Transcranial direct current stimulation for balance rehabilitation in neurological disorders: a systematic review and meta-analysis

Victor Spiandor Beretta, Paulo Cezar Rocha Santos, Diego Orcioli-Silva, Vinicius Cavassano Zampier, Rodrigo Vitório, Lilian Teresa Bucken Gobbi

PII: S1568-1637(22)00178-7

DOI: https://doi.org/10.1016/j.arr.2022.101736

Reference: ARR101736

To appear in: *Ageing Research Reviews*

Received date: 21 March 2022
Revised date: 14 September 2022
Accepted date: 14 September 2022

Please cite this article as: Victor Spiandor Beretta, Paulo Cezar Rocha Santos, Diego Orcioli-Silva, Vinicius Cavassano Zampier, Rodrigo Vitório and Lilian Teresa Bucken Gobbi, Transcranial direct current stimulation for balance rehabilitation in neurological disorders: a systematic review and meta-analysis, *Ageing Research Reviews,* (2022) doi:https://doi.org/10.1016/j.arr.2022.101736

Transcranial direct current stimulation for balance rehabilitation in neurological disorders: a systematic review and meta-analysis

Victor Spiandor Beretta[a], Paulo Cezar Rocha Santos[b], Diego Orcioli-Silva[a,c], Vinicius Cavassano Zampier[a], Rodrigo Vitório[a,d], Lilian Teresa Bucken Gobbi[a*].

[a] São Paulo State University (Unesp), Institute of Biosciences, Graduate Program in Movement Sciences, Posture and Gait Studies Laboratory (LEPLO), Rio Claro, Brazil.
[b] Department of Computer Science and Applied Mathematics, Weizmann Institute of Science, Israel.
[c] University of Campinas (UNICAMP), School of Applied Sciences (FCA), Laboratory of Applied Sport Physiology (LAFAE), Limeira, Brazil.
[d] Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle upon Tyne, United Kingdom.

***Corresponding author:** São Paulo State University (Unesp), Institute of Biosciences, Avenida 24-A, 1515, Bela Vista, 13506-900 – Rio Claro, São Paulo State, Brazil; E-mail address: lilian.gobbi@unesp.br (LTB Gobbi).

Declarations of Interest: none.

ABSTRACT

Postural instability is common in neurological diseases. Although transcranial direct current stimulation (tDCS) seems to be a promising complementary therapy, emerging evidence indicates mixed results and protocols' characteristics. We conducted a systematic review and meta-analysis, on PubMed, EMBASE, Scopus, and Web of Science, to synthesize key findings of the effectiveness of single and multiple sessions of tDCS alone and combined with other interventions on balance in adults with neurological disorders. Thirty-seven studies were included in the systematic review and 33 in the meta-analysis. The reviewed studies did not personalize the stimulation

protocol to individual needs/characteristics. A random-effects meta-analysis indicated that tDCS alone (SMD = -0.44; 95%CI = -0.69/-0.19; p<0.001) and combined with another intervention (SMD = -0.31; 95%CI = -0.51/-0.11; p=0.002) improved balance in adults with neurological disorders (small to moderate effect sizes). Balance improvements were evidenced regardless of the number of sessions and targeted area. In summary, tDCS is a promising therapy for balance rehabilitation in adults with neurological disorders. However, further clinical trials should identify factors that influence responsiveness to tDCS for a more tailored approach, which may optimize the clinical use of tDCS.

Keywords: Brain stimulation, Postural balance, Parkinson's disease, Stroke, Ageing, tDCS.

1. **INTRODUCTION**

Several neurological diseases, such as Parkinson's disease (PD), stroke, cerebellar ataxia, and Alzheimer's disease, affect static, dynamic, and reactive postural control (Halmi et al., 2020; Mancini et al., 2020; Mesbah et al., 2017; Nonnekes et al., 2018; Tyson et al., 2006; van de Warrenburg et al., 2005). Neural impairments related to such diseases impair the sensory-motor system and neuromuscular control, leading to deficits in mechanical and muscular coordination during postural/balance tasks (Horak et al., 1997, 1992). Since adequate postural control is important to maintain balance during activities of daily living (Gandolfi et al., 2018), neurological-related impairments on postural control interfere with functional independence and quality of life, and increase the risk of falls (Nonnekes et al., 2018; Stolze et al., 2004). It is, therefore, reasonable that one major concern in the field refers to the development of enhanced

therapies to minimize postural impairments in neurological populations (Nonnekes et al., 2018).

The postural control and balance impairments are less responsive to drug therapy in neurological diseases (Curtze et al., 2015). Alternatively, complementary therapies have been proposed to improve postural control and balance (Beretta et al., 2020a, 2020b; de Moura et al., 2019; Morya et al., 2019; Vitório et al., 2019). Particularly, a growing body of evidence suggests transcranial direct current stimulation (tDCS) as a promising therapy for cognition and motor impairments such as postural control and balance (Andrade et al., 2017; Baharlouei et al., 2020; Beretta et al., 2020a; de Moura et al., 2019; Guo et al., 2020; Orrù et al., 2019; Sandrini et al., 2020; Sohn et al., 2013; Summers et al., 2016; Zandvliet et al., 2018). tDCS is a non-invasive brain stimulation technique that applies a weak electrical current (1-4 mA) over the scalp to modulate the spontaneous neuronal network activity (Brunoni et al., 2012; Farnad et al., 2021; Nitsche et al., 2008). The modulation of neuronal activity is dependent on tDCS polarity, in which anodal tDCS increases neuronal excitability whereas cathodal stimulation decreases neuronal excitability (Nitsche and Paulus, 2001, 2000).

Several mechanisms have been proposed for the postural improvements achieved with tDCS. For example, tDCS can modulate functional connectivity of different brain areas involved in the direct and indirect pathways of postural control (Beretta et al., 2020b; Morya et al., 2019; Schoellmann et al., 2019). Even deeper basal ganglia areas (e.g., caudate nucleus and striatum) involved in postural control have been shown to be modulated by tDCS in patients with neurological diseases (Filmer et al., 2020; Rudroff et al., 2022; Stagg et al., 2009; Tanaka et al., 2013). tDCS can also modulate the activity of cortical areas involved in compensatory mechanisms of executive control (Chan et al., 2021; Conceição et al., 2021). Additionally, specifically

for neurological diseases characterized by asymmetric brain damage, such as PD and stroke (Agius Anastasi et al., 2017; Brunoni et al., 2012; Cosentino et al., 2017), tDCS may improve the equilibrium in imbalanced neural networks between brain hemispheres (Cosentino et al., 2017; Fregni and Pascual-Leone, 2007). However, although promising, mixed results have been reported about the effect of tDCS on balance (Forogh et al., 2018; Manenti et al., 2016; Seo et al., 2017), likely due to the heterogeneity of the stimulation characteristics (Beretta et al., 2020a; Madrid and Benninger, 2021; Morya et al., 2019; Orrù et al., 2019). Therefore, systematically reviewing the literature might help to understand whether the potential tDCS benefits on postural control are consistently and functionally relevant in the context of neurological diseases.

Although systematic reviews on the topic exist (Beretta et al., 2020a; Broeder et al., 2015; de Moura et al., 2019; Dong et al., 2021; Lee et al., 2019; Liu et al., 2021; Oliveira et al., 2022), the knowledge is limited. Specifically, there is no consensus regarding the effects of tDCS on postural control in specific neurological populations, such as stroke and PD (Dong et al., 2021; Liu et al., 2021; Oliveira et al., 2022). In addition, the optimum tDCS montage (i.e., target area and electrodes position) and dosage have not been established for protocols targeting postural rehabilitation (Liu et al., 2021; Orrù et al., 2019). For example, current intensity and the number of sessions (e.g., single vs. multiple session(s) of tDCS) may influence the effects of tDCS on postural tasks (Beretta et al., 2020b; Orrù et al., 2019; Workman et al., 2020), but the evidence is limited, thus making solid conclusions difficult (Orrù et al., 2019). Also, it has not been established which brain area should be targeted for optimal benefits. Furthermore, it remains unclear whether the combination of tDCS with an additional physical/motor or cognitive intervention may enhance benefits to balance/posture.

These factors together indicate relevant niches to examine and verify the use of tDCS as a potential complementary therapy for posture and balance in neurological populations (Santos Ferreira et al., 2019; Vitório et al., 2019). Therefore, the primary aim of this study was to analyze the effect of single and multiple sessions of tDCS, as a stand-alone intervention and when combined with other interventions, on postural control and balance in adults with different neurological disorders. We also examined the influence of specific parameters of the stimulation protocol (i.e., target area, outcome domain, and type of neurological diseases) on the effect of tDCS on postural control and balance.

2. MATERIAL AND METHODS

The present systematic review and meta-analysis was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; CRD42021254481) and written following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

2.1 Eligibility criteria

Inclusion criteria followed PICOS: (1) adults with neurological disorders (i.e., young and older adults), (2) tDCS alone or combined with another intervention, (3) presence of sham stimulation or control group (CG) (without active tDCS condition), (4) included at least one measurement of postural control or balance as an outcome, and (5) randomized and non-randomized controlled trials, observational studies, and experimental designs. We excluded manuscripts written in a non-English language, pre-print, any open-label studies, review articles, book chapters, commentaries, conference abstracts, study protocols, and manuscripts with the population composed of children.

For the synthesis of the information, the postural control and balance outcomes were grouped in main domains according to the characteristics of the test: static (e.g., posturography during standing or seated), dynamic/functionality (e.g., Berg Balance Scale-BBS, Timed Up and Go test-TUG, etc), and postural adjustments (e.g., parameter of the anticipatory and reactive postural adjustments). We considered the definition for the outcomes (balance and posture) as it was originally described by their respective authors.

2.2 Search strategy

The following databases (PubMed, EMBASE, Scopus, and Web of Science) were searched for articles until May 27th, 2021. One of the authors (VSB) created the search strategy, reviewed by a librarian (Institute of Biosciences, São Paulo State University, Rio Claro), and approved by all authors. The search strategy was presented in Table 1. Also, additional articles were included by screening reference lists from other systematic reviews on similar topics.

Insert Table 1

2.3 Selection process

Duplicates of the manuscripts identified by the databases search were excluded using a reference manager software and the remaining titles were then summarized into a table. Two independent authors (VSB and PCRS) screened the titles and abstracts and checked for the eligibility of the studies. Full texts were reviewed when titles and abstracts information was not clear. A third author (RV) made the final decision in case of inconsistencies between the two authors.

2.4 Data collection process

Data from each study were extracted by two authors independently, confirmed by a third, and synthesized into a table format. All authors (VSB, PCRS, DOS, VCZ, RV, and LTBG) participated in the data extraction process. The WebPlotDigitizer software (Drevon et al., 2017; Rohatgi, 2020) was used to extract data from figures for the meta-analysis. In addition, if results were not conclusive reported, we emailed the corresponding author of the respective study requesting data. Data included were summarized using the PICOS (population, intervention, comparison, outcomes, and study design) and also including the main results. The study details (author's name, publication year, type of neurological disease, sample size, and study design), participant's characteristics (groups, age, and sex), intervention details (characteristics of the tDCS protocol and the presence of additional intervention), comparison/control, outcome measures (main and additional outcomes, and measurement times) and key findings were tabulated.

2.5 Methodological quality assessment risk of bias

Two authors (VSB and PCRS) assessed, independently, the methodological quality and the risk of the bias of the included studies using the Physiotherapy Evidence Database (PEDro) rating scale (Maher et al., 2003) and the Cochrane risk of bias assessment (Higgins et al., 2020, 2011), respectively, and a third author solved inconsistencies (RV). The PEDro scale estimated study methodological quality using a checklist of 11 items regarding the group allocation, blinding, attrition, statistical analyses, and data variability. However, the first item is not used to calculate the score (Baharlouei et al., 2020; Maher et al., 2003). Studies with scores 9-10 were considered with excellent methodological quality, 6-8 good, 4-5 fair, and <4 poor (Baharlouei et al., 2020; de Morton, 2009). The Cochrane risk of bias assessment includes seven

domains (Higgins et al., 2020): random sequence allocation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, incomplete outcome data, selective reporting, and other sources of bias. Review Manager 5.4 software (The Cochrane Collaboration, 2020) was used to evaluate the risk of bias assessment which has three levels in each domain: low risk, high risk, and unclear.

2.6 Meta-analysis

We conducted the meta-analysis using Review Manager 5.4 (The Cochrane Collaboration, 2020). The standardized mean difference (SMD) and standard error (SE) were calculated to quantify individual effect sizes due to the differences in the data nature (outcomes and tests) (Lee et al., 2019; Murad et al., 2019). Statistical analysis was performed using the generic inverse variance method for the comparison between the effects of the active tDCS vs. sham tDCS and between the experimental group (i.e., active tDCS combined with another intervention) vs. CG on postural control and balance. The included data on meta-analysis are detailed in Supplementary Table S1. To address the aims of this study we conducted subgroup analysis for single and multiple sessions with tDCS for each comparison. In addition, we collapsed the studies of tDCS alone and combined with another intervention, and performed subgroup analysis to investigate possible differences of tDCS effect regarding the characteristics of the target area stimulated, the outcome domain, and the population characteristics. Negative SMD indicated a favoring for active tDCS/experimental group and a positive value indicated a favoring for sham/CG. For that, in the parameters whose higher value reflects better performance (e.g., BBS), a transformation was carried out by multiplying by -1. We interpreted the SMD values similar to Cohen's d ($\leq$0.2 as small, around 0.5 as moderate, and > 0.8 as large effects) (Cohen, 1998).

A random-effect model was used in all comparisons due to heterogeneity in participant, intervention, and outcome characteristics of the included studies (de Moura et al., 2019; Lee et al., 2019). Also, the heterogeneity between the studies was assessed using the I^2 statistics which represents the percentage of the heterogeneity ($I^2 > 50\%$ indicate a substantial heterogeneity between studies that difficult the interpretation of the results) (Higgins and Thompson, 2002). Thus, when the heterogeneity threshold is above 50%, we performed a sensitivity analysis to control the heterogeneity by excluding one study at a time (Dong et al., 2021). For that, we investigate the presence of possible publication bias by the funnel plot observation (Supplementary material).

3. RESULTS

3.1 Study selection

The PRISMA flow diagram shows the information regarding the different steps of the search and screening process (Figure 1). Initially, our database search identified 1585 potential studies. Eight hundred and ninety-eight duplicates were removed. After reviewing titles and abstracts, 51 studies were included, and five additional studies (Forogh et al., 2018; Geroin et al., 2011; Madhavan et al., 2020; Manenti et al., 2016; Tahtis et al., 2014) were included from other systematic reviews on similar topics. After full text review, 19 studies were excluded due to the following reasons: without sham/CG (n = 9) (Alexoudi et al., 2018; Dumont et al., 2015; Hadoush et al., 2018; Mohammadi et al., 2021; Naro et al., 2020; Pilloni et al., 2019; Rezaee et al., 2020; Ricci et al., 2019; Solanki et al., 2021), another population (n = 3) (Jafarzadeh et al., 2019; Maldonado and Bernard, 2021; Manor et al., 2018), another intervention (n = 1) (Koganemaru et al., 2019), and another outcome (n = 6). Finally, 37 articles were included for the systematic reviews and 33 for the meta-analysis (two studies were

excluded from the meta-analysis because of the design (case reports) and two due to incomplete data) (Costa et al., 2020; Forogh et al., 2018; Kaski et al., 2014a; Verheyden et al., 2013).

