BMC Pediatrics

RESEARCH Open Access

Effects of transcranial direct current stimulation and mirror therapy on mental health and dopamine level among spastic quadriplegic cerebral palsy children

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Abstract

Background Cerebral palsy (CP) is a neurological condition affecting a child's motor development, potentially disturbing their mental health, which is an emerging challenge for rehabilitation. Transcranial direct current stimulation (tDCS) and mirror therapy (MT) are novel neurorehabilitation techniques that enhance mental health and motor development.

Methods A double-blinded randomized clinical trial was conducted on 105 children with spastic quadriplegic CP between the ages of three to seven years. The study was conducted in the Physical Therapy Center of Ghurki Hospital, Lahore. The patients were divided into three groups of 35 patients: Group A (tDCS + MT + Routine Physical Therapy (RPT)), Group B (MT + RPT), and Group C (tDCS + RPT) through Randomized Allocation Software Version 1.0. Patients underwent 10 sessions of tDCS and MT, each lasting for 15 min per side (right and left), along with 20 min of RPT five days a week, which continued for the next ten weeks on follow-up. The mental health of CP children from different age ranges was assessed by the Strengths and Difficulties Questionnaire (SDQ), a brief and accessible screening tool covering a child's emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and social behavior. Designed for teachers and parents, the self-report versions have a reliability of 0.80. Dopamine was measured using a plasma lab test to explore its potential relationship with changes in mental health status following the intervention. Assessment was conducted at baseline, after two weeks, and again after ten weeks of follow-up. The data was analyzed via SPSS version 26.0.

Results The results revealed a significant change in the mean score of Strengths and Difficulties Questionnaires (SDQ) after ten weeks ($P = 0.004$) and in dopamine levels after two weeks ($P < 0.001$). Additionally, group comparison revealed statistically significant changes in both SDQ scores ($P = 0.001$ for group A and $P = 0.002$ for group C) and dopamine levels ($P = 0.000$ for group A and $P = 0.002$ for group C) but not group B at the specified time intervals.

Conclusion The combined treatment of tDCS and MT improved mental health and increased dopamine levels more than either treatment alone. Dopamine levels increased initially but decreased during follow-up.

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Trial registration The trial was registered in the Iranian Registry of Clinical Trials (IRCT20231227060542N1) on 26-01-2024. https://irct.behdasht.gov.ir/.

Keywords Dopamine level, Mirror therapy, Mental health, Spastic quadriplegic CP, Transcranial direct current stimulation.

Introduction

CP is a neurological condition affecting an immature, underdeveloped brain due to vascular insults disturbing motor development [1]. Impaired motor development in children can hinder movement, social behavior, communication, and daily tasks, leading to increased peer pressure affecting their physical, social, and mental health [2]. Spastic quadriplegic CP (SQCP) is a neurological disorder caused by damage to the motor cortex, which affects all four limbs and the trunk. They experience increased muscle tone, leading to reduced movement control and impaired coordination [3]. These challenges significantly affect their ability to perform daily activities [4, 5].

In Pakistan, the most common types are diplegic and SQCP, with a prevalence of 1.22 per 1000 live births. In India, the prevalence is higher at 3 per 1,000 live births [6–8]. Major risk factors for spastic CP include low birth weight, placental abnormalities, and hypoxia at birth [9]. A child with CP experiences neuromuscular abnormalities in muscle tone, balance, coordination, and strength. These challenges can lead to social isolation and emotional distress, impacting their overall well-being [10].

Technological advancements in medical sciences have introduced non-invasive transcranial direct current stimulation (tDCS) as a novel neuromodulation treatment for neurological patients with disturbed mental health [11]. Impaired motor activity often leads to reduced dopamine levels, affecting both mood, cognition, and mental health [12]. More than one-third of patients with disturbed mental health do not benefit from existing evidence-based treatments [13]. tDCS may provide high-quality adjunct treatment to enhance the benefits of medicines and psychotherapy [14]. The method is affordable, portable, and safe, utilizing two scalp electrodes to target the desired brain area [15]. Anodal tDCS reduces spasticity in upper extremities as well as improves balance and gait parameters in CP patients [16]. The anode depolarizes neuronal tissues of the brain that are adjacent to the stimulation site, referred to as excitatory tDCS which enhances cortical excitability that is dependent on N-methyl-d-aspartate receptor and calcium channel activity [17], whereas the cathode repolarizes the adjacent brain region, referred to as inhibitory tDCS, though this simplification is still debated [18]. tDCS has a beneficial impact on patients with various mental illnesses and strongly promotes mental health. tDCS has been shown to benefit patients suffering from a variety of mental illnesses by improving mental health [19]. Application of tDCS lowers the physiological stress markers (salivary cortisol and alpha-amylase) resulting in cortisol depletion [20] and an inhibitory impact on a radiotracer raclopride, suggesting an increase in extracellular dopamine release resulting in a stimulatory effect on dopamine levels among humans [21].

