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Towards optimal multi-channel EMG electrode configurations in muscle force estimation: a high density EMG study

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Abstract

Surface EMG is an important tool in biomechanics, kinesiology and neurophysiology. In neurophysiology the concept of high-density EMG (HD-EMG), using two dimensional electrode grids, was developed for the measurement of spatiotemporal activation patterns of the underlying muscle and its motor units (MU). The aim of this paper was to determine, with the aid of a HD-EMG grid, the relative importance of a number of electrode sensor configurations for optimizing muscle force estimation. Sensor configurations are distinguished in two categories. The first category concerns dimensions: the size of a single electrode and the inter electrode distance (IED). The second category concerns the sensor's spatial distribution: the total area from which signals are obtained (collection surface) and the number of electrodes per cm^2 (collection density). Eleven subjects performed isometric arm extensions at three elbow angles and three contraction levels. Surface-EMG from the triceps brachii muscle and the external force at the wrist were measured. Compared to a single conventional bipolar electrode pair, the force estimation quality improved by about 30% when using HD-EMG. Among the sensor configurations, the collection surface alone appeared to be responsible for the major part of the EMG based force estimation quality by improving it with 25%.

Keywords: Human; Force estimation; Surface electromyography; Instrumentation

1. Introduction

Surface electromyography (sEMG) is an important tool in biomechanics, kinesiology and neurophysiology. In biomechanics and kinesiology, EMG is often used to estimate muscle activation, force and moments from the signal's amplitude [3,12,14,17,19,27]. In (clinical) neurophysiology, EMG is used to determine the anatomical properties of the underlying muscular tissue, like the location of innervations zones or fiber lengths [15], but also to analyze neurological properties like the conduction velocity of single motor unit action potentials [34]. For these neurophysiologic applications one-dimensional linear electrode arrays [15] and two-dimensional high-density EMG (HD-EMG) grids [1] have been developed.

Studies on muscle joint systems have shown that EMG signals, collected during sustained and repetitive exertions, showed variability at different levels. At the level of individual muscles [9,21], as well as at the level of muscle parts [22,28,33] and even of motor units (MU) [7,30] EMG activity varies over time. However, it remains unclear to what extent the variability of the EMG signal reflects variability in MU activity and to what extent it is based on the stochastic interference of the potentials of different MUs (e.g. phase cancellation).

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To improve EMG based predictions of muscle activation and force, it is important to reduce any unwanted variability, so that the real muscle activity is best represented in the collected signal. Previous research has contributed to optimization of the technical aspects, instrumentation [5,8,11,18,29] and appropriate filter techniques [2,19]. A decrease in EMG variability, resulting in an improvement of EMG based force estimation quality, can be obtained when using multiple bipolar electrodes spatially distributed over the muscle belly [4,10]. However, only limited experimental evidence exists on how the EMG is affected by sensor configuration properties.

HD-EMG grids developed and used in (clinical) neurophysiology may also have advantages in the field of biomechanics for a number of reasons. First, as mentioned, an improvement of EMG based force estimation quality can be obtained when using multiple bipolar electrodes spatially distributed over the muscle belly. Second, an analysis of different conceivable configurations can be constructed with a HD-EMG grid due to the substantial collection-surface and the large number of single electrode surfaces. Third, stable inter electrode distances (IEDs) can be obtained because of the rigid construction of the electrodes. Finally, the raw data are collected monopolarly, allowing the post-hoc construction of various bipolar electrode sensor configurations over the muscle belly.

The aim of this paper is to determine, with the aid of a HD-EMG grid, the relative importance of a number of electrode sensor configuration properties for optimizing muscle force estimation. These factors are distinguished in two categories. The first category concerns dimensions, such as the size of a single electrode and the IED. The second category concerns the sensor's spatial distribution, such as the total area from which signals are obtained (collection surface) and the number of electrodes per cm^2 (collection density).

2. Methods and material

2.1. Subjects

Eleven healthy subjects, eight males (age 28.3 ± 4.7 years, weight 70.6 ± 9.0 kg, stature 1.8 ± 0.1 m) and three females (age 27.3 ± 2.1 years, weight 60.7 ± 7.1 kg, body length 1.7 ± 0.1 m) participated in the experiment after signing an informed consent. The experiment was approved by the local ethics committee.

2.2. Procedure

The subjects performed isometric right arm extensions. The contraction was a block-shaped pattern and consisted of an isotonic contraction, starting from rest, over a plateau of 5 seconds and back to rest again. These efforts were performed at 20%, 50% and 80% of maximum voluntary contraction (%MVC) at three different elbow angles (60°, 90° and 130°). The MVC was defined as the maximum value of three repetitive pyramidal shaped contraction patterns at each corresponding elbow angle. To prevent effects of fatigue, a rest period of 2 min between all efforts was provided. All extension efforts were performed in the horizontal plane, so that gravitational force components had no effect on the elbow moment. To prevent a variation of arm angle during efforts, subjects had the medial side of their right elbow and the lateral side of the left shoulder supported against an anchor and their left arm free for additional active support of stability. With this setup (Fig. 1) it can be assumed that the triceps brachii muscle is the major contributor to the extension moment.

Surface EMG and force output were measured simultaneously and synchronized. A one-dimensional force transducer (FUTEK L2353, advanced sensor technology, Irvine, USA), was attached orthogonal to the forearm at the level of the wrist. The output of the force-transducer was A/D converted with a sample frequency of 1000 Hz. To ensure extension efforts at desired force levels, real time feedback of the force signal was provided. The subjects were asked to maintain the force output at a given target level (%MVC), indicated with a horizontal bar, during 5 s.

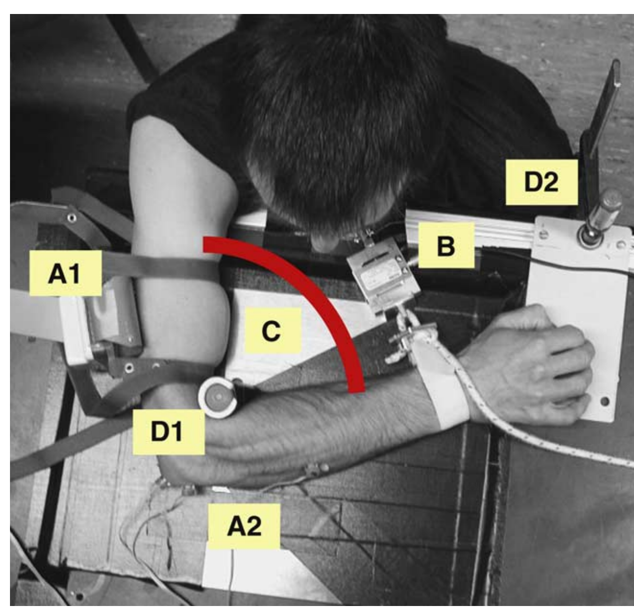

Fig. 1. Top view of the measurement setup. Subjects were sitting at a breast height table with a flexed arm positioned in the horizontal plane: (A1) lateral view of the longitudinal HD-EMG array direction; (A2) reference electrode, common mode sensor (both on the olecranon of the elbow) and most distal the driven right leg electrode; (B) force transducer; (C) elbow angle; (D1) medial elbow anchor; (D2) lateral shoulder anchor.