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Motor effects of transcranial direct current stimulation associated with physiotherapy in children with cerebral palsy: a systematic review

Efeitos motores da eletroestimulação transcraniana por corrente contínua associada à fisioterapia em crianças com paralisia cerebral: revisão sistemática

Efectos motores de la estimulación transcraneal por corriente continua asociada a la fisioterapia en niños con parálisis cerebral: revisión sistemática

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ABSTRACT

Cerebral palsy (CP) is a prevalent cause of motor, cognitive, communicative, and behavioral impairments in children, imposing significant limitations on their daily lives. Transcranial direct current stimulation (tDCS) is a non-invasive neuromodulation technique employing low-intensity electrical currents to alter neuronal activity, and it can be effectively integrated into physiotherapy regimens. The objective of this study was to assess the motor effects of tDCS in children and adolescents diagnosed with CP. A comprehensive literature search was performed across the PubMed, MEDLINE, and Physiotherapy Evidence Database (PEDro). The methodological quality of the included studies was evaluated using the PEDro scale. The analysis incorporated four studies, encompassing a total of 113 children aged between 5 to 12 years, of both sexes, diagnosed with spastic CP. These studies spanned various levels of the Gross Motor Function Classification System (GMFCS), ranging from I to III, and included children classified at levels I or II of the Manual Ability Classification System (MACS). The intervention groups receiving tDCS demonstrated positive outcomes. The findings from this review confirm that tDCS, when combined with conventional physiotherapeutic techniques, significantly enhances motor functions in children with cerebral palsy.

Keywords: Cerebral Palsy. Transcranial Direct Current Stimulation. Physiotherapy. Motor Skills.

RESUMO

A paralisia cerebral (PC) é uma das causas mais frequente de disfunções motoras, cognitivas, comunicativas e comportamentais em crianças, originando limitações nas suas vidas. A eletroestimulação transcraniana por corrente contínua (tDCS) é uma técnica não invasiva que emprega uma corrente elétrica de baixa intensidade para modulação dos neurônios cerebrais e pode ser aliada a fisioterapia. O objetivo da pesquisa foi analisar os efeitos motores da eletroestimulação transcraniana por corrente contínua em crianças e adolescentes com PC. Foi efetuada uma pesquisa nas bases de dados Pubmed, MEDLINE e Physiotherapy Evidence Database (PEDro). A qualidade metodológica dos diferentes tipos de estudos foi analisada segundo pela escala PEDro. Foram incluídos 4 estudos, com um total de 113 crianças, com idades entre os 5 e os 12 anos de ambos os sexos, com PC espástica em vários níveis, distintas classificações do Gross Motor Function Classification System (GMFCS) do I ao III e classificação funcional em nível I ou II do MACS. Os resultados foram positivos nos grupos de intervenção com a eletroestimulação transcraniana por corrente contínua (tDCS). A partir da pesquisa realizada, foi possível constatar que a eletroestimulação transcraniana por corrente contínua (tDCS), quando associada a outras técnicas da fisioterapia, promoveram melhorias significativas nas habilidades motoras de crianças com PC.

Palavras-chave: Paralisia Cerebral. Estimulação Transcraniana por Corrente Contínua. Fisioterapia. Habilidades Motoras.

RESUMEN

La parálisis cerebral (PC) es una causa prevalente de discapacidades motoras, cognitivas, comunicativas y conductuales en niños, imponiendo limitaciones significativas en sus vidas diarias. La estimulación transcraneal por corriente directa (tDCS) es una técnica de neuromodulación no invasiva que utiliza corrientes eléctricas de baja intensidad para alterar la actividad neuronal y puede ser integrada efectivamente en regímenes de fisioterapia. El objetivo de este estudio fue evaluar los efectos motores del tDCS en niños y adolescentes diagnosticados con PC. Se realizó una búsqueda exhaustiva de literatura en las bases de datos PubMed, MEDLINE y Physiotherapy Evidence Database (PEDro). La calidad metodológica de los estudios incluidos fue evaluada utilizando la escala PEDro. El análisis incorporó cuatro estudios, abarcando un total de 113 niños de entre 5 a 12 años, de ambos sexos, diagnosticados con PC espástica. Estos estudios cubrieron varios niveles del Sistema de Clasificación de la Función Motora Gruesa (GMFCS), desde I hasta III, e incluyeron niños clasificados en los niveles I o II del Sistema de Clasificación de la Capacidad Manual (MACS). Los grupos de intervención que recibieron tDCS demostraron resultados positivos. Los hallazgos de esta revisión confirman que el tDCS, cuando se combina con técnicas fisioterapéuticas convencionales, mejora significativamente las funciones motoras en niños con parálisis cerebral.