MT activates the mirror neuron system in the premotor cortex [22], which responds to specific movements performed by an individual or observed in a mirror [23]. MT was introduced in 1996 for phantom pain [24] and proved to be an effective intervention for CP rehabilitation [25, 26]. In MT, the brain hemisphere contralateral to the moving limb exhibits activation in the primary motor cortex and an alteration in inter- or intra-hemispheric inhibition [5]. MT stimulates muscle activity in affected limbs, balances the ipsilateral primary motor cortex, normalizes electrical activity, and activates the posterior cingulate cortex [27]. These effects facilitate neuroplastic changes, promote motor development, enhance mental health, and activate dopamine release [28].

Under the umbrella of routine physical therapy (RPT), goal-directed functional training and reflex inhibitory patterns were used in combination for better rehabilitation to constrain the financial burdens of CP treatment [29]. Goal-directed functional training comprises tasks such as prone neck raises, rolling, sit-to-stand, step-ups, supine bridges, and transfer practice based on the Canadian Occupational Performance Measure (COPM) [30]. The reflex inhibitory pattern targets exaggerated or diminished primitive, postural, or righting reflexes through repeated stimuli and specific postures [31].

CP patients encounter challenges such as motor skill deficiencies that hinder mobility and affect their self-esteem [32]. This can lead to increased stress, elevated cortisol levels, fluctuating dopamine levels, and disturbed emotional and mental health [33, 34]. Movement activation by these interventions tailored to CP child can reduce stress by stimulating dopamine release, thereby enhancing their overall health [12, 35]. This study aimed to assess the impact of tDCS combined with MT on hormonal changes and mental health in SQCP children. These novel rehabilitation approaches aim to enhance an individual's functional, structural, and emotional states by triggering the release of dopamine hormone, a factor directly linked to mental health that can significantly improve one's quality of life by fostering greater rationality.

Methods

Study design

A double-blinded (assessor and caregiver) randomized clinical trial was conducted. The trial was registered on the Iranian registry of clinical trials with reference number IRCT20231227060542N1 and conducted according to the guidelines of the consolidated standards of reporting trials (CONSORT) (Fig. 1).

Sample size

A pilot study was conducted with thirty patients to ensure adequate design of a full trial to test its efficacy [36]. The sample size was calculated using the open epi tool [37]. The mean values and standard deviations were 19 ± 6.93 for group I, and 23.87 ± 6.17 for group II, respectively. With 80% power and a 95% confidence level, the resultant sample size was 29. After adding 20% to account for expected dropouts, each group size was determined to be 35, making a total of 105 patients.

Patients

A thorough examination of CP patients was conducted at the Ghurki Hospital's Physical Therapy & Rehabilitation Center in Lahore, Pakistan, by an orthopedic physician, neurologist, psychologist, and physical therapist from January 2024 to July 2024. A systematic awareness campaign was launched through social media to maximize patients' responses to join this study. The diagnosed SQCP patients were referred to Physical Therapy rehabilitation section. Patients aged 3–7 years [8] with SQCP, GMFCS level I to III [38, 39], spasticity < 3 on modified Ashworth scale [40] and with a good understanding of verbal directions, or the usage of communication aids, were included in the study [41]. Patients with ataxia, monoplegia, diplegic hemiplegic CP, neurosurgery, neurolytic block, cancerous history [8], musculoskeletal deformity, skin ailment, seizure history, metallic implant or hearing aid [38] use were excluded from the study. Informed consent was obtained from the parents and guardians before participating in the study. Detailed descriptions of the intervention protocol were guided to the patients to ensure confidentiality.

Randomization and blinding

Randomized Allocation Software version 1.0 was used for randomization. 105 patients were allocated to three groups Group A (tDCS + MT + RPT), Group B (MT + RPT), and Group C (tDCS + RPT) (35 in each

