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# Transcranial direct current stimulation (tDCS) over primary motor cortex leg area promotes dynamic balance task performance

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## HIGHLIGHTS

- Anodal tDCS over primary motor cortex leg area promotes dynamic balance performance and decreases error scores.
- Improvement in balance performance can be predicted by the kinematic profile of the movement.
- TDCS strengthens the relationship between dynamic balance performance and the kinematic variable velocity.

## ABSTRACT

*Objective:* The aim of the study was to investigate the effects of facilitatory anodal tDCS (a-tDCS) applied over the leg area of the primary motor cortex on learning a complex whole-body dynamic balancing task (DBT). We hypothesized that a-tDCS during DBT enhances learning performance compared to sham tDCS (s-tDCS).

*Methods:* In a randomized, parallel design, we applied either a-tDCS ($n = 13$) or s-tDCS ($n = 13$) in a total of 26 young subjects while they perform the DBT. Task performance and error rates were compared between groups. Additionally, we investigated the effect of tDCS on the relationship between performance and kinematic variables capturing different aspects of task execution.

*Results:* A-tDCS over M1 leg area promotes balance performance in a DBT relative to s-tDCS, indicated by higher performance and smaller error scores. Furthermore, a-tDCS seems to mediate the relationship between DBT performance and the kinematic variable velocity.

*Conclusions:* Our findings provide novel evidence for the ability of tDCS to improve dynamic balance learning, a fact, particularly important in the context of treating balance and gait disorders.

*Significance:* TDCS facilitates dynamic balance performance by strengthening the inverse relationship of performance and velocity, thus making tDCS one potential technique to improve walking ability or help to prevent falls in patients in the future.

## 1. Introduction

Non-invasive brain stimulation techniques such as transcranial direct current stimulation (tDCS) have been extensively shown to modify motor learning in various scenarios including motor sequence learning (Nitsche et al., 2003; Vines et al., 2008; Kantak et al., 2012; Waters-Metenier et al., 2014) or visuo-motor coordination (Antal et al., 2004; Reis et al., 2009; Vollmann et al., 2013). Aside from deviations in electrode setup, tDCS intensity

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*Abbreviations:* tDCS, transcranial direct current stimulation; a-tDCS, anodal transcranial direct current stimulation; s-tDCS, sham transcranial direct current stimulation; M1, primary motor cortex; DBT, dynamic balance task; TD, training day; TiB, time in balance; RMSE, root-mean-square error; ZC, number of zero crossings.

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(Cuypers et al., 2013) and the type of the motor task being used (Saucedo Marquez et al., 2013; Kwon et al., 2015), the majority of studies provide evidence for the distinct role of the primary motor cortex (M1) during the initial skill acquisition and early consolidation phase of learning. However, these paradigms were mainly established to investigate motor skill learning involving the hands (Nitsche et al., 2003; Antal et al., 2004; Reis et al., 2009).

Besides the fact, that tDCS enhances hand motor performance, a number of studies have also investigated the effects of tDCS over M1 leg area on lower limb excitability, muscle strength and postural control. In 2007, Jeffery et al. found that 10 min of anodal tDCS (a-tDCS) increased the excitability of corticospinal tract projections to the tibialis anterior muscle (Jeffery et al., 2007). Furthermore, it could be demonstrated that tDCS enhances primary movement parameters of the lower extremity, such as the force of the toes (Tanaka et al., 2009). Remarkably, even more complex tasks involving lower extremities such as static balance (Dutta et al., 2014) or locomotion (Kaski et al., 2012) might be affected by tDCS over M1 leg area. Indeed, first proof of principle studies show that tDCS supports hemiplegic stroke patients in improving their balance ability and increases the lower extremity strength of their affected side (Sohn et al., 2013). These studies point towards the ability of tDCS to affect postural control mechanisms, which is in agreement with work showing that M1 leg area is particularly involved in postural tasks (Beck et al., 2007) and upright standing (Tokuno et al., 2009). Neuroimaging data also showed an association between balance learning in a dynamic balancing task (DBT) and functionally relevant structural brain alterations in motor-related areas (Taubert et al., 2010), though these were not specific to M1 leg area.

