# Can Transcranial Direct Current Stimulation Enhance Performance of Myoelectric Control for Multifunctional Prosthesis?*

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***Abstract*— Pattern recognition based myoelectric control has been studied by many researchers. However, the classification accuracy was pretty low for amputees towards multifunctional prosthesis control in practice. In this work, a novel method of transcranial direct current stimulation (tDCS) which can modulate brain activity was used to enhance performance for myoelectric prosthesis control. The pilot study was conducted on three able-bodied subjects and one transradial amputee. Surface electromyography (EMG) signals were acquired from both arms when performing eleven hand and wrist motions in pre-tDCS and post-tDCS sessions. Time domain (TD) features and linear discriminant analysis (LDA) classifier were adopted to process EMG. For the non-dominant hand of the healthy subjects, active anodal tDCS of the contralateral primary motor cortex was able to significantly improve average classification accuracy by 3.82% ($p < 0.05$), while sham tDCS could not have such effect ($p > 0.05$). For amputated (phantom) hand of the amputee, active anodal tDCS was able to significantly improve average classification accuracy by 12.56%, while sham tDCS could not have such effect. For the dominant hand and intact hand, the average classification accuracies were stable and not significantly improved using either active tDCS or sham tDCS. The results show that tDCS is a powerful noninvasive method to modulate brain function and enhance EMG classification performance especially for the amputated hand towards multifunctional prosthesis control. The method proposed has a huge potential to promote EMG pattern recognition based control scheme to clinical application.**

## I. INTRODUCTION

Surface electromyography (EMG) signals acquired from the muscles have been widely used as the control inputs of a myoelectric prosthesis for several decades [1]. Pattern recognition of EMG signals has been an approach to control multifunctional prostheses for about 20 years [2]. However, the clinical applicability of multifunctional prostheses based on pattern recognition is still limited. The main reason is the relative few motions that can be classified from EMG signals acquired from the amputee's residual muscles with the acceptable accuracy.

Some studies showed that repetitive exercise could improve the motor function of transradial amputees and increase classification accuracy (CA) of EMG pattern recognition. Kato et al. [3] have increased the number of classes that can be classified from 3 to 6 (the CA maintains above 80%). Powell et al. have done some similar work on this topic too, and their research demonstrated that three weeks' exercise can promote the CA from 77.5% to 94.4% with 8 classes of motion gestures [4]. However, exercise would take a lot of time and consume large efforts of the users and researchers (or therapists). Thus, a new method is required to assist the amputees to promote their motion ability and enhance the quality of EMG signals for the prosthesis control.

Recently, many researchers focused on the technologies of neurostimulation and neuromodulation, such as transcranial magnet stimulation (TMS) [5], transcranial focused ultrasound stimulation (tFUS) [6] and transcranical electrical stimulation (tES) [7], [8]. All these methods can be used to modulate different brain cortical areas and associate physiological signals. Compared to repetitive exercise, neurostimulation or neuromodulation can be more effective. Transcranial direct current stimulation (tDCS) that belongs to tES is emerging to be an effective approach, whereas anodal stimulation increases cortical excitability and cathodal stimulation decreases it, during rehabilitation or motor function recovery [9]. A pilot work has been done by Boggio et al. [10], which has indicated the positive effect of anodal tDCS on enhancement of non-dominant hand motor function in healthy subjects. These subjects used their hands asymmetrically in the normal life which induced the cortical excitability of non-dominant hand lower than dominant hand. For unilateral transradial amputees, they have a similar situation that their amputated limbs have not been used for a long time, which decreases the cortical excitability of relevant motor cortex much more than the healthy subjects' non-dominant hands. So we infer that the modulation of the amputees' motor cortex may promote their motor function, which thus could enhance the quality of EMG signals for prosthesis control. Dutta et al. have done some related work on facilitating myoelectric control for triggering functional electrical stimulation with tDCS [11], which is quite different from myoelectric control for multifunctional prosthesis in fact.

In this work, we firstly investigated whether the anodal tDCS of the contralateral primary motor cortex can enhance EMG signals acquired from able-bodied subjects' non-dominant limb for pattern recognition of eleven classes of hand and wrist motions. Then, we conducted experiments on an amputee to test if anodal tDCS had positive effects on amputated hand. The common methods of linear discriminant analysis (LDA) classifier and time domain (TD) feature extraction were used, which aimed to attribute the improve-

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ment in EMG performance to the effects of anodal tDCS rather than the sophisticated signal processing methods. To the best of the authors' knowledge, this study is the first attempt to use anodal tDCS to enhance EMG signals acquired from either able-bodied subjects or transradial amputees for multifunctional prosthesis control.

