Biomedical Signal Processing and Control 40 (2018) 149–155

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Research Paper

Dimensionality effect of myoelectric-controlled interface on the coordination of agonist and antagonist muscles during voluntary isometric elbow flexion and extension

Wenbo Sun[a,b], Jiaqi Wang[a,b], Linchuan Deng[a,b], Huihua Liu[c], Tiebin Yan[c], Rong Song[a,b,*]

[a] Guangdong Provincial Engineering and Technology Center of Advanced and Portable Medical Devices, School of Engineering, Sun Yat-sen University, Guangzhou, Guang Dong, PR China
[b] Key Laboratory of Sensing Technology and Biomedical Instrument of GuangDong Province, Guangzhou, Guang Dong, PR China
[c] Department of Rehabilitation Medicine, Sun Yat-sen Memorial Hospital, Sun Yat-sen University, Guangzhou, Guang Dong, PR China

ARTICLE INFO

Article history:
Received 6 August 2016
Received in revised form 26 August 2017
Accepted 16 September 2017

Keywords:
Dimensionality
Myoelectric-controlled interface
Muscle coordination
Visual feedback

ABSTRACT

This study aimed to investigate the dimensionality effect of myoelectric-controlled interface (MCI) on the coordination of agonist and antagonist muscles during voluntary isometric elbow flexion and extension. Eighteen healthy subjects were recruited to control a controllable cursor to track a target cursor by real-time modulating the biceps and triceps activities within one-dimensional and two-dimensional MCIs. Electromyographic (EMG) signals were collected to calculate the normalized muscle activation, while the slope of the best-fitting linear relationship between the normalized agonist and antagonist activations was used to quantify the muscle co-activation. The tracking error and the normalized net torque of the elbow joint were also calculated. Results showed that no significant difference was found in the tracking error between one-dimensional and two-dimensional MCIs. The normalized antagonist activation, the muscle co-activation and the normalized net torque were significantly lower within two-dimensional MCI than within one-dimensional MCI. In addition, significant decrease in the normalized agonist activation was also found during elbow extension. These results implied that within two-dimensional MCI, subjects were able to modulate the coordination of agonist and antagonist precisely by inhibiting unnecessary muscle activities. Therefore, two-dimensional MCI might be applied as a rehabilitation tool aiming at fine control of abnormal muscle coordination.

1. Introduction

The generation of joint movement involves the coordination of agonist and antagonist muscles, which is vital in daily activities. For instance, the simultaneous contraction of agonist and antagonist around a single joint, named muscle co-contraction, could make voluntary motion as accuracy as possible [1,2] and maintain the stability [3,4] and stiffness [5,6] of a certain joint. In contrast, an inability to coordinate the agonist and antagonist might cause a loss of movement accuracy, an increased risk of joint injury and movement disorders [7,8].

Muscle activities could be finely modulated via sensory feedback, such as visual and auditory feedback [9] and haptic feedback [10]. Myoelectric-controlled interface (MCI), a kind of visual feedback tool, has been proven useful in rehabilitation [11]. MCI uses the surface electromyography (EMG), which is a physiological signal containing the information of motor intent [12], muscle properties [13], and muscle impairment [14]. MCI is designed for users with motor disabilities and has been widely applied [15]. It could decode muscle activities into control outputs, such as cursor movements [15–17], and help users modulate their muscle activation patterns. Previous study found that children with dystonia were able to reduce the excessive activation of elbow antagonist muscles within a two-dimensional MCI [17]. Besides, it was shown that healthy subjects could learn to modify muscle co-activation patterns in the upper limb within a two-dimensional MCI [15,16]. In these previous studies, Young et al. [17] only investigated the effect of MCI on the antagonist muscles, while Radhakrishnan et al. [15] and Wright et al. [16] mainly focused on the co-activation of proximal and distal muscles (e.g., co-activation of the shoulder and elbow muscles). In addition, previous study has demonstrated that two-dimensional visual feedback of the center of pressure (COP) was more helpful than one-dimensional visual feedback in keeping standing balance

---

[*] Corresponding author at: Room B522, School of Engineering, Sun Yat-sen University, Guangzhou Higher Education Mega Center, Guangzhou, PR China.
E-mail address: songrong@mail.sysu.edu.cn (R. Song).

http://dx.doi.org/10.1016/j.bspc.2017.09.016

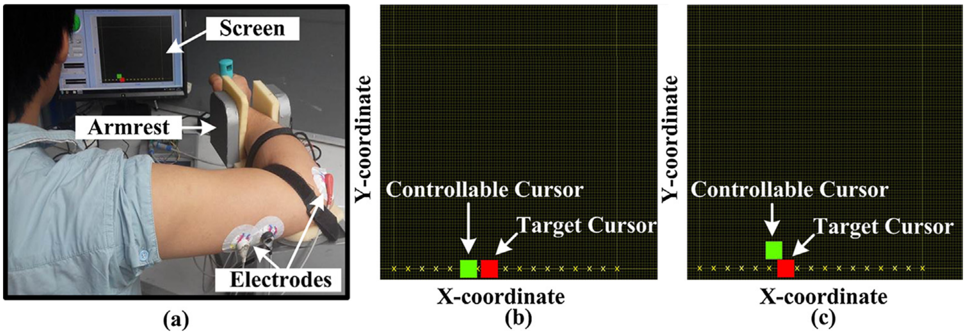

Fig. 1. (a) One subject under trial; (b) One-dimensional MCI, in which the green square represented the controllable cursor, the red square represented the target cursor, and the dashed line represented the target trajectory during elbow extension. (c) Two-dimensional MCI. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