Insert Figure 1

3.2 Study characteristics

Table 2 presents the characteristics of the 37 included studies in the systematic review. The studies were published from 2011 to 2021. Of the 37 included studies, 19 were conducted with people with stroke (Andrade et al., 2017; Babyar et al., 2018, 2016; Chang et al., 2015; Coppens et al., 2019; Danzl et al., 2013; Fruhauf et al., 2017; Geroin et al., 2011; Liang et al., 2020; Madhavan et al., 2020; Manji et al., 2018; Ojardias et al., 2020; Prathum et al., 2021; Saeys et al., 2015; Seo et al., 2017; Sohn et al., 2013; Tahtis et al., 2014; Yang et al., 2021; Zandvliet et al., 2018), 10 with PD (Beretta et al., 2020b; Costa-Ribeiro et al., 2017; Forogh et al., 2018; Kaski et al., 2014b, 2014a; Lattari et al., 2017; Lu et al., 2018; Manenti et al., 2016; Verheyden et al., 2013; Workman et al., 2020), three with cerebellar ataxia (Barretto et al., 2019; Benussi et al., 2015; Grimaldi and Manto, 2013), one with multiple sclerosis (Costa et al., 2020), one with vestibular dysfunction (Saki et al., 2020), one with Mal de debarquement syndrome (Cha et al., 2016), one with Leukoaraiosis (Kaski et al., 2013), and one with Spinal cord injury (Raithatha et al., 2016). Regarding the target area, 26 studies applied active tDCS (anodal current) over motor cortex (Andrade et al., 2017; Barretto et al., 2019; Beretta et al., 2020b; Chang et al., 2015; Coppens et al., 2019; Costa-Ribeiro et al., 2017; Costa et al., 2020; Danzl et al., 2013; Fruhauf et al., 2017; Geroin et al., 2011; Kaski et al., 2014b, 2014a, 2013; Liang et al., 2020; Lu et al., 2018;

Madhavan et al., 2020; Manji et al., 2018; Ojardias et al., 2020; Prathum et al., 2021; Raithatha et al., 2016; Saeys et al., 2015; Seo et al., 2017; Sohn et al., 2013; Tahtis et al., 2014; Verheyden et al., 2013; Yang et al., 2021), five over prefrontal cortex (PFC) (Cha et al., 2016; Forogh et al., 2018; Lattari et al., 2017; Manenti et al., 2016; Saki et al., 2020), four over the cerebellum (Benussi et al., 2015; Grimaldi and Manto, 2013; Workman et al., 2020; Zandvliet et al., 2018), and two over parietal-insular vestibular cortex (PIVC) (Babyar et al., 2018, 2016). For the characteristics of stimulation, the current intensity ranged from 0.6 to 4 mA, with 2 mA being the most commonly used intensity (n = 25 studies) (Andrade et al., 2017; Babyar et al., 2018, 2016; Barretto et al., 2019; Benussi et al., 2015; Beretta et al., 2020b; Chang et al., 2015; Coppens et al., 2019; Costa-Ribeiro et al., 2017; Costa et al., 2020; Danzl et al., 2013; Fruhauf et al., 2017; Kaski et al., 2014b, 2014a, 2013; Lattari et al., 2017; Liang et al., 2020; Manenti et al., 2016; Ojardias et al., 2020; Prathum et al., 2021; Raithatha et al., 2016; Saki et al., 2020; Seo et al., 2017; Sohn et al., 2013; Tahtis et al., 2014). The stimulation duration ranged from 7 to 40 minutes, with 20 minutes of stimulation applied in 21 studies (Babyar et al., 2016; Benussi et al., 2015; Beretta et al., 2020b; Cha et al., 2016; Costa et al., 2020; Danzl et al., 2013; Forogh et al., 2018; Fruhauf et al., 2017; Grimaldi and Manto, 2013; Lattari et al., 2017; Liang et al., 2020; Manji et al., 2018; Ojardias et al., 2020; Prathum et al., 2021; Raithatha et al., 2016; Saeys et al., 2015; Saki et al., 2020; Seo et al., 2017; Workman et al., 2020; Yang et al., 2021; Zandvliet et al., 2018). Among all the included articles, there were 15 studies that applied tDCS as a stand-alone intervention (Babyar et al., 2018, 2016; Barretto et al., 2019; Benussi et al., 2015; Beretta et al., 2020b; Coppens et al., 2019; Grimaldi and Manto, 2013; Lattari et al., 2017; Lu et al., 2018; Ojardias et al., 2020; Sohn et al., 2013; Tahtis et al., 2014; Verheyden et al., 2013; Workman et al., 2020; Yang et al., 2021), and 22 combined

tDCS with other interventions (Andrade et al., 2017; Cha et al., 2016; Chang et al., 2015; Costa-Ribeiro et al., 2017; Costa et al., 2020; Danzl et al., 2013; Forogh et al., 2018; Fruhauf et al., 2017; Geroin et al., 2011; Kaski et al., 2014a, 2013, 2014b; Liang et al., 2020; Madhavan et al., 2020; Manenti et al., 2016; Manji et al., 2018; Prathum et al., 2021; Raithatha et al., 2016; Saeys et al., 2015; Saki et al., 2020; Seo et al., 2017; Zandvliet et al., 2018). Regarding tDCS alone, 14 studies applied a single session (Babyar et al., 2018, 2016; Benussi et al., 2015; Beretta et al., 2020b; Coppens et al., 2019; Grimaldi and Manto, 2013; Lattari et al., 2017; Lu et al., 2018; Ojardias et al., 2020; Sohn et al., 2013; Tahtis et al., 2014; Verheyden et al., 2013; Workman et al., 2020; Yang et al., 2021) and one conducted five sessions (Barretto et al., 2019). Five studies applied a single session of tDCS combined with other interventions (Fruhauf et al., 2017; Kaski et al., 2014b, 2013; Liang et al., 2020; Zandvliet et al., 2018), and 17 conducted multiples (2 to 36) sessions (Andrade et al., 2017; Cha et al., 2016; Chang et al., 2015; Costa-Ribeiro et al., 2017; Costa et al., 2020; Danzl et al., 2013; Forogh et al., 2018; Geroin et al., 2011; Kaski et al., 2014a; Madhavan et al., 2020; Manenti et al., 2016; Manji et al., 2018; Prathum et al., 2021; Raithatha et al., 2016; Saeys et al., 2015; Saki et al., 2020; Seo et al., 2017). Most studies conducted motor/physical interventions combined with tDCS (n = 20) (Andrade et al., 2017; Chang et al., 2015; Costa-Ribeiro et al., 2017; Costa et al., 2020; Danzl et al., 2013; Forogh et al., 2018; Geroin et al., 2011; Kaski et al., 2014b, 2014a, 2013; Liang et al., 2020; Madhavan et al., 2020; Manenti et al., 2016; Manji et al., 2018; Prathum et al., 2021; Raithatha et al., 2016; Saeys et al., 2015; Saki et al., 2020; Seo et al., 2017; Zandvliet et al., 2018). In relation to the postural control and balance outcomes, among the 37 articles included, 22 analyzed parameters related to the domain of dynamic/functionality of balance (Andrade et al., 2017; Benussi et al., 2015; Cha et al., 2016; Chang et al., 2015; Costa-

Ribeiro et al., 2017; Costa et al., 2020; Danzl et al., 2013; Forogh et al., 2018; Geroin et al., 2011; Kaski et al., 2014a; Lattari et al., 2017; Madhavan et al., 2020; Manenti et al., 2016; Manji et al., 2018; Prathum et al., 2021; Raithatha et al., 2016; Saeys et al., 2015; Saki et al., 2020; Seo et al., 2017; Tahtis et al., 2014; Verheyden et al., 2013; Workman et al., 2020), eight analyzed static postural control (Babyar et al., 2018, 2016; Barretto et al., 2019; Fruhauf et al., 2017; Grimaldi and Manto, 2013; Ojardias et al., 2020; Sohn et al., 2013; Zandvliet et al., 2018), and seven analyzed parameters of postural adjustments (Beretta et al., 2020b; Coppens et al., 2019; Kaski et al., 2014b, 2013; Liang et al., 2020; Lu et al., 2018; Yang et al., 2021).

Insert Table 2

3.3 Methodological quality assessment (risk of bias)

The methodological quality, rated with PEDro score, ranged from 2 to 10, and the included studies were classified (percentage of the studies) as excellent (40.54%), good (51.35%), fair (5.41%), and poor (2.70%) methodological quality (Table 3).

Insert Table 3

Most included studies demonstrated some potential risk for bias (34/37) according to Cochrane's recommendation.(Higgins et al., 2011) Our assessment of the risk of bias revealed that 48.65% of the studies presented a low risk of randomization bias, allocation concealment (48.65% of studies), blinding of participants and personnel (89.19% of studies), blinding of outcome assessors (70.27% of studies), incomplete outcome data (86.49% of studies) and other sources of bias (78.38% of studies). Also,

most studies presented an unclear risk of bias for selective reporting (83.78%). Figure 2 shows the risk of bias with Cochrane's recommendation (Higgins et al., 2011).

Insert Figure 2

3.4 Meta-analysis results

The data of each study inserted on meta-analysis are shown in Supplementary Table S1.

3.4.1 Single and multiple sessions of tDCS alone

As reported above, multiple sessions of tDCS alone were conducted in only one study (Barretto et al., 2019). Thus, we collapsed the studies with single and multiple sessions of tDCS for the meta-analysis. The analysis of 15 studies indicated a significant improvement on postural control and balance after active tDCS compared with sham/CG (SMD = -0.44 (moderate); 95% CI = -0.69 to -0.19; Z = 3.48; $p < 0.001$). There is no heterogeneity between the included studies ($I^2 = 21\%$; $p = 0.22$) (Figure 3a).

3.4.2 Single and multiple sessions of tDCS combined with another intervention

Five studies performed a single session of tDCS and 17 conducted multiples sessions. Thus, we performed a subgroup analysis for single and multiple sessions of tDCS. The analysis indicated no significant subgroup effect ($p = 0.66$), suggesting that the number of tDCS sessions does not influence the effect of the tDCS in experimental group compared with CG (SMD = -0.43 (moderate); 95% CI = -0.71 to -0.14; Z = 2.90; $p = 0.004$). However, heterogeneity was significant among studies in the multiple session's subgroup ($I^2 = 66\%$; $p = 0.0003$) (Figure S1a). Thus, a sensitivity analysis was

performed by the funnel plot observation (Figure S1b-c) and one study (Andrade et al., 2017) was excluded achieving I^2 = 24% for multiple sessions subgroup and I^2 = 9% (p = 0.34) for overall analysis. The analysis continued showing no subgroup differences (p = 0.90) indicating a significant improvement on postural control and balance for experimental group compared with CG (SMD = -0.31 (moderate); 95% CI = -0.51 to -0.11; Z = 3.04; p = 0.002) (Figure 3b) when single and multiple sessions were combined with another intervention.

Insert Figure 3

3.4.3 tDCS for postural control and balance

As there were no statistical differences between single and multiple sessions of tDCS for postural control and balance, we collapsed the studies to investigate the effect of tDCS alone and combined with other interventions. Fifteen studies were included for the tDCS alone subgroup and 19 in tDCS combined with another intervention subgroup. The analysis indicated no significant subgroup effect (p = 0.93), suggesting that the combination (or not) with another intervention does not influence the effect of the tDCS in experimental group compared with CG (SMD = -0.44 (moderate); 95% CI = -0.63 to -0.24; Z = 4.43; p<0.001). However, there was significant heterogeneity among the included studies in tDCS combined with another intervention subgroup (I^2 = 57%; p = 0.001) (Figure S2a). After the sensitivity analysis (Figure S2b-c), one study (Andrade et al., 2017) was excluded achieving I^2 = 9% for tDCS combined with another intervention subgroup and I^2 = 14% (p = 0.24) for overall analysis. The analysis continued indicating no subgroup differences (p = 0.42), revealing significant improvements on postural

control and balance for experimental group compared with CG (SMD = -0.37 (moderate); 95% CI = -0.52 to -0.21; Z = 4.63; p<0.001) (Figure 4).

Insert Figure 4

3.4.4 Target area

We collapsed the studies of tDCS alone and combined with another intervention (due to the lack of difference between these factors on the overall effect of tDCS on postural control) to investigate the influence of the target area that the tDCS was applied. Four subgroups were included regarding the stimulated target area: motor cortex (n = 23), PFC (n = 4), cerebellum (n = 4) and PIVC (n = 2 studies). The meta-analysis indicated no significant subgroup effect (p = 0.87), suggesting that the target area does not influence the greater effect observed for the experimental group compared with CG (SMD = -0.45 (moderate); 95% CI = -0.64 to -0.25; Z = 4.48; p<0.001) (Figure S3a). A significant heterogeneity was revealed for motor cortex (I^2 = 51%; p = 0.003) and PIVC (I^2 = 83%; p = 0.02) subgroups (Figure S3b-c). After the sensitivity analysis, one study (Andrade et al., 2017; Babyar et al., 2018) was excluded for each subgroups achieving I^2 = 5% for motor cortex and because the number of study remaining in PIVC (n = 1) this subgroup was excluded from the analysis. The heterogeneity for overall analysis was I^2 = 14% (p = 0.24). The analysis continued revealing no subgroup differences (p = 0.68) indicating a significant improvement on postural control and balance in experimental group vs. CG (SMD = -0.36 (moderate); 95% CI = -0.51 to -0.21; Z = 4.69; p<0.001) (Figure 5) regardless of stimulated area.

Insert Figure 5

3.4.5 Outcome domain of postural control and balance

Three subgroups were included regarding the outcome of postural control and balance: static (n = 8), dynamic/functionality (n = 18), and postural adjustments (n = 7 studies). No significant subgroup effect was revealed (p = 0.88) suggesting that the outcome does not influence the greater effect observed for the experimental group compared with CG (SMD = -0.45 (moderate); 95% CI = -0.64 to -0.25; Z = 4.48; p<0.001) (Figure S4a). A significant heterogeneity was indicated for dynamic/functionality subgroup (I^2 = 57%; p = 0.002) (Figure S4b-c). After the sensitivity analysis, one study (Andrade et al., 2017) was excluded achieving I^2 = 1% for dynamic/functionality and I^2 = 15% (p = 0.23) for overall analysis. The analysis continued revealing no subgroup differences (p = 0.44) indicating a significant improvement on postural control and balance in experimental group vs. CG (SMD = -0.38 (moderate); 95% CI = -0.54 to -0.22; Z = 4.67; p<0.00001) regardless of outcome domain (Figure 6).

Insert Figure 6

3.4.6 Type of neurological disorders

Three subgroups were included regarding the type of neurological disorders: PD (n = 7), stroke (n = 19), and cerebellar ataxia (n = 3 studies). No significant subgroup effect were indicated (p = 0.75) suggesting that the type of neurological disorders does not influence the greater effect of tDCS on balance observed for the experimental group compared with CG (SMD = -0.40 (moderate); 95% CI = -0.61 to -0.20; Z = 3.79; p = 0.0002) (Figure S5a). Heterogeneity was significant for stroke subgroup (I^2 = 59%; p =

0.0005) (Figure S5b-c). One study(Andrade et al., 2017), after the sensitivity analysis, was excluded achieving I^2 = 22% for stroke and I^2 = 10% (p = 0.32) for overall analysis. The analysis continued indicating no subgroup differences (p = 0.97) and improvement in experimental group compared with CG remained significant in all neurological disorders (SMD = -0.32 (moderate); 95% CI = -0.48 to -0.16; Z = 3.91; p<0.0001) (Figure 7).

Insert Figure 7

Figure 8 summarizes the main findings of the effect size (i.e., SMD) from the meta-analysis regarding the primary and secondary aims of the study.

Insert Figure 8

4. DISCUSSION

The present study primarily aimed to analyze the effect of single and multiple sessions of tDCS, as a stand-alone intervention and when combined with other interventions, on postural control and balance in adults with neurological disorders. We also examined the influence of specific parameters of the stimulation protocol (i.e., target area, outcome domain, and type of neurological disease) on the effect of tDCS on postural control and balance. Overall, tDCS effects on balance and postural tasks were small to moderate (SMD ranged from -0.28 to -0.58) and consistent (heterogeneity ≤21% after sensitivity analysis). Those tDCS effects were non-specific for single and multiple sessions alone and combined with physical/motor therapy and regardless of the neurological disease subgroups (i.e., PD, Stroke, Cerebellar ataxia). In addition, it is important to highlight that studies included in the current review presented substantial

diversity in terms of tDCS protocols, additional combined interventions, and populations, which might blur solid conclusions (Table 2) (Fregni et al., 2021; Orrù et al., 2019).

4.1 Single and Multiple sessions of tDCS (potential mechanisms)

Single and multiple sessions of tDCS moderately improved postural control. These findings signal tDCS as a relevant intervention to treat postural control deficits in adults with neurological diseases. Potentially, the observed effects might be related to tDCS capacity to modulate/improve cortical excitability (Nitsche and Paulus, 2001, 2000) and brain functional connectivity (Hordacre et al., 2018; Morya et al., 2019; Polanía et al., 2011). Single sessions of tDCS may enhance the equilibrium and functioning of imbalanced neural brain networks (Cosentino et al., 2017; Fregni and Pascual-Leone, 2007) and pathways involved in postural control (Beretta et al., 2020b; Nonnekes et al., 2014). tDCS has been shown to modulate the NMDA receptors' activities and the calcium levels improving the strength of the neuronal synapsis (Islam et al., 1995; Nitsche et al., 2004; Polanía et al., 2011) and favoring neuroplasticity (Chan et al., 2021; Nitsche et al., 2008; Polanía et al., 2011). In addition, tDCS changes blood flow, increasing the oxygenation of the neurons and enhancing excitability, functionality, and functional connectivity of the target area (Zheng et al., 2011). A cumulative effect on cortical excitability was evidenced after five consecutive days of anodal tDCS applied over the motor cortex (Ho et al., 2016). The long-term improvements of functional connectivity are factors of the motor circuits reorganization (Ward, 2011) which may influence the motor function recovery (Fregni and Pascual-Leone, 2007). In summary, both single and multiple sessions of tDCS on cortical excitability and motor impairments, such as postural control and balance, may suggest

possible therapeutic applications in healthy older adults and adults with neurological diseases (Fregni et al., 2021; Fregni and Pascual-Leone, 2007; Lüdemann-Podubecká et al., 2014; Morya et al., 2019; Tatti et al., 2016).

4.2 tDCS alone and tDCS combined with another intervention

tDCS improved postural control and balance in adults with neurological diseases regardless of being applied as a stand-alone intervention or combined with another intervention. Although the meta-analysis indicated no subgroup effect (stand-alone vs. combination with another intervention), findings suggested a slightly superior effect size of tDCS as a stand-alone intervention when compared with tDCS combined with other interventions (SMD = -0.44 vs. -0.31, Figure 4). This may be due to methodological differences in study design, which allows more room for change when tDCS is applied alone. Studies investigating tDCS as a stand-alone intervention usually have no-intervention control groups/conditions (i.e., sham vs. active tDCS). On the other hand, studies investigating the effects of tDCS combined with other interventions usually have active control groups (e.g., exercise + tDCS vs. exercise + sham); in the later scenario, findings favoring tDCS represent effects that go beyond those observed with the combined intervention. This observation makes tDCS very attractive for postural control and balance rehabilitation as the tDCS can enhance benefits achieved with conventional interventions.

4.3 Target areas

Surprisingly, our results indicated no subgroup differences across stimulated brain areas. In summary, tDCS over the motor cortex, PFC and cerebellum improve balance in adults with neurological diseases (Figure 5). Because postural control

involves several cortical and subcortical areas (Mancini et al., 2020; Peterson and Horak, 2016; Takakusaki, 2017), studies investigating the effect of tDCS on postural control have stimulated different encephalic areas (Babyar et al., 2018; Beretta et al., 2020b; Lattari et al., 2017; Workman et al., 2020). Although most studies included in our review stimulated motor cortex (i.e., 70.3%), our results indicate a slightly superior positive effect of tDCS applied over PFC on balance (SMD = -0.58 vs. -0,32, Figures 8). The positive effects of tDCS over PFC on postural control reinforce the compensatory role of PFC due to deficits in movement automaticity in adults with neurological disorders (Beretta et al., 2020b; Herold et al., 2017; St George et al., 2021). However, our results may have been influenced by the low number of studies included in the PFC subgroup (n = 4), hence results should be considered carefully.

