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## Effect of transcranial direct current stimulation (tDCS) on maximal voluntary isometric strength and endurance of the elbow flexors

Benjamin Kan  
*Edith Cowan University*

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# **MASTERS THESIS**

## **Effect of transcranial direct current stimulation (tDCS) on maximal voluntary isometric strength and endurance of the elbow flexors**

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(Exercise and Sports Science)**

**Principal Supervisor: Professor Kazunori Nosaka  
Associate Supervisor: Ms Jane Dundas**

**This thesis is presented for the award of:  
Master of Science (Sports Science)**

**School of Exercise, Biomedical and Health Sciences,  
Faculty of Computing, Health and Science,  
Edith Cowan University, Joondalup, Western Australia.**

**Date of Submission: 15<sup>th</sup> of July 2011**

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## ABSTRACT

The present study investigated the effects of transcranial direct current stimulation (tDCS) on maximal voluntary contraction strength (MVC) and the time to failure (TTF) of an isometric muscle endurance test of the elbow flexors. Prior to the main study, the test-retest reliability of MVC and TTF measures was investigated using 10 men ( $33.2 \pm 9.4$  y) for the measurements separated by 60 min (within-day) and one week (between-day). Coefficient of variation (CV), Intraclass correlation (ICC, R), a paired t-test and the Bland-Altman plots revealed that TTF at 30% MVC task was reliable, and was able to detect a possible effect of tDCS on TTF, if the magnitude of effect was greater than 11%. Based on the reliability study results, it was hypothesised that tDCS would increase TTF from the first test to the second test separated by 60 min, when a tDCS treatment was administered immediately before the second test. Fifteen men ( $27.7 \pm 8.4$  y) were tested for MVC and TTF at 30%-MVC before and immediately after tDCS or sham intervention (10 min) in three separate sessions. In two sessions direct current (2 mA) was delivered through saline-soaked sponge electrodes, with the anode placed on the scalp overlying the right motor cortical representation of the left arm and the cathode secured over the right shoulder. One session was a sham intervention (current delivery for the first 30s). The order of the intervention sessions was randomised and counterbalanced amongst the subjects and subjects who were blinded to intervention type. Changes in MVC strength and TTF from pre to post intervention were compared between the interventions by a two-way repeated measures ANOVA. No significant differences were evident for the two tDCS sessions. MVC strength (baseline:  $66.0 \pm 11.4$  Nm) decreased by  $5.9 \pm 4.2$  % ( $P < 0.05$ ) in the post-intervention measures, but no significant difference in the changes was evident between sham and tDCS interventions. TTF did not change significantly from pre ( $309.2 \pm 91.6$  s) to post intervention ( $327.2 \pm$

128.5 s), and no significant difference was found between interventions. In conclusion, tDCS did not affect TTF and MVC of the elbow flexors. It appears that the tDCS intervention did not affect cortical excitability due to ceiling effects that made it unable to modulate voluntary activation of motor units. Since the present study did not assess motor evoked potentials (MEP) that could show changes in cortical excitability following tDCS or sham treatment, further studies are required to examine the effects of tDCS on cortical excitability.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Transcranial direct current stimulation (tDCS) is a method of altering cortical excitability using low intensity (1~2 mA) direct current delivered to the scalp overlying a target region of the brain via surface electrodes connected to a controlled current-generating unit (Jeffrey et al. 2007). tDCS modulates cortical excitability (Nitsche and Paulus 2000; Paulus 2004) by altering the motor unit firing rates due to a shift of resting membrane potentials of cortical neurons (Purpura and McMurtry 1965). tDCS has been used clinically in reducing pain (Fregni et al. 2006; Csifcsak et al. 2009), treatment for depression (Boggio et al. 2008a) and improving dexterity following stroke (Hummel et al. 2005; Boggio et al. 2007).

Cortical excitability changes induced by tDCS are dependent on the current polarity (anodal/cathodal), intensity and duration of the stimulation (Nitsche and Paulus 2000). It has been consistently shown that anodal stimulation over the motor cortex increases corticomotor excitability which is indicated by an increase in amplitude of motor evoked potentials (MEP) induced by transcranial magnetic stimulation (TMS) applied over the same cortical site; by contrast cathodal stimulation decreases cortical excitability (Liebetanz et al. 2002; Nitsche et al. 2007; Nitsche and Paulus 2000; Power et al. 2006). It has been shown that as little as 5-min anodal stimulation of the motor cortex using a low intensity 1mA current affects MEP amplitude by 30-40% for 5min following stimulation (Nitsche and Paulus 2000), whereas the effects of doubling this current intensity 2 mA and applying for a slightly longer duration (7-10min) can

enhance cortical excitability for 60 min following stimulation and increasing MEP amplitude by 40% (Jeffrey et al. 2007; Nitsche et al. 2005).

Application of tDCS has also shown increases in neuronal activation in motor cortex and interconnected areas of motor circuits and pathways as indicated by enhanced blood-oxygen level dependency Functional magnetic resonance imaging (fMRI) studies (Jang et al. 2009). Furthermore, anodal tDCS of motor cortex also increases spinal network excitability, for example stimulation of hand area of motor cortex increases disynaptic inhibition directed from extensor carpi radialis (ECR) to flexor carpi radialis (FCR) with no modification of presynaptic inhibition of FCR Ia terminals and no change to FCR Hoffmann reflex (H-reflex) recruitment curves, indicating that anodal stimulation of motor cortex increases disynaptic interneuron excitability in spinal networks (Roche et al. 2009). Recent studies have shown improvement in outcomes after applying anodal tDCS over regions controlling hand motor function such as dexterity tasks and pinch forces in stroke rehabilitation (Hummel et al. 2009) and also with regions controlling leg motor pinch forces (Jeffrey et al. 2007; Tanaka et al. 2009).

To the best of our knowledge, only one study (Cogiamanian et al. 2007) has reported the effects of tDCS on muscle function. The study compared the effects of tDCS intervention (n=9) and no intervention (control: n=15) on a time to failure (TTF) in a submaximal (35% maximal voluntary contraction strength: 35% MVC) isometric contraction task of the elbow flexors using 24 healthy men (n=10) and women (n=14). The participants in the intervention group received anodal and cathodal tDCS (1.5 mA) for 10 min in random order (with a week separating each session) before the second muscle endurance test (50 min after the first test). The control group had the second muscle endurance test without tDCS at 60 min after the first test. The study found that



the TTF decreased significantly in the second test compared with the first test for both groups; however, the magnitude of the decrease in TTF was significantly smaller (20%) for the anodal tDCS intervention compared with the cathodal tDCS intervention (35%) and the control conditions (30%). From this the authors concluded that anodal tDCS was effective in improving muscle endurance.

Our pilot study data showed no significant changes in TTF in a sustained submaximal (30% MVC) isometric contraction task from the first to the second test separated by a 60-min rest. This is contrary to the aforementioned study (Cogiamanian et al., 2007) which reported a decrease in TTF in the second test. In order to confirm the pilot study results, and examine the test-retest reliability of the TTF and MVC measures, further study is necessary to compare between two tests separated by 60 min or one week for both TTF and MVC.

Whilst the aforementioned study used both male and female participants, gender difference in endurance and fatigability exists. It has been reported that women are less fatigable and have longer endurance time than men (Hunter et al. 2006; Hunter and Enoka 2001). Furthermore, two studies have reported gender differences in responses to tDCS (Chaieb et al. 2008; Kuo et al. 2006). Thus, it may be that the effect of tDCS treatment on muscle function particularly strength endurance, differs between men and women. The previous study (Cogiamanian et al., 2007) compared two different groups of male and female participants. It should be also noted that a large variability exists in the muscle endurance time amongst individuals. Testing participants of the same gender only for both tDCS and control conditions in a crossover manner may be a more appropriate design. It is also possible that a higher tDCS intensity (e.g. 2 mA) affects muscle function greater than the current intensity used in the previous study (1.5 mA).

## **1.2 Purpose of the Study**

Therefore the present study investigated the reliability of MVC and TTF test at 30% MVC for the measurements separated by 60 min (within-day) and one week (between-day) in STUDY 1. In STUDY 2, the hypothesis that anodal tDCS (2 mA) intervention applied over the motor cortex for 10 min would increase TTF and MVC strength of the elbow flexors in comparison to a sham intervention using men only in a randomised, crossover design.

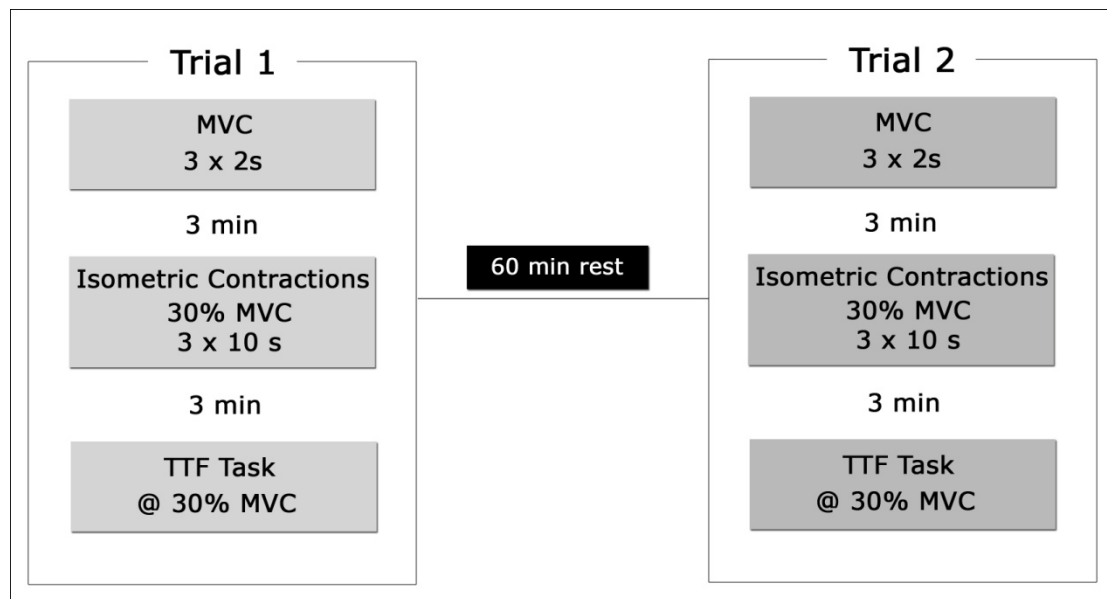
## **CHAPTER 2**

### **METHODS**

#### **2.1 Study 1 - Reliability of time to failure muscle endurance tests at submaximal intensity for the elbow flexors**

##### **2.1.1 Experimental design**

The present study consisted of one familiarisation and two experimental sessions, each session scheduled one week apart. In the familiarisation session, participants performed five MVC contractions (2 s) followed by three practice contractions at 30% MVC and one TTF task of the elbow flexors using the left arm. As shown in Figure 1, all participants performed a set of measurements consisting of MVC, 10 s isometric contraction at 30% MVC, and isometric contraction time to failure test at 30% MVC twice separated by a 60-min rest to examine the within-day reliability. The same protocol was repeated one week later to examine the between-day reliability. All tasks involved only the non-dominant (left) arm.