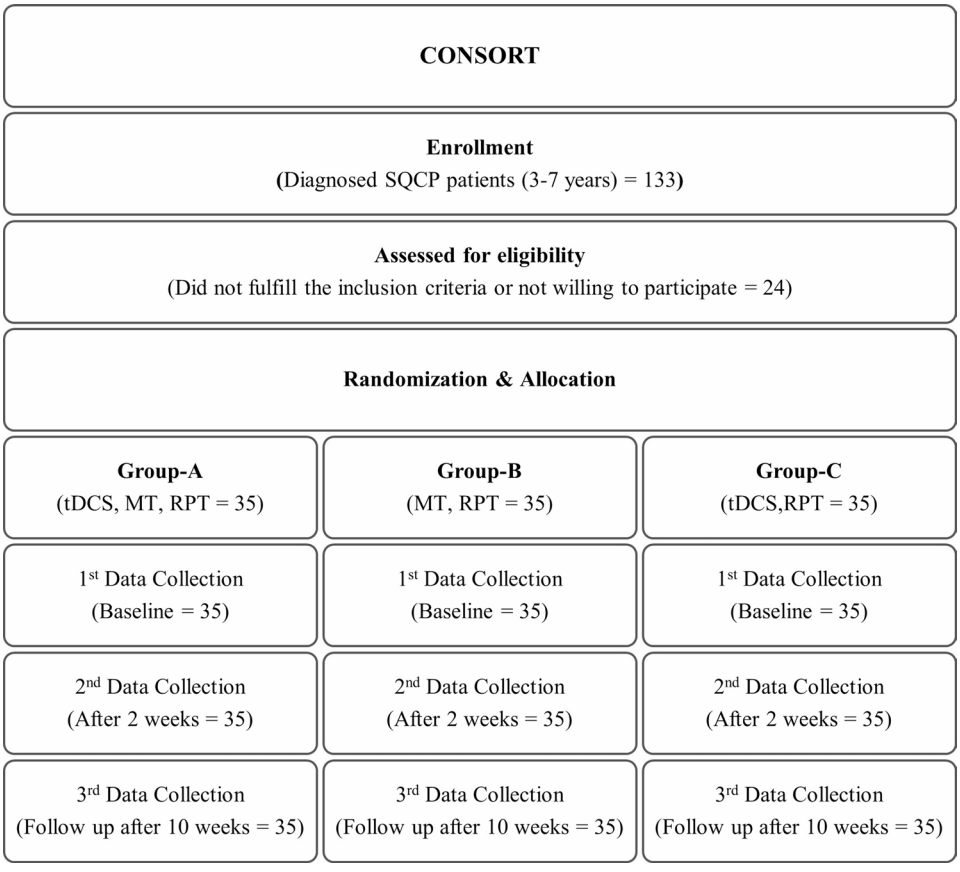

Fig. 1 Consort Diagram

group) with a 1:1:1 ratio with a unique identity number. Both the outcome assessors and caregivers were blinded to the randomization process and the allocation of treatment groups, which helped to reduce bias and enhance the validity of the study results.

Treatment

Transcranial direct current stimulation

The patients were positioned in a CP chair, with hip and knee joints at 90 degrees flexion and forearms resting on a table in front. For the group receiving tDCS, a wireless rechargeable tDCS device (Segal Stim SG-2023004 by Framed Company) was used. The device consists of two sponge electrodes, each measuring 5*7 cm in length, which were saturated with 0.9% physiological saline. The electrodes were meticulously positioned around the patient's head and firmly secured to guarantee optimal contact and alignment [8].

tDCS was administered with a current intensity of 2 milliamperes to modulate cortical excitability in both hemispheres of the brain [36]. The stimulation targeted the primary motor cortex (M1) bilaterally, with 15 min of stimulation applied to each hemisphere, resulting in a total stimulation duration of 30 min [42]. For the first 15 min, to target the right-sided extremities, the anode was positioned over the left primary motor cortex (M1), facilitating cortical excitability, while the cathode was placed over the right supraorbital area to serve as the reference electrode [38]. Consequently, the electrode arrangement was reversed to target the left-sided extremities. Specifically, the anode was repositioned over the right primary motor cortex (M1) to enhance neural activity in the right hemisphere, while the cathode was placed over the left supraorbital area [36]. This electrode placement protocol was implemented following the 10–20 EEG international system, ensuring precise localization of stimulation sites for better effectiveness and reproducibility of tDCS [38] (Fig. 2) & (Fig. 3).

Mirror therapy

Left-sided extremities were hidden behind a 35 × 35-centimeter mirror, with the right targeted side in front of it, where the movement of the right-sided upper and lower extremities was mirrored in a mirror for 15 min and repeated for the left targeted side as explained for the right side for the next 15 min [43]. The upper extremity MT program included pronation, supination, and flexion-extension of fingers, wrist, and elbow [44], while the lower extremity MT program included ball rolling, rocker-boarding, and pedaling [45]. Following a 30-minute MT treatment, the patients completed ten sets of 20 repetitions of each exercise, taking two minutes off in between, and were given feedback on how to focus better [46].

Routine physical therapy

Under RPT, goal-directed functional training and reflex inhibitory pattern techniques were applied to all groups (A, B, and C) as a standardized physical therapy treatment. Each technique was administered for 10 min, resulting in a total therapy duration of 20 min for each group. tDCS and MT were applied for 10 sessions only, whereas RPT continued from week 0 to week 10 to ensure sustained therapeutic benefits. Goal-directed functional training focused on tasks tailored to the patient's functional level and competencies like (prone neck raises, rolling, sit-to-stand, step-up, supine bridges, and transfer practice) [30]. In the reflex inhibitory pattern's regime, any exaggerated or diminished primitive, postural, or righting reflexes were targeted through repeated stimuli and specific postures designed to develop reflexes that would help overall development, leading to better mental health.