Palabras clave: Parálisis Cerebral. Estimulación Transcraneal por Corriente Continua. Fisioterapia. Habilidades Motoras.

1 INTRODUCTION

Cerebral palsy (CP) is a developmental condition characterized by motor and postural deficits, as well as sensory and cognitive impairments. It results from non-progressive injuries to the developing brain during prenatal, perinatal, or postnatal periods (Reitz *et al*., 2018). It represents a common cause of physical disability in early childhood, characterized by impairments in sensory perception and communication, alongside the acquisition of inappropriate postures. These factors lead to deformities and impede the proper development of motor functions (Ferreira *et al*., 2015).

The severity of disability in children with cerebral palsy (CP) is highly variable, receiving classifications based on voluntary movements, depending on the age range of the child and functional performance (Silva *et al*., 2016).

A common consequence of CP is the decline in gross motor function, which manifests as altered movement patterns and decreased functional capacity. It presents with spasticity, dyskinesia, or ataxia, either unilaterally or bilaterally (Ferreira *et al*., 2015).

Physiotherapy is a widely used treatment strategy for CP, aimed at improving quality of life, functionality, and mobility, as well as reducing spasticity.

However, despite the clear benefits of physiotherapy, some children with CP still exhibit significant motor deficits (Novak *et al*., 2017).

The physiotherapeutic resources utilized in children with CP are based on the principles of neuroplasticity, repetition of correct movements, postural correction, muscle strengthening, and/or stretching. Thus, it is necessary to carefully evaluate the intensity of the treatment for each individual case (Novak *et al*., 2013).

Transcranial direct current stimulation (tDCS) is a non-invasive neurostimulation technique that has shown potential to improve motor function in a variety of neurological conditions. In pediatric populations with CP, it has been investigated as an adjunct intervention to physiotherapy to enhance the efficacy of motor rehabilitation (Gillick *et al*., 2014).

However, the existing literature is still insufficient and inconclusive to clearly demonstrate the benefits of this combination of treatments. The aim of this study was to analyze the motor effects of tDCS when combined with physiotherapy in CP, summarizing and synthesizing the scientific evidence. Specifically, the focus was on motor skills, functionality, spasticity, and gait changes in these children.

2 THEORETICAL FRAMEWORK

2.1 CEREBRAL PALSY

Cerebral Palsy (CP) is a neurological disorder resulting from damage to the central nervous system, which can occur prenatally, postnatally, or during childbirth. It mainly appears as motor dysfunction but also includes cognitive, communicative, sensory, behavioral disorders, and epilepsy. Other symptoms include muscular hypertonia, balance and coordination problems, and impaired manual function. Early signs in infants, particularly between 3 and 6 months, include reduced neck control, joint stiffness, lower limb rigidity, and a scissor-like leg movement pattern, along with poor coordination in the upper limbs (Paul *et al*., 2022).

2.1.1 Risk factors

It is believed that the majority of Cerebral Palsy (CP) cases are linked to cerebral hypoxia occurring intrapartum or perinatally. Prenatal factors account for about 75% of cases, while infant and neonatal risks account for 10-18%. Other significant risk factors include premature birth (before 37 weeks) and low birth weight (less than 2.5 kg). Additionally, conditions such as brain malformations, genetic causes, and infections of the uterine veins are also relevant. These risk factors can be identified at different stages: before, during, and after pregnancy. (Sadowska *et al*., 2020).

2.1.2 Diagnosis

Early diagnosis begins with medical history and includes the use of neurological and kinematic tests. For diagnosing CP, neonatal magnetic resonance imaging (MRI) (sensitivity 86%), qualitative gross motor assessment (GM) (sensitivity 98%), and the Hammersmith Neonatal Neurological Examination (HINE) (sensitivity 90%) are used. After 5 months of corrected age, MRI (sensitivity 86-89%), HINE (sensitivity 90%), and early childhood development assessment (sensitivity 83%) are the best predictive tools for risk detection (Novak *et al*., 2017).