*Figure 1: Measurement protocol. The measurement protocol consisted of two trials (Trial 1 and Trial 2) performed 60 min apart. During each trial, participants performed 3 maximal voluntary contraction (MVC) for 2 s with a 60-s rest between contractions to determine MVC followed a 3-min rest by 3 sustained (10 s) isometric contractions at 30% MVC with a 60-s rest between contractions, then after a 3-min rest by a time to failure (TTF) isometric contraction endurance task at 30% MVC. This entire protocol was repeated one week later.*

### **2.1.2 Participants**

Ten healthy men (mean  $\pm$  SD age, height, and weight:  $33.2 \pm 9.4$  y,  $177.2 \pm 8.1$  cm,  $77.4 \pm 14.4$  kg, respectively) participated in the present study. All participants were right hand dominant based on handedness test (Oldfield 1971). They completed a medical questionnaire to screen for neuromuscular disorders, musculoskeletal disorders or injuries apparent in the upper body, or the presence of other medical conditions known to affect muscle endurance (e.g. chronic fatigue syndrome). They signed an

informed written consent form before participating in the study. The participants were prohibited consumption of caffeine four hours prior to the testing, as it is reported that ingestion of caffeine may influence rating of perceived exertion during submaximal exercise task (Doherty et al. 2004). Participants were also advised not to engage in any physical activity 24 hrs prior to the experimental sessions. Ethical approval from the Human Research Ethics Committee of Edith Cowan University was obtained prior to commencement of the study.

### **2.1.3 MVC and muscle endurance tests**

Participants were seated on a preacher curl bench by securing the shoulder joint angle at 45° flexion. The forearm of the left arm was kept supinated and the elbow joint angle was set at 90° with the joint aligned with the axis of rotation of a Cybex 6000 Isokinetic Dynamometer (Lumex Inc. Ronkonkoma, USA) (Figure 2). Torque output of the elbow's movement and contractions were collected onto a data acquisition system (PowerLab16, ADInstruments, Bella Vista, Australia) at a sampling rate of 2000 Hz, and real-time visual feedback of torque signals were displayed on a computer monitor. Although the generic torque output levels were displayed, actual torque values and duration of contractions were not shown, thus participants were blinded to actual values of output.

#### **2.1.3.1 MVC test**

MVC torque was determined by the mean of the peak torque of three MVC trials (2 s each) with a 3-min rest between trials.

### 2.1.3.2 TTF test

TTF was determined by the point in time whereby participants were unable to maintain 90% of the target torque for more than 2 s, in spite of continual verbal encouragement (Yue et al. 1997) (Figure 3).



*Figure 2: Experimental setup for participants. The maximal voluntary isometric contraction strength at the elbow joint of 90°(MVC) and time to failure (TTF) isometric task at 30% MVC. This shows the limb posture, positioning of the arm (90 °) with forearm supinated, when performing the required contractions.*

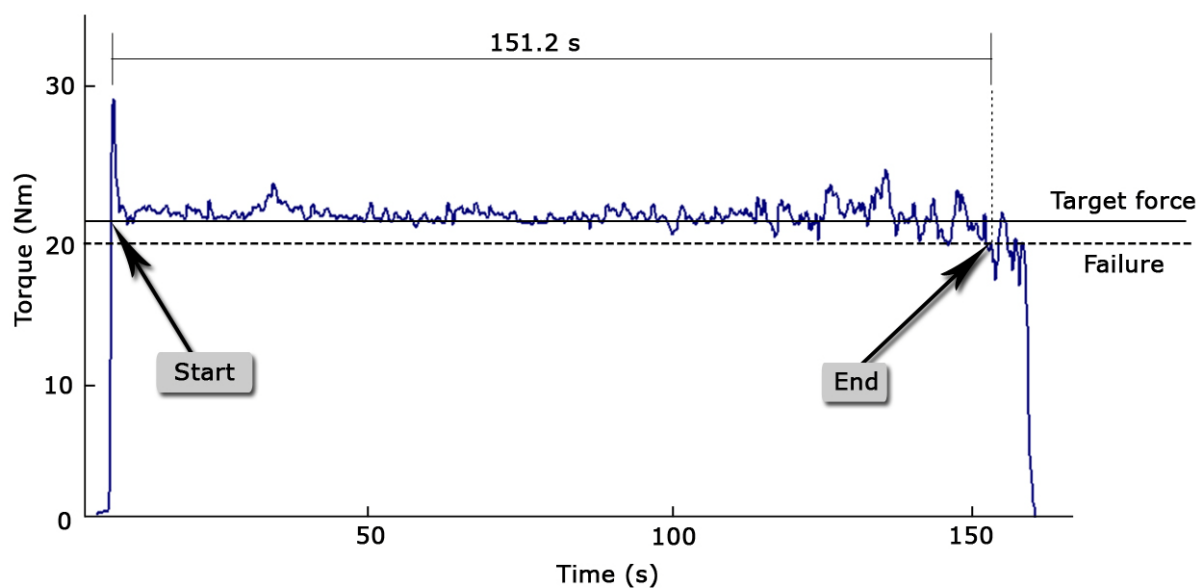


Figure 3: An example of torque output during a time to failure (TTF) task for a participant. The time started when the torque exceeds the target (22.3 Nm in this case) and ended when a participant was not able to maintain the target and the torque output decreased more than 10% of the target torque (20 Nm in this case) for more than 2 s consecutively. The TTF was 151.2 s for this subject.

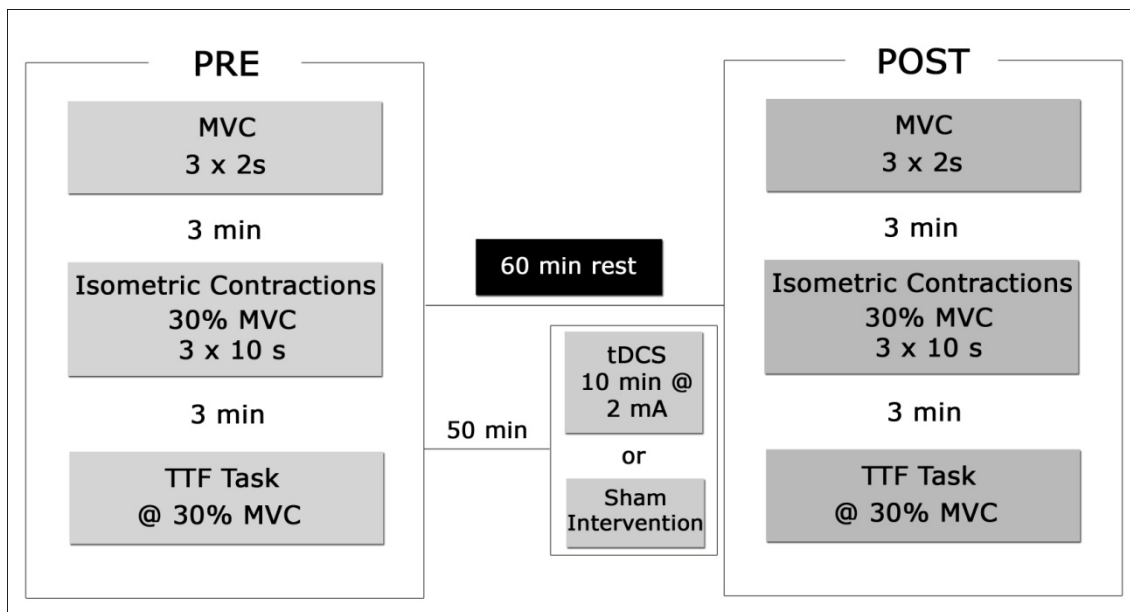
## **2.2 Study 2 - Effect of transcranial direct current stimulation (tDCS) on maximal voluntary isometric strength and endurance of the elbow flexors**

### **2.2.1 Experimental design**

The present study consisted of one familiarisation and three experimental sessions, each session conducted one week apart. All tasks involved only the non-dominant arm, which was the left arm for all participants. In the familiarisation session, participants performed five MVC contractions (2 s) followed by three practice contractions at 30% MVC and one TTF task of the elbow flexors using the left arm and at the end of the session sham tDCS intervention (see below) was applied for 10-min (Figure 4).

All subjects participated in three experimental sessions separated by a week; two sessions employed a tDCS intervention and one session employed a sham intervention. Each experimental session consisted of pre and post intervention measures and a 10-min intervention. As shown in Figure 4, the measurements consisted of three MVC followed by a 3-min rest, thereafter performing three 10-s isometric contractions at 30% MVC. Following another 3-min of rest, a TTF isometric contraction at 30% MVC was measured. This protocol was repeated 60-min later, and participants remained awake and interactive during the rest period. During the last 10-min of the 60-min rest, either a sham or tDCS intervention was administered. All participants were blinded to the type of intervention administered and outcomes of TTF task. The order for intervention conditions was randomised and counterbalanced among the participants such that the sham intervention and tDCS intervention was arranged either Sham-tDCS-tDCS, tDCS-Sham-tDCS or tDCS-Sham-tDCS, with 5 participants for each sequence.