Outcome measures

Patients received 10 sessions of tDCS and MT, each lasting 15 min per side (right and left), as well as 20 min of RPT five days a week for the next ten weeks as a follow-up. Every patient was assessed by one independent assessor using by SDQ with a reliability of 0.80 [47, 48] and a plasma lab test of dopamine [49, 50] at baseline, after ten sessions or two weeks, and then after ten weeks of follow-up, by extending the notion of the standard of care in physical therapy, which was extended RPT. The extended RPT program was planned first because, as a matter of ethics, patients had to have the best and maximum chance of benefit from treatment, and secondly, neural, mechanical, biochemical, and structural changes for growth start in the second week and mature in 8–12 weeks [38].

Statistical analysis

The data was analyzed by SPSS 26.0 (Chicago, USA), and normality was assessed by the Shapiro-Wilk test. For descriptive statistics, categorical and nominal variables were presented as frequencies and percentages, while the mean and standard deviation represented continuous variables. For inferential statistics, A multivariate mixed-design ANOVA was conducted to see the effects of group (A, B, C) and time (baseline, 2 weeks, and 10 weeks) on mental health and dopamine levels. Post-hoc pairwise comparisons using the Bonferroni test were applied to evaluate specific group-wise differences. A 95% confidence interval was considered to analyze the whole data, with a significance value of $P < 0.05$.

Fig. 2 Anodal stimulation of left-sided extremities

Results

During the trial, 105 SQCP patients participated and completed their treatment, whose mean age was 6.64 ± 0.5 years: 61 males (58%) and 44 females (42%). Among the males, 22 (36%) were from Group A, 18 (30%) were from Group B, and 21 (34%) were from Group C. In contrast, among the females, 13 (30%) were from Group A, 17 (39%) were from Group B, and 14 (32%) were from Group C. The socioeconomic status showed that 22 patients (21%) were from the upper class, 59 (56%) were

Fig. 3 Anodal stimulation of right-sided extremities

Table 1 Demographic Distribution

Variables	Group A (35)	Group B (35)	Group C (35)	Total (105)
	n (%)	*n* (%)	*n* (%)	*n* (%)
Age				
Mean ± SD	6.82 ± 0.451	6.45 ± 0.465	6.66 ± 0.456	6.643 ± 0.457
Gender				
Males	22 (36)	18 (30)	21 (34)	61 (58)
Females	13 (30)	17 (39)	14 (32)	44 (42)
Socioeconomic Status				
Upper Class	8 (36)	7 (32)	7 (32)	22 (21)
Middle Class	17 (29)	22 (37)	20 (34)	59 (56)
Lower class	10 (42)	6 (25)	8 (33)	24 (23)
Level of CP on GMFCS				
Level-I	5 (42)	4 (33)	3 (25)	12 (11)
Level-II	12 (35)	11 (32)	11 (32)	34 (33)
Level-III	18 (31)	20 (34)	21 (36)	59 (56)
Tone on MAS				
Grade-I	3 (3)	2 (2)	1(1)	6 (6)
Grade-I+	13 (12)	9 (9)	7 (7)	29 (28)
Grade-II	10 (10)	12 (11)	13 (12)	35 (33)
Grade-III	9 (9)	12 (11)	14 (13)	35 (33)

from the middle class, and 24 (23%) were from the lower class. Regarding the GMFCS levels, 12 patients (11%) were at Level I, 34 (33%) were at Level II, and 59 (56%) were at Level III. According to the modified Ashworth scale, 6 patients (6%) had Grade 1, 29 patients (28%) had Grade 1+, and 35 patients (33%) had Grade 2 and 3. (Table 1)

Description of mental health

The Shapiro-Wilk test confirmed that the data were normally distributed ($P > 0.05$). The results of a multivariate mixed-design ANOVA comparing mean SDQ scores at different time intervals (completion of the 2nd and 10th weeks) showed a significant difference in group mean scores at 10 weeks. The mean scores of SDQ at baseline were 76.9 ± 1.9 for Group A, 77.1 ± 1.9 for Group B, and 77.1 ± 1.9 for Group C. After 10 sessions or two weeks, the mean scores were 58.9 ± 4.1 for Group A, 58.5 ± 4.4 for Group B, and 59.4 ± 4.2 for Group C, showing a difference in mean scores but not statistically significant ($F = 2.8$, $P = 0.064$). After 10 weeks, during the follow-up, the SDQ mean scores were 32.2 ± 5.3 for Group A, 38.6 ± 10.8 for Group B, and 37.9 ± 8.4 for Group C, with a statistically significant difference between the groups ($F = 5.9$, $P = 0.004$) (Table 2) & (Fig. 4).