[18]. It was suggested that within three-dimensional visual force feedback rather than one-dimensional visual force feedback, subjects were able to reduce experiment muscle pain by using more complex muscle synergy patterns [19]. Although the dimensionality of visual feedback could affect movement performance as previously described [18,19], little work had been done on investigating the dimensionality effect of MCI on the muscle coordination, especially on the real-time coordination of agonist and antagonist muscles to track a dynamic target.

The purpose of this study was to examine the dimensionality effect of MCI on the real-time coordination of agonist and antagonist muscles to track a dynamic target. Within one-dimensional or two-dimensional MCI, tracking tasks were conducted through modulating activities of agonist and antagonist muscles during voluntary isometric elbow flexion and extension. The tracking error, the normalized agonist and antagonist activations, the muscle co-activation and the normalized net torque of the elbow joint, which might enable a deeper understanding of the dimensionality effect of MCI on the coordination of agonist and antagonist muscles, and provide guidance for the MCI's clinical applications, were analyzed.

2. Methods

2.1. Subjects

Eighteen healthy subjects (10 males and 8 females; age, 23.7 ± 1.8 years; height, 167.1 ± 8.0 cm; weight, 60.5 ± 10.6 kg) were recruited in this study. All the subjects were free of any neurological or motor disorders, and gave fully informed consent, which was approved by the ethics committee of the Sun Yat-sen Memorial Hospital. All the subjects were right-handed.

2.2. Apparatus

The experiment setup was illustrated in Fig. 1(a). An adjustable chair enabled the subjects to be comfortably seated with their right arm positioned horizontally on the armrest, and the elbow joint was positioned in 90° flexion and shoulder was positioned in 90° abduction [2]. The armrest had a handle, which could be adjusted according to the length of forearms.

In this study, MCIs were developed using LabVIEW$^{\mathrm{TM}}$ (LabVIEW 2012,National Instruments Corporation, Austin, TX, USA) program, in which there were a two-dimensional coordinate system (200 × 200 mm in size) and two square cursors (10 × 10 mm in size), a controllable (green) cursor and a target (red) cursor (Fig. 1). The normalized triceps and biceps activations, which were calculated by normalizing the muscle activation to the maximum muscle activation, were mapped to the X-axis and Y-axis of the two-dimensional coordinate system. The X-coordinate and Y-coordinate of the controllable cursor reflected the normalized triceps activation and the normalized biceps activation, respectively. In the elbow flexion task, agonist muscles mainly included biceps brachii, brachialis, and brachioradialis, and in the elbow extension task, agonist muscles mainly included triceps brachii and anconeus. In this study, only the medial head of triceps brachii and biceps brachii were studied. Within the one-dimensional MCI, the controllable cursor could only reflect the activation of agonist muscle and move along X-axis or Y-axis at a time, and X-coordinate was set as 0 during elbow flexion and Y-coordinate was set as 0 during elbow extension atinitial (Fig. 1(b)). Within the two-dimensional MCI, both agonist and antagonist muscles were simultaneously controlling the controllable cursor's X and Y axes movements (Fig. 1(c)).

Torque signals produced during voluntary isometric elbow flexion and extension were recorded by a torque sensor (AKC-205, 701 st Research Institute of China Aerospace Science and Technology Corporation, China) connected to the armrest. EMG signals were recorded by a customized EMG amplifier. The amplifier gain was 5000. Two circular silver-silver chloride (Ag-AgCl) electrodes (diameter 10 mm, center-to-center distance 20 mm) were placed in parallel to the muscle fibers and on the bellies of biceps and triceps after the skin shaved and cleaned [20], and cross-correlation analysis between EMG signals of biceps and triceps was performed to make sure that the EMG corss-talk was negligible [21]. In this study, a simple method was adopted to verify the innervation zone (IZ). Before the experiment, subjects were asked to perform maximum voluntary contraction (MVC) with different electrode configurations for several times. The electrode configuration with larger EMG amplitude was suggested to be used in the following experiment, since the EMG signals might be relatively weak and noisy when the electrodes were placed over the IZ [22]. Torque and EMG signals were sampled at a rate of 1000 Hz with a 16 bit resolution (DAQ USB-6341, National instrument Corporation, Austin, Texas, USA) and processed and stored by the LabVIEW$^{\mathrm{TM}}$ program.

2.3. Procedure

Before the experiment, subjects were firstly instructed to perform isometric submaximal elbow flexion and extension several trials. Then subjects were required to perform 5 s MVC during isometric elbow flexion and extension for three times, with a 2 min rest period between each trial. The maximal EMG signals during MVCs were recorded for the normalization of biceps and triceps activations.

After MVC, subjects were instructed to practice moving the controllable cursor for several minutes, by modulating the agonist and antagonist activities during voluntary isometric elbow flexion and extension. Following familiarization with the task, each subject performed tracking tasks by moving the controllable cursor