*Figure 4: Experimental design and measurement protocol. Participants performed 3 maximal voluntary contractions (MVC) for 2 s with a 60-s rest between trials to determine the baseline MVC torque for the following 3 sustained (10 s) isometric contractions at 30%-MVC with a 60-s rest in between, and the time to failure isometric contraction endurance test (TTF) at 30%-MVC, with a 3-min rest period between each stage of testing. The whole protocol was repeated 60-min later (Post), with either tDCS or sham intervention (10-min) administered at 50-min after the baseline measures (Pre).*

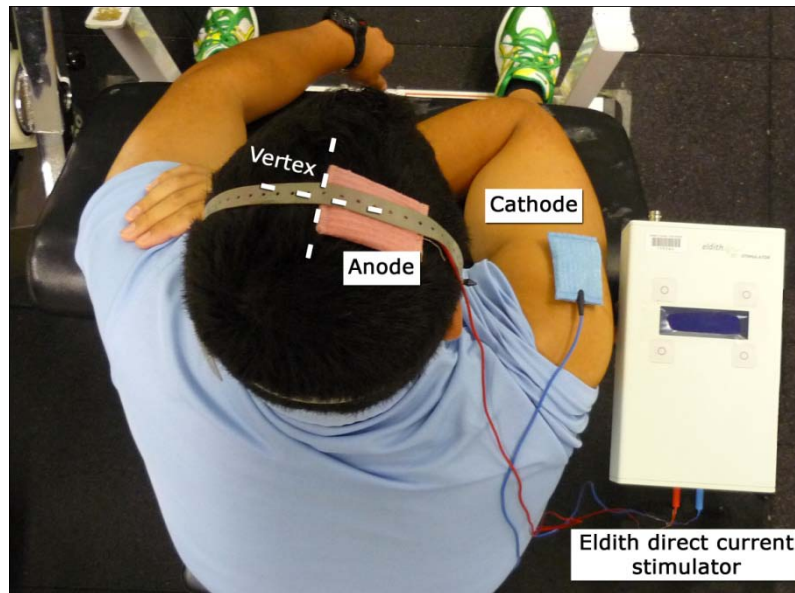
## **2.2.2 Participants**

Fifteen healthy men (mean  $\pm$  SD age, height, and weight:  $27.7 \pm 8.4$  y,  $176.4 \pm 7.4$  cm,  $72.7 \pm 8.7$  kg, respectively) participated in the present study. All of them were right-hand dominant based on the Edinburgh Handedness Inventory (Oldfield, 1971). They completed a medical questionnaire to screen for neuromuscular and musculoskeletal disorders or injuries of the upper body, or the presence of other medical conditions known to affect muscle endurance (e.g. chronic fatigue syndrome), and the participants who had any of these were excluded from the study. They signed an

informed written consent form before participating in the study. The participants were prohibited consumption of caffeine four hours prior to the testing, since it has been reported that ingestion of caffeine influences rating of perceived exertion during submaximal exercise task (Doherty et al. 2004). Ethical approval from the Human Research Ethics Committee of Edith Cowan University was obtained prior to commencement of the study, and the study was conducted in conformity with the Declaration of Helsinki.

### **2.2.3 tDCS and Sham interventions**

An Eldith direct current stimulator (Neuroconn, Ilmenau, Germany) was used in the present study, which delivered constant direct current (2 mA) through a pair of 0.3 cm thick square (24 cm<sup>2</sup>) sponge electrodes (Figure 5). The anode electrode was placed on the scalp overlying the right hemisphere motor cortical representation of the left arm, and the cathode was placed over the contralateral shoulder (Figure 5) based on the method described by (Cogiamanian et al., 2007). The sham intervention was identical to the tDCS intervention, except that the current was programmed to return to zero for the remaining time period after 30 s of stimulation (Boggio et al., 2008b; Vines et al., 2008). Rubber electrodes were kept constantly wet with saline solution in order to prevent heat from building up as well as to aid conductivity (Figure 6). Safety standards were in accordance with the limits discussed by Bikson et al. (2009). Apart from a slight tingling sensation below electrodes as reported by Dundas et al. (2007) no other side effects were expected.



*Figure 5: tDCS and sham intervention electrode placement and protocol. A participant sit on an arm curl bench, and a pair of 6 x 4 cm rubber electrodes were placed on the region overlying motor cortex controlling the left elbow flexor muscles (anode) and ipsilateral shoulder (cathode). The current was delivered through the Eldith Direct Current Stimulator.*



*Figure 6: Administration of saline solution on the electrode covered by sponge.*

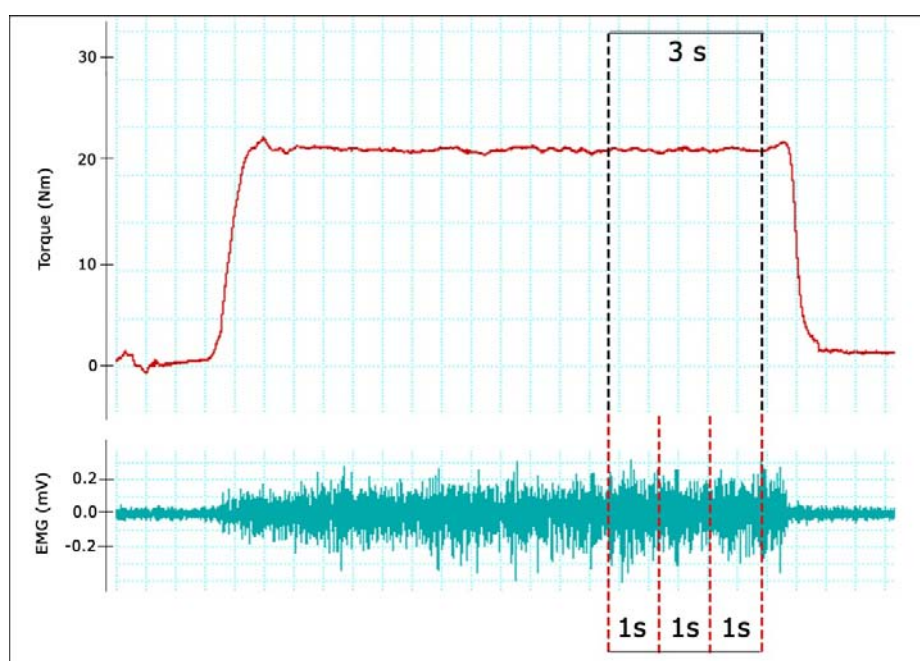
#### **2.2.4 MVC and muscle endurance tests**

In a similar way to those explained in STUDY 1, participants were seated on a preacher curl bench by securing the shoulder joint angle at 45° flexion (Figure 1). The forearm of the left arm was kept supinated and the elbow joint angle was set at 90° with the joint aligned with the axis of rotation of a Cybex 6000 isokinetic dynamometer (Lumex Inc. Ronkonkoma, USA) operated by a HUMAC system (CSMI Medical Solutions, Massachusetts, USA) installed on a personal computer (Lenovo Think Center, IBM, New York, USA). Torque signals were collected onto a data acquisition system (PowerLab16, ADInstruments, Bella Vista, Australia) at a sampling rate of 2000 Hz, and real-time visual feedback of torque signals were displayed on the computer monitor. Although the torque output levels were displayed on the monitor to show the trace of the torque in relation to the target torque, actual torque values of MVC test and duration of contractions in the muscle endurance test were not informed to the participants. MVC was determined by taking the mean torque of the three MVC trials, and the 30% MVC was set based on the MVC measures immediately before each TTF test. The TTF was determined by the time point in which participants were unable to maintain greater than 90% of the target torque output for more than 2 s (Figure 3), in spite of continual verbal encouragement (Yue et al. 1997).

#### **2.2.5 Surface electromyography (EMG) and torque fluctuation**

Biceps brachii muscle activity was recorded by EMG using pre-gelled 20-mm diameter Ag-AgCl disposable electrodes (Uni-Patch, Wasbasha, Minnesota, USA) placed 2 cm apart over the mid-belly of the biceps brachii and triceps brachii of the left arm in bipolar configuration. EMG signals were amplified and band-pass filtered (5 Hz-1 kHz) using an data acquisition system (PowerLab16 with Chart 6 software,

ADInstruments, Bella Vista, Australia) recorded at a sampling rate of 2000 Hz. EMG activity during the last 3 s of the third 10-s 30%-MVC sustained isometric task was analysed for root mean square (RMS) amplitude at every 1 s interval. Using the same time period as the EMS analysis, fluctuation of torque during the 3 s was quantified as a coefficient of variation of the torque ( $CV = SD/mean \times 100$ ) according to a previous study (Lavender and Nosaka, 2006) (Figure 7).



*Figure 7: Analysis of torque fluctuation and electromyography root-mean-square (EMG RMS) values for the last 3 s of 10 s sustained isometric contraction at 30% MVC. Torque fluctuation was sampled over the 3 s block calculating the coefficient of variation ( $CV = SD/mean \times 100$ ). RMS was calculated with every 1 s block of data across the 3 s.*

### **2.2.6 Pain perception**

Participants reported their pain perception levels before and immediately after performing the TTF task according to a modified version of the CR-10 scale, in which 1 indicated “no pain at all” and 10 indicated “extreme pain.”

### 2.2.7 Statistical Analysis

MVC strength, TTF, RMS amplitude, CV for torque fluctuation and pain perception were compared between the baseline and the post-intervention measures for each session (two tDCS intervention sessions: tDCS 1 and tDCS 2, and one sham intervention session) by a paired t-test. The Mauchly's Test of Sphericity was conducted to ensure normality of the data collected. A two-way repeated measures analysis of variance (ANOVA) was used to compare the changes in these variables from baseline to post-intervention measures among the three sessions, and between sham and tDCS 1, sham and tDCS 2, and tDCS 1 and tDCS 2, separately. For all analyses, a Predictive Analytics Software (PASW) for Windows (Version 18.0) was used. Statistical significance was accepted at  $\alpha = 0.05$ . The results are shown in mean  $\pm$  SD unless otherwise stated.