Description of dopamine level

The results of a multivariate mixed-design ANOVA comparing mean dopamine scores at different time intervals (completion of the 2nd and 10th weeks) revealed a significant difference in mean score, especially after completing the 2nd week of treatment. The dopamine mean scores at baseline were 4.2 ± 1.7 for Group A, 4.4 ± 1.6 for Group B, and 4.2 ± 1.7 for Group C. After 10 sessions or two weeks, the mean scores were 20.6 ± 2.4 for Group A, 18.3 ± 2.1 for Group B, and 19.1 ± 2.5 for Group C, showing a significant difference in mean ($F = 9.1$, $P = < 0.001$). After 10 weeks, during the follow-up, the dopamine scores were 10.4 ± 1.6 for Group A, 10.2 ± 0.9 for Group B, and 10.4 ± 1.3 for Group C, with a difference in mean scores concerning baseline that was not significant ($F = 0.3$, $P = 0.762$) (Table 2) & (Fig. 5).

Groupwise comparison of mental health and dopamine

The results of the Bonferroni test for multiple comparisons between groups at baseline for SDQ revealed that the mean difference between Groups A and B was – 0.14, between Groups B and C was – 0.03, and between Groups C and A was 0.2, with no significant difference ($P = 1.000$). After two weeks, the mean differences were 0.5 between Groups A and B, -2.3 between Groups B and C, and 1.8 between Groups C and A, with no significant difference ($P = 1.000$, $P = 0.08$, and $P = 0.23$, respectively). However, after ten weeks, the mean differences were – 6.4 between

Table 2 Between-group comparison of mental health and dopamine

Assessments	Intervention						
	Group-A tDCS + MT + RPT (*n* = 35)	Group-B MT + RPT (*n* = 35)	Group-C tDCS + RPT (*n* = 35)	Total (*n* = 105)	F value	Partial Eta squared	*P* value
Mental Health Baseline	76.91 ± 1.86	77.05 ± 1.98	77.08 ± 1.98	77.01 ± 1.94	0.77	0.002	---
Mental Health 2 Weeks	58.97 ± 4.09	58.51 ± 4.44	60.80 ± 4.23	59.43 ± 4.25	2.818	0.052	0.064
Mental Health 10 Weeks	32.20 ± 5.25	38.57 ± 10.81	37.85 ± 8.38	36.21 ± 8.15	5.954	0.105	0.004
Dopamine Baseline	4.20 ± 1.74	4.40 ± 1.63	4.20 ± 1.67	4.27 ± 1.68	0.164	0.036	---
Dopamine 2 Weeks	20.60 ± 2.37	18.31 ± 2.02	19.02 ± 2.45	19.31 ± 2.28	9.092	0.151	< 0.001
Dopamine 10 Weeks	10.40 ± 1.61	10.20 ± 0.90	10.40 ± 1.31	10.33 ± 1.27	0.273	0.005	0.762