## II. METHODOLOGY

### A. Subjects

Four subjects participated in the experiment, including three able-bodied subjects (all males; aged 23-26) and one transradial amputee (male; aged 72; time since amputation: 34 years; side of amputation: right). All the subjects were right-handed dominant, and they all had never tried tDCS before. One able-bodied subject and the transradial amputee had some experience on the EMG pattern recognition experiment. Specially, the subjects were not informed about the positive effects of tDCS in order to avoid the placebo effect on their mind. This work was approved by the Ethics Committee of Shanghai Jiao Tong University. All subjects participating in the experiment had signed the informed consent and the procedures were in compliance with the Declaration of Helsinki.

### B. Experiment Setup

Each subject underwent two different treatments: sham and active anodal tDCS of primary motor cortex of non-dominant hand (right hemisphere) or amputated hand (left hemisphere). There are 3 experiments for each subject in three days. For the first day, each subject did not take tDCS treatment and just got familiar with the experimental protocol. For the second day, each subject underwent active anodal tDCS treatment. For the third day, each subject underwent sham tDCS treatment. There was an interval of 48h between each experiment. Each experiment included 3 continuous sessions which were pre-tDCS session, dur-tDCS session (sham or active) and post-tDCS session. Here, "pre-tDCS" indicates the session that is accomplished before the application of tDCS, "dur-tDCS" indicates the session of performing tDCS, and "post-tDCS" is the session after the application of tDCS.

For pre-tDCS session and post-tDCS session, the subjects were instructed to perform eleven classes of hand and wrist motions, which were hand close, hand open, key grip, fine pinch, wrist flexion, wrist extension, radial deviation, ulnar deviation, supination, pronation and "no movement". The subjects performed each motion for 10s in each trial. And 10 trials were accomplished for each hand of these two sessions.

For dur-tDCS session, the subjects underwent 1mA sham or active anodal tDCS for 20min. A DC-Stimulator (NeuroConn Inc., Germany) was used. The 5cm×7cm saline-soaked sponge anodal electrode was placed over C3 or C4 (international 10/20 EEG system) and the other cathodal electrode was placed over the contralateral supraorbital area (as shown in Fig. 1). For the sham stimulation, the electrodes were placed on the same positions; however, the current was ramped up and then down to zero in 30 sec.

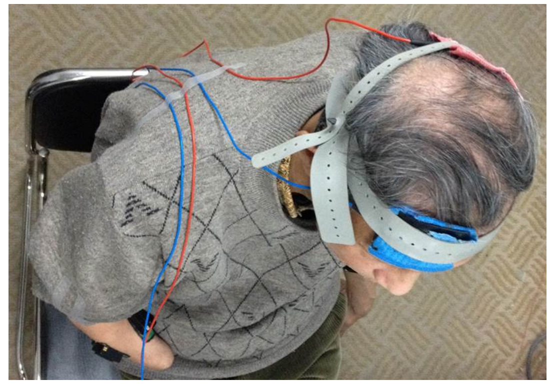

Fig. 1. tDCS electrodes on C3 area and contralateral supraorbital area of the transradial amputee. The red one is the anodal electrode, and the blue one is the cathodal electrode.

During all the sessions, the subjects were instructed to sit in a chair with their forearms along the body and naturally extended toward the ground. Motions to be performed were displayed in advance on a monitor located in front of the subject. In order to avoid fatigue, the subjects could have a 30-sec break between two trials.

### C. Data acquisition

A Trigno wireless system (Delsys Inc., USA) was used to measure and collect EMG signals. As illustrated in Fig. 2, four-channel EMG signals were recorded from four forearm muscles of both arms: 1. flexor carpi ulnaris (FCU), 2. flexor carpi radialis (FCR), 3. extensor carpi radialis (ECR), 4. extensor carpi ulnaris (ECU). All electrodes were placed over the targeted muscles using medical adhesive tape. The electrodes were wirelessly connected to the Trigno Base Station communicating with a computer through the USB link. The EMG signals were band-pass filtered (pass band 20-450Hz) and sampled at 2000Hz by the EMG data acquisition system.

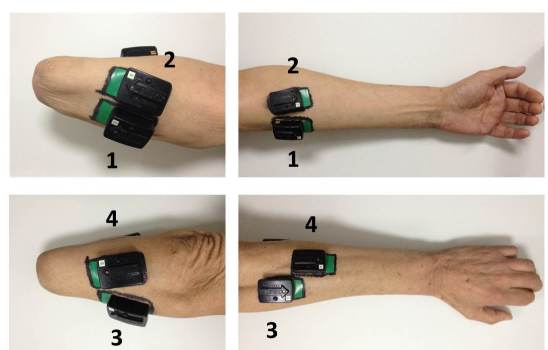


Fig. 2. Positions of the surface EMG electrodes on intact and amputated limb of the transradial amputee. The amputee's right hand was lost.