2.2 CEREBRAL PALSY CLASSIFICATIONS

2.2.1 General classification

The main characteristic of the general classification of children with cerebral palsy (CP) is the impairment of movement, posture, and muscle tone, which affects their functional performance. Thus, they can be classified based on two criteria: the type of motor dysfunction present, which includes extrapyramidal or dyskinetic types (athetoid, chorea, and dystonia), ataxia, hypotonia, and pyramidal or spasticity; and the topography of the lesion, characterized by the location and predominance of changes in the body, such as hemiplegia, tetraplegia, monoplegia, paraplegia, or diplegia. Mixed forms are also possible (Pereira *et* *al*.,2020).

2.2.2 Gross Motor Function Classification System – GMFCS

The Gross Motor Function Classification System (GMFCS) is a widely recognized, simple five-level ordinal classification system used to describe the gross motor function of children and adolescents up to 18 years old with cerebral palsy (CP). It categorizes their capabilities and limitations in motor functions, detailing self-initiated movements, use of mobility aids like walkers, canes, and wheelchairs, and typical behaviors in various settings. The levels range from I, indicating minimal or no limitations in functional mobility, to V, where the individual requires transportation due to significant impairments. This system helps in assessing the extent of support needed for mobility and planning appropriate interventions (Novak *et al*., 2017).

2.2.3 Manual Ability Classification System – MACS

The Manual Ability Classification System (MACS) is a specific tool developed in 2002 to classify manual changes in children with cerebral palsy (CP). It assesses children based on different levels to evaluate their manual functioning, aiming to identify limitations, potentialities, and track the developmental progress of upper limb manipulative skills. This system helps in understanding and guiding the development of manual abilities in these children (Silva *et al*., 2015).

2.2.4 Classification of spasticity levels - Modified Ashworth Scale

The Ashworth Scale is the primary clinical measure of spasticity and is readily available to physicians and researchers. Brian Ashworth developed the original five-point scale. Bohannon and Smith modified it by adding a 1+ grade to create a six-point scale, enhancing the precision of the grading. This modification is known as the Modified Ashworth Scale (Ansari, 2022).

2.3 ASSESSMENT IN CEREBRAL PALSY

2.3.1 Gross Motor Function Measure – GMFM

The Gross Motor Function Measure (GMFM) is a quantitative assessment system designed to evaluate motor function changes in children with cerebral palsy (CP). It helps in treatment planning by describing the level of function without considering the quality of performance. GMFM is widely used globally and serves as a descriptive tool to address various issues, including the risk of hip dislocation in children with CP. Initially comprising 88 items across five dimensions—lying down, sitting, crawling, kneeling, standing, walking, running, and climbing stairs—the scale was later streamlined into a shorter, 66-item version (GMFM-66) to enhance efficiency and objectivity in assessments (Cantú, 2020).

2.3.2 Instrumented Gait Analysis – IGA

Rehabilitation and gait habilitation for individuals with neurological disorders, such as cerebral palsy, is facilitated by Instrumented Gait Analysis (IGA), the gold standard for evaluating gait abnormalities. This method uses advanced technology to analyze patient movements objectively through video, clinical measurements, and kinematic data. However, operating such gait testing laboratories involves significant investment and specialized training, and these facilities are not always readily accessible for routine clinical use. Each IGA session can last between 3 to 6 hours, including detailed assessments and interpretations of results (White, 2020).

2.3.3 Role of physiotherapy in cerebral palsy

Physiotherapy plays a crucial role in rehabilitating children with cerebral palsy (CP). Its primary goal is to modulate primitive reflexes and muscle tone while always respecting typical motor development to prevent or minimize musculoskeletal changes such as the development of contractures and deformities (Oliveira & Golin, 2017).

2.3.4 Transcranial Direct Current Stimulation – tDCS

Transcranial Direct Current Stimulation (tDCS) is a non-invasive brain stimulation technique used in patients with various neurological conditions. It utilizes low-intensity electric currents to modulate brain neurons, altering cortical excitability and, therefore, motor function (Bastani & Jaberzadeh, 2012). tDCS has shown potential to improve motor function in a wide range of neurological disorders. In pediatric populations with cerebral palsy (CP), tDCS has been explored as an adjunctive intervention to physiotherapy to enhance motor efficacy (Gillick *et al*., 2014).