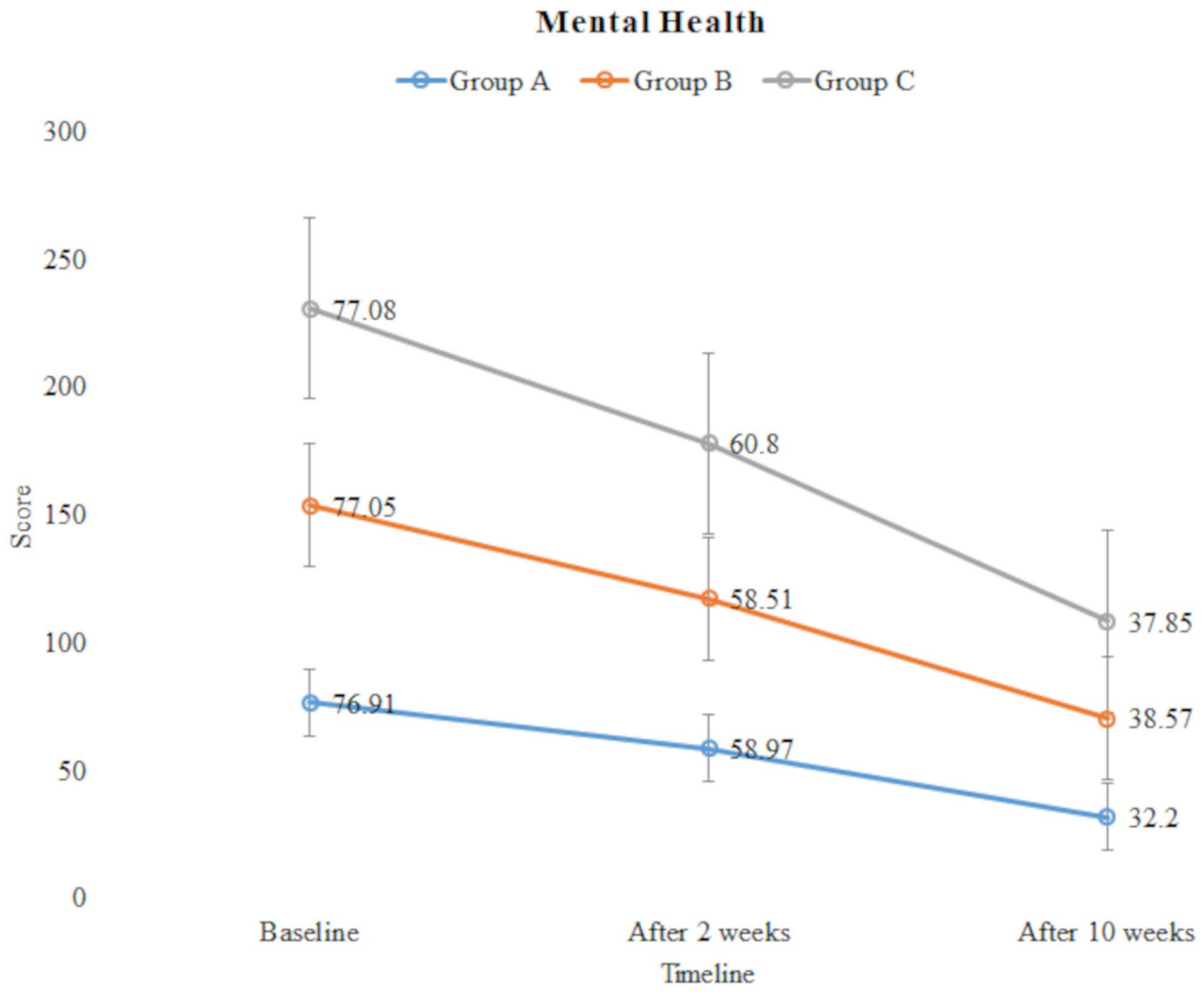

Fig. 4 Graphical representation of mental health

Groups A and B, 0.7 between Groups B and C, and 5.7 between Groups C and A, with statistically significant differences between Group A and B and between Group C and A ($P = 0.01$ and $P = 0.02$, respectively) (Table 3).

* = statistically significant difference between two groups

For a multiple-group comparison regarding dopamine, the mean difference between Groups A and B was – 0.2, between Groups B and C was 0.2, and between Groups C and A was 0.0, with no significant difference ($P = 1.000$). However, after two weeks, the mean differences were 2.3 between Groups A and B, 0.8 between Groups B and C, and – 1.6 between Groups C and A, with statistically significant differences between Group A and B and between Group C and A ($P = 0.00$ and $P = 0.02$, respectively). After ten weeks, the mean differences were 0.2 between Groups A and B, -0.2 between Groups B and C, and 0.0 between Groups C and A, with no significant difference ($P = 1.000$) (Table 3).

Pairwise comparison of mental health and dopamine

Pairwise comparisons of SDQ and dopamine levels indicated statistically significant differences in all pairings of these two outcomes ($p = 0.001$) at a 95% confidence interval. The mean difference between the baseline and second-week pairs was 17.6, the second-week to tenth-week pair was 23.2, and the tenth-week to baseline was 40.8. For dopamine, the mean difference between the baseline and second week was – 15.1, between the second and tenth weeks was 8.9, and between the tenth week and baseline was 6.1 (Table 4).

Discussion

The present study demonstrated promising results in patients with CP through the use of tDCS and MT. Significant improvements in mental health were observed after 10 weeks, as shown by follow-up assessments. Interestingly, an increase in dopamine levels was observed as early as two weeks into the intervention, but this increase