## CHAPTER 3

### RESULTS

#### 3.1 Study 1 - Reliability of time to failure muscle endurance tests at submaximal intensity for the elbow flexors

##### 3.1.1 Within-day reliability

Table 1 shows within-day reliability based on the combined outcomes over 2 weeks (n=20) of measurements (Trial 1 and Trial 2) separated by 60-min for MVC and TTF measures. A significant decrease ( $5.9 \pm 4.2$  %) in MVC was evident from Trial 1 to Trial 2. However, CV and ICC R showed that the test-retest reliability of the MVC measure was good. Regarding the TTF, no significant difference was found between Trial 1 and 2, and CV and ICC R showed that the test-retest reliability was acceptable.

*Table 1: Within-day reliability for maximal voluntary isometric contraction strength at 90° elbow flexion (MVC) and time to failure (TTF) of isometric contraction sustained task at 30% MVC. Trial 1 and Trial 2 were separated by 60-min. The results of paired t-test to compare between Trial 1 and Trial 2, and coefficient of variation (CV) and Intra-class correlation (ICC, R) based on the two trials are shown.*

	Trial 1	Trial 2	Paired T-Test (P)	CV (%)	ICC (R)
MVC (Nm)	$64.4 \pm 20.3$	$61.2 \pm 19.7$	0.000	4.3	0.99
TTF (s)	$334.4 \pm 132.3$	$309.8 \pm 94.3$	0.119	10.9	0.84

### 3.1.2 Between-day reliability

Between-day reliability was based on Trial 1 measurements taken one week apart. A significant decrease ( $5.9 \pm 5.0\%$ ) in MVC was evident from Week 1 to Week 2. However, CV and ICC R showed that the test-retest reliability of the MVC measure was good. Regarding the TTF, no significant difference was found between Week 1 and Week 2, and CV and ICC R showed that the test-retest reliability was acceptable.

*Table 2: Between-day reliability for maximal voluntary isometric contraction strength at 90° elbow flexion (MVC) and time to failure (TTF) of isometric contraction sustained task at 30% MVC. Week 1 and Week 2 were separated by one week. The results of paired t-test to compare between Week 1 and Week 2, and coefficient of variation (CV) and Intra-class correlation (ICC, R) based on the two measures from Week 1 and Week 2 are shown.*

	Week 1	Week 2	Paired T-Test (P)	CV (%)	ICC (R)
MVC (Nm)	$66.6 \pm 21.0$	$62.1 \pm 20.4$	0.000	5.9	0.987
TTF (s)	$319.7 \pm 113.8$	$347.11 \pm 153.6$	0.174	9.4	0.906



### 3.1.3 Bland Altman Plots

Figure 8 shows Bland-Altman plots for MVC and TTF. Although there are some outliers, most of the plots are located within the 2 SD limits of agreement.

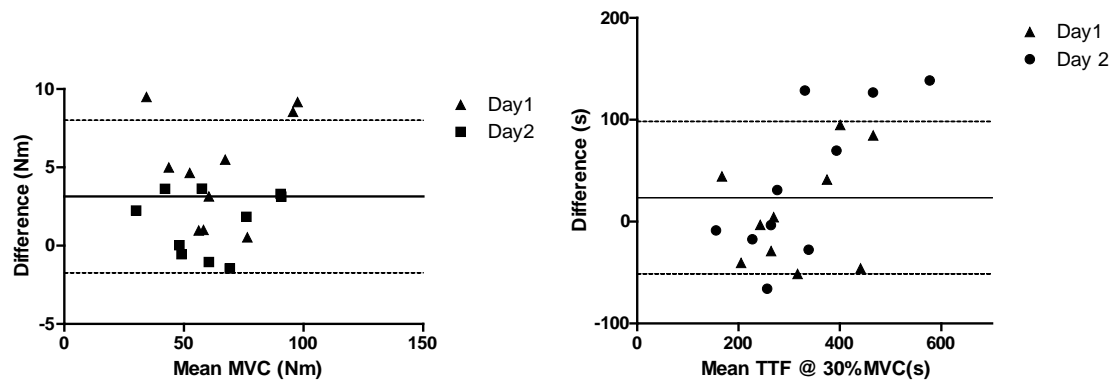


Figure 8: Bland-Altman plots for MVC and TTF based on the two measurements taken 60-min apart. Every plot represents the difference vs. mean value measured during the testing session (Day 1 and Day 2). Straight lines represent the mean difference (central line) and mean  $\pm$  2 SD (depicted by both upper and lower dotted lines).

## 3.2 Study 2 - Effect of transcranial direct current stimulation (tDCS) on maximal voluntary isometric strength and endurance of the elbow flexors

### 3.2.1 tDCS and sham interventions

Participants were unaware of the difference between the sham and tDCS interventions, and did not report any adverse effects during and after interventions.

### 3.2.2 MVC

No significant difference in the baseline MVC strength (average:  $66.0 \pm 11.4$  Nm) was evident across the conditions. As shown in Table 1, MVC torque decreased by 4.3

$\pm 2.1$  % from pre to post measurements, but no significant difference in change was evident between interventions.

*Table 3: Comparison between the measurements taken at baseline (Pre) and after either sham or tDCS interventions (tDCS1, tDCS2) (Post) for maximal voluntary isometric contraction strength (MVC) and time to failure in the 30%-MVC task (TTF). Mean  $\pm$  SD values of 15 subjects and the 95% confidence interval are shown. Differences between Pre and Post assessed by a paired t-test (P values), effect size, and comparison between interventions for the changes in the measures from Pre to Post based on a two-way repeated measures ANOVA (P values) are shown when comparing among Sham, tDCS1 and tDCS2 (3 groups), and between Sham and tDCS1, Sham and tDCS2, and tDCS1 and tDCS2 (2 groups).*

	Intervention	Pre	Post	Pre – Post	Effect size	Comparison between interventions (2-way ANOVA, P)	
		mean $\pm$ SD (95% CI)	mean $\pm$ SD (95% CI)	(t-test, P)		3 groups	2 groups
<b>MVC (Nm)</b>	Sham	65.5 $\pm$ 12.2 (58.7 – 72.3)	62.2 $\pm$ 11.1 (56.1 – 68.4)	0.00	0.28		Sham - tDCS1 0.71
	tDCS1	66.6 $\pm$ 11.3 (60.3 – 72.9)	62.0 $\pm$ 11.2 (55.8 – 68.2)	0.00	0.41	0.15	Sham - tDCS2 0.14
	tDCS2	64.9 $\pm$ 11.3 (58.6 – 71.9)	62.0 $\pm$ 10.5 (56.2 – 67.8)	0.00	0.27		tDCS1 - tDCS2 0.08
<b>TTF (s)</b>	Sham	318.6 $\pm$ 90.9 (268.3 – 368.9)	354.5 $\pm$ 144.8 (274.3 – 434.7)	0.08	0.30		Sham - tDCS1 0.45
	tDCS1	309.7 $\pm$ 93.7 (257.8 – 361.6)	328.8 $\pm$ 122.4 (261.0 – 396.6)	0.36	0.18	0.60	Sham - tDCS2 0.35
	tDCS2	308.7 $\pm$ 138.6 (231.9 – 385.5)	325.7 $\pm$ 138.6 (248.9 – 402.5)	0.29	0.12		tDCS1 - tDCS2 0.93

### 3.2.3 TTF

As shown in Table 1, TTF did not change significantly from pre to post measures, and no significant difference was found between interventions.

### **3.2.4 Muscle activity and torque fluctuation**

No significant changes in RMS amplitude were observed between baseline ( $0.29 \pm 0.14$  mV) and post-intervention measures ( $0.30 \pm 0.15$  mV) for any of the sessions. The torque fluctuation indicated by CV showed no significant difference across interventions at the baseline measures ( $1.3 \pm 0.6$  %), and no significant change in CV from the baseline was evident for the post-intervention measures ( $1.4 \pm 0.6$  %).

### **3.2.5 Pain perception**

CR-10 showed a significant increase from pre ( $0.4 \pm 0.5$ ) to post TTF task ( $7.1 \pm 1.5$ ); however, no significant difference in the change was evident between interventions.

## CHAPTER 4: DISCUSSION

Study 1 results showed that both within-day (separated by 60 min) and between-day (separated by 1 week) reliability were acceptable for MVC and TTF tests. It should be noted that MVC decreased significantly ( $P=0.000$ ) from Trial 1 to Trial 2 by  $5.9 \pm 4.2\%$  with a 60 min rest between trials; however, when the measurement was taken one week later, significant difference ( $P=0.000$ ) was evident between tests (Table 2). Cogiamanian et al. (2007) also reported a significant decrease in MVC of the elbow flexors between trials separated by 60 min. This magnitude of significant decrease was similar to that found in the reliability study. Hammer & Lindmark (2003) reported the ability to repeat MVC of a grip force in both hands with stroke patients, having no significant difference in trials performed one hour apart with complete rest in between. This would suggest the likelihood of being normally able to replicate MVC outcomes should there be complete rest. However, in the present study, additional isometric contractions were included in the procedure (Figure 1). The decrease in MVC from the first to the second trial was probably due to the sustained isometric contractions ( $3 \times 10$  s) and the time to failure test at 30% MVC that were performed after the MVC measures, which induced neuromuscular fatigue. It is interesting that although the MVC was lower in the second test, no significant difference in TTF was evident between the first and second test separated by 60 min. This is different from the finding of Cogiamanian et al. (2007) who showed a significant decrease in TTF in the second test by 40% compared with the first test separated by 60 min. The lack of correspondence in results could be due to the different position adopted to perform the elbow flexor tasks, the difference in gender population and intensity of stimulation as well as the size of electrodes used to deliver the intervention. Although the test-retest reliability is acceptable for both MVC and TTF measures as shown in CV (4.3-10.9%), ICC R (0.84

- 0.99) and Bland-Altman plots (Figure 8), a large variability exists for both measures such that more than 10% difference in TTF between trials is occasionally found. This should be considered when examining the effect of tDCS on TTF as discussed below.

The results of the present study showed no significant effects of tDCS intervention on TTF and MVC, and other variables such as RMS, torque fluctuation and pain perception. Thus the hypothesis that the tDCS intervention would increase TTF and MVC was not supported by the results, and the present study did not replicate the findings of the previous study by Cogiamanian et al. (2007) who reported a ~20% difference in TTF between anodal tDCS and control conditions.