### D. Data processing

Feature extraction is a necessary step for pattern recognition. As the effectiveness of TD features has been shown in previous EMG studies [2], [12], it was also adopted in this study. TD features were originally proposed by Hudgins et al. [2], where continuous EMG signals were segmented into multiple analysis windows and TD features were extracted from each analysis window. Here, the analysis window was set to 200 ms and the increment of analysis window which was the interval between two adjacent windows was set to 50 ms. A feature set was computed on each of the four channels, and then concatenated to form a 16-dimension feature vector. In one session, 11000 feature samples were taken for each subject.

As a simple classifier which is fast to be trained, LDA classifier has been widely used in pattern recognition of EMG signals [13]. It has been presented in previous studies that LDA classifier can have the same performance as those more complex and more powerful classifiers [14]. Hence, LDA classifier was adopted to identify the eleven classes of hand and wrist motions. One half of the data were used as a training set to train LDA classifier, and the other half were used as a testing set to evaluate the classifier's performance. A two-fold cross validation procedure was adopted.

## III. RESULT

### A. Classification Accuracy of Dominant Hand and Non-dominant Hand

For the able-bodied subjects, Fig. 3 and Fig. 4 demonstrate the average classification accuracies of dominant hand and non-dominant hand across three able-bodied subjects in different sessions. As shown in Fig. 3, the average CA of dominant hand was stable from 93.28% to 95.51%. There is no significant difference between pre-tDCS session and post-tDCS session ($p > 0.05$) on CA of dominant hand on the day of active and sham tDCS. As shown in Fig. 4, the average CA of non-dominant hand changed sharply from 91.48% to 97.00%. There is a significant improvement between pre-tDCS session and post-tDCS session ($p < 0.05$) on CA of non-dominant hand on the day of active tDCS. However, there is no significant difference between pre-tDCS session and post-tDCS session ($p > 0.05$) on CA of non-dominant hand on the day of sham tDCS.

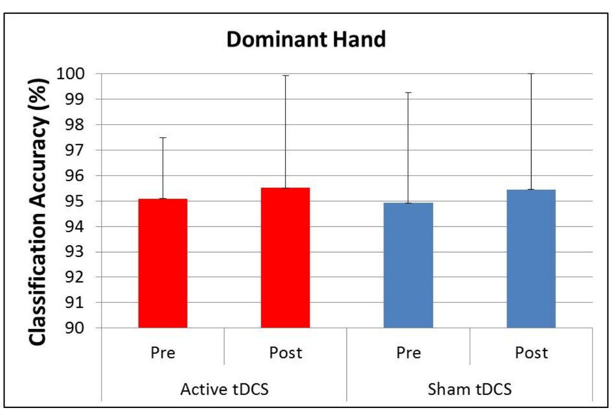


Fig. 3. CA of EMG for dominant hand of able-bodied subjects. Error bars represented the standard deviation.

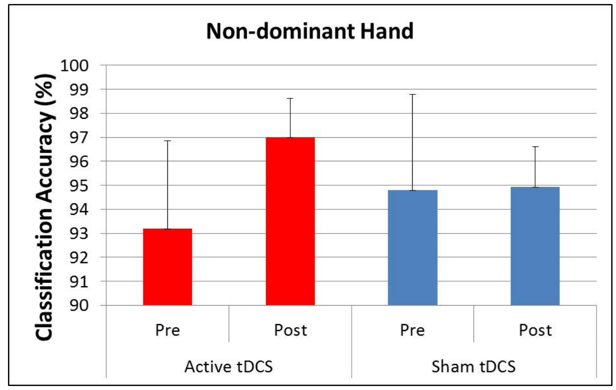


Fig. 4. CA of EMG for non-dominant hand of able-bodied subjects. Error bars represented the standard deviation.

### B. Classification Accuracy of Intact Hand and Amputated Hand

For transradial amputee, Fig. 5 and Fig. 6 demonstrate the classification accuracies of intact hand and amputated hand in different sessions. As shown in Fig. 5, like the dominant hand of able-bodied subjects, the average CA of intact hand was stable from 90.29% to 94.72%. There is no big difference between pre-tDCS session and post-tDCS session on CA of dominant hand on the day of active and sham tDCS. As shown in Fig. 6, the CA of amputated hand was significantly improved by 12.56% on the day of active tDCS. But there is no big change between pre-tDCS session and post-tDCS session on CA of amputated hand on the day of sham tDCS.