Because neurological diseases may affect the function of several brain areas involved in postural control, some studies have explored the effects of multi-target stimulation (Benninger et al., 2010; Dagan et al., 2018; Hadoush et al., 2018; Orrù et al., 2019). Multi-target stimulation (applied over both PFC and motor cortex) has shown superior effects (relative to mono-target) on motor function in patients with PD (Benninger et al., 2010; Dagan et al., 2018; Hadoush et al., 2018; Orrù et al., 2019). A possible explanation for the superior effect of multi-target is the improved communication between PFC and motor cortex and subcortical structures (Dagan et al., 2018; Vaseghi et al., 2015). Thus, future studies should consider investigating multi-target stimulation for postural control.

4.5 Postural control and balance outcomes

tDCS improved balance in adults with neurological disorders regardless of the outcome domain. In short, tDCS can improve static and dynamic/functional balance as

well as postural adjustments in situations with external perturbation. Despite the statistical analysis indicating no difference between the subgroups, our results suggested that dynamic/functionality had a lower effect size induced by tDCS (SMD = -0.28, Figure 8). This finding may be explained, at least in part, by differences in the "nature" of the outcome measures used across the different subgroups. Functional measures generally obtained by field tests may be less sensitive to detect the effectiveness of tDCS in postural control than kinetic, kinematic, and neuromuscular parameters analyzed in other balance domains (e.g., static and postural adjustments to perturbation) (Duarte and Freitas, 2010). Although field tests, such as the TUG and BBS, are valid and widely used, they involve the subjectivity of the evaluator (e.g., starting and stopping the stopwatch, and judging the level of functionality based on eye observation of behavior) and may indicate a ceiling effect (Sabchuk et al., 2012). On the other hand, kinetic, kinematic, and neuromuscular parameters are measures that do not involve the evaluator's subjectivity and ceiling effect and, therefore, can be more sensible to detect subtle differences in postural control induced by the tDCS (Quijoux et al., 2020; Sabchuk et al., 2012).

4.6 Neurological diseases condition

Curiously, tDCS indicated similar sensibility as a complementary therapy to balance for people with PD, stroke, and cerebellar ataxia. Although particular aspects of these diseases differently affect postural control, it should be highlighted that the tDCS in overall improved balance in adults with neurological disorders (SMD = 0.32). The benefits on balance may be due to improved functional connectivity of brain areas involved in postural control (Beretta et al., 2020b; Morya et al., 2019). Non-invasive brain stimulation can improve cortical and subcortical dysfunction in adults with

neurological disorders (Fregni and Pascual-Leone, 2007; Nonnekes et al., 2014; Takakusaki, 2017). Specifically for PD and stroke (asymmetric brain disease) (Agius Anastasi et al., 2017; Brunoni et al., 2012; Cosentino et al., 2017), tDCS may improve the equilibrium in imbalanced neural networks between the brain hemispheres (Cosentino et al., 2017; Fregni and Pascual-Leone, 2007).

4.7 Existing limitations in the literature and future directions

Various aspects that may influence tDCS responsiveness remain poorly understood. The included studies did not investigate the level of baseline characteristics of the individuals that best respond to the tDCS. To date, individual characteristics have been shown to influence the effects of tDCS on motor and cognitive functions in healthy individuals and patients with PD (Beretta et al., 2021; Dagan et al., 2018; Li et al., 2015; Mizuguchi et al., 2018). Patients with PD with worse balance (Beretta et al., 2021) and more severity of freezing of gait (Dagan et al., 2018) at baseline showed greater improvement after tDCS protocol, while the clinical characteristics (disease duration and motor impairments) of PD seem to not influence the responsiveness to tDCS (Beretta et al., 2021; Fregni et al., 2006). Also, there is an unmet need for studies investigating optimal protocols by directly comparing specific tDCS parameters as well as studies applying a more tailored approach (Albizu et al., 2020), accounting for individual characteristics such as level of disease severity/stage. The typically applied "one size fits all" approach may result in some participants not receiving appropriate stimulation, which ultimately may lead to non-optimal effects. In addition, it should be noted that a high number of studies were excluded from this systematic review due to the lack of a CG or sham stimulation (n = 9) making the interpretation of the tDCS effect for postural control and balance in these neurological populations more difficult

(Ekhtiari et al., 2019). Thus, we encourage future studies to investigate the characteristics of the stimulation and patients that may increase the response to tDCS, and also report the information and include a CG/sham condition in the experimental design.

4.8 Strengths and limitations of the current study

Although we observed interesting findings, our study has limitations. The low number of studies included in some subgroup analyses may increase the risk of bias, making the indication of clinical applicability of these results less robust. The included studies are highly diversified in terms of tDCS protocol and additional intervention, population characteristics, and sample sizes. Such heterogeneity makes specific comparisons challenging. However, our analysis demonstrated good to excellent methodological quality and a generally low risk of bias (except for the reporting bias) for the reviewed studies. We also carefully checked all potential heterogeneity, excluding studies from the analysis in cases where heterogeneity was reached. We did not include studies published in the non-English language and the grey literature which could decrease the number of evidence about this topic. Also, we were unable, due low number of studies, to compare between single and multiple sessions of tDCS alone and between all types of neurological diseases identified in the systematic review. In addition, we have not analyzed the effect of tDCS for longer follow-up periods after the end of the interventions, which may help to understand the long-lasting tDCS effects on postural control and balance in adults with neurological disease.

5. CONCLUSION

tDCS is a promising complementary therapy to improve postural control and balance in adults with neurological disorders. The number of sessions, target area, combination or not with another intervention, the outcome measure, and type of neurological disease did not influence the effects of tDCS on postural control and balance. There is an unmet need for the development of tailored tDCS protocols and the identification of predictors of response, which may optimize the clinical use of tDCS. Also, future studies should investigate the effect of multiple sessions of tDCS alone on postural control and balance.

Acknowledgments

Funding: This work was supported by the São Paulo Research Foundation (FAPESP) [grant number #2018/07385-9]; National Council for Scientific and Technological Development (CNPq) [grant number #429549/2018-0, #309045/2017-7]; and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) [Finance Code 001].

Systematic Review Registration: International Prospective Register of Systematic Reviews (PROSPERO). Registration number (CRD42021254481).

REFERENCES

Agius Anastasi, A., Falzon, O., Camilleri, K., Vella, M., Muscat, R., 2017. Brain Symmetry Index in Healthy and Stroke Patients for Assessment and Prognosis. Stroke Res. Treat. 2017, 8276136. https://doi.org/10.1155/2017/8276136

Albizu, A., Fang, R., Indahlastari, A., O'Shea, A., Stolte, S.E., See, K.B., Boutzoukas, E.M., Kraft, J.N., Nissim, N.R., Woods, A.J., 2020. Machine learning and

individual variability in electric field characteristics predict tDCS treatment response. Brain Stimul. 13, 1753–1764. https://doi.org/https://doi.org/10.1016/j.brs.2020.10.001

Alexoudi, A., Patrikelis, P., Fasilis, T., Deftereos, S., Sakas, D., Gatzonis, S., 2018. Effects of anodal tDCS on motor and cognitive function in a patient with multiple system atrophy. Disabil. Rehabil. https://doi.org/10.1080/09638288.2018.1510043

Andrade, S.M., Ferreira, J.J.D.A., Rufino, T.S., Medeiros, G., Brito, J.D., da Silva, M.A., Moreira, R.D.N., 2017. Effects of different montages of transcranial direct current stimulation on the risk of falls and lower limb function after stroke. Neurol. Res. 39, 1037–1043. https://doi.org/10.1080/01616412.2017.1371473

Babyar, S., Santos-Pontelli, T., Will-Lemos, T., Mazin, S., Bikson, M., Truong, D.Q., Edwards, D., Reding, M., 2016. Center of Pressure Speed Changes with tDCS Versus GVS in Patients with Lateropulsion after Stroke. Brain Stimul. 9, 796–798. https://doi.org/10.1016/j.brs.2016.06.053

Babyar, S., Santos, T., Will-Lemos, T., Mazin, S., Edwards, D., Reding, M., 2018. Sinusoidal Transcranial Direct Current Versus Galvanic Vestibular Stimulation for Treatment of Lateropulsion Poststroke. J. Stroke Cerebrovasc. Dis. 27, 3621–3625. https://doi.org/10.1016/j.jstrokecerebrovasdis.2018.08.034

Baharlouei, H., Saba, M.A., Shaterzadeh Yazdi, M.J., Jaberzadeh, S., 2020. The effect of transcranial direct current stimulation on balance in healthy young and older adults: A systematic review of the literature. Neurophysiol. Clin. 50, 119–131. https://doi.org/10.1016/j.neucli.2020.01.006

Barretto, T.L., Bandeira, I.D., Jagersbacher, J.G., Barretto, B.L., de Oliveira e Torres, Â.F.S., Peña, N., Miranda, J.G.V., Lucena, R., 2019. Transcranial direct current stimulation in the treatment of cerebellar ataxia: A two-phase, double-blind, auto-

matched, pilot study. Clin. Neurol. Neurosurg. 182, 123–129. https://doi.org/10.1016/j.clineuro.2019.05.009

Benninger, D.H., Lomarev, M., Lopez, G., Wassermann, E.M., Li, X., Considine, E., Hallett, M., 2010. Transcranial direct current stimulation for the treatment of Parkinson's disease. J. Neurol. Neurosurg. Psychiatry 81, 1105–1111. https://doi.org/10.1136/jnnp.2009.202556

Benussi, A., Koch, G., Cotelli, M., Padovani, A., Borroni, B., 2015. Cerebellar transcranial direct current stimulation in patients with ataxia: A double-blind, randomized, sham-controlled study. Mov. Disord. 30, 1701–1705. https://doi.org/10.1002/mds.26356

Beretta, V.S., Conceição, N.R., Nóbrega-Sousa, P., Orcioli-Silva, D., Dantas, L.K.B.F., Gobbi, L.T.B., Vitório, R., 2020a. Transcranial direct current stimulation combined with physical or cognitive training in people with Parkinson's disease: a systematic review. J. Neuroeng. Rehabil. 17, 74. https://doi.org/10.1186/s12984-020-00701-6

Beretta, V.S., Orcioli-Silva, D., Conceição, N.R., Nóbrega-Sousa, P., Pereira, M.P., Gobbi, L.T.B., Vitório, R., 2021. tDCS application for postural control in Parkinson's disease: Effects are associated with baseline characteristics. Parkinsonism Relat. Disord. 93, 62–65. https://doi.org/https://doi.org/10.1016/j.parkreldis.2021.11.012

Beretta, V.S., Vitório, R., Nóbrega-Sousa, P., Conceição, N.R., Orcioli-Silva, D., Pereira, M.P., Gobbi, L.T.B., 2020b. Effect of Different Intensities of Transcranial Direct Current Stimulation on Postural Response to External Perturbation in Patients With Parkinson's Disease. Neurorehabil. Neural Repair 34, 1009–1019. https://doi.org/10.1177/1545968320962513

Broeder, S., Nackaerts, E., Heremans, E., Vervoort, G., Meesen, R., Verheyden, G., Nieuwboer, A., 2015. Transcranial direct current stimulation in Parkinson's disease: Neurophysiological mechanisms and behavioral effects. Neurosci. Biobehav. Rev. 57, 105–117. https://doi.org/10.1016/j.neubiorev.2015.08.010

Brunoni, A.R., Nitsche, M.A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., Edwards, D.J., Valero-Cabre, A., Rotenberg, A., Pascual-Leone, A., Ferrucci, R., Priori, A., Boggio, P.S., Fregni, F., 2012. Clinical research with transcranial direct current stimulation (tDCS): challenges and future directions. Brain Stimul. 5, 175–195. https://doi.org/10.1016/j.brs.2011.03.002

Cha, Y.-H., Urbano, D., Pariseau, N., 2016. Randomized Single Blind Sham Controlled Trial of Adjunctive Home-Based tDCS after rTMS for Mal De Debarquement Syndrome: Safety, Efficacy, and Participant Satisfaction Assessment. Brain Stimul. 9, 537–544. https://doi.org/10.1016/j.brs.2016.03.016

Chan, M.M.Y., Yau, S.S.Y., Han, Y.M.Y., 2021. The neurobiology of prefrontal transcranial direct current stimulation (tDCS) in promoting brain plasticity: A systematic review and meta-analyses of human and rodent studies. Neurosci. Biobehav. Rev. 125, 392–416. https://doi.org/10.1016/j.neubiorev.2021.02.035

Chang, M.C., Kim, D.Y., Park, D.H., 2015. Enhancement of cortical excitability and lower limb motor function in patients with stroke by transcranial direct current stimulation. Brain Stimul. 8, 561–566. https://doi.org/10.1016/j.brs.2015.01.411

Cohen, J., 1998. Statistical Power Analysis for the Behavioral Sciences, 2nd. ed, Statistical Power Analysis for the Behavioral Sciences. Hillsdale (NJ): Lawrence Erlbaum Associates, New York. https://doi.org/10.4324/9780203771587

Conceição, N.R., Gobbi, L.T.B., Nóbrega-Sousa, P., Orcioli-Silva, D., Beretta, V.S., Lirani-Silva, E., Okano, A.H., Vitório, R., 2021. Aerobic Exercise Combined With

Transcranial Direct Current Stimulation Over the Prefrontal Cortex in Parkinson Disease: Effects on Cortical Activity, Gait, and Cognition. Neurorehabil. Neural Repair 35, 717–728. https://doi.org/10.1177/15459683211019344

Coppens, M.J.M., Staring, W.H.A., Nonnekes, J., Geurts, A.C.H., Weerdesteyn, V., 2019. Offline effects of transcranial direct current stimulation on reaction times of lower extremity movements in people after stroke: a pilot cross-over study. J. Neuroeng. Rehabil. 16. https://doi.org/10.1186/s12984-019-0604-y

Cosentino, G., Valentino, F., Todisco, M., Alfonsi, E., Davi, R., Savettieri, G., Fierro, B., D'Amelio, M., Brighina, F., 2017. Effects of more-affected vs. less-affected motor cortex tDCS in Parkinson's disease. Front. Hum. Neurosci. 11, 309. https://doi.org/10.3389/fnhum.2017.00309

Costa-Ribeiro, A., Maux, A., Bosford, T., Aoki, Y., Castro, R., Baltar, A., Shirahige, L., Moura Filho, A., Nitsche, M.A., Monte-Silva, K., 2017. Transcranial direct current stimulation associated with gait training in Parkinson's disease: A pilot randomized clinical trial. Dev. Neurorehabil. 20, 121–128. https://doi.org/10.3109/17518423.2015.1131755

Costa, G.C., Kunitake, A.I., Fonseca Junior, P.R., Ledur, Â.C., Elord Júlio, C., Pereira, G.S., Corrêa, J.C.F., Correa, F.I., 2020. Effect of transcranial direct current stimulation combined with a virtual reality exercise on balance in a patient with multiple sclerosis: a case report. Adapt. Behav. 28, 307–313. https://doi.org/10.1177/1059712319873912

Curtze, C., Nutt, J.G., Carlson-Kuhta, P., Mancini, M., Horak, F.B., 2015. Levodopa Is a Double-Edged Sword for Balance and Gait in People With Parkinson's Disease. Mov. Disord. 30, 1361–1370. https://doi.org/10.1002/mds.26269

Dagan, M., Herman, T., Harrison, R., Zhou, J., Giladi, N., Ruffini, G., Manor, B.,

Hausdorff, J.M., 2018. Multitarget transcranial direct current stimulation for freezing of gait in Parkinson's disease. Mov. Disord. 33, 642–646. https://doi.org/10.1002/mds.27300

Danzl, M.M., Chelette, K.C., Lee, K., Lykins, D., Sawaki, L., 2013. Brain stimulation paired with novel locomotor training with robotic gait orthosis in chronic stroke: A feasibility study. NeuroRehabilitation 33, 67–76. https://doi.org/10.3233/NRE-130929

de Morton, N.A., 2009. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. Aust. J. Physiother. 55, 129–133. https://doi.org/10.1016/s0004-9514(09)70043-1

de Moura, M.C.D.S., Hazime, F.A., Marotti Aparicio, L. V, Grecco, L.A.C., Brunoni, A.R., Hasue, R.H., 2019. Effects of transcranial direct current stimulation (tDCS) on balance improvement: a systematic review and meta-analysis. Somatosens. Mot. Res. 36, 122–135. https://doi.org/10.1080/08990220.2019.1624517

Dong, K., Meng, S., Guo, Z., Zhang, R., Xu, P., Yuan, E., Lian, T., 2021. The Effects of Transcranial Direct Current Stimulation on Balance and Gait in Stroke Patients: A Systematic Review and Meta-Analysis. Front. Neurol. 12, 650925. https://doi.org/10.3389/fneur.2021.650925

Drevon, D., Fursa, S.R., Malcolm, A.L., 2017. Intercoder Reliability and Validity of WebPlotDigitizer in Extracting Graphed Data. Behav. Modif. 41, 323–339. https://doi.org/10.1177/0145445516673998

Duarte, M., Freitas, S.M., 2010. Revision of posturography based on force plate for balance evaluation. Rev. Bras. Fisioter. 14, 183–192.