Test-retest reliability of the two TTF tests separated by 60 min or 1 week was examined, and the results showed that the reliability of the TTF test was acceptable (CV = 9-11%) and sensitive enough to detect a possible change in TTF that was reported in the previous study (Cogiamanian et al. 2007). It should be noted that TTF did not decrease from the pre to post intervention in the present study (Table 1), but the previous study reported a significant decrease (20-35%) in TTF from the first to the second test. MVC decreased by ~6% from pre to post intervention in the present study (Table 1), and Cogiamanian et al. (2007) reported ~8% decrease in MVC between measures separated by 60 min. In the present study, the target torque was set at 30% of MVC that was measured immediately before the TTF task, but in the previous study (Cogiamanian et al. 2007), the target torque was set at 35% of baseline MVC. This may be the reason for no significant decrease in TTF in the present study. In fact, TTF was longer for the present study (average: >300 s) when compared to the previous study reporting a shorter TTF (e.g. 248 s before and 153 s after tDCS treatment).

The arm positions were different between the studies such that the present study had upper arm resting on a preacher curl bench angled at 45° from the torso (Figure 2), but the previous study had the participant's upper arm in a vertical position and the forearm

horizontally exerting an upward force. The position of the present study was adopted, because it was deemed to reduce arm and shoulder movements during the MVC and TTF measures thus improve the test-retest reliability. Rudroff et al. (2007) investigated the effect of upper arm position on TTF, and reported that TTF was shorter when the upper arm vertically positioned, as compared to when the arm was horizontally positioned. It is possible that the longer TTF outcomes in present study suggest that the muscle endurance task induced less fatigue, which attributed to the non-significant effect of tDCS on TTF.

Other differences between the two studies include the study design, gender of participants, stimulation amplitude, and electrode placement. The present study used a crossover design in which all subjects were tested for the tDCS and sham interventions in a randomised, counterbalanced order, but the previous study (Cogiamanian et al. 2007) used two groups of subjects (tDCS and Sham). Regarding the gender, the present study used only men while the previous study used both men and women. Several studies reported that the effects of tDCS intervention on cortical excitability was different between men and women (Chaieb et al. 2008; Kuo et al. 2006), probably due to sex hormones such that estrogen was found to increase cortical excitability (Inghilleri et al. 2004). It is also reported that women are less fatigable and have longer TTF than men (Hunter et al. 2006; Yoon et al. 2007). Thus, using men only in the present study was necessary to reduce potential gender effects. It is necessary to replicate the study using female participants in future research, and it is interesting to compare men and women for the effect of tDCS on MVC and TTF.

The present study delivered 2 mA in tDCS intervention, but the previous study used 1.5 mA. Jeffrey et al. (2007) reported that 2 mA tDCS stimulation when compared with 1 mA could penetrate deeper into the area controlling the leg muscles. The present study followed this, and set the amplitude higher than that of the previous study, in the assumption that the higher amplitude could increase the effect of tDCS on MVC and TTF, if such effect exists. The present study used a smaller pair of electrode (24 cm<sup>2</sup>) as

compared to the previous study (35cm<sup>2</sup>), because a smaller electrode would increase current density (Nitsche et al. 2007), and minimise the possible effects on other areas due to less focal stimulation with a larger electrode (Boros et al. 2008). This would suggest that a larger electrode would affect not only the motor cortex but also the sensory cortex that is located adjacent to the primary motor cortex. It is not known how the tDCS protocol affected the sensory cortex in the present study, but no significant changes in pain perception may suggest that the tDCS did not affect sensory cortex. Boggio et al. (2008b) reported that pain perception and pain threshold increased after applying anodal tDCS to the motor cortex. It is interesting to examine if applying tDCS on the sensory cortex affects MVC and TTF outcomes.

tDCS is known to alter firing rates of motor neurons due to a shift of resting membrane potentials (Purpura and McMurtry 1965). It is assumed that anodal tDCS intervention can increase motor unit recruitment due to the depolarisation of resting membrane potentials of neurons (Liebetanz et al. 2002) and corticospinal excitability (Nitsche and Paulus 2000). Christou & Carlton (2002) stated that increases in discharge rates of motor units induce fluctuations of motor output, and increased the amplitude of force fluctuation during voluntary contractions, suggesting an increase in motor unit recruitment. Current results showed no changes in torque fluctuation before and after either treatment. Likewise, muscle activity of the elbow flexor muscles, as reflected in EMG RMS, also showed no changes with sham and tDCS intervention. Thus, it seems reasonable to assume that tDCS did not affect motor unit recruitment in the present study.

When maximal voluntary activation is possible, tDCS would not further increase voluntary activation, suggesting a ceiling effect at corticospinal levels. Tanaka et al. (2009) did not find any effects of anodal tDCS over the leg motor cortex on contralateral reaction time, and explained that this was due to performance ceiling such that the reaction time was already quite short before the intervention. Antal et al. (2006) reported no effects of anodal tDCS on visual perception and stated that no effect was probably due to a ceiling effect; the

visual perception could not be improved further by tDCS. Moreover, Hummel et al. (2006) showed greater improvement in dexterity performance with anodal tDCS in stroke patients who had higher levels of impairment than those found with lower levels. This would suggest the more inhibited the motor cortex is, the greater the effects of tDCS on increasing voluntary activation. It is possible that when cortical excitability is decreased due to central fatigue for example, tDCS can increase cortical excitability or decrease fatigue perception, resulting in improving muscle function. This speculation should be investigated further by checking the effect of tDCS on muscle function in different levels of cortical excitability.

In conclusion, the 10-min anodal tDCS at 2 mA did not affect TTF and MVC of the elbow flexors. It appears that the tDCS was not effective when muscle function is not decreased due to central fatigue. It may be that a tDCS intervention does not increase muscle function when it is possible to maximise cortical excitability voluntarily. Since the present study did not assess MEP that could show changes in cortical excitability following tDCS or sham treatment, further studies are required to examine the effects of tDCS on cortical excitability.



## REFERENCES

- Antal A, Nitsche MA, Paulus W (2006) Transcranial direct current stimulation and the visual cortex. *Brain Res Bull* 68:459-463
- Bikson M, Datta A, Elwassif M (2009) Establishing safety limits for transcranial direct current stimulation. *Clin Neurophysiol* 120:1033-1034
- Boggio PS, Nunes A, Rigonatti SP, Nitsche MA, Pascual-Leone A, Fregni F (2007) Repeated sessions of noninvasive brain DC stimulation is associated with motor function improvement in stroke patients. *Restor Neurol Neurosci* 25:123-129
- Boggio PS, Rigonatti SP, Ribeiro RB, Myczkowski ML, Nitsche MA, Pascual-Leone A, Fregni F (2008a) A randomized, double-blind clinical trial on the efficacy of cortical direct current stimulation for the treatment of major depression. *Int J Neuropsychop* 11:249-254
- Boggio PS, Zaghi S, Lopes M, Fregni F (2008b) Modulatory effects of anodal transcranial direct current stimulation on perception and pain thresholds in healthy volunteers. *Eur J Neurosci* 15:1124-1130
- Boros K, Poreisz C, Munchau A, Paulus W, Nitsche MA (2008) Premotor transcranial direct current stimulation (tDCS) affects primary motor excitability in humans. *Eur J Neurosci* 27:1292-1300
- Chaieb L, Antal A, Paulus W (2008) Gender-specific modulation of short-term neuroplasticity in the visual cortex induced by transcranial direct current stimulation. *Vis Neurosci* 25:77-81
- Christou EA, Carlton LG (2002) Motor output is more variable during eccentric compared with concentric contractions. *Med Sci Sports Exerc* 34:1773-1778
- Cogiamanian F, Marceglia S, Ardolino G, Barbieri S, Priori A (2007) Improved isometric force endurance after transcranial direct current stimulation over the human motor cortical areas. *Eur J Neurosci* 26:242-249
- Csifcsak G, Antal A, Hillers F, Levold M, Bachmann CG, Happe S, Nitsche MA, Ellrich J, Paulus W (2009) Modulatory effects of transcranial direct current stimulation on laser-evoked potentials. *Pain Med* 10:122-132
- Doherty M, Smith PM, Hughes MG, Davidson RCR (2004) Caffeine lowers perceptual responses and increases power output during high-intensity cycling. *J Sport Sci* 22:637-643
- Fregni F, Gimenes R, Valle AC, Ferreira MJ, Rocha RR, Natalle L, Bravo R, Rigonatti SP, Freedman SD, Nitsche MA, Pascual-Leone A, Boggio PS (2006) A randomized, sham-controlled, proof of principle study of transcranial direct current stimulation for the treatment of pain in fibromyalgia. *Arthritis Rheum* 54:3988-3998

- Hammer A, Lindmark B (2003) Test-retest intra-rater reliability of grip force in patients with stroke. *J Rehabil Med* 35:189-194
- Hummel FC, Celnik P, Giraux P, Floel A, Wu WH, Gerloff C, Cohen LG (2005) Effects of non-invasive cortical stimulation on skilled motor function in chronic stroke. *Brain* 128:490-499
- Hummel FC, Heise K, Celnik P, Floel A, Gerloff C, Cohen LG (2009) Facilitating skilled right hand motor function in older subjects by anodal polarization over the left primary motor cortex. *Neurobiol Aging* 31:2160-2168
- Hummel FC, Voller B, Celnik P, Floel A, Giraux P, Gerloff C, Cohen LG (2006) Effects of brain polarization on reaction times and pinch force in chronic stroke. *BMC Neurosci* 7:73
- Hunter SK, Butler JE, Todd G, Gandevia SC, Taylor JL (2006) Supraspinal fatigue does not explain the sex difference in muscle fatigue of maximal contractions. *J Appl Physiol* 101:1036-1044
- Hunter SK, Enoka RM (2001) Sex difference in the fatigability of arm muscles depends on absolute force during isometric contractions. *J Appl Physiol* 91:2686-2694
- Inghilleri M, Conte A, Curra A, Frasca V, Lorenzano C, Berardelli A (2004) Ovarian hormones and cortical excitability. An rTMS study in humans. *Clin Neurophysiol* 115:1063-1068
- Jang SH, Ahn SH, Byun WM, Kim CS, Lee MY, Kwon YH (2009) The effect of transcranial direct current stimulation on the cortical activation by motor task in the human brain: an fMRI study. *Neurosci Lett* 460:117-120
- Jeffrey DT, Norton JA, Roy FD (2007) Effects of transcranial direct current stimulation on the excitability of the leg motor cortex. *Exp Brain Res* 182:281-287
- Kuo MF, Paulus W, Nitsche MA (2006) Sex differences in cortical neuroplasticity in humans. *Neuroreport* 17:1703-1707
- Liebetanz D, Nitsche MA, Tergau F, Paulus W (2002) Pharmacological approach to the mechanisms of transcranial DC-stimulation-induced after effects of human motor cortex excitability. *Brain* 125:2238-2247
- Nitsche MA, Doemkes S, Karakose T, Antal A, Liebetanz D, Lang N, Tergau F, Paulus W (2007) Shaping the Effects of Transcranial Direct Current Stimulation of the Human Motor Cortex. *J Neurophysiol* 97:3109-3117
- Nitsche MA, Paulus W (2000) Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *J Physiol* 527:633-639
- Nitsche MA, Seeber A, Frommann K, Klein CC, Rochford C, Nitsche MS, Fricke K, Liebetanz D, Lang N, Antal A, Paulus W, Tergau F (2005) Modulating parameters of excitability during and after transcranial direct current stimulation of the human motor cortex. *J Physiol* 568:291-303