On the other hand, there is accumulating evidence that changes in postural control are associated with changes in movement kinematics. During quiet standing, velocity information seems to be the most accurate form of sensory information used to stabilize postural control (Jeka et al., 2004) but also acceleration, (Jeka et al., 2004; Yu et al., 2008), the smoothness of the movement, quantified by the jerk (Hogan and Sternad, 2009) as well as information on the postural sway speed (Manor et al., 1985) or movement frequency (Wulf and Lewthwaite, 2009) are important predictors of how well posture is kept. However, to our knowledge, the relationship between tDCS, movement kinematics and DBT performance has not been investigated, yet.

Taken together, these results indicate that M1 leg area is strongly involved in postural control scenarios (Beck et al., 2007) and that tDCS is capable of enhancing M1 leg area in its excitability and muscle strength (Tanaka et al., 2009). As tDCS enhances motor performance of the hands, examining the effects of tDCS over M1 leg area on motor skill learning scenarios involving lower limbs and the associated movement kinematics seems to be a promising approach.

Thus, the main aim of the present study was to determine if enhancing neural processing in this region with a-tDCS can improve balance performance in healthy young adults. Since a-tDCS has been shown to increase learning performance by up-regulating excitability of the underlying brain tissue (Nitsche and Paulus, 2000; Kantak et al., 2012; Waters-Metenier et al., 2014), we hypothesized that (A) a-tDCS over M1 leg area during DBT learning would facilitate learning performance when compared to sham tDCS (s-tDCS). We expect that these enhanced learning capabilities after a-tDCS outlast the stimulation period and superior performance will be maintained on a second day of training. According to previous studies, we also hypothesized that a-tDCS improves the transfer of information from one training day to the other, which is represented in how much of the previously learned skill is retained on the first trial of the second training day (Reis et al., 2009). We assume that (B) a-tDCS would positively promote consolidation of the DBT skill from the first to the second day of training. To shed more light on the kinematics that might be crucial for improving DBT learning performance, we also assessed (C) how tDCS alters the relationship between movement relevant kinematic variables such as velocity, acceleration, jerk and the number of zero crossings and learning performance.

## 2. Material and methods

### 2.1. Participants

26 healthy young subjects (13 females, mean age = 26.04 ± 3.14 years) participated in this study. Due to a hardware fault, two datasets were excluded from all comparisons involving the second day of training (TD2) resulting in comparisons of only 24 participants on TD2 (12 females, mean age = 26.08 ± 3.19 years). All participants gave written informed consent and underwent a detailed neurological examination to exclude any evidence for neurological disease and/or contraindications relevant for the study procedures outlined below. All were right-handed as assessed by the Edinburgh Handedness Inventory (mean score 85.75; range 68–100) (Oldfield, 1971), free of any medication, and highly-skilled participants such as musicians and sportsmen were not included. Demographic data on age, number of sport sessions and number of hours of sport per week was assessed before the experiment started. All participants were task naïve. The study procedures were approved by the local ethics committee of the University of Leipzig and conducted in accordance with the declaration of Helsinki.

### 2.2. Study design

The study was performed using a randomized, sham-controlled, single-blinded parallel design. The study consisted of two consecutive training sessions that were separated by 24 h. On the first training day (TD1), participants were asked to perform the DBT during 20 min of tDCS, which was applied over bilateral M1 leg area. Participants either received 20 min of a-tDCS or s-tDCS. Participants were allocated to either experimental or sham-control conditions with a balanced randomization list that was prepared prior to testing. We also conducted a second training day (TD2) to assess whether superior performance maintains without tDCS and to examine the effects of tDCS on consolidation of the newly acquired motor skill. During each session, the balance board deviation from horizontal position (in°) of each subject on the platform was continuously recorded using the Spike2 (Cambridge electronic design limited, Cambridge) software.

### 2.3. Whole-body dynamic balancing task (DBT)

The DBT was performed on a stability platform (model 16030, LaFayette Instruments, US) that has a maximal deviation of 26° to each side of the platform. The main goal of the participant during DBT performance is to keep the movable platform in a horizontal position as long as possible over the trial. The platform movement was captured by transforming voltage to an amplifier that translated the signal into a Spike waveform at 5000 hertz (Hz). Data preprocessing was done using MATLAB version 8.2 with custom-build scripts which included low-pass-filtering the data at 5 Hz to remove hardware derived artifacts. After data preprocessing, the primary outcome measure time in balance (TiB) was calculated. TiB was defined as the total time that participants are able to keep the platform in a horizontal position within a range of ±3° to each side (Taubert et al., 2010; Kaminski et al., 2013) (see Fig. 1). Additionally, root-mean square (RMS) error (degrees) was calculated by measuring participants' average per-trial deviation from