Dumont, A.J.L., Araujo, M.C., Lazzari, R.D., Santos, C.A., Carvalho, D.B., de Moura, R.C.F., Ferreira, L.A.B., Galli, M., Oliveira, C.S., 2015. Effects of a single session

of transcranial direct current stimulation on static balance in a patient with hemiparesis: A case study. J. Phys. Ther. Sci. 27, 955–958. https://doi.org/10.1589/jpts.27.955

Ekhtiari, H., Tavakoli, H., Addolorato, G., Baeken, C., Bonci, A., Campanella, S., Castelo-Branco, L., Challet-Bouju, G., Clark, V.P., Claus, E., Dannon, P.N., Del Felice, A., den Uyl, T., Diana, M., di Giannantonio, M., Fedota, J.R., Fitzgerald, P., Gallimberti, L., Grall-Bronnec, M., Herremans, S.C., Herrmann, M.J., Jamil, A., Khedr, E., Kouimtsidis, C., Kozak, K., Krupitsky, E., Lamm, C., Lechner, W. V, Madeo, G., Malmir, N., Martinotti, G., McDonald, W.M., Montemitro, C., Nakamura-Palacios, E.M., Nasehi, M., Noël, X., Nosratabadi, M., Paulus, M., Pettorruso, M., Pradhan, B., Praharaj, S.K., Rafferty, H., Sahlem, G., Salmeron, B.J., Sauvaget, A., Schluter, R.S., Sergiou, C., Shahbabaie, A., Sheffer, C., Spagnolo, P.A., Steele, V.R., Yuan, T.-F., van Dongen, J.D.M., Van Waes, V., Venkatasubramanian, G., Verdejo-García, A., Verveer, I., Welsh, J.W., Wesley, M.J., Witkiewitz, K., Yavari, F., Zarrindast, M.-R., Zawertailo, L., Zhang, X., Cha, Y.-H., George, T.P., Frohlich, F., Goudriaan, A.E., Fecteau, S., Daughters, S.B., Stein, E.A., Fregni, F., Nitsche, M.A., Zangen, A., Bikson, M., Hanlon, C.A., 2019. Transcranial electrical and magnetic stimulation (tES and TMS) for addiction medicine: A consensus paper on the present state of the science and the road ahead. Neurosci. Biobehav. Rev. 104, 118–140. https://doi.org/10.1016/j.neubiorev.2019.06.007

Farnad, L., Ghasemian-Shirvan, E., Mosayebi-Samani, M., Kuo, M.-F., Nitsche, M.A., 2021. Exploring and optimizing the neuroplastic effects of anodal transcranial direct current stimulation over the primary motor cortex of older humans. Brain Stimul. 14, 622–634. https://doi.org/10.1016/j.brs.2021.03.013

Filmer, H.L., Mattingley, J.B., Dux, P.E., 2020. Modulating brain activity and behaviour with tDCS: Rumours of its death have been greatly exaggerated. Cortex 123, 141–151. https://doi.org/10.1016/j.cortex.2019.10.006

Forogh, B., Rafiei, M., Arbabi, A., Motamed, M.R., Madani, S.P., Sajadi, S., 2018. Repeated sessions of transcranial direct current stimulation evaluation on fatigue and daytime sleepiness in Parkinson's disease. J. Neurol. Neurosci. 9, 250. https://doi.org/10.21767/2171-6625.1000250

Fregni, F., Boggio, P.S., Santos, M.C., Lima, M., Vieira, A.L., Rigonatti, S.P., Silva, M.T., Barbosa, E.R., Nitsche, M.A., Pascual-Leone, A., 2006. Noninvasive cortical stimulation with transcranial direct current stimulation in Parkinson's disease. Mov. Disord. 21, 1693–1702. https://doi.org/10.1002/mds.21012

Fregni, F., El-Hagrassy, M.M., Pacheco-Barrios, K., Carvalho, S., Leite, J., Simis, M., Brunelin, J., Nakamura-Palacios, E.M., Marangolo, P., Venkatasubramanian, G., San-Juan, D., Caumo, W., Bikson, M., Brunoni, A.R., 2021. Evidence-Based Guidelines and Secondary Meta-Analysis for the Use of Transcranial Direct Current Stimulation in Neurological and Psychiatric Disorders. Int. J. Neuropsychopharmacol. 24, 256–313. https://doi.org/10.1093/ijnp/pyaa051

Fregni, F., Pascual-Leone, A., 2007. Technology Insight: Noninvasive brain stimulation in neurology - Perspectives on the therapeutic potential of rTMS and tDCS. Nat. Clin. Pract. Neurol. 3, 383–393. https://doi.org/10.1038/ncpneuro0530

Fruhauf, A.M.A., Politti, F., Dal Corso, S., Costa, G.C., Teodósio, A.C., Silva, S.M., Corrêa, J.C.F., Corrêa, F.I., 2017. Immediate effect of transcranial direct current stimulation combined with functional electrical stimulation on activity of the tibialis anterior muscle and balance of individuals with hemiparesis stemming from a stroke. J. Phys. Ther. Sci. 29, 2138–2146. https://doi.org/10.1589/jpts.29.2138

Gandolfi, M., Valè, N., Filippetti, M., Dimitrova, E.K., Geroin, C., Picelli, A., Smania, N., 2018. Postural Control in Individuals with Parkinson's Disease, in: IntechOpen. IntechOpen, pp. 1–18. https://doi.org/10.5772/intechopen.81098

Geroin, C., Picelli, A., Munari, D., Waldner, A., Tomelleri, C., Smania, N., 2011. Combined transcranial direct current stimulation and robot-assisted gait training in patients with chronic stroke: a preliminary comparison. Clin. Rehabil. 25, 537–548. https://doi.org/10.1177/0269215510389497

Grimaldi, G., Manto, M., 2013. Anodal transcranial direct current stimulation (tDCS) decreases the amplitudes of long-latency stretch reflexes in cerebellar ataxia. Ann. Biomed. Eng. 41, 2437–2447. https://doi.org/10.1007/s10439-013-0846-y

Guo, Z., Bao, D., Manor, B., Zhou, J., 2020. The Effects of Transcranial Direct Current Stimulation (tDCS) on Balance Control in Older Adults: A Systematic Review and Meta-Analysis. Front. Aging Neurosci. 12. https://doi.org/10.3389/fnagi.2020.00275

Hadoush, H., Al-Jarrah, M., Khalil, H., Al-Sharman, A., Al-Ghazawi, S., 2018. Bilateral anodal transcranial direct current stimulation effect on balance and fearing of fall in patient with Parkinson's disease. NeuroRehabilitation 42, 63–68. https://doi.org/10.3233/NRE-172212

Halmi, Z., Stone, T.W., Dinya, E., Málly, J., 2020. Postural instability years after stroke. J. stroke Cerebrovasc. Dis. Off. J. Natl. Stroke Assoc. 29, 105038. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105038

Herold, F., Wiegel, P., Scholkmann, F., Thiers, A., Hamacher, D., Schega, L., 2017. Functional near-infrared spectroscopy in movement science: a systematic review on cortical activity in postural and walking tasks. Neurophotonics 4, 041403. https://doi.org/10.1117/1.NPh.4.4.041403

Higgins, J., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M., Welch, V., 2020. Cochrane Handbook for Systematic Reviews of Interventions version 6.1. Cochrane.

Higgins, J.P.T., Altman, D.G., Gøtzsche, P.C., Jüni, P., Moher, D., Oxman, A.D., Savovic, J., Schulz, K.F., Weeks, L., Sterne, J.A.C., 2011. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 343, d5928. https://doi.org/10.1136/bmj.d5928

Higgins, J.P.T., Thompson, S.G., 2002. Quantifying heterogeneity in a meta-analysis. Stat. Med. 21, 1539–1558. https://doi.org/10.1002/sim.1186

Ho, K., Taylor, J.L., Chew, T., Gálvez, V., Alonzo, A., Bai, S., Dokos, S., Loo, C.K., 2016. The Effect of Transcranial Direct Current Stimulation (tDCS) Electrode Size and Current Intensity on Motor Cortical Excitability : Evidence From Single and Repeated Sessions. Brain Stimul. 9, 1–7. https://doi.org/10.1016/j.brs.2015.08.003

Horak, F.B., Henry, S.M., Shumway-Cook, A., 1997. Postural perturbations: new insights for treatment of balance disorders. Phys. Ther. 77, 517–533. https://doi.org/10.1093/ptj/77.5.517.

Horak, F.B., Nutt, J.G., Nashner, L.M., 1992. Postural inflexibility in parkinsonian subjects. J. Neurol. Sci. 111, 46–58. https://doi.org/https://doi.org/10.1016/0022-510X(92)90111-W

Hordacre, B., Moezzi, B., Ridding, M.C., 2018. Neuroplasticity and network connectivity of the motor cortex following stroke: A transcranial direct current stimulation study. Hum. Brain Mapp. 39, 3326–3339. https://doi.org/10.1002/hbm.24079

Islam, N., Aftabuddin, M., Moriwaki, A., Hattori, Y., Hori, Y., 1995. Increase in the

calcium level following anodal polarization in the rat brain. Brain Res. 684, 206–208. https://doi.org/10.1016/0006-8993(95)00434-r

Jafarzadeh, A., Ehsani, F., Yosephi, M.H., Zoghi, M., Jaberzadeh, S., 2019. Concurrent postural training and M1 anodal transcranial direct current stimulation improve postural impairment in patients with chronic low back pain. J. Clin. Neurosci. 68, 224–234. https://doi.org/10.1016/j.jocn.2019.07.017

Kaski, D., Allum, J.H., Bronstein, A.M., Dominguez, R.O., 2014a. Applying anodal tDCS during tango dancing in a patient with Parkinson's disease. Neurosci. Lett. 568, 39–43. https://doi.org/10.1016/j.neulet.2014.03.043

Kaski, D., Dominguez, R.O., Allum, J.H., Bronstein, A.M., 2013. Improving gait and balance in patients with leukoaraiosis using transcranial direct current stimulation and physical training: An exploratory study. Neurorehabil. Neural Repair 27, 864–871. https://doi.org/10.1177/1545968313496328

Kaski, D., Dominguez, R.O., Allum, J.H., Islam, A.F., Bronstein, A.M., 2014b. Combining physical training with transcranial direct current stimulation to improve gait in Parkinson's disease: A pilot randomized controlled study. Clin. Rehabil. 28, 1115–1124. https://doi.org/10.1177/0269215514534277

Koganemaru, S., Kitatani, R., Fukushima-Maeda, A., Mikami, Y., Okita, Y., Matsuhashi, M., Ohata, K., Kansaku, K., Mima, T., 2019. Gait-Synchronized Rhythmic Brain Stimulation Improves Poststroke Gait Disturbance: A Pilot Study. Stroke 50, 3205–3212. https://doi.org/10.1161/STROKEAHA.119.025354

Lattari, E., Costa, S.S., Campos, C., de Oliveira, A.J., Machado, S., Maranhao Neto, G.A., 2017. Can transcranial direct current stimulation on the dorsolateral prefrontal cortex improves balance and functional mobility in Parkinson's disease? Neurosci. Lett. 636, 165–169. https://doi.org/10.1016/j.neulet.2016.11.019

Lee, H.K., Ahn, S.J., Shin, Y.M., Kang, N., Cauraugh, J.H., 2019. Does transcranial direct current stimulation improve functional locomotion in people with Parkinson's disease? A systematic review and meta-analysis. J. Neuroeng. Rehabil. 16, 84. https://doi.org/10.1186/s12984-019-0562-4

Li, L.M., Uehara, K., Hanakawa, T., 2015. The contribution of interindividual factors to variability of response in transcranial direct current stimulation studies. Front. Cell. Neurosci. 9, 181. https://doi.org/10.3389/fncel.2015.00181

Liang, J.N., Ubalde, L., Jacklin, J., Hobson, P., Wright-Avila, S., Lee, Y.-J., 2020. Immediate Effects of Anodal Transcranial Direct Current Stimulation on Postural Stability Using Computerized Dynamic Posturography in People With Chronic Post-stroke Hemiparesis. Front. Hum. Neurosci. 14. https://doi.org/10.3389/fnhum.2020.00341

Liu, X., Liu, H., Liu, Z., Rao, J., Wang, J., Wang, P., Gong, X., Wen, Y., 2021. Transcranial Direct Current Stimulation for Parkinson's Disease: A Systematic Review and Meta-Analysis. Front. Aging Neurosci. 13, 691.

Lu, C., Amundsen Huffmaster, S.L., Tuite, P.J., MacKinnon, C.D., 2018. The effects of anodal tDCS over the supplementary motor area on gait initiation in Parkinson's disease with freezing of gait: a pilot study. J. Neurol. 265, 2023–2032. https://doi.org/10.1007/s00415-018-8953-1

Lüdemann-Podubecká, J., Bösl, K., Rothhardt, S., Verheyden, G., Nowak, D.A., 2014. Transcranial direct current stimulation for motor recovery of upper limb function after stroke. Neurosci. Biobehav. Rev. 47, 245–259. https://doi.org/10.1016/j.neubiorev.2014.07.022

Madhavan, S., Cleland, B.T., Sivaramakrishnan, A., Freels, S., Lim, H., Testai, F.D., Corcos, D.M., 2020. Cortical priming strategies for gait training after stroke: a

controlled, stratified trial. J. Neuroeng. Rehabil. 17, 111. https://doi.org/10.1186/s12984-020-00744-9

Madrid, J., Benninger, D.H., 2021. Non-invasive brain stimulation for Parkinson's disease: Clinical evidence, latest concepts and future goals: A systematic review. J. Neurosci. Methods 347, 108957. https://doi.org/10.1016/j.jneumeth.2020.108957

Maher, C.G., Sherrington, C., Herbert, R.D., Moseley, A.M., Elkins, M., 2003. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys. Ther. 83, 713–721.

Maldonado, T., Bernard, J.A., 2021. The Polarity-Specific Nature of Single-Session High-definition Transcranial Direct Current Stimulation to the Cerebellum and Prefrontal Cortex on Motor and Non-motor Task Performance. Cerebellum. https://doi.org/10.1007/s12311-021-01235-w

Mancini, M., Nutt, J.G., Horak, F.B., 2020. Chapter 1 - How is balance controlled by the nervous system?, in: Mancini, M., Nutt, J.G., Horak, F.B. (Eds.), Balance Dysfunction in Parkinson's Disease. Academic Press, pp. 1–24. https://doi.org/https://doi.org/10.1016/B978-0-12-813874-8.00001-5

Manenti, R., Brambilla, M., Benussi, A., Rosini, S., Cobelli, C., Ferrari, C., Petesi, M., Orizio, I., Padovani, A., Borroni, B., Borroni, B., Cotelli, M., 2016. Mild cognitive impairment in Parkinson's disease is improved by transcranial direct current stimulation combined with physical therapy. Mov. Disord. 31, 715–724. https://doi.org/10.1002/mds.26561

Manji, A., Amimoto, K., Matsuda, T., Wada, Y., Inaba, A., Ko, S., 2018. Effects of transcranial direct current stimulation over the supplementary motor area body weight-supported treadmill gait training in hemiparetic patients after stroke.

Neurosci. Lett. 662, 302–305. https://doi.org/10.1016/j.neulet.2017.10.049

Manor, B., Zhou, J., Harrison, R., Lo, O.-Y., Travison, T.G., Hausdorff, J.M., Pascual-Leone, A., Lipsitz, L., 2018. Transcranial Direct Current Stimulation May Improve Cognitive-Motor Function in Functionally Limited Older Adults. Neurorehabil. Neural Repair 32, 788–798. https://doi.org/10.1177/1545968318792616

Mesbah, N., Perry, M., Hill, K.D., Kaur, M., Hale, L., 2017. Postural Stability in Older Adults With Alzheimer Disease. Phys. Ther. 97, 290–309. https://doi.org/10.2522/ptj.20160115

Mizuguchi, N., Katayama, T., Kanosue, K., 2018. The Effect of Cerebellar Transcranial Direct Current Stimulation on A Throwing Task Depends on Individual Level of Task Performance. Neuroscience 371, 119–125. https://doi.org/10.1016/j.neuroscience.2017.11.048

Mohammadi, R., Mahmoudi, Z., Mahmoodian, N., 2021. Effects of cerebellar transcranial direct current stimulation (Tdcs) on timed up and go test with foot placement in chronic stroke patients. Middle East J. Rehabil. Heal. 8, 1–6. https://doi.org/10.5812/mejrh.106180

Morya, E., Monte-Silva, K., Bikson, M., Esmaeilpour, Z., Biazoli, C.E.J., Fonseca, A., Bocci, T., Farzan, F., Chatterjee, R., Hausdorff, J.M., da Silva Machado, D.G., Brunoni, A.R., Mezger, E., Moscaleski, L.A., Pegado, R., Sato, J.R., Caetano, M.S., Sá, K.N., Tanaka, C., Li, L.M., Baptista, A.F., Okano, A.H., 2019. Beyond the target area: an integrative view of tDCS-induced motor cortex modulation in patients and athletes. J. Neuroeng. Rehabil. 16, 141. https://doi.org/10.1186/s12984-019-0581-1

Murad, M.H., Wang, Z., Chu, H., Lin, L., 2019. When continuous outcomes are measured using different scales: guide for meta-analysis and interpretation. BMJ

364, k4817. https://doi.org/10.1136/bmj.k4817

Naro, A., Billeri, L., Manuli, A., Balletta, T., Cannavò, A., Portaro, S., Lauria, P., Ciappina, F., Calabrò, R.S., 2020. Breaking the ice to improve motor outcomes in patients with chronic stroke: a retrospective clinical study on neuromodulation plus robotics. Neurol. Sci. https://doi.org/10.1007/s10072-020-04875-8

Nitsche, M.A., Cohen, L.G., Wassermann, E.M., Priori, A., Lang, N., Antal, A., Paulus, W., Hummel, F., Boggio, P.S., Fregni, F., Pascual-Leone, A., 2008. Transcranial direct current stimulation: State of the art 2008. Brain Stimul. 1, 206–223. https://doi.org/10.1016/j.brs.2008.06.004

Nitsche, M.A., Liebetanz, D., Schlitterlau, A., Henschke, U., Fricke, K., Frommann, K., Lang, N., Henning, S., Paulus, W., Tergau, F., 2004. GABAergic modulation of DC stimulation-induced motor cortex excitability shifts in humans. Eur. J. Neurosci. 19, 2720–2726. https://doi.org/10.1111/j.0953-816X.2004.03398.x

Nitsche, M.A., Paulus, W., 2001. Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. Neurology 57, 1899–1901. https://doi.org/10.1212/wnl.57.10.1899

Nitsche, M.A., Paulus, W., 2000. Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. J. Physiol. 527, 6. https://doi.org/10.1111/j.1469-7793.2000.t01-1-00633.x

Nonnekes, J., Arrogi, A., Munneke, M.A.M., Van Asseldonk, E.H.F., Nijhuis, L.B.O., Geurts, A.C., Weerdesteyn, V., 2014. Subcortical structures in humans can be facilitated by transcranial direct current stimulation. PLoS One 9, e107731. https://doi.org/10.1371/journal.pone.0107731

Nonnekes, J., Goselink, R.J.M., Růžička, E., Fasano, A., Nutt, J.G., Bloem, B.R., 2018. Neurological disorders of gait, balance and posture: a sign-based approach. Nat.