- Oldfield RC (1971) The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9:97-113
- Paulus W (2004) Outlasting excitability shifts induced by direct current stimulation of the human brain. *Suppl Clin Neurophysiol* 57:708-714
- Power HA, Norton JA, Porter CL, Doyle Z, Hui I, Chan KM (2006) Transcranial direct current stimulation of the primary motor cortex affects cortical drive to human musculature as assessed by intermuscular coherence. *J Physiol* 577:795-803
- Purpura DP, McMurtry JG (1965) Intracellular activities and evoked potential changes during polarisation of motor cortex. *J Neurophysiol* 28:166-185
- Roche N, Lackmy A, Achache V, Bussel B, Katz R (2009) Impact of transcranial direct current stimulation on spinal network excitability in humans. *J Physiol* 587:5653-5664
- Rudroff T, Barry BK, Stone AL, Barry CJ, Enoka RM (2007) Accessory muscle activity contributes to the variation in time to task failure for different arm postures and loads. *J Appl Physiol* 102:1000-1006
- Tanaka S, Hanakawa T, Honda M, Watanabe K (2009) Enhancement of pinch force in the lower leg by anodal transcranial direct current stimulation. *Exp Brain Res* 196:459-465
- Yoon T, Schlinder Delap B, Griffith EE, Hunter SK (2007) Mechanisms of fatigue differ after low- and high-force fatiguing contractions in men and women. *Muscle Nerve* 36:515-524
- Yue GH, Bilodeau M, Hardy PA, Enoka RM (1997) Task-depedent effect of limb immobilization on the fatigability of the elbow flexor muslces in humans. *Experimental Physiology* 82:567-592

## APPENDIX A – ADVERTISEMENT

SCHOOL OF EXERCISE,  
BIOMEDICAL AND HEALTH SCIENCES



# MIND OVER MATTER FACT OR FICTION?



Come join and be part of this interesting study to explore the possibility of improving muscular endurance by changing brain activity levels. Do NOT miss out on this chance to be part of a breakthrough study which will open doors to the unknown!

**\*Participants who complete this study will receive a Goodie Bag worth \$50 and more!\***

"That's one small step for man, one giant leap for mankind."

- Neil Armstrong

If interested, please contact  
Benjamin @ 0411569212  
b.kan@ecu.edu.au

"Mind Over Matter"  
Benjamin  
0411569212

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## APPENDIX B – INFORMATION LETTER: STUDY 1

SCHOOL OF EXERCISE,  
BIOMEDICAL AND HEALTH SCIENCES



### Information Letter

*For Study 1 of*

## **Reliability of 30% and 100% Maximum voluntary isometric contraction (MVIC) “time-to-failure” tasks**

Investigator: Benjamin Kan

Supervisor: Prof Ken Nosaka

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

270 Joondalup Drive, Joondalup WA 6027

Phone: 6304-2264

email: [b.kan@ecu.edu.au](mailto:b.kan@ecu.edu.au)

Thank you for expressing your interest in this research.

The purpose of this information sheet is to provide you with an overview of the study that you may participate in as a subject.

Please read the following information carefully and feel free to ask for any further explanation, should you have any other doubts or enquiries.

**Purpose of study**

The purpose of this study is to find out if muscle endurance time of the elbow flexor muscles (biceps) is similar between tests separated by 1 hour and 1 week. You are required to performed a muscle endurance test; being a 30% effort, and maximal effort contractions of the bicep muscles as shown below. You will be asked to maintain the endurance task for as long as possible, and the time that you can maintain the contraction will be measured.

**Description of study**

If you agree to participate in this study, you will be asked to come to the Exercise Physiology Laboratory (Joondalup campus, Building 19.150) on 3 separate occasions consisting of 1 familiarisation session and 2 experimental sessions. All sessions will be scheduled over 3 consecutive weeks with one week between sessions and each session will take approximately 1.5 hours or less.

*Familiarisation session*

During the familiarisation session, you will be shown the muscle endurance tasks performed at the two required intensities, as well as all experimental procedures. You will be performing the endurance task with both a 30% effort and also maximal effort contractions to help familiarize you on how to perform the task best.

### *Experimental sessions*

There will be in total 3 experimental sessions. During the first two sessions, you will be required to perform a 30% effort produced at the bicep muscles, and hold it for as long as you can till you reach failure (point at which you can no longer maintain the required intensity). In each session, the designated muscle endurance task will be performed twice with 60 minutes rest in between.

### **Muscle endurance tasks**

You will be seated on a preacher curl bench, with your forearm of the non-dominant arm set at 90° strapped securely to a Cybex 6000 isokinetic dynamometer (Lumex Inc. Ronkonkoma, USA). This machine sends the force output signals to a computer which indicates your force generated on a computer screen, and will act as a feedback for you. While seated on the preacher curl bench, you will be requested to perform two bouts of muscle endurance tasks at the elbow flexor muscles of the non-dominant hand, with 60 minutes of rest between the two bouts. This muscle endurance task is also known as a “time-to-failure” task, whereby the time point in which you are unable to hold the contraction any longer, will be determined from these tests. The intensity at which the task is to be performed will be either fixed at 30% of your maximal effort or at maximal effort.

### **Measurements**

The following measurements will be taken during the course of each session in the following order.

## 1. Maximal voluntary contraction (MVC) and muscle endurance task

You will be required to perform three 3 seconds maximal bicep curl contractions with 60 seconds rest between each trial. After a 60 seconds rest period you will be required to perform 2 bouts of the 30% effort endurance task or 100% effort endurance task as shown below.

### *30% effort endurance task*

You will be required to perform the endurance task at 30% effort for a minimum of 150 seconds or till failure. Failure is determined by the torque levels, when you are unable to maintain the required force for 2 seconds. You will be given 60 minutes of rest before repeating the muscle endurance test.

### **Requirements and Benefits**

You will be asked to report to the laboratory as explained above. You will be requested not to be involved in any form of upper body training, exercises or activities involving the elbow flexors muscles during the course of this study. Prior to testing days, you are to refrain from any form of strenuous activity for at least 24 hours. Caffeine consumption is not allowed for at least 4 hours prior to the test. Should you not feeling well or are on any medication, do let the investigator know and other arrangements could be made.

Your participation is greatly appreciated as it helps us to know whether muscle endurance time is similar between tests. If so, interventions can be introduced to help increase endurance outcomes. You will also understand the research topic and methods



used in this study. We are most happy to provide some information associated with this study upon your request.

### **Risk and Ethical Considerations**

You may experience a small degree of muscle soreness, at the elbow flexors, following the testing days, all of which should subside by the second day or so. This is often seen after any form of unaccustomed exercise containing concentric muscle actions. No direct comparisons between individuals participating in the study will be made at any stage of the testing. You are therefore not in competition with any other individual in the study and will in no way be made to feel that your results are inadequate or incorrect. All personal information and test results will remain confidential and will not be used to any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will also be free to withdraw from this study at any stage and for any reason without prejudice.

### **Medical Questionnaire**

As this study involves a testing protocol, it is required that you be healthy at the time of testing. For this reason you will be asked to complete a medical questionnaire prior to the commencement of testing. Answering 'Yes' to a question will not always disqualify you from participation in the study. However you may be asked to consult your doctor for clearance prior to participation.

### **Questions / Further Information**

This project has been approved by the ECU Human Research Ethics Committee. It is intended to present the results of this research through conferences and publish journals

and reports. Published results will not contain information that can be used to identify participants unless specific consent for this has been obtained. A copy of published results may be obtained by the participants upon requests.

If you have read and understood the description of this study and wish to volunteer as a subject, the next step is to sign the informed consent form. By signing this form you acknowledge that you are aware of the procedures, tests and risks involved. You remain free to withdraw from the study at any time for whatever reason; signing the informed consent form does not remove your rights to withdraw from this study.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would like to speak to an independent person, you may contact:

**Research Ethics Officer**

Human Research Ethics Committee,

Edith Cowan University

270 Joondalup Drive

Joondalup WA 6027

Phone: (08) 6304 2170

Email: [research.ethics@ecu.edu.au](mailto:research.ethics@ecu.edu.au)

Thank you for taking time to read this information letter. If you have any questions or require any further information about this project, please contact Benjamin Kan ([b.kan@ecu.edu.au](mailto:b.kan@ecu.edu.au)).

Investigator: Benjamin Kan (MSc Candidate)

Signature: \_\_\_\_\_

Date: \_\_\_\_ / \_\_\_\_ / \_\_\_\_

## APPENDIX C – INFORMATION LETTER: STUDY 2

SCHOOL OF EXERCISE,  
BIOMEDICAL AND HEALTH SCIENCES



### Information Letter

*For Study 2 of*

**Effects of Transcranial Direct Current Stimulation (tDCS) on  
corticomotor excitability and muscular endurance of the elbow flexors.**

Investigator: Benjamin Kan

Supervisor: Prof Ken Nosaka

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

270 Joondalup Drive, Joondalup WA 6027

Phone: 6304-2264

email: [b.kan@ecu.edu.au](mailto:b.kan@ecu.edu.au)

Thank you for expressing your interest in this research.