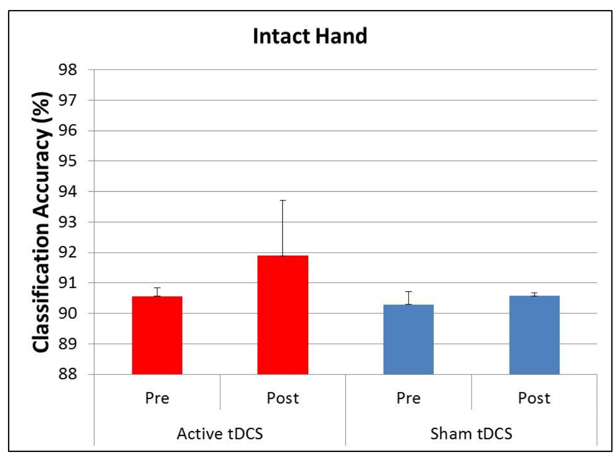


Fig. 5. CA of EMG for intact hand of transradial amputee. Error bars represented the standard deviation.

## IV. DISCUSSION AND CONCLUSIONS

In this work, some preliminary work were done regarding whether the effect of anodal tDCS of the contralateral primary motor cortex can enhance the classification performance of EMG signals acquired from non-dominant or amputated hand. The results show that there was a significant enhancement of CA of the EMG signals acquired from either non-dominant or amputated hand on the day of active

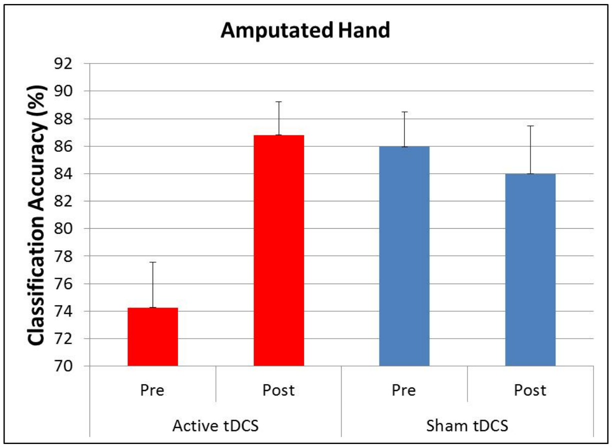


Fig. 6. CA of EMG for amputated hand of transradial amputee. Error bars represented the standard deviation.

tDCS, but not on the day of sham tDCS. After active tDCS, classification performance of non-dominant or amputated hand can be improved to nearly the same level as the dominant or intact hand.

After the first day's enough repetitions of all the motions, the performance of non-dominant and amputated hand should be stable without any significant difference between pre-tDCS and post-tDCS sessions (see the day of sham tDCS). Therefore, the significant enhancement of CA of the EMG signals acquired from either non-dominant or amputated hand on the day of active anodal tDCS should be induced by active anodal tDCS of contralateral primary motor cortex. As active anodal tDCS can increase the cortical excitability, it is reasonable to believe that classification performance enhancement of EMG signals is due to the increase of related cortical excitability. This method improves CA not from advanced algorithms but from the source of EMG signals that is related to the neural plasticity.

The results show that there is no significant difference of CA of the EMG signals acquired from either dominant or intact hand between pre-tDCS and post-tDCS on the day of active and sham tDCS. We attribute this phenomenon to the reason that all subjects only underwent active anodal tDCS of their non-dominant and amputated hands related cortex area, but not dominant and intact hands, so there is no enhancement on the day of active tDCS.

From the results of amputee, we find a much higher improvement of CA of amputated hand after active anodal tDCS compared with that of non-dominant hand of able-bodied subjects. It is understandable that the able-bodied subjects initially has good CA performance, and it is hard to further improve CA due to the ceiling effect. CA of amputated hand is pretty low before active anodal tDCS, and it has a large room to improve. The performance of amputated hand in pre-tDCS and post-tDCS session on the day of sham tDCS are around 85% close to the performance in post-tDCS on the day of active tDCS. In our opinion, the amputee learned how to use his amputated hand to perform all the motions better as his cortical excitability increased after active anodal tDCS on the day of active tDCS. Therefore, the method proposed has a huge potential to dramatically improve the CA of EMG for amputees and promote pattern recognition based myoelectric control to clinical application. Certainly, there is only one amputee's data, which can not draw this conclusion definitely now. For further study, extended experiments analyzing the tDCS's enhancement of EMG signals acquired from more amputees will be performed.

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