Rev. Neurol. 14, 183–189. https://doi.org/10.1038/nrneurol.2017.178

Ojardias, E., Azé, O.D., Luneau, D., Mednieks, J., Condemine, A., Rimaud, D., Chassagne, F., Giraux, P., 2020. The Effects of Anodal Transcranial Direct Current Stimulation on the Walking Performance of Chronic Hemiplegic Patients. Neuromodulation 23, 373–379. https://doi.org/10.1111/ner.12962

Oliveira, P.C.A. de, Araújo, T.A.B. de, Machado, D.G. da S., Rodrigues, A.C., Bikson, M., Andrade, S.M., Okano, A.H., Simplicio, H., Pegado, R., Morya, E., 2022. Transcranial Direct Current Stimulation on Parkinson's Disease: Systematic Review and Meta-Analysis. Front. Neurol. 12, 2378.

Orrù, G., Baroni, M., Cesari, V., Conversano, C., Hitchcott, P.K., Gemignani, A., 2019. The effect of single and repeated tDCS sessions on motor symptoms in Parkinson's disease: A systematic review. Arch. Ital. Biol. 157, 89–101. https://doi.org/10.12871/00039829201925

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372, n71. https://doi.org/10.1136/bmj.n71

Peterson, D.S., Horak, F.B., 2016. Neural Control of Walking in People with Parkinsonism. Physiol. 31, 95–107. https://doi.org/10.1152/physiol.00034.2015

Pilloni, G., Shaw, M., Feinberg, C., Clayton, A., Palmeri, M., Datta, A., Charvet, L.E., 2019. Long term at-home treatment with transcranial direct current stimulation (tDCS) improves symptoms of cerebellar ataxia: a case report. J. Neuroeng.

Rehabil. 16. https://doi.org/10.1186/s12984-019-0514-z

Polanía, R., Nitsche, M.A., Paulus, W., 2011. Modulating functional connectivity patterns and topological functional organization of the human brain with transcranial direct current stimulation. Hum. Brain Mapp. 32, 1236–1249. https://doi.org/10.1002/hbm.21104

Prathum, T., Piriyaprasarth, P., Aneksan, B., Hiengkaew, V., Pankhaew, T., Vachalathiti, R., Klomjai, W., 2021. Effects of home-based dual-hemispheric transcranial direct current stimulation combined with exercise on upper and lower limb motor performance in patients with chronic stroke. Disabil. Rehabil. 1–12. https://doi.org/10.1080/09638288.2021.1891464

Quijoux, F., Vienne-Jumeau, A., Bertin-Hugault, F., Zawieja, P., Lefèvre, M., Vidal, P.-P., Ricard, D., 2020. Center of pressure displacement characteristics differentiate fall risk in older people: A systematic review with meta-analysis. Ageing Res. Rev. 62, 101117. https://doi.org/10.1016/j.arr.2020.101117

Raithatha, R., Carrico, C., Powell, E.S., Westgate, P.M., Chelette, K.C., Lee, K., Dunsmore, L., Salles, S., Sawaki, L., 2016. Non-invasive brain stimulation and robot-assisted gait training after incomplete spinal cord injury: A randomized pilot study. NeuroRehabilitation 38, 15–25. https://doi.org/10.3233/NRE-151291

Rezaee, Z., Kaura, S., Solanki, D., Dash, A., Padma Srivastava, M.V., Lahiri, U., Dutta, A., 2020. Deep cerebellar transcranial direct current stimulation of the dentate nucleus to facilitate standing balance in chronic stroke survivors—a pilot study. Brain Sci. 10. https://doi.org/10.3390/brainsci10020094

Ricci, M., Di Lazzaro, G., Pisani, A., Scalise, S., Alwardat, M., Salimei, C., Giannini, F., Saggio, G., 2019. Wearable electronics assess the effectiveness of transcranial direct current stimulation on balance and gait in Parkinson's disease patients.

Sensors (Switzerland) 19. https://doi.org/10.3390/s19245465

Rohatgi, A., 2020. WebPlotDigitizer (version 4.4) [WWW Document]. URL https://automeris.io/WebPlotDigitizer

Rudroff, T., Fietsam, A.C., Deters, J.R., Workman, C.D., Boles Ponto, L.L., 2022. On the Effects of Transcranial Direct Current Stimulation on Cerebral Glucose Uptake During Walking: A Report of Three Patients With Multiple Sclerosis. Front. Hum. Neurosci. 16. https://doi.org/10.3389/fnhum.2022.833619

Sabchuk, R.A.C., Bento, P.C.B., Rodacki, A.L.F., 2012. Comparison between field balance tests and force platform. Rev. Bras. Med. do Esporte 18, 404–408. https://doi.org/10.1590/s1517-86922012000600012

Saeys, W., Vereeck, L., Lafosse, C., Truijen, S., Wuyts, F.L., Van De Heyning, P., 2015. Transcranial direct current stimulation in the recovery of postural control after stroke: A pilot study. Disabil. Rehabil. 37, 1857–1863. https://doi.org/10.3109/09638288.2014.982834

Saki, N., Bayat, A., Nikakhlagh, S., Mirmomeni, G., 2020. Vestibular rehabilitation therapy in combination with transcranial direct current stimulation (tDCS) for treatment of chronic vestibular dysfunction in the elderly: a double-blind randomized controlled trial [Terapia de reabilitação vestibular em combinaç. Braz. J. Otorhinolaryngol. https://doi.org/10.1016/j.bjorl.2020.11.004

Sandrini, M., Manenti, R., Sahin, H., Cotelli, M., 2020. Effects of transcranial electrical stimulation on episodic memory in physiological and pathological ageing. Ageing Res. Rev. 61, 101065. https://doi.org/10.1016/j.arr.2020.101065

Santos Ferreira, I., Teixeira Costa, B., Lima Ramos, C., Lucena, P., Thibaut, A., Fregni, F., 2019. Searching for the optimal tDCS target for motor rehabilitation. J. Neuroeng. Rehabil. 16, 90. https://doi.org/10.1186/s12984-019-0561-5

Schoellmann, A., Scholten, M., Wasserka, B., Govindan, R.B., Krüger, R., Gharabaghi, A., Plewnia, C., Weiss, D., 2019. Anodal tDCS modulates cortical activity and synchronization in Parkinson's disease depending on motor processing. NeuroImage. Clin. 22, 101689. https://doi.org/10.1016/j.nicl.2019.101689

Seo, H.G., Lee, W.H., Lee, S.H., Yi, Y., Kim, K.D., Oh, B.-M., 2017. Robotic-assisted gait training combined with transcranial direct current stimulation in chronic stroke patients: A pilot double-blind, randomized controlled trial. Restor. Neurol. Neurosci. 35, 527–536. https://doi.org/10.3233/RNN-170745

Sohn, M.K., Jee, S.J., Kim, Y.W., 2013. Effect of transcranial direct current stimulation on postural stability and lower extremity strength in hemiplegic stroke patients. Ann. Rehabil. Med. 37, 759–765. https://doi.org/10.5535/arm.2013.37.6.759

Solanki, D., Rezaee, Z., Dutta, A., Lahiri, U., 2021. Investigating the feasibility of cerebellar transcranial direct current stimulation to facilitate post-stroke overground gait performance in chronic stroke: a partial least-squares regression approach. J. Neuroeng. Rehabil. 18. https://doi.org/10.1186/s12984-021-00817-3

St George, R.J., Hinder, M.R., Puri, R., Walker, E., Callisaya, M.L., 2021. Functional Near-infrared Spectroscopy Reveals the Compensatory Potential of Pre-frontal Cortical Activity for Standing Balance in Young and Older Adults. Neuroscience 452, 208–218. https://doi.org/10.1016/j.neuroscience.2020.10.027

Stagg, C.J., O'Shea, J., Kincses, Z.T., Woolrich, M., Matthews, P.M., Johansen-Berg, H., 2009. Modulation of movement-associated cortical activation by transcranial direct current stimulation. Eur. J. Neurosci. 30, 1412–1423. https://doi.org/10.1111/j.1460-9568.2009.06937.x

Stolze, H., Klebe, S., Zechlin, C., Baecker, C., Friege, L., Deuschl, G., 2004. Falls in frequent neurological diseases--prevalence, risk factors and aetiology. J. Neurol.

251, 79–84. https://doi.org/10.1007/s00415-004-0276-8

Summers, J.J., Kang, N., Cauraugh, J.H., 2016. Does transcranial direct current stimulation enhance cognitive and motor functions in the ageing brain? A systematic review and meta- analysis. Ageing Res. Rev. 25, 42–54. https://doi.org/10.1016/j.arr.2015.11.004

Tahtis, V., Kaski, D., Seemungal, B.M., 2014. The effect of single session bi-cephalic transcranial direct current stimulation on gait performance in sub-acute stroke: A pilot study. Restor. Neurol. Neurosci. 32, 527–532. https://doi.org/10.3233/RNN-140393

Takakusaki, K., 2017. Functional Neuroanatomy for Posture and Gait Control. J. Mov. Disord. 10, 1–17. https://doi.org/10.14802/jmd.16062

Tanaka, T., Takano, Y., Tanaka, S., Hironaka, N., Kobayashi, K., Hanakawa, T., Watanabe, K., Honda, M., 2013. Transcranial direct-current stimulation increases extracellular dopamine levels in the rat striatum. Front. Syst. Neurosci. 7, 6. https://doi.org/10.3389/fnsys.2013.00006

Tatti, E., Rossi, S., Innocenti, I., Rossi, A., Santarnecchi, E., 2016. Non-invasive brain stimulation of the aging brain: State of the art and future perspectives. Ageing Res. Rev. 29, 66–89. https://doi.org/10.1016/j.arr.2016.05.006

The Cochrane Collaboration, 2020. Review Manager (RevMan) [Computer program]. Version 5.4.

Tyson, S.F., Hanley, M., Chillala, J., Selley, A., Tallis, R.C., 2006. Balance disability after stroke. Phys. Ther. 86, 30–38. https://doi.org/10.1093/ptj/86.1.30

van de Warrenburg, B.P.C., Steijns, J.A.G., Munneke, M., Kremer, B.P.H., Bloem, B.R., 2005. Falls in degenerative cerebellar ataxias. Mov. Disord. 20, 497–500. https://doi.org/10.1002/mds.20375

Vaseghi, B., Zoghi, M., Jaberzadeh, S., 2015. How does anodal transcranial direct current stimulation of the pain neuromatrix affect brain excitability and pain perception? A randomised, double-blind, sham-control study. PLoS One 10, e0118340. https://doi.org/10.1371/journal.pone.0118340

Verheyden, G., Purdey, J., Burnett, M., Cole, J., Ashburn, A., 2013. Immediate effect of transcranial direct current stimulation on postural stability and functional mobility in Parkinson's disease. Mov. Disord. 28, 2040–2041. https://doi.org/10.1002/mds.25640

Vitório, R., Stuart, S., Charvet, L.E., Godfrey, A., 2019. Introducing the thematic series on transcranial direct current stimulation (tDCS) for motor rehabilitation: on the way to optimal clinical use. J. Neuroeng. Rehabil. 16, 34. https://doi.org/10.1186/s12984-019-0507-y

Ward, N., 2011. Assessment of cortical reorganisation for hand function after stroke. J. Physiol. 589, 5625–5632. https://doi.org/10.1113/jphysiol.2011.220939

Workman, C.D., Fietsam, A.C., Uc, E.Y., Rudroff, T., 2020. Cerebellar transcranial direct current stimulation in people with parkinson's disease: A pilot study. Brain Sci. 10. https://doi.org/10.3390/brainsci10020096

Yang, C.-L., Gad, A., Creath, R.A., Magder, L., Rogers, M.W., Waller, S.M.C., 2021. Effects of transcranial direct current stimulation (tDCS) on posture, movement planning, and execution during standing voluntary reach following stroke. J. Neuroeng. Rehabil. 18. https://doi.org/10.1186/s12984-020-00799-8

Zandvliet, S.B., Meskers, C.G.M., Kwakkel, G., van Wegen, E.E.H., 2018. Short-Term Effects of Cerebellar tDCS on Standing Balance Performance in Patients with Chronic Stroke and Healthy Age-Matched Elderly. Cerebellum 17, 575–589. https://doi.org/10.1007/s12311-018-0939-0

Zheng, X., Alsop, D.C., Schlaug, G., 2011. Effects of transcranial direct current stimulation (tDCS) on human regional cerebral blood flow. Neuroimage 58, 26–33. https://doi.org/10.1016/j.neuroimage.2011.06.018

Figure Captions

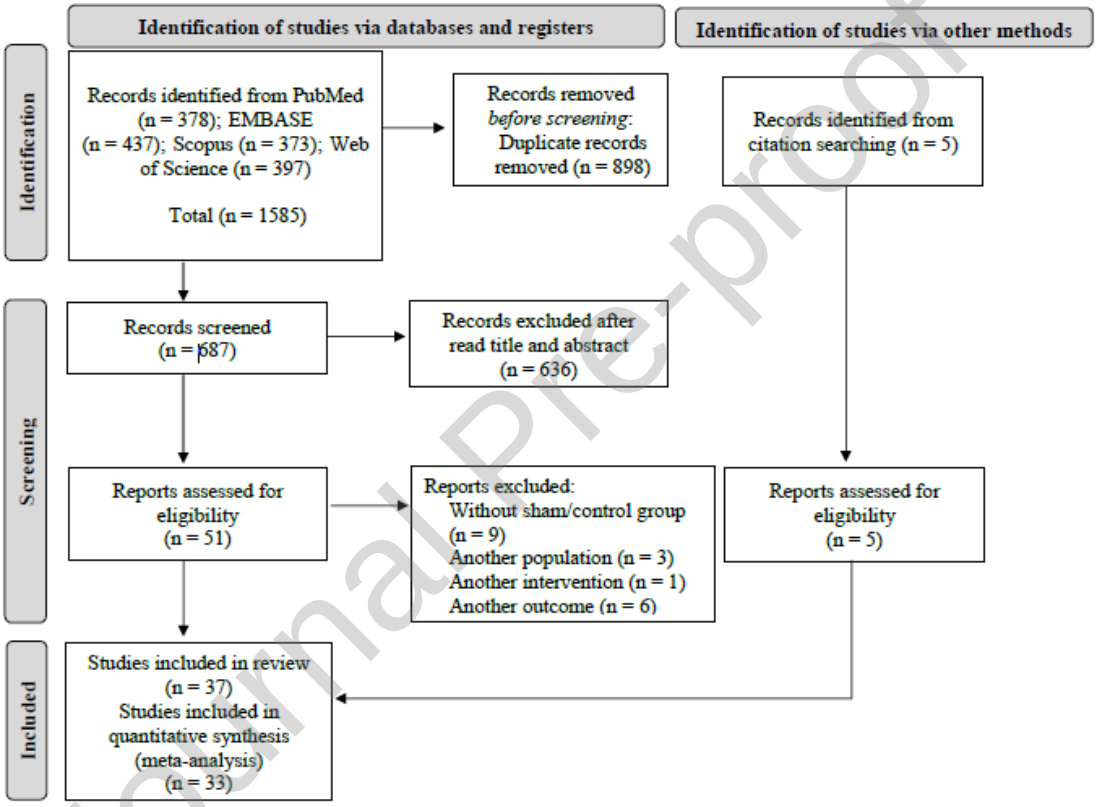

Figure 1. PRISMA flowchart showing the screening process.

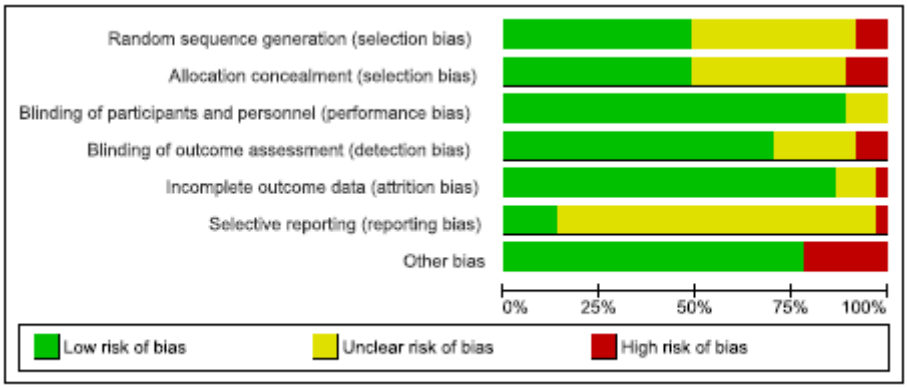

Figure 2. Risk of bias assessment.