The purpose of this information sheet is to provide you with an overview of the study that you may participate in as a subject.

Please read the following information carefully and feel free to ask for any further explanation, should you have any other doubts or enquiries.

## **Purpose of study**

The purpose of this study is to investigate how electrical stimulation to your brain affects your muscle endurance. This electrical stimulation technique is called transcranial direct current stimulation (tDCS), whereby a very weak electrical current (2 milli amperes [mA], which is about the intensity of a 1.5v battery) is delivered and applied to the surface of the scalp via electrodes. There are two electrodes used, the positive electrode also known as the “anode”, and the negative electrode otherwise known as the “cathode”. The methods of tDCS we are using is known as anodal tDCS, whereby the anode is placed on the scalp to deliver the electrical current. Although this method of tDCS treatment has been used clinically with patients who suffer from depression, epilepsy and chronic pain, little is known about the effect of tDCS on muscle function, especially on muscle endurance of the elbow flexors. This study will examine the effect of 10 minutes of anodal tDCS applied to the scalp, on muscle endurance of the bicep muscle, by applying a 30% effort and holding and enduring that contraction for as long as possible, together with its effect on excitability of your brain, your fatigue perception, brain and muscle oxygen levels

## **Description of study**

If you agree to participate in this study, you will be asked to come to the Exercise Physiology Laboratory (Joondalup campus, Building 19.150) on 4 separate occasions consisting of 1 familiarisation session and 3 experimental sessions. All sessions will be scheduled over 4 consecutive weeks with one week between sessions.

### *Familiarization session*

During the familiarisation session, you will be shown two muscle endurance tasks and all experimental procedures. Weak electric current of tDCS treatment will also be applied to the scalp for approximately 30 seconds. This is to familiarize you with the weak intensity of current used during actual experimental sessions.

### *Experimental sessions*

For the 3 experimental sessions, you will perform either a 30% effort of your maximal strength produced at the bicep muscles and hold it for as long as you can. In each session, the designated muscle endurance task will be performed twice with a 60 minutes rest in between. During the last 10 minutes of the 60 minutes rest period, tDCS will be applied to your scalp for 10 minutes. Measurements of brain excitability will be taken before and after tDCS application as described below. All sessions will take approximately 1.5 hours or less.

### **Muscle endurance tasks**

You will be seated on a preacher curl bench, with your forearm of the non-dominant arm set at 90° strapped securely to a Cybex 6000 isokinetic dynamometer (Lumex Inc. Ronkonkoma, USA). This machine then send the force output signals to computer screen which indicates your force generated, and will act as a feedback for you. While seated on a preacher curl bench, you will be requested to perform two bouts of muscle endurance tasks at the elbow flexor muscles of the non-dominant hand, with 60 minutes of rest between the two bouts. The muscle endurance task will be either at 30% effort of

your maximal force produced, or a maximal strength endurance test, the “time-to-failure” will be determined from these tests.

### **Transcranial direct current stimulation (tDCS)**

Weak tDCS electric currents will be delivered via a pair of electrodes, with the positive electrode (anode) placed on the surface of the scalp, over where the motor cortex lies which controls the non dominant hand, and the cathode placed over the shoulder of the same side of where the electrode is placed. Stimulating electrodes will be a pair of 0.3 cm thick square (35cm<sup>2</sup>) sponge electrodes soaked with saline, which helps conductivity of the electric currents and to reduce any irritation to the skin during treatment There is no known side effect to tDCS so far but it has only been reported that a very slight tingly sensation can be felt initially for the first 30 seconds or less which then fades away. This tingly sensation occurs due to your skin sensing a change in electrical field when either slowly increasing or decreasing the intensity of electric current. Once the required intensity of 2mA (this intensity is similar to that of a normal AA battery) or ramping down to 0mA has been reached, the skin does not feel anymore changes in electric current (as intensity in current has stabilized) the tingly sensation disappears instantaneously.

### **Measurements**

The following measurements will be taken during the course of each session in the following order.

1. Muscle Activity

Muscle activity of the biceps and triceps brachii is recorded by the use of electromyography. After swabbing the skin with alcohol, electrodes will be placed on the muscle belly and tendon of the biceps and triceps, to detect your muscle activity. This will tell us if muscle activation is altered with tDCS.

## 2. Maximal voluntary contraction (MVC) and muscle endurance task

You will be required to perform three 3-second maximal bicep curl contractions with 60 seconds of rest between each trial. After a 60 second rest period, you will be required to perform 2 bouts of the 30% effort endurance task or 100% effort endurance task as shown below.

### *30% effort endurance task*

You will be required to sustain a 30% effort endurance task for a minimum of 150 seconds or till failure that is determined by the torque levels, when you are unable to maintain the required force for 2 s. You will be given 60 minutes of rest before repeating the muscle endurance test. However 50 minutes into the rest period, tDCS treatment will be applied for 10 minutes. Immediately after the tDCS treatment, both MVC and the muscle endurance task will be performed again.

## 3. Pain / Fatigue perception

You will be asked to indicate your perception of pain / fatigue and exertion or alertness before and during the tests (i.e. after muscle endurance tests, before and after tDCS) using a -Borg category-ratio 10 (CR-10) RPE scale . The scale consists of 1 to 10 where 1 represents very little pain / effort exerted and 10 represents an extremely pain / strong effort exerted.



## **Requirements and Benefits**

You will be asked to report to the laboratory as explained above. You will be requested not to be involved in any form of upper body training, exercises or activities involving the elbow flexors muscles during the course of this study. Prior to testing days, you are to refrain from any form of strenuous activity for at least 24 hours. Caffeine consumption is not allowed for at least 4 hours prior to the test. Should you not feeling well or are on any medication, do let the investigator know and other arrangements could be made.

Your participation is greatly appreciated as it helps us to understand how tDCS might help muscular endurance and would open doors to explore and investigate the underlying mechanisms behind it.

You will understand the research topic and methods used in this study. We are most happy to provide more information associated with this study upon your request.

## **Risk and Ethical Considerations**

Application of tDCS is safe and is currently used to patients suffering from depression, epilepsy and also chronic stroke. There has been no side effects of tDCS reported but has only been reported that during stimulation, a light tingling sensation can be felt on the skin below the electrodes which will disappear within 30 s or so (as explained in detail above). You may experience a small degree of muscle soreness, at the elbow flexors, following the testing days, all of which should subside by the second day or so. This is often seen after any form of unaccustomed exercise containing concentric muscle actions. No direct comparisons between individuals participating in the study

will be made at any stage of the testing. You are therefore not in competition with any other individual in the study and will in no way be made to feel that your results are inadequate or incorrect. All personal information and test results will remain confidential and will not be used to any purpose other than the current study. Moreover, no data analysis will include your name or information that may identify you specifically as a subject. You will also be free to withdraw from this study at any stage and for any reason without prejudice.

### **Medical Questionnaire**

As this study involves stimulation of the brain and the use of magnetism for taking measurements, there are various factors which may exclude you from participation in this study. These include having a pacemaker or metal objects like cerebral aneurysm clips inside your body. Additionally, as this study involves a testing protocol, it is required that you be healthy at the time of testing. For this reason you will be asked to complete a medical questionnaire prior to the commencement of testing. Answering 'Yes' to a question will not always disqualify you from participation in the study. However you may be asked to consult your doctor for clearance prior to participation.

### **Questions / Further Information**

This project has been approved by the ECU Human Research Ethics Committee. It is intended to present the results of this research through conferences and publish journals and reports. Published results will not contain information that can be used to identify participants unless specific consent for this has been obtained. A copy of published results may be obtained by the participants upon requests.

If you have read and understood the description of this study and wish to volunteer as a subject, the next step is to sign the informed consent form. By signing this form you acknowledge that you are aware of the procedures, tests and risks involved. You remain free to withdraw from the study at any time for whatever reason; signing the informed consent form does not remove your rights to withdraw from this study.

Should you have any questions relating to any of the information provided above, please feel free to contact me for a further explanation. If you have any concerns about this research, or would like to speak to an independent person, you may contact:

**Research Ethics Officer**

Human Research Ethics Committee,

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270 Joondalup Drive

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Phone: (08) 6304 2170

Email: [research.ethics@ecu.edu.au](mailto:research.ethics@ecu.edu.au)

Thank you for taking time to read this information letter. If you have any questions or require any further information about this project, please contact Benjamin Kan ([b.kan@ecu.edu.au](mailto:b.kan@ecu.edu.au)).

Investigator: Benjamin Kan (MSc Candidate)

Signature: \_\_\_\_\_

Date: \_\_\_\_ / \_\_\_\_ / \_\_\_\_

# APPENDIX D – INFORMED CONSENT FORM: STUDY 1

SCHOOL OF EXERCISE,  
BIOMEDICAL AND HEALTH SCIENCES



## Informed Consent Document

### Title of Study:

Reliability of 30% and 100% Maximum voluntary isometric contraction (MVIC) “time-to-failure” tasks

### Researcher (contact details)

Investigator:

Benjamin Kan  
Tel: 6304 – 2264,  
Email: [b.kan@ecu.edu.au](mailto:b.kan@ecu.edu.au)

Supervisor:

Professor Ken Nosaka  
Tel: 6304 – 5655  
Email: [k.nosaka@ecu.edu.au](mailto:k.nosaka@ecu.edu.au)

School of Exercise, Biomedical and Health Sciences  
Faculty of Computing, Health and Science  
Edith Cowan University  
270 Joondalup Drive, Joondalup WA 6027, Australia

### Indication of consent of participation

I confirm the following:

- I have been provided with clear information as given in the “Information letter”, which explains all the procedures of the study.
- I have read and understood the information provided and the possible risks involved while participating in the study.
- I have been given ample opportunity to enquire on my doubts and questions and I have been answered adequately.
- I am aware that should there be any further questions and doubts, I can contact the research team.
- I understand the requirements and instructions of the study as clearly mentioned in the “Information letter”.
- I understand that the information I provide will be kept confidential and my identity will not be disclosed without prior consent.
- I understand the information provided will only be used for the purposes of this research project, and I understand how the information will be used.
- I understand that I am free to withdraw from further participation at anytime without any given explanation or penalty.
- I give my full consent and agree to participate in this study.