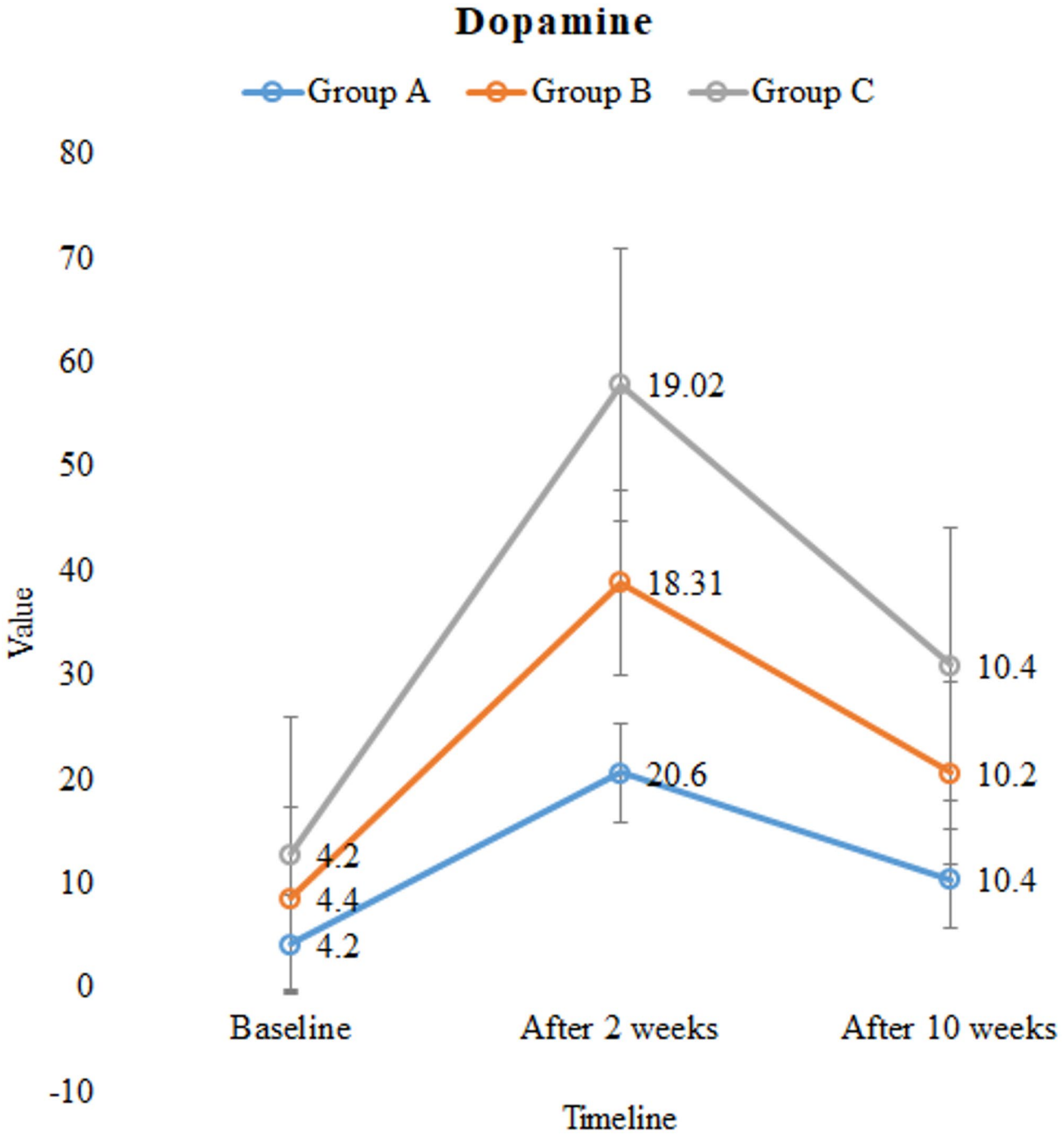

Fig. 5 Graphical representation of Dopamine

was not consistent at the 10-week mark. The study found that tDCS and MT significantly improved mental health outcomes in CP patients when combined with RPT, possibly due to dopamine release, a neurotransmitter known for reward and mood regulation. Our results suggest that therapies inducing dopamine release could be promising for treating mental health issues in patients with CP.

In support of anodal tDCS, a study was conducted to discover its effects on healthy individuals. The findings indicated transient increases in dopamine levels during rehabilitation, suggesting that anodal tDCS may temporarily enhance dopamine production or release. This elevation could potentially improve cognitive and motor functions during treatment. These results aligned with broader evidence supporting neuroplasticity and the optimization of brain function during targeted therapeutic interventions [51]. However, in the current study, a significant increase in dopamine levels from baseline to

Table 3 Groupwise comparison of mental health and dopamine

Dependent Variable	(I) groups	(J) groups	Mean Difference (I-J)	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Mental Health-Baseline	A	B	-0.143	1.00	-1.283	0.997
	B	C	-0.029	1.00	-1.168	1.111
	C	A	0.171	1.00	-0.968	1.311
Mental Health-2 weeks	A	B	0.457	1.00	-2.023	2.937
	B	C	-2.286	0.08	-4.766	0.195
	C	A	1.829	0.23	-0.652	4.309
Mental Health-10 weeks	A	B	-6.371*	0.01	-11.296	-1.447
	B	C	0.714	1.00	-4.210	5.639
	C	A	5.657*	0.02	0.733	10.582
Dopamine-Baseline	A	B	-0.200	1.00	-1.180	0.780
	B	C	0.200	1.00	-0.780	1.180
	C	A	0.000	1.00	-0.980	0.980
Dopamine-2 weeks	A	B	2.285*	0.00	0.951	3.621
	B	C	-0.714	0.59	-2.049	0.621
	C	A	-1.571*	0.02	-2.906	-0.237
Dopamine-10 weeks	A	B	0.200	1.00	-0.561	0.961
	B	C	-0.200	1.00	-0.961	0.561
	C	A	0.000	1.00	-0.761	0.761