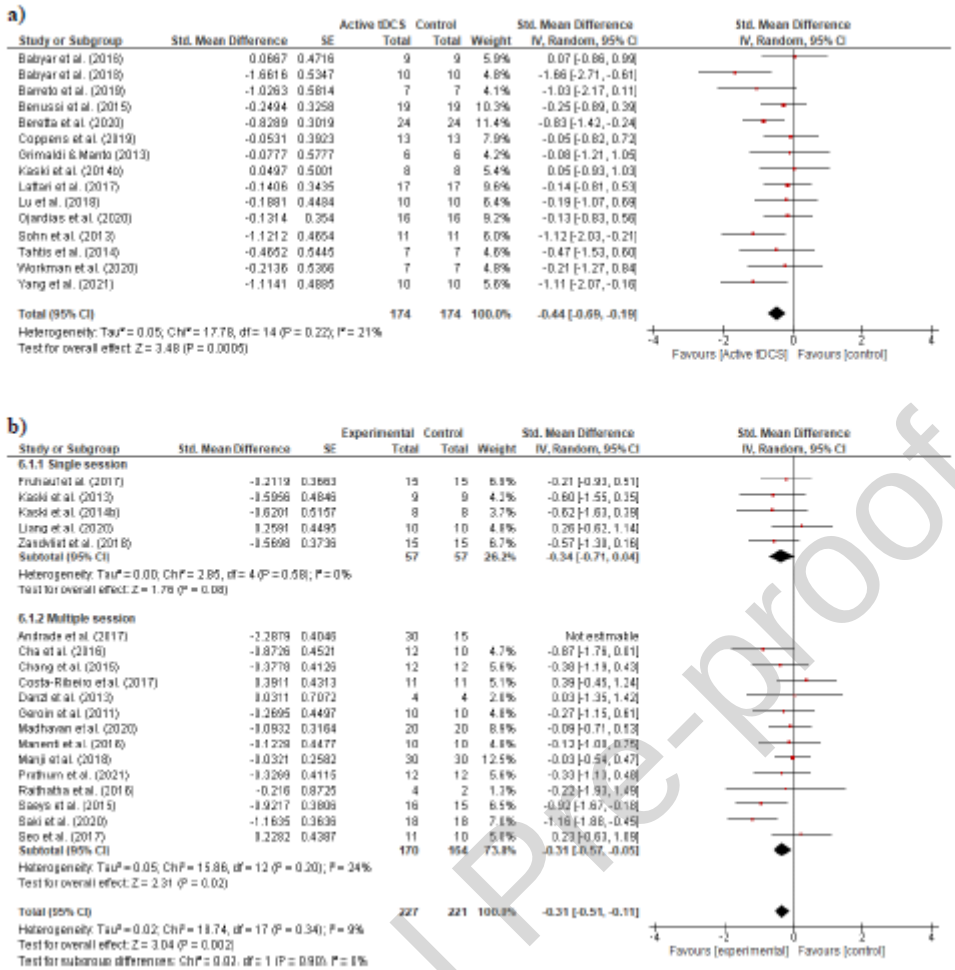

Figure 3. Forrest plots of the meta-analysis. a) tDCS alone; b) single and multiple sessions of tDCS combined with another intervention after sensitivity analysis.

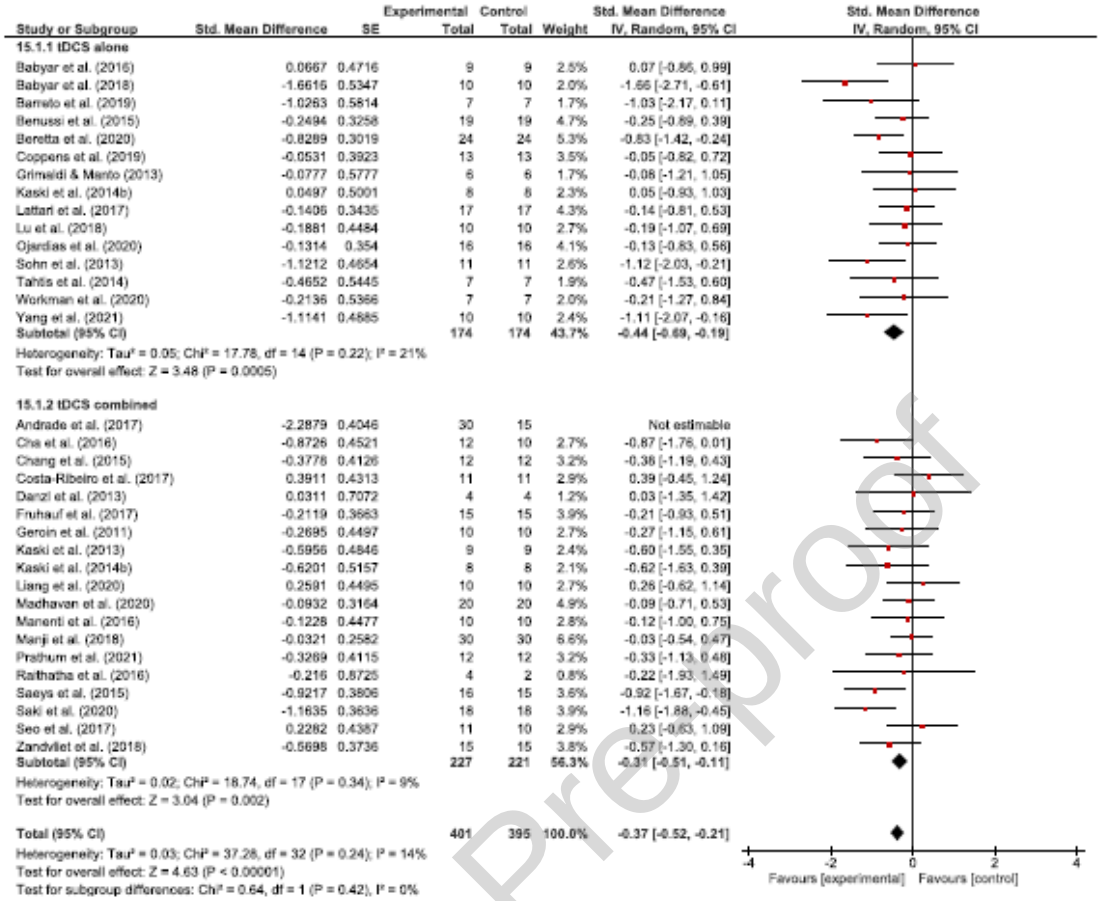

Figure 4. Forrest plots of the meta-analysis with the tDCS alone subgroup and tDCS combined with another intervention subgroup after sensitivity analysis.

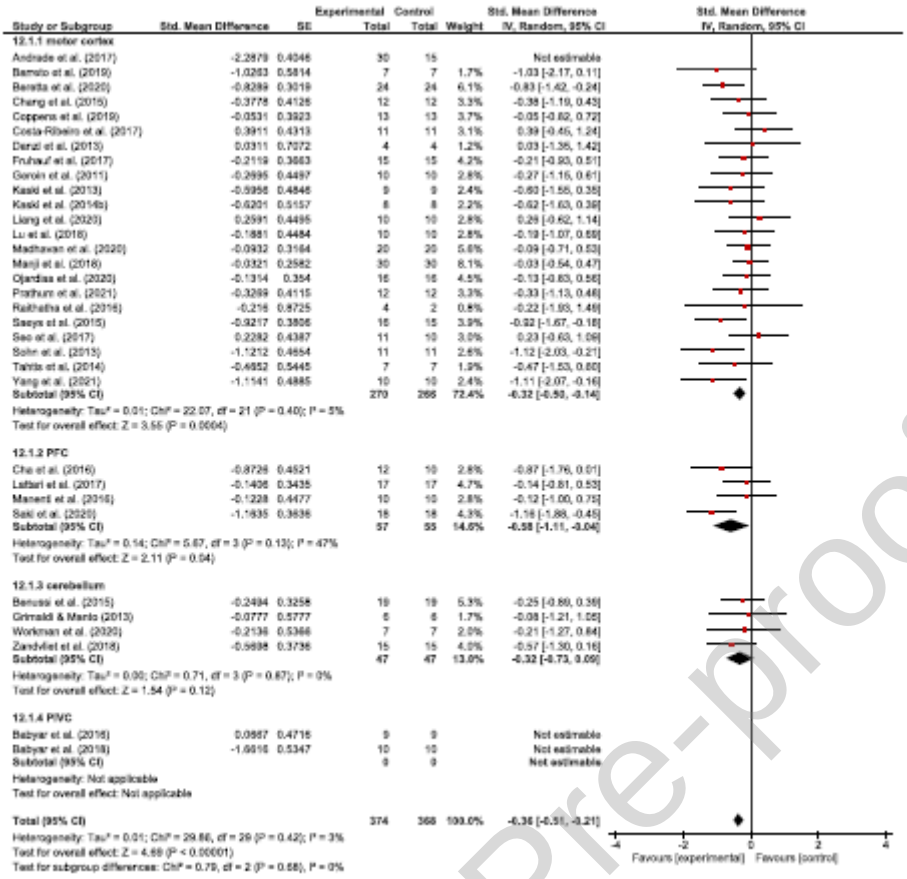

Figure 5. Forrest plots of the meta-analysis regarding the target area stimulated with the motor cortex subgroup, PFC subgroup, and cerebellum subgroup after sensitivity analysis. PFC: Prefrontal cortex; PIVC: parietal-insular vestibular cortex.

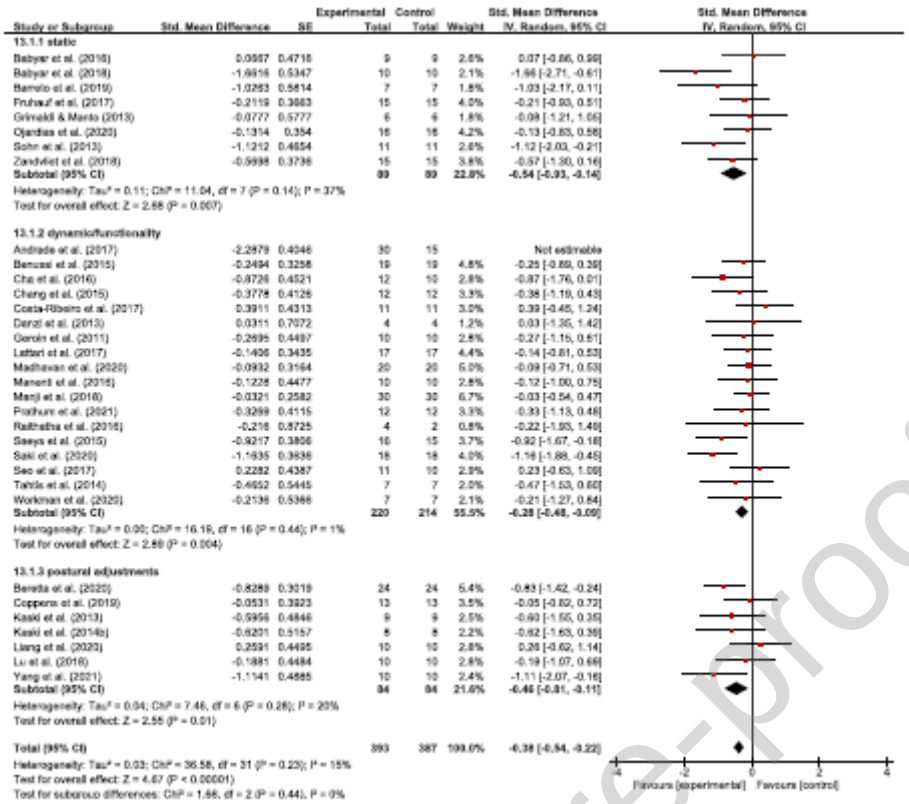

Figure 6. Forrest plots of the meta-analysis regarding the outcome domain with the static subgroup, dynamic/functionality subgroup, and postural adjustments in situations with external perturbation subgroup after sensitivity analysis.

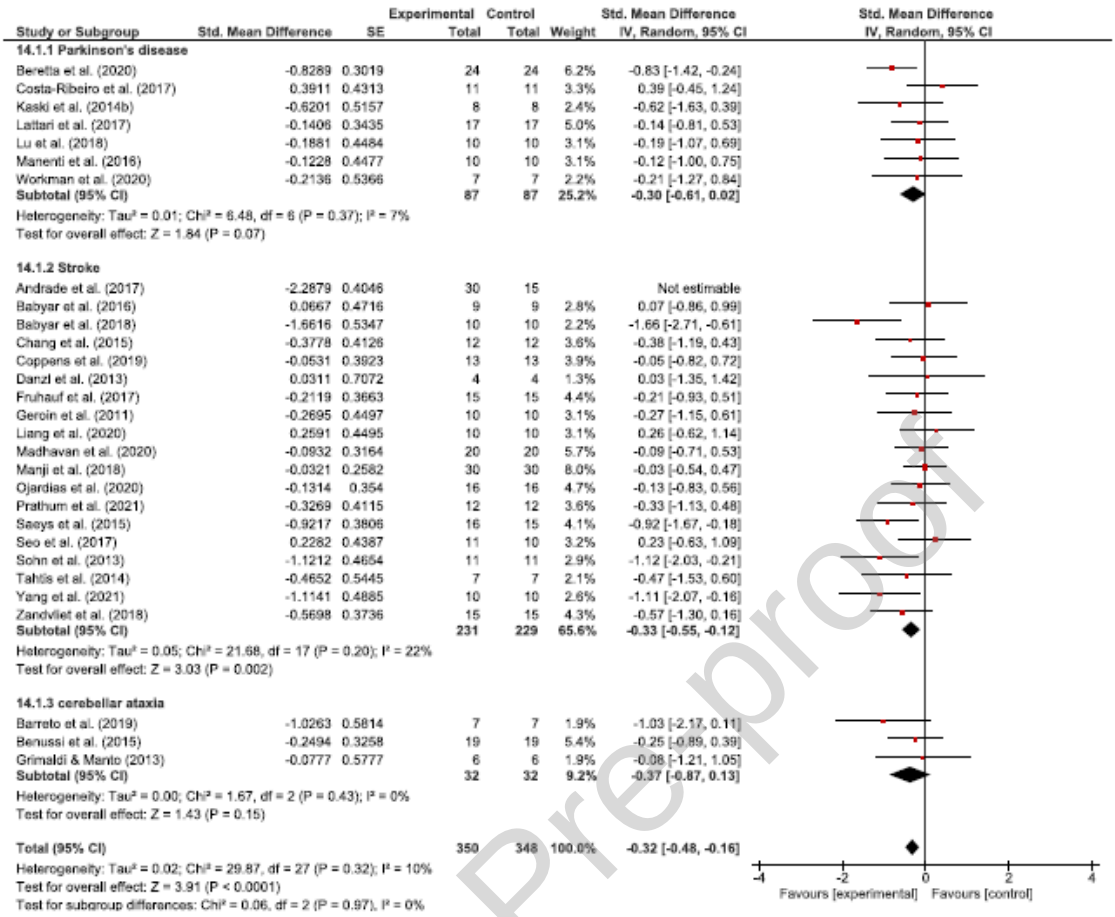

Figure 7. Forrest plots of the meta-analysis regarding the type of neurological disorders with the Parkinson's disease subgroup, Stroke subgroup, and Cerebellar ataxia subgroup after sensitivity analysis.

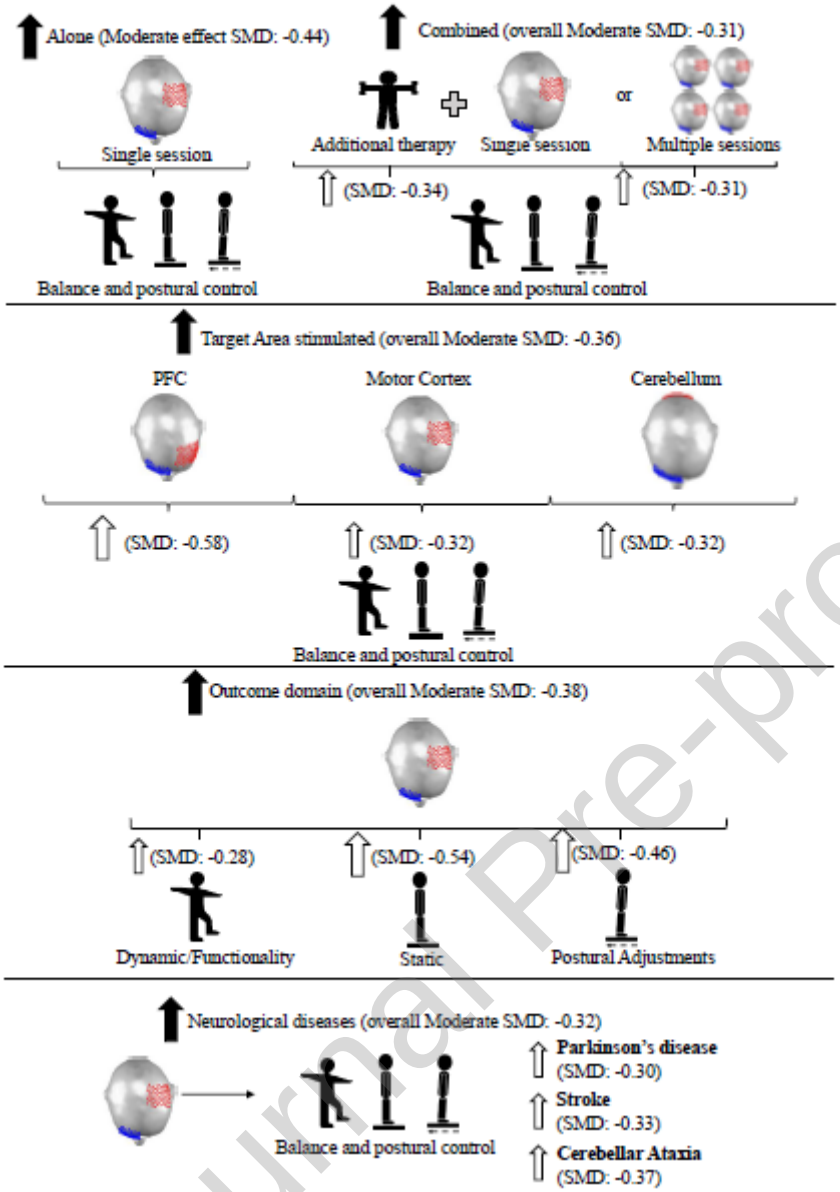

Figure 8. Synthesis of the main findings of the effect of tDCS on postural control and balance in adults with neurological disease tDCS. Filled-up-oriented arrows indicate an overall positive effect in favor of tDCS and the Unfilled-up-oriented arrows indicate positive tDCS effects for each subgroup. SMDs are reported for group and subgroup analysis.