Signature: \_\_\_\_\_

Investigator’s Signature

Name: \_\_\_\_\_  
\_\_\_\_\_

Date: \_\_\_\_\_  
\_\_\_\_\_

Date:

Contact: \_\_\_\_\_

# APPENDIX E – INFORMED CONSENT FORM: STUDY 2

SCHOOL OF EXERCISE,  
BIOMEDICAL AND HEALTH SCIENCES



## Informed Consent Document

### Title of Study:

Effects of transcranial direct current stimulation (tDCS) on corticomotor excitability and muscular endurance of the elbow flexors

### Researcher (contact details)

Investigator:

Benjamin Kan  
Tel: 6304 – 2264,  
Email: [b.kan@ecu.edu.au](mailto:b.kan@ecu.edu.au)

Supervisor:

Professor Ken Nosaka  
Tel: 6304 – 5655  
Email: [k.nosaka@ecu.edu.au](mailto:k.nosaka@ecu.edu.au)

School of Exercise, Biomedical and Health Sciences  
Faculty of Computing, Health and Science  
Edith Cowan University  
270 Joondalup Drive, Joondalup WA 6027, Australia

### Indication of consent of participation

I confirm the following:

- I have been provided with clear information as given in the “Information letter”, which explains all the procedures of the study.
- I have read and understood the information provided and the possible risks involved while participating in the study.
- I have been given ample opportunity to enquire on my doubts and questions and I have been answered adequately.
- I am aware that should there be any further questions and doubts, I can contact the research team.
- I understand the requirements and instructions of the study as clearly mentioned in the “Information letter”.
- I understand that the information I provide will be kept confidential and my identity will not be disclosed without prior consent.
- I understand the information provided will only be used for the purposes of this research project, and I understand how the information will be used.
- I understand that I am free to withdraw from further participation at anytime without any given explanation or penalty.

- I agree to be treated with Transcranial Direct Current Stimulation (tDCS) and I also understand that tDCS is safe and has no side effects on me, and the investigator has been trained in all aspects of the delivery of safe tDCS.
- I give my full consent and agree to participate in this study.

Signature: \_\_\_\_\_

Investigator's Signature

Name: \_\_\_\_\_  
\_\_\_\_\_

Date: \_\_\_\_\_

Date: \_\_\_\_\_

Contact: \_\_\_\_\_

# APPENDIX F – MEDICAL QUESTIONNAIRE

SCHOOL OF EXERCISE,  
BIOMEDICAL AND HEALTH SCIENCES



## Pre-Exercise Medical Questionnaire

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/ or illness that may influence your testing and performance. If you are under 18 then a parent or guardian should complete the questionnaire on your behalf or check your answers and then sign in the appropriate section to verify that they are satisfied the answers to all questions are correct to the best of their knowledge.

Please answer all questions as accurately as possible, and if you are unsure about anything please ask for clarification. All information provided is strictly confidential.

### Personal Details

Name: \_\_\_\_\_

Date of Birth (DD/MM/YYYY): \_\_\_\_\_ Gender: Female/ Male

### PART A

1. Are you a male over 45 yr, or female over 55 yr or who has had a hysterectomy or are postmenopausal?

Yes No

If YES, please provide details

2. Are you a regular smoker or have you quit in the last 6 months? Y N

3. Did a close family member have heart disease or surgery, or stroke before the age of 60 years? Y N Unsure

4. Do you have, or have you ever been told you have blood pressure above 140/90 mmHg, or do you current take blood pressure medication? Y N Unsure



- |    |  |   |   |        |
|----|--|---|---|--------|
| 5. | Do you have, or have you ever been<br>_____ told you have, a total cholesterol level above 5.2 mmol/L (200 mg/dL)? | Y | N | Unsure |
| 6. | Is your BMI (weight/height <sup>2</sup> ) greater<br>_____ than 30 kg/m <sup>2</sup> ?                             | Y | N | Unsure |

**PART B**

- |    |  |   |   |
|----|--|---|---|
| 1. | Have you ever had a serious asthma<br>_____ attack during exercise?  | Y | N |
| 2. | Do you have asthma that requires<br>_____ medication?  | Y | N |
| 3. | Have you had an epileptic seizure in<br>_____ the last 5 years?  | Y | N |
| 4. | Do you have any moderate or severe<br>_____ allergies?   | Y | N |
| 5. | Do you, or could you reasonably, have<br>_____ an infectious disease?  | Y | N |
| 6. | Do you, or could you reasonably, have<br>_____ an infection or disease that might be aggravated by exercise? | Y | N |
| 7. | Are you, or could you reasonably be,<br>_____ pregnant?  | Y | N |

**PART C**

1. Are you currently taking any prescribed or non-prescribed medications?

Y N

\_\_\_\_\_

2. Have you had, or do you currently have, any of the following?

If YES, please provide details

Rheumatic fever

Y N

\_\_\_\_\_

Heart abnormalities

Y N

\_\_\_\_\_

Diabetes

Y N

\_\_\_\_\_

Epilepsy

Y N

\_\_\_\_\_

Recurring back pain that would make

Y N

\_\_\_\_\_

exercise problematic, or where exercise may aggravate the pain

Recurring neck pain that would make

Y N

\_\_\_\_\_

exercise problematic, or where exercise may aggravate the pain

Any neurological disorders that would

Y N

\_\_\_\_\_

make exercise problematic, or where exercise may aggravate the condition

Any neuromuscular disorders that would

Y N

\_\_\_\_\_

make exercise problematic, or where exercise may aggravate the condition

Recurring muscle or joint injuries that

Y N

\_\_\_\_\_

would make exercise problematic, or where exercise may aggravate the condition

A burning or cramping sensation in your

Y N

\_\_\_\_\_

legs when walking short distances

Chest discomfort, unreasonable Y N

\_\_\_\_\_  
breathlessness, dizziness or fainting,  
or blackouts during exercise

#### **PART D**

Have you had flu in the last week? Y N

\_\_\_\_\_  
Do you currently have an injury that might Y N

\_\_\_\_\_  
affect, or be affected by, exercise?

#### **PART E**

1. Have you had Transcranial Direct Current Y N

\_\_\_\_\_  
Stimulation (tDCS) / Transcranial Magnetic  
Stimulation (TMS) before? If 'Yes', have  
you been tested in the last 6 months?

2. Have you participated in an upper body Y N

\_\_\_\_\_  
resistance training program in the last month?

3. Do you have any neurological disorders? Y N

\_\_\_\_\_  
4. Do you have any neuromuscular disorders? Y N

\_\_\_\_\_  
5. Have you ever had cardiac surgery? Y N

\_\_\_\_\_  
i.e. valve replacement, pacemaker. If 'Yes',  
provide details.

6. Have you ever had ear surgery? Y N

\_\_\_\_\_  
i.e. cochlear implants, hearing aid. If 'Yes',  
provide details.

7. Have you ever had brain surgery? Y N

\_\_\_\_\_  
i.e. shunt, aneurysm clip. If 'Yes',  
provide details.

8. Do you have any history of severe migraines?      Y      N  
\_\_\_\_\_

9. Do you have any surgically implanted foreign      Y      N  
objects in your body? If 'Yes',  
provide details.

10. Are you aware that you should talk to your      Y      N  
doctor about your participation in this study if  
you have a mental illness or disorder?

\*Is there any other condition not previously mentioned that may affect your ability to  
participate in this study?

Y      N  
\_\_\_\_\_

### **Declaration (to be signed in the presence of the researcher)**

I acknowledge that the information provided on this form, is to the best of my  
knowledge, a true and accurate indication of my current state of health.

#### **Participant**

Name: \_\_\_\_\_ Date (DD/MM/YYYY): \_\_\_\_\_

Signature: \_\_\_\_\_

#### **Researcher:**

Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date (DD/MM/YYYY): \_\_\_\_\_

\_\_\_\_\_

**Parent/ Guardian** (only if applicable)

I, \_\_\_\_\_, as parent / guardian of  
Mr/ Miss \_\_\_\_\_, acknowledge  
that I have checked the answers provided to all questions in the medical  
questionnaire and verify that they are correct to the best of my knowledge.

Signature: \_\_\_\_\_

Date (DD/MM/YYYY): \_\_\_\_\_

**Practitioner** (only if applicable)

I, Dr \_\_\_\_\_ have read the medical  
questionnaire and information/ consent form provided to my patient Mr/Miss/  
Ms \_\_\_\_\_, and clear him/ her medically for  
involvement in exercise testing.

Signature: \_\_\_\_\_

Date (DD/MM/YYYY): \_\_\_\_\_

# APPENDIX G –HANDEDNESS INVENTORY

## Edinburgh Handedness Inventory<sup>1</sup>

Your Initials: \_\_\_\_\_

Please indicate with a check (✓) your preference in using your left or right hand in the following tasks.

Where the preference is so strong you would never use the other hand, unless absolutely forced to, put two checks (✓✓).

If you are indifferent, put one check in each column (✓ | ✓).

Some of the activities require both hands. In these cases, the part of the task or object for which hand preference is wanted is indicated in parentheses.

Task / Object	Left Hand	Right Hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking a Match (match)		
10. Opening a Box (lid)		
Total checks:	LH =	RH =
Cumulative Total	CT = LH + RH =	
Difference	D = RH – LH =	
Result	R = (D / CT) × 100 =	
Interpretation: (Left Handed: R < -40) (Ambidextrous: -40 ≤ R ≤ +40) (Right Handed: R > +40)		

<sup>1</sup> Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97-113.

## APPENDIX H– ETHICS APPROVAL

Dear Benjamin

**Project Number: 4021**

**Project Name: Effect of transcranial direct current stimulation (tDCS) on corticomotor excitability and muscular endurance**

Ethics approval for your research project was granted from 17 November 2009 to 31 July 2011.

The *National Statement on Ethical Conduct in Human Research* requires that all approved projects are subject to monitoring conditions. This includes completion of an annual report (for projects longer than one year) and completion of a final report at the end of the project.

An **ANNUAL REPORT** is due on **17 November 2010**.

A copy of the ethics report form can be found on the [Ethics Website](#)

Please complete the ethics report form and return the signed form.

Regards

Kim

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