated: (1) forces up to 50 N (referred to as high-force) and (2) forces up to 25 N (referred to as low-force). Two trials were recorded for each force profile per level and a rest of 1 min followed each trial.

2.1.3. Data recording

The force produced during power grip was measured using a commercially available hand grip dynamometer (Vernier Software & Technology, accuracy ±0.6 N, operational range 0–600 N, grip size 50 mm × 25 mm). The output voltage was linearly related to the force applied to the sensor. The analog output of the dynamometer was filtered (0–500 Hz) and A/D converted on 12 bits. sEMG was measured in bipolar configuration using disposable Ag/AgCl surface electrodes (Ambu Neuroline 720, Denmark) from the m. extensor carpi radialis (ECR), flexor digitorum superficialis (FDS), and flexor carpi radialis (FCR). These three muscles were selected since they have previously shown to be suitable for force prediction during power grip (Hoozemans and Van Dieën, 2005). The sEMG signals were amplified by a factor 2000 with a multi-channel sur-