Table 1. Search strategy used to identify relevant studies.

Search key terms
tDCS intervention: "transcranial direct current stimulation" OR "tDCS" OR

"transcranial electrical stimulation" OR "non-invasive brain stimulation" OR "transcranial current stimulation" (TITLE-ABS-KEY)

AND

Postural control/balance assessment: "postural control" OR "postural responses" OR "postural function" OR "postural stability" OR "static balance" OR "postural adjustments" OR "postural balance" OR "postural equilibrium" OR posturography OR stabilometry OR posture OR balance OR equilibrium OR "postural sway" OR sway OR standing (TITLE-ABS-KEY)

TITLE-ABS-KEY indicates a title, abstract, and keyword search.

Table 2. Methodological characteristics and main results of the reviewed studies.

First author (year)	**Study characteristics** 1. Population (type of neurological disease) 2. Sample size 3. Study design	**Population** - Groups or condition (n; age (mean ± standard deviation); and sex)	**Intervention (tDCS characteristics)** 1. Polarity of stimulation current 2. Target area stimulated 3. Reference electrode 4. Electrode size 5. Duration 6. Intensity 7. Number of sessions 8. Additional intervention (moment of the intervention in relation to tDCS -before, together, after))	**Comparison** - (active vs sham or experimental vs CG)	**Outcomes** 1. Outcome domain 2. Measurement tool/Main outcomes 3. Additional outcomes (cortical activity) 4. Measurement time 5. Side effects of active tDCS	**Results** - Effect of tDCS on main outcomes
Andrade et al. (2017)	1. Stroke 2. 60 3. Parallel-arms, randomized, double-blind, sham-controlled.	- 4 Groups: - Anodal-tDCS (n=15; 68.86±4.66; 8M/7F) - Bilateral-tDCS (n=15; 69.06±4.43; 9M/6F)	1. Anodal and cathodal 2. M1 affected hemisphere (anodal condition); M1 unaffected hemisphere (cathodal condition) 3. Contralateral supraorbital	- Anodal vs. cathodal vs. bilateral vs. sham-tDCS	1. Dynamic/functionality 2. Biodex Balance System/Overall Stability Index; BBS/lower limb function; FSST/balance 3. No 4. Pre, post, 1- and 3-months follow-up 5. No adverse	- Anodal, cathodal and bilateral-tDCS performed better the BBS, Overall Stability Index and FSST

		- Cathodal-tDCS (n=15; 70.40±2.32; 8M/7F) - Sham (n=15; 68.00±1.46; 10M/5F)	area 4. 35 cm^2 5. NR 6. 2 mA 7. 10 sessions 8. Yes. Physical rehabilitation intervention. Moment NR.		effects	than sham. - Bilateral-tDCS further increased the BBS score compared to anodal, cathodal and sham-tDCS.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Babyar et al. (2016)	1. Stroke 2. 9 3. Crossover, randomized, single-blind, sham-controlled.	- Bipolar balanced-tDCS; single-tDCS; GVS; sham-tDCS (n=9; NR; 5M/4F)	1. Anodal 2. Ipsilesional PIVC; PIVC contralesional side 3. Contralateral supraorbital area 4. 25 cm^2 5. 20 min 6. 2 mA 7. 1 session 8. No	- Bipolar active-tDCS vs single active-tDCS vs. sham	1. Static (seated) 2. Force plate/mean speed of CoP 3. No 4. Pre, 5-, 10- and 15-min during stimulation, and post 5. NR	- Bipolar active-tDCS increased the mean speed of CoP at 5 min compared to pre. - Bipolar active-tDCS reflected a higher mean speed of CoP at 5 min than sham.
Babyar et al. (2018)	1. Stroke 2. 10 3. Crossover, sham-controlled	- HD-tDCS, GVS and sham-tDCS (n=10; 66±9.5; 6M/4F)	1. Anodal 2. PIVC 3. Contralateral parietal cortex 4. 3.14 cm^2 5. 15 min 6. 2 mA sinusoidal 7. 1 session 8. No	- Active-tDCS vs. sham	1. Static 2. Force plate (CoP velocity)/seated haptic 3. No 4. Pre, 5, 10 and 15 min during tDCS session 5. NR	- Greater CoP velocity in HD-tDCS compared to sham at 10 min.
Barretto et al. (2019)	1. Cerebellar ataxia 2. 7 3. Crossover,	- Active and sham-tDCS (n=7; 36.57±17.19; 3M/4F)	1. Anodal 2. Motor cortex 3. Contralateral supraorbital	- Active vs. sham-tDCS	1. Static 2. Wii Fit platform/CoP oscillation; CvMob software/total	- Active-tDCS increased the total gain of the CoP oscillation. - No effect of

	double-blind, sham-controlled		area 4. 35 cm^2 5. 40 min (20 min for each motor cortex) 6. 2 mA 7. 5 sessions 8. No		trajectory of the displacement 3. No 4. Pre and post 5. 37.5% reported itching (27.5% light intensity)	active-tDCS on the gain of the total trajectory of the displacement.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Benussi et al. (2015)	1. Cerebellar ataxia 2. 19 3. Crossover, randomized, double-blind, sham-controlled	- Active and sham-tDCS (n=19; 53.8± 18.4; 8M/11F)	1. Anodal 2. Cerebellum 3. Right deltoid muscle 4. 35 cm^2 5. 20 min 6. 2 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Dynamic/functionality 2. ICARS/posture 3. No 4. Pre and post 5. NR	- Active tDCS decreased the ICARS score at post than sham.
Beretta et al. (2020b)	1. Parkinson's disease 2. 24 3. Crossover, randomized, double-blind, sham-controlled	- Active and sham-tDCS (n = 24; 68.91±8.47 ; 14M/10F)	1. Anodal 2. M1 3. Contralateral supraorbital area 4. 35cm^2 5. 20 min 6. 2 mA 7. 1 session 8. No.	- Active vs. sham-tDCS	1. Postural adjustments 2. EMG/MG onset latency; force plate/recovery time 3. fNIRS/PFC activity 4. After each tDCS condition 5. without difference between active and sham	- Decrease in MG onset latency and recovery time in active compared to sham-tDCS.
Cha et al. (2016)	1. Mal de debarquement syndrome 2. 24 3. Parallel-arms, randomized, single-blind, sham-controlled	- r-TMS+tDCS (n=12) - r-TMS+sham (n=10) (59.9±12.2 ; 24F)	1. Anodal 2. Dominant DLPFC 3. Contralateral DLPFC 4. 35 cm^2 5. 20 min 6. 1 mA 7. 20 sessions 8. Yes. rTMS before tDCS	- Experimental vs. CG	1. Dynamic/functionality 2. MdDS Balance Rating Scale/ rocking perception 3. No 4. Pre, 1-week post, 2-week post, 3-week post and 4-week Post 5. No adverse effects	- r-TMS+tDCS decreased the MdDS Balance Rating Scale at 4-week post compared to pre.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Chang et al. (2015)	1. Stroke 2. 24 (15M/9F) 3. Parallel-arms, randomized, double-blind, sham-controlled	- Active-tDCS+conventional therapy (n=12;59.9±10.2) - Sham-tDCS+conventional therapy (n=12;65.8±10.6)	1. Anodal 2. M1 3. Contralateral supraorbital area 4. 7.07 cm^2 5. 10 min 6. 2 mA 7. 10 sessions 8. Yes. Conventional therapy during tDCS	- Experimental vs. CG	1. Dynamic/functionality 2. BBS/balance 3. TMS/MEP 4. Pre and post 5. NR	- No additional effect of active-tDCS + conventional therapy on BBS.
Coppens et al. (2019)	1. Stroke 2.13 3. Crossover, single-blind, sham-controlled	- Anodal, cathodal and sham-tDCS (n=13; 62±11.6; 12M/1F)	1. Anodal and cathodal 2. Ipsilesional M1 (anodal) and contralesional M1 (cathodal) 3. Contralateral supraorbital area 4. 35 cm^2 5. 15 min 6. 2 mA 7. 1 session 8. No	- Anodal vs. cathodal vs. sham-tDCS	1. Postural adjustments 2. EMG/TA onset latency; 8-camera 3D motion analysis system (Vicon)/Body sway-maximum displacement 3. No 4. After each tDCS condition 5. No adverse events	- No effect of anodal and cathodal tDCS on TA onset latency. - Greater body sway in anodal-tDCS compared to cathodal and sham-tDCS.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Costa et al. (2020)	1. Multiple sclerosis 2. 1 3. Crossover, case study,	- Active tDCS+VR and Sham tDCS+VR (n=1;51;1M	1. Anodal 2. M1 3. Contralateral supraorbital	- Experimental vs. CG	1.Dynamic/functionality 2. BESTest/balance 3. No 4. Pre, post and 14-days follow-up	- No additional effect of active-tDCS+VR on

	single-blind, sham-controlled	)	area 4. 25 cm^2 5. 20 min 6. 2 mA 7. 5 sessions 8. Yes. Balance training with Nintendo Wii VG during tDCS.		5. No adverse effects after sham and itching sensation after active tDCS	BESTest score.
Costa-Ribeiro et al. (2017)	1. Parkinson's disease 2. 24 3. Parallel-arms, randomized controlled trial, double-blind, sham-controlled.	- Active-tDCS+gait training (n=11; 61.1±9.1; 8M/3F) - Sham-tDCS+gait training (n=11; 62.0±16.7; 7M/4F)	1. Anodal 2. Motor cortex 3. Contralateral supraorbital area 4. 35 cm^2 5. 13 min 6. 2 mA 7. 10 sessions 8. Yes. Gait training with visual cues after tDCS.	- Experimental vs. CG	1.Dynamic/functionality 2. BBS/balance 3. No 4. Pre, post, 1-month follow-up 5. No adverse effects	- No additional effect of active-tDCS+gait training on BBS score.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Danzl et al. (2013)	1. Stroke 2. 8 3. Parallel-arms, randomized, double-blind, sham-controlled	- Active-tDCS+RAGT (n=4; 64.75±14.86; 3M/1F) - Sham-tDCS+RAGT (n=4; 70.75±11.15; 1M/3F)	1. Anodal 2. Motor cortex 3. Supraorbital area 4. 25 cm^2 5. 20 min 6. 2 mA 7. 12 sessions 8. Yes. Locomotor training with RAGT after tDCS	- Experimental vs. CG	1.Dynamic/functionality 2. BBS/balance; TUG/balance 3. No 4. Pre, post and 1-month follow-up 5. No adverse effect	- Active-tDCS trended to improve the TUG performance compared to sham. - No effect of active-tDCS on BBS score.
Foro	1.	- Active-	1. anodal	-	1.Dynamic/functio	- No additional

gh et al. (2018)	Parkinson's disease 2. 23 3. Parallel-arms, randomized, double-blind, sham-controlled	tDCS+occupational therapy (n=12; 61.33±NR; 7M/7F) - Sham-tDCS+ occupational therapy (n=11; 64.81±NR; 7M/7F)	2. Left DLPFC 3. Right forearm 4. 35 cm^2 5. 20 min 6. 0.6 mA/cm^2 7. 8 sessions 8. Yes. Occupational therapy after tDCS	Experimental vs. CG	nality 2. BBS/balance 3. No 4. Pre, post and 3-months follow-up 5. NR	effect of active-tDCS+occupational therapy on BBS score.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Fruhauf et al. (2017)	1. Stroke 2. 30 3. Crossover, randomized, double-blind, sham-controlled	- Active-tDCS+active-FES; active-tDCS+sham-FES; sham-tDCS+active-FES; and sham-tDCS+sham-FES (n=30; 61.0±9.7; 23M/7F)	1. Anodal 2. M1 3. Contralateral supraorbital area 4. 35 cm^2 5. 20 min 6. 2 mA 7. 1 session 8. Yes. FES on TA muscle during tDCS	- Experimental vs. CG	1. Static 2. Force plate/static balance (sway velocity and sway frequency) 3. No 4. Pre and post 5. NR	- No effects of experimental conditions on postural control.
Geroin et al. (2011)	1. Stroke 2. 30 3. Parallel-arms, randomized, sham-controlled	- tDCS+RAGT (n=10; 63.6±6.7; 8M/2F) - Sham+RAGT (n=10; 63.3±6.4; 6M/4F) - overground walking exercises (n=10; 61.1±6.3; 9M/1F)	1. Anodal 2. M1 (leg area) 3. Contralateral supraorbital area 4. 35 cm^2 5. 7 min 6. 1.5 mA 7. 10 sessions 8. Yes. RAGT during tDCS	- Experimental vs. CG	1. Dynamic/functionality 2. 6-min walk test/dynamic balance 3. No 4. Pre, post and 2-weeks follow-up 5. No adverse effects	- tDCS and sham+RAGT increased the distance in the 6-min walk test compared to overground walking exercises. - No additional effect of active-tDCS on 6-min walk test.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Grimaldi & Manto (2013)	1. Cerebellar ataxia 2. 9 3. Crossover, single-blind, sham-controlled	- Active and sham-tDCS (n=9; 51.3±14.0; 7M/2F)	1. Anodal 2. Cerebellum 3. Contralateral supraorbital area 4. 20 cm^2 5. 20 min 6. 1 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Static 2. FootScan pressure platform/AP, ML and total displacement 3. No 4. Pre, post-sham, post-active 5. NR	- No effect of active-tDCS on postural control.
Kaski et al. (2013)	1. Leukoaraiosis 2. 9 3. Crossover, randomized, double-blind, sham-controlled	- Active-tDCS+physical training; sham-tDCS+physical training (n=9; 79.4±5.5; 7M/2F)	1. Anodal 2. Motor cortex 3. Inion 4. 40 cm^2 5. 15 min 6. 2 mA 7. 1 session 8. Yes. Physical training during tDCS	- Experimental vs. CG	1. Dynamic/functionality and postural adjustments 2. TUG/balance; retropulsion test-digitally-based angular-velocity transducers/recovery time 3. No 4. Pre and post 5. NR	- Active-tDCS+physical training decreased the TUG and recovery time at post compared to pre.
Kaski et al. (2014a)	1. Parkinson's disease 2. 1 3. Crossover, randomized, double-blind, sham-controlled, case study	- Dance + tDCS; Dance + sham (n=1; 79 years; 1M)	1. Anodal 2. Bilateral M1 and PMC 3. Inion 4. 40 cm^2 5.. 7 min 30 sec 6. 2 mA 7. 2 sessions 8. Yes. Dance-Tango (together with tDCS)	- Experimental vs. CG	1. Dynamic/functionality 2. Digitally-based angular-velocity transducers/Angular trunk velocity; Tinetti gait index/gait and balance 3. No 4. Trunk velocity (during tango); Tinetti Gait index (pre and post) 5. NR	- Dance+tDCS increased the trunk velocity and Tinetti gait index score compared to CG.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Kaski et al. (2014b)	1. Parkinson's disease 2. 16 3. Randomized, double-blind, sham-controlled	- Group I (active and sham-tDCS+physical training) (n=8; NR; NR) - Group II (active and sham-tDCS without training) (n=8; NR; NR)	1. Anodal 2. Motor cortex 3. Inion 4. 40 cm^2 5. 15 min 6. 2 mA 7. 1 session 8. Yes. Physical training during tDCS	- Experimental vs. CG	1. Postural adjustments 2. Pull test/recovery time (angular trunk movement) 3. No 4. Pre and post 5. NR	- tDCS+physical training decreased the recovery time compared to tDCS without physical training. - No isolated effect of tDCS or physical training on recovery time.
Lattari et al. (2017)	1. Parkinson's disease 2. 17 3. Crossover, randomized, double-blind, sham-controlled	- active and sham-tDCS (n=17; 69.18±9.98; 13M/4F)	1. Anodal 2. Left DLPFC -3. Right orbitofrontal cortex 4. 35 cm^2 5. 20 min 6. 2 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Dynamic/functionality 2. BBS/dynamic balance 3. No 4. After each tDCS condition 5. NR	- Active-tDCS had better scores on BBS compared to sham.
Liang et al. (2020)	1. Stroke 2. 10 3. Crossover, randomized, double-blind, sham-controlled	- active-tDCS+limits of stability training; sham-tDCS+limits of stability training (n=10; 58.96±9.56; 6M/4F)	1. Anodal 2. Motor cortex 3. Contralateral supraorbital area 4. 25 cm^2 5. 20 min 6. 2 mA 7. 1 session 8. Yes. Limits of stability training during tDCS	- Experimental vs. CG	1. Dynamic/functionality and postural adjustments 2. BBS/balance; force plate/reactive postural adjustments (Toes down = sway energy and backward translation = latency) 3. No 4. Pre and post 5. NR	- No additional effect of active-tDCS+limits of stability training on BBS. - No additional effect of active-tDCS+limits of stability training on reactive postural adjustments.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Lu et al. (2018)	1. Parkinson's disease 2. 10 3. Crossover, randomized, double-blind, sham-controlled	- Active and sham-tDCS (n=10; 66.3±9.9; 7M/3F)	1. Anodal 2. SMA 3. Forehead 4. 8.1 cm^2 5. 10 min 6. 1 mA 7. 1 session 8. No.	- Active vs. sham-tDCS	1. Postural adjustments (APA) 2. Force plate/Peak (magnitude and time) of CoP- ML; force plate/ground reaction forces- time to step peak loading 3. No 4. Pre, 0 min post, 12 min post, 24-min post, 36-min post, 48-min post and 60 min-pos 5. No adverse effects	- Active-tDCS demonstrated lower time to step peak loading compared to sham.
Madhavan et al. (2020)	1. Stroke 2. 81 3. Parallel-arms, randomized, sham-controlled	- CG (n=20; 58±10; 11M/9F) - Sham+ ankle motor tracking (n=20; 60±9; 15M/5F) - tDCS (n=21; 58±11; 14M/7F) - tDCS+ ankle motor tracking (n=20; 59±9; 15M/5F)	1. Anodal 2. M1 3. Contralateral supraorbital area 4. 12.5 cm^2 5. 15 min 6. 1 mA 7. 12 sessions 8. Yes. High-intensity speed-based treadmill training after tDCS (for all conditions)	- Experimental vs. CG	1. Dynamic/functionality 2. BBS/balance; MiniBESTest/balance; ABC scale/balance 3. Corticomotor excitability 4. Pre, post and 3-months follow-up 5. No adverse effects	- No additional effect of tDCS on BBS, MiniBESTest and ABC scale.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Manenti et al. (2016)	1. Parkinson's disease 2. 20 3. Parallel-arms,	- Active-tDCS+physical therapy (n=10;69.0±9.1; 4M/6F)	1. Anodal 2. DLPFC 3. Contralateral supraorbital	- Experimental vs. CG	1. Static and dynamic/functionality 2. Standing stork test/ static balance; FSST/dynamic	- No additional effect of tDCS on static and