3 METHODOLOGY

3.1 STUDY DESIGN

A systematic review of the literature was conducted with the following steps: identification of objectives and formulation of the guiding questions; database searches and setting of inclusion and exclusion criteria; classification of the studies; critical analysis of the selected studies; and finally, interpretation of the results.

3.2 GUIDING QUESTION

The central research question was: What is the impact of transcranial direct current stimulation (tDCS) combined with physical therapy on the motor effects in children with cerebral palsy (CP)? This systematic review was undertaken to address this query. The PICO strategy was employed to structure the research question, facilitating the identification of the target population, the intervention, the comparison group, and the outcomes. Specifically, the population (P) included children and adolescents with CP; the intervention (I) involved transcranial direct current electrostimulation; the comparison (C) was with other physiotherapeutic methodologies not combined with tDCS; and the outcomes (O) focused on changes in motor skills, functionality, spasticity, and gait.

Table 1. Description of the Components in the PICO Strategy for the Systematic Review.

Acronym	Definition	Description
P	Population	Children with cerebral palsy (CP)
I	Intervention	Transcranial Direct Current Electrostimulation (tDCS)
C	Comparison	tDCS combined with physiotherapy versus physiotherapy alone without tDCS.
O	Outcome	Changes in motor skills, functionality, spasticity, and gait.

Source: Horing *et al*, 2023.

3.3 ELECTRONIC DATABASES

To conduct this systematic review, searches were performed in August 2023 using the following databases: PubMed, MEDLINE, and the Physiotherapy Evidence Database (PEDro). This research followed the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page *et al*., 2021).

3.4 SEARCH STRATEGY

In the Physiotherapy Evidence Database (PEDro), the search operator "AND" was utilized, with the keywords: "transcranial direct current stimulation," "cerebral palsy," "child," and "motor." The keyword combination was systematically controlled. Filters applied included full texts in Portuguese, English, and Spanish published within the last ten years (2013 to 2023).

3.5 SELECTION AND ANALYSIS OF PUBLICATIONS

A table was constructed to assist in the selection of articles, which included the following details: author, year, study type, objectives, sample characteristics, intervention protocol, parameters, assessment instruments, and results.

3.5.1 Inclusion criteria

Included were children of any gender with a diagnosis of cerebral palsy of any type, articles in English, Portuguese, or Spanish, published in the last ten years (2013-2023); articles that involved transcranial direct current electrostimulation combined with physiotherapy as the intervention program, and those that were experimental or quasi-experimental.

3.5.2 Exclusion criteria

Excluded were duplicate articles, abstracts, editorials, literature reviews (both integrative and systematic), empirical syntheses, empirical reports, case studies, letters to the editor, research project descriptions, scientific event yearbooks, dissertations, and articles that did not focus on the proposed study objectives.

The methodological quality was assessed using the PEDro scale, the most widely used in the rehabilitation field. This scale, developed by the Physiotherapy Evidence Database, scores up to 10 points, reflecting internal validity and the presentation of statistical analyses. For each defined criterion, a score of 1 indicates the presence of quality evidence indicators; a score of 0 is given when these indicators are absent. The PEDro scale criteria include: 1) specification of inclusion criteria (this item is not scored); 2) random allocation; 3) allocation concealment; 4) baseline similarity of groups; 5) subject blinding; 6) therapist blinding; 7) assessor blinding; 8) measurement of at least one primary outcome for 85% of the subjects allocated; 9) intention-to-treat analysis; 10) comparison of at least one primary outcome between groups; and 11) reporting of variability measures and estimates for at least one primary variable (PEDro, 2023).