"*"=statistically significant difference between two groups

Table 4 Pairwise comparison of mental health and dopamine

Outcome Measures	Blending at different treatment time	Mean difference	95% Confidence Interval of the Difference		P value
			Lower	Upper	
Mental Health	Baseline – 2nd Week	17.59	16.652	18.529	< 0.001
	2nd Week – 10th Week	23.22	21.378	25.060	< 0.001
	10th Week - Baseline	40.81	39.073	42.546	< 0.001
Dopamine	Baseline – 2nd Week	-15.05	-15.546	-14.550	< 0.001
	2nd Week – 10th Week	8.98	8.530	9.432	< 0.001
	10th Week - Baseline	6.07	5.731	6.402	< 0.001

two weeks post-treatment was observed, which indicates the effectiveness of the combination in enhancing dopamine production and regulation. This rise may be due to the initial therapeutic benefit or the natural homeostatic response of the body which diminishes the initial gains. However, by the tenth week, dopamine levels returned to baseline, which suggests that the benefits of the treatment were not sustained. This decrease in dopamine level after termination of tDCS may be due to a neuroadaptive mechanism in which biochemical effects may not translate into long-term synaptic modifications or neuroanatomical restructuring. The frequency and intensity of treatment may not be sufficient to induce long-term neurochemical changes.

In contrast, a study was carried out by using cathodal tDCS to investigate its effects on dopamine release in rats. The study found that a 10-minute application of cathodal tDCS generates a significant increase in extracellular dopamine levels in the striatum, which lasted for over 400 min without affecting serotonin levels. This indicates that cathodal tDCS has a notable and prolonged effect on the dopaminergic system, particularly within the basal ganglia through direct stimulation of dopaminergic neurons or via indirect pathways influencing dopamine release, emphasizing the potential of tDCS to target specific neurotransmitter systems [52]. In contrast, the current study observed similar effects with anodal tDCS stimulation rather than cathodal stimulation. This contrast is a significant and distinguishing feature of the study, as it underscores the differential effects of tDCS polarity on neurophysiological outcomes, specifically regarding cortical excitability and dopamine change.

In alignment with the results of the present study, a study investigated the effects of anodal tDCS on cortical regions to improve mental health in sixteen patients with psychiatric disorders. The intervention involved ten sessions of tDCS, with data gathered using the Symptom Checklist-10. The findings revealed significant therapeutic effects of anodal tDCS, which results in marked improvements in mental health. This emphasizes its potential as a non-invasive and effective treatment modality for managing psychiatric conditions by

modulating cortical activity, offering a promising avenue for enhancing therapeutic outcomes in mental health [53]. The current study shared a similar concept which observes the application of tDCS led to improvements in mental health as measured by the Strengths and Difficulties Questionnaire scores, highlighting its potential as an effective intervention for enhancing mental health outcomes in clinical settings.

A pilot study was conducted to investigate the efficacy of tDCS combined with MT on motor development and control among CP patients. The study concluded that this combination significantly improves motor development, motor control, and muscle performance, and directly elevates movement capabilities. This improvement is important, as enhanced movement outcomes are associated with dopamine release, which can positively affect the mental health of patients with CP [36]. These findings align with the current study, which indicates that tDCS and MT enhance motor outcomes with overall well-being by potentially altering neurochemical balances in CP patients. This alignment reinforces the therapeutic value of this intervention, emphasizing its potential to address both physical and psychological aspects of CP.

tDCS is a user-friendly, low-cost, and low-risk therapeutic modality that improves spasticity, balance, gross motor function, and gait. It is related to improved mobility and physical functioning, which connects to stress management, reduces cortisol function, and influences mental health. Recent studies suggest that tDCS may have broader mental health effects through neuroplasticity mechanisms, enhancing cortical excitability and causing persistent synaptic changes, improving mood and cognitive function, and affecting GABA modulation may also contribute to anxiety and stress reduction, complementing dopaminergic pathways [54]. In alignment with the results of the present study, researchers found significant effects of tDCS on depression symptoms, raising dopamine levels and improving mental health.

Research on the relationship between physical exercise and dopamine levels shows mixed results. A systematic review was conducted in which consistently showed a positive influence of dopamine on habitual