	randomized, double-blind, sham-controlled	- Sham-tDCS+physical therapy (n=10; 69.1±5.6; 7M/3F)	area 4. 35 cm^2 5. 25 min 6. 2 mA 7. 10 sessions 8. Yes. Physical therapy during tDCS		balance 3. No 4. Pre, post and 3-months follow-up 5. No adverse effects	dynamic balance.
Manji et al. (2018)	1. Stroke 2. 30 3. Crossover, randomized, double-blind, sham-controlled	- Group A (active and sham-tDCS+body weight-supported treadmill training) (n=15; 62.2±10.1; 10M/5F) - Group B (sham and active-tDCS+body weight-supported treadmill training) (n=15; 63.7±11.0; 11M/4F)	1. Anodal 2. Motor cortex (SMA) 3. Inion 4. 25 cm^2 5. 20 min 6. 1 mA 7. 5 sessions (1 week) 8. Yes. Body weight-supported treadmill training during tDCS	- Experimental vs. CG	1. Dynamic/functionality 2. POMA/balance and gait function 3. No 4. Pre, post-test 1 and post-test 2 5. NR	- No additional effect of the active-tDCS on POMA score.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Ojardias et al. (2020)	1. Stroke 2. 18 3. Crossover, randomized, double-blind, sham-controlled	- Active and sham-tDCS (n=18; 57.4±3.6; 12M/6F)	1. Anodal 2. Ipsilesional M1 cortex of the lower limb 3.. Contralesional orbitofrontal cortex 4.. 25 cm^2 5. 20 min 6. 2 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Static 2. Force plate (CoP)/Excursion of CoP and CoP trajectory length with Eyes Open and Eyes Closed 3. No 4. Pre (during tDCS session) and post each tDCS session 5. Minor adverse events with tDCS (1 participant reported headache and another participant reported transient fatigue)	- No effect of active-tDCS on postural control.

Prathum et al. (2021)	1. Stroke 2. 24 3. Parallel-arms, randomized, double-blind, sham-controlled	- Active-tDCS (n=12; 58.67±3.70; 8M/4F) - Sham-tDCS (n=12; 56.83±3.58; 8M/4F)	1. Anodal 2. M1 (lesioned hemisphere) 3. M1 (non-lesioned hemisphere) 4. 35 cm^2 5. 20 min 6. 2 mA 7. 12 sessions 8. Yes. Lower and upper limb exercises after tDCS	- Experimental vs. CG	1. Dynamic/functionality 2. TUG/dynamic balance 3. No 4. Pre, Post and 1-month follow-up 5. Mild tDCS-related adverse effects (tingling: active-tDCS = 34.72% and sham-tDCS = 88.19%).	- Active-tDCS decreased the time to perform TUG at Post and follow-up periods compared to pre. - No additional effects of active-tDCS on TUG performance.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Raithatha et al. (2016)	1. Spinal cord injury 2. 15 3. Parallel-arms, randomized, double-blind, sham-controlled	- Active-tDCS+ RAGT (n=9; 40.56±12.24; 5M/4F) - Sham-tDCS+ RAGT (n=6; 58±5.37 5M/1F)	1. Anodal 2. Motor cortex 3. Supraorbital area 4. 25 cm^2 5. 20 min 6. 2 mA sinusoidal 7. 36 sessions 8. Yes. RAGT after tDCS session	- Experimental vs. CG	1. Dynamic/functionality 2. BBS/balance 3. No 4. Pre, post and 1-month follow-up 5. No adverse events	- No additional effect of active-tDCS+ RAGT on BBS score.
Saeys et al. (2014)	1. Stroke 2. 31 3. Crossover, randomized, double-blind, sham-controlled	- Group 1: active and sham-tDCS (sequence) (n=16; 62±9.61; 9M/7F) - Group 2: sham-active tDCS (sequence) (n=15; 64.53±7.23; 8M/7F)	1. Anodal 2. M1 ipsilesional hemisphere 3. M1 intact hemisphere 4. 35 cm^2 5. 20 min 6. 1.5 mA sinusoidal 7. 16 sessions 8. Yes. Regular physical and	- Experimental vs. CG	1. Dynamic/functionality 2. Tinetti/balance and gait 3. No 4. Pre, post-first tDCS condition (mild – 4 weeks) and post-second tDCS condition (post – 8 weeks) 5. No adverse events	- Active-tDCS increased the Tinetti score compared to sham.

			occupational therapy. Moment NR			
Saki et al. (2020)	1. Vestibular dysfunction 2. 36 3. Parallel-arms, randomized, double-blind, controlled trial	- tDCS+VRT (n=18; 72.11±5.09; 10M/8F) - VRT (n=18; 71.33±6.16; 11M/7F)	1. Anodal 2. Right DLPFC 3. Left DLPFC 4. 35 cm^2 5. 20 min 6. 2 mA 7. 18 sessions 8. Yes. VRT after tDCS.	- Experimental vs. CG	1. Dynamic/functionality 2. ABC scale/balance 3. No 4. Pre, 1-week post, 2-week post and 3-week post 5. 79.3% in tDCS+VRT and 53.3% in VRT reported itching (most common adverse event)	- tDCS+VRT increased the score on ABC scale. - Superior effect of tDCS+VRT on balance compared to VRT.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Seo et al. (2017)	1. Stroke 2. 21 3. Parallel-arms, randomized, double-blind, sham-controlled	- Active-tDCS+ RAGT (n=11; 61.1±8.9; 9M/2F) - Sham-tDCS+ RAGT (n=10; 62.9±8.9; 7M/3F)	1. Anodal 2. Motor cortex 3. Contralateral supraorbital area 4. 35 cm^2 5. 20 min 6. 2 mA 7. 10 sessions 8. Yes. RAGT after tDCS	- Experimental vs. CG	1. Dynamic/functionality 2. BBS/balance 3. Yes. Cortical excitability 4. Pre, post and 1-month follow-up 5. NR	- No additional effects of active-tDCS on BBS score.
Sohn et al. (2013)	1. Stroke 2. 11 3. Crossover, randomized, single-blind, sham-controlled	- Active and sham-tDCS (n=11; 58.45±14.55; 9M/2F)	1. Anodal 2. M1 affected hemisphere 3. Supraorbital area 4. 25 cm^2 5. 10 min 6. 2 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Static 2. Biodex Balance System/postural stability indices (static balance, overall, AP and ML) 3. No 4. Pre and post 5. NR	- Active-tDCS improved the overall, AP and ML postural stability indices compared to sham.
Tahtis et al. (2014)	1. Stroke 2. 14 3. Parallel-arms,	- Active-tDCS (n=7; 67.3±11.8;	1. Anodal 2. Affected M1 3. Non-	- Active vs. sham-tDCS	1. Dynamic/functionality 2. POMA/balance	- No additional effects of active-

	randomized, double-blind, sham-controlled	5M/2F) - Sham-tDCS (n=7; 56.4±12.3; 6M/1F)	affected M1 4. 25 cm^2 5. 15 min 6. 2 mA 7. 1 session 8. No		and gait function. 3. No 4. Pre and post 5. No adverse effects	tDCS on POMA score.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Verheyden et al. (2013)	1. Parkinson's disease 2. 20 3. Crossover, randomized, double-blind, sham-controlled	- Active and sham-tDCS (n=20; 71±7; NR)	1. Anodal 2. M1 3. Contralateral supraorbital area 4. NR 5. 15 min 6. 1 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Dynamic/functionality 2. Functional reach/balance; TUG/balance 3. No 4. Pre, during and post 5. NR	- No effect of active-tDCS on functional reach and TUG performance.
Workman et al. (2020)	1. Parkinson's disease 2. 7 3. Crossover, randomized, double-blind, sham-controlled	- Unilateral-2 mA; bilateral-2 mA; unilateral-2 mA; bilateral-4 mA; and sham (n=7; 72.4± 6.4; 5M/2F)	1. Anodal 2. Cerebellum 3. Contralateral cerebellum hemisphere (bilateral)/contralateral upper arm (unilateral) 4. 35 cm^2 5. 20 min 6. 2 mA and 4 mA 7. 1 session 8. No	- Active vs. sham-tDCS	1. Static and dynamic/functionality 2. Force platform/CoP area and CoP Velocity; BBS/balance 3. No 4. After each tDCS condition 5. Mild burning, itching, tingling, and pins/needles in all conditions (without difference between conditions)	- No effect active-tDCS conditions on static posture. - Only bilateral-4 mA demonstrates a higher BBS score than sham for responders' patients.
Yang et al. (2021)	1. Stroke 2. 10 3. Crossover, randomized	- Cathodal PMA and anodal M1 (n=10; 69.13±7.61;7M/3F)	1. Cathodal and anodal 2. SMA-PMC (PMA)/M1 (anodal) 3. contralateral supraorbital area 4. 15 cm^2 5. 20 min 6. 1 mA 7. 1 session 8. No	- Cathodal PMA (CG) vs. anodal M1	1. Postural adjustments 2. Force plate/CoP (APA-reach); EMG/onset latency (APA-reach) 3. TMS/MEP 4. Pre and post 5. NR	- TA onset latency was later in cathodal PMA than anodal M1 of the LAS time point−500 ms.

Table 2. Methodological characteristics and main results of the reviewed studies (Continued).

Zandvliet et al. (2018)	1. Stroke 2. 15 3. Crossover, randomized, single-blind, sham-controlled	- Active-ctDCS contra-lesional hemisphere; active-ctDCS ipsi-lesional hemisphere; and sham-ctDCS (n=15; 57.1±10.0; 12M/3F)	1. Anodal 2. Cerebellar (3 cm lateral of the inion) 3. Ipsilateral buccinators muscles 4. 3.14 cm^2 5. 20 min 6. 1.5 mA sinusoidal 7. 1 session 8. Yes. ML postural tracking task during tDCS	- Active-ctDCS contra-lesional hemisphere vs. active-ctDCS ipsi-lesional hemisphere vs. sham-tDCS	1. Static 2. Force plate (CoP)/semi-tandem (range and velocity of CoP) 3. No 4. Pre and post each tDCS session 5. 11 reported higher score on fatigue but without difference between tDCS conditions	- Active-ctDCS contra-lesional demonstrated lower range and velocity of CoP at post period compared to sham-ctDCS.

Note: tDCS = transcranial direct current stimulation; M = male; F = female; NR = not reported; CG = control group; EMG = electromyography; fNIRS = functional near-infrared spectroscopy; FSST = Four Square Step test; CoP = center of pressure; GVS = galvanic stimulation; ICARS = International Cooperative Ataxia Rating Scale; MdDS = mal de debarquement syndrome; r-TMS = repetitive transcranial magnetic stimulation; MG = medial gastrocnemius; TA = tibialis anterior; BBS = Berg Balance Scale; FES = functional electrical stimulation; RAGT = robot-assisted gait training; POMA = Performance Oriented Mobility Assessment; TUG = Timed up and Go test; VRT = vestibular rehabilitation therapy; ctDCS = cerebellar tDCS; M1 = primary motor cortex; TMS = transcranial magnetic stimulation; MEP = motor evoked potential; PIVC = parietal-insular vestibular cortex; SMA = supplementary motor area; PMC = premotor cortex; PMA= premotor area; DLPFC = dorsolateral prefrontal cortex; PFC = prefrontal cortex; LAS = loud acoustic stimulus; AP = anteriorposterior; ML = medio-lateral; APA = anticipatory postural adjustments; VR = virtual reality.

Table 3. Methodological quality assessment.

Studies	**PEDro score - items**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
Andrade et al. (2017)	1	1	1	1	1	0	1	1	1	1	1	9
Babyar et al. (2016)	1	1	0	1	1	0	0	1	1	1	1	7
Babyar et al. (2018)	0	0	0	1	0	0	0	1	1	1	1	5
Barretto et al. (2019)	1	0	0	0	1	0	1	1	1	1	1	6
Benussi et al. (2015)	1	1	1	1	1	1	1	1	1	1	1	10
Beretta et al. (2020b)	1	1	1	1	1	0	1	1	1	1	1	9
Cha et al. (2016)	1	1	1	1	1	0	0	1	1	1	1	8
Chang et al. (2015)	1	1	0	1	1	1	1	1	1	1	1	9
Coppens et al. (2019)	1	0	0	1	1	0	0	1	1	1	1	6
Costa et al. (2020)	1	0	0	0	1	0	0	0	1	0	0	2
Costa-Ribeiro et al. (2017)	1	1	1	1	1	1	1	1	1	1	1	10

Danzl et al. (2013)	1	1	1	1	1	1	1	0	1	1	1	9
Forogh et al. (2018)	1	1	0	1	1	0	1	1	1	1	0	7
Fruhauf et al. (2017)	1	1	1	1	1	0	1	1	1	1	1	9
Geroin et al. (2011)	1	1	0	1	0	0	1	1	1	1	1	7
Grimaldi & Manto (2013)	1	0	0	1	1	0	0	0	1	1	1	5
Kaski et al. (2013)	1	1	0	1	1	0	1	1	1	1	1	8
Kaski et al. (2014a)	1	1	1	0	1	0	1	0	1	1	1	7
Kaski et al. (2014b)	1	1	1	1	1	0	1	1	1	1	1	9
Lattari et al. (2017)	1	1	1	1	1	0	1	1	1	1	1	9
Liang et al. (2020)	1	1	0	1	1	0	1	1	1	1	1	8
Lu et al. (2018)	1	1	1	1	1	0	1	1	1	1	1	9
Madhavan et al. (2020)	1	1	1	1	1	0	1	1	1	1	1	9
Manenti et al. (2016)	1	1	0	1	1	1	1	1	1	1	1	9
Manji et al. (2018)	1	1	0	1	1	1	0	1	1	1	1	8
Ojardias et al. (2020)	1	1	1	1	1	1	0	1	1	1	1	9
Prathum et al. (2021)	1	1	1	1	1	1	1	1	1	1	1	10
Raithatha et al. (2016)	1	1	1	1	1	1	1	0	0	1	1	8
Saeys et al. (2015)	1	1	1	1	1	1	1	1	1	1	1	10
Saki et al. (2020)	1	1	1	1	1	0	1	0	1	1	1	8
Seo et al. (2017)	1	1	1	1	1	1	1	1	1	1	1	10
Sohn et al. (2013	1	1	0	0	1	0	0	1	1	1	1	6
Tahtis et al. (2014)	1	1	0	1	1	0	1	1	1	1	1	8
Verheyden et al. (2013)	1	0	0	1	1	0	1	1	1	1	1	7
Workman et al. (2020)	0	1	1	0	1	0	1	1	1	1	1	8
Yang et al. (2021)	1	1	0	1	0	0	0	1	1	1	1	6
Zandvliet et al. (2018)	1	1	0	1	1	0	0	1	1	1	1	7

Note: PEDro = Physiotherapy Evidence Database rating scale.

Highlights

- tDCS as stand-alone therapy improved balance in adults with neurological disorders
- tDCS alone and combined with interventions are promising for balance rehabilitation
- tDCS improved balance regardless of the number of sessions
- Balance improvements were evidenced regardless of the brain area stimulated
- Reviewed studies did not personalize the protocol to individual characteristics