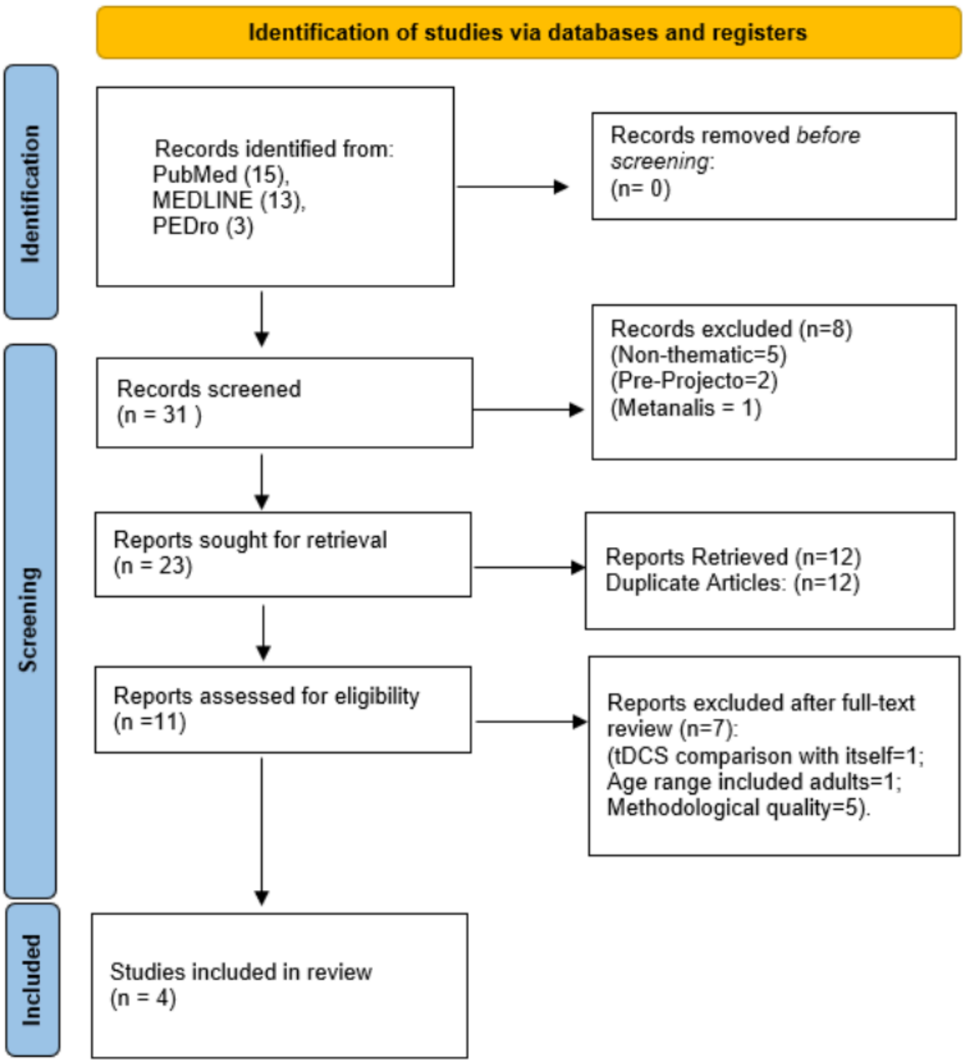
4 RESULTS

4.1 STUDY SELECTION

Following the search in the specified databases, a total of 31 articles were identified. Of these, 27 were subsequently excluded for various reasons. Initially, 8 articles were excluded for the following reasons: one was conducted with children exhibiting typical development; two involved children diagnosed with stroke; and two focused on children with various neurological alterations not specifically related to cerebral palsy (CP), thereby falling outside the intended scope of the review. Additionally, one meta-analysis and one pre-research project were excluded as they passed the initial database filtering.

In a second phase of screening, 12 articles were identified as duplicates and thus excluded. The final phase of screening involved a thorough reading and careful analysis, leading to the exclusion of 7 more publications. Among these, one article included a very broad age range of patients, extending to adults, and another compared the application of tDCS in different electrode positions rather than comparing it with other physiotherapy techniques. Five articles were further excluded due to insufficient methodological rigor, which would hinder the potential replication of the protocols in the CP child population. Ultimately, four articles m*et al*l inclusion criteria and were included in this study. The PRISMA flow diagram related to the bibliographic research conducted is depicted in table 2.

Table 2. PRISMA diagram – literature selection process.



Source: Prisma, 2020.

4.2 METHODOLOGICAL QUALITY

The average methodological quality score of the included studies was 8.75 on the PEDro scale. The most prevalent methodological shortcoming was the absence of "blinded therapists," noted in three studies (Radwan *et al*., 2023; Grecco *et al*., 2014a; Moura *et al*., 2017). Additionally, the lack of "blinded evaluators" and "blinded participants" constituted a methodological limitation in one study (Radwan *et al*., 2023). Nonetheless, one study achieved a full score on the scale, indicating no methodological weaknesses (Grecco *et al*., 2014b).

Table 3. Methodological quality of the studies analyzed

References	Pedro											Conflict of interests	Score
	E	2	3	4	5	6	7	8	9	10	11		
Radwan et al. (2023)	+	+	+	+	-	-	-	+	+	+	+	no	7
Grecco et al. (2014 a)	+	+	+	+	+	-	+	+	+	+	+	no	9
Moura et al (2017)	+	+	+	+	+	-	+	+	+	+	+	no	9
Grecco et al. (2014 b)	+	+	+	+	+	+	+	+	+	+	+	no	10

Randomized Controlled Trials; E: eligibility criteria (this item does not count towards the score final); 2: random allocation; 3: concealed allocation; 4: comparability; 5: participant blinding; 6: therapist blinded; 7: assessor blinded; 8: <15% dropout; 9: intention-to-treat analysis; 10: statistical comparisons between groups; 11: statistical measures of variability.
Source: Horing *et al*, 2023.

4.3 STUDY CHARACTERISTICS

The sample comprised children and 12 dolescentes aged between 5 and 12 years, diagnosed with spastic cerebral palsy (CP). In terms of the Gross Motor Function Classification System (GMFCS), the participants varied across levels I to III. Radwan *et al*. (2023) evaluated spasticity severity using the modified Ashworth scale, recording grades 1 and 1+. Moura *et al*. (2017) utilized both the Manual Ability Classification System (MACS) and the Manipulation Abilities Classification System (SCCM) for classifying and assessing patients.

For gait analysis, the studies by Grecco *et al*. (2014a) and Grecco *et al*.

(2014b) employed the SMART-D 1401 system (BTS Engineering, Italy), featuring eight infrared cameras, a SMART-D1 integrated workstation with 32 analog channels, and a synchronized video system. Additionally, Grecco *et al*. (2014) conducted balance assessments using a Kistler model 9286BA force platform, which facilitates stabilometric analysis through center of pressure (CoP) oscillation readings.

Table 4 delineates the data concerning the four selected studies, including the authors, publication dates, types of study designs, study objectives, sample characteristics, intervention protocols, parameters, assessment instruments, and results.

Table 4. Summary of the Selected Studies

Author/Year/Study Type	**Objective**	**Sample Characteristics**	**Intervention Protocol**	**Assessment Tools and Parameters**	**Results**
Radwan et al. (2023) Prospective Randomized Clinical Trial	Compare the effects of tDCS vs. VR on spatiotemporal and kinetic gait parameters in children with bilateral spastic cerebral palsy.	Initial N=40; Final N=34 Male: 23 / Female: 17 VR Group: 20 / tDCS Group: 20 Age: 7–12 years Type:Bilateral spastic CP	tDCS Group: Active tDCS (1 mA) over primary motor cortex. VR Group: Virtual balance training (Nintendo Wii). Both groups: Standard gait therapy.	GMFM; Gait Analysis: WalkwayTM Pressure Measurement System.	Both interventions improved gait. tDCS showed better kinetic improvements and lasting effects after 10 weeks.
Grecco et al. (2014a) Randomized Controlled Trial	Determine the effect of a single tDCS session on gait and balance in children with CP.	N=20 (EG:10 / CG:10) Age: 6–10 years Type: Spastic CP	Experimental Group: Active tDCS session. Control Group: Sham tDCS session.	GMFM; Gait Analysis (SMART-D 140); Balance Platform (Kistler 9286BA)	Significant improvements in balance and gait speed in the experimental group. No changes in controls.
Moura et al. (2017) Randomized, Placebo-Controlled Trial	Evaluate the effect of a single anodal tDCS session combined with functional training on upper limb movement in children with spastic hemiparesis.	N=20 Age: 6–12 years Type: Spastic hemiparetic CP	Experimental Group: Functional training + active tDCS. Control Group: Functional training + sham tDCS.	MACS; Pre- and post-treatment assessments.	Reductions in movement duration in both limbs in the tDCS group. No significant changes in the control group.
Grecco et al. (2014b)	Determine the effect of tDCS	Initial N=39; Final N=24	Experimental Group:	GMFM; Gait Analysis	Improvements in mobility and

Double-Blind, Randomized Clinical Trial	during treadmill training on gait in children with spastic diparetic CP.	(EG:12 / CG:12) Age: 5–10 years Type: Spastic diparetic CP	Active tDCS + treadmill training. Control Group: Sham tDCS + treadmill training. 10 sessions over 2 weeks.	(SMART-D 1401).	gait maintained after one month. Enhanced corticospinal excitability.

Source: Horing *et al*, 2023.

5 DISCUSSION OF RESULTS

The utilization of treadmills in neurological rehabilitation has proven particularly effective for gait training and is widely employed in treating children with cerebral palsy (CP), especially those with the spastic type. Reitz (2018) investigated the impact of treadmill training on enhancing gross motor skills in 12 children with CP. This study, conducted over a period of 12 weeks with a subsequent break, compared treadmill training to conventional gait training without a treadmill. GMFM-66 assessments conducted before and after each training phase indicated that treadmill training significantly improved gross motor functions in these children.

Given the significant gait impairments in children with CP, Grecco *et al*. (2014b) introduced a regimen combining treadmill training with transcranial direct current stimulation (tDCS). This study aimed to explore the effects of tDCS administered during treadmill training on the gait patterns of children with spastic diparetic CP. The participants in the experimental group underwent 10 sessions of this combined treatment, showing notable improvements in both temporal functional mobility and various gait parameters, such as spatiotemporal and kinematic variables. Remarkably, these improvements were maintained for a month post-intervention, as confirmed through follow-up evaluations. Additionally, there was a significant enhancement in corticospinal excitability compared to the control group. The findings concluded that tDCS administration during treadmill training amplifies the benefits of motor training in children with spastic diparetic CP.

The study by Grecco *et al*. (2014a) investigated the immediate effects of a single session combining treadmill training and tDCS on spatiotemporal gait and center of pressure oscillations in children with CP. This clinical trial involved 20 children, aged six to ten years, whose gait and balance were evaluated at three intervals: pre-stimulation, immediately post-stimulation, and 20 minutes post-stimulation. The protocol entailed a 20-minute session of tDCS at an intensity of 1 mA applied to the primary motor cortex. Significant reductions in oscillations during orthostatic positions in both anteroposterior and mediolateral directions were observed ($p<0.05$). Additionally, there were marked improvements in gait speed, cadence, and center of pressure oscillations during orthostatism ($p<0.05$), leading to the conclusion that even a single session of tDCS can promote positive changes in static balance and gait speed.

Grecco *et al*.'s studies from 2014, both prolonged and single-session, indicate that tDCS, when applied to children with CP, can yield positive and significant outcomes, enhancing mobility and gait in children with spastic diparetic CP, thus presenting potential clinical benefits worth exploring further.

In contrast, Radwan *et al*. (2023) examined the effects of gait training combined with two different interventions—tDCS and virtual reality (VR)—on spatiotemporal and kinetic gait impairments in children with bilateral spastic CP. This study differentiated itself by comparing techniques in combination with gait training, whereas earlier studies such as those by Grecco *et al*. in 2014 compared identical groups, one with placebo tDCS and the other with active tDCS.

Moreover, VR in pediatric neurorehabilitation is recognized for its ability to establish flexible, individualized intervention programs that integrate the child's preferences, thereby enhancing engagement through improved attention, motivation, and increased sensory feedback. These elements foster more successful learning outcomes (Wang & Reid, 2011).

Virtual reality (VR) is a computer technology that simulates real-world experiences by providing artificial sensory feedback, allowing individuals to develop motor skills within a three-dimensional virtual environment that mimics real-life scenarios. The core attributes of VR systems, interaction and immersion, are pivotal. Interaction involves the engagement of multiple sensory channels—vision, hearing, touch, and even smell—whereas immersion refers to the individual's level of involvement with the virtual environment. These elements collectively enhance the sense of presence, defined as the feeling of being in a specific situation. High levels of presence are crucial for effectively manipulating cognitive processes involved in motor control, suggesting that systems offering greater immersion result in stronger integration between the patient and the system (Wang & Reid, 2011).

Physiotherapeutic interventions like gait training and the utilization of rehabilitation devices are known to positively influence spatiotemporal variables of gait, balance, and functional status. Techniques such as vibration platform training, treadmill gait training, electrical stimulation, and transcranial stimulation have shown efficacy in improving gait spatiotemporal parameters, particularly speed. The Pediatric Spatial-Temporal Deviation Index has been developed to quantify gait disturbances in children with these conditions (Reitz, 2018).

The study by Radwan *et al*. (2023) concluded that both tDCS and VR interventions demonstrated improvements in spatiotemporal gait parameters, such as speed, step length, and stride length, after a two-week intervention, with additional gains observed 10 weeks post-treatment. Notably, the tDCS group exhibited more significant and sustained improvements compared to the VR group, with additional gains in maximum force and peak pressure. Furthermore, the tDCS group showed greater enhancements in gait speed, stride length, and step length, indicating a broader and more enduring impact of tDCS on gait in children with bilateral spastic CP.

In children with spastic hemiparetic CP, motor impairments are often more pronounced in the affected upper limb, leading to limitations in hand function due to deficits in motor coordination, selective motor control, muscle weakness, delayed movement execution, and poor sensorimotor integration (Moura *et al*., 2017). The study by Moura *et al*. (2017) focused on assessing the effects of a single session of anodal tDCS combined with functional training on the spatiotemporal variables of arm movements in these children. This randomized, placebo-controlled, blinded evaluator study involved 20 children and analyzed upper limb spatiotemporal variables before and immediately after stimulation. The session consisted of 20 minutes of functional training of the paretic upper limb combined with tDCS at 1 mA over the primary motor cortex contralateral to the motor impairment.

Several interventions can enhance upper limb spatiotemporal variables in children with spastic hemiplegia. Supervised constraint-induced movement therapy (CIMT) has been effective in improving motor functions. CIMT, especially when combined with techniques such as VR or tDCS, has shown promising results. Distinct improvements in movement duration, trajectory, and velocity of hand movements have been documented in CIMT studies. Constraint therapy can enhance upper limb movement, function, proprioception, wrist flexor synergy, coordination speed, and overall upper extremity scores. Combining CIMT with other methodologies has been proven effective in improving spatiotemporal variables of upper limb movement in children with spastic hemiplegia (Chopra, 2013).

The limitations of this review include a small sample size of articles with good methodological quality, low risk of bias, and restricted participation to children only. Additionally, the limited duration of the interventions in the analyzed studies may compromise the reliability of the results.

6 CONCLUSION

Recent research has substantiated that transcranial direct current stimulation (tDCS), when utilized in conjunction with physiotherapeutic interventions, significantly enhances motor skills in children with cerebral palsy (CP). Results indicate that children undergoing a regimen of tDCS, whether through multiple sessions combined with physiotherapy or a single session, exhibit marked improvements in gait quality, balance, and coordination of upper limb motor functions, including an accelerated execution of movements. These findings advocate that tDCS may potentiate the therapeutic effects of physiotherapy in pediatric patients, contributing substantially to their motor development.

The implications of these outcomes are significant within pediatric health and rehabilitation domains, presenting novel therapeutic avenues for children afflicted with cerebral palsy. Incorporating tDCS as an adjunct tool in physical therapy regimens could potentially expedite the rehabilitation process, thereby enhancing life quality and broadening opportunities for social inclusion for these children.

Despite these promising results, comprehensive research is required to elucidate the underlying mechanisms by which tDCS facilitates enhancements in conjunction with physical therapy and to determine optimal application practices. It is imperative to assess potential adverse effects and confirm the safety of this modality prior to its widespread adoption in clinical settings.

The encouraging results derived from integrating tDCS with physiotherapy in children with CP suggest that this therapeutic combination may effectively ameliorate motor functions. While further research is essential to corroborate these findings and refine treatment protocols, the initial evidence remains promising.

In summary, this study highlights tDCS as a potentially valuable adjunctive therapy to physical therapy in the management of cerebral palsy. Nonetheless, like any therapeutic intervention, its benefits must be carefully weighed against potential risks, including adverse effects, and practical considerations such as cost and accessibility.

Future studies should aim to include a greater number of randomized clinical trials with rigorous methodological quality, significant sample sizes, and a broad participant base. There is merit in comparing the impact of tDCS across various forms of cerebral palsy, extending beyond solely spastic manifestations. Moreover, investigations should encompass longer intervention durations to more definitively determine the sustained effects of tDCS. It is also advisable to explore additional motor variables, extending beyond improvements in gait and upper limb motor skills, to deepen the understanding of tDCS's potential benefits across diverse clinical scenarios and motor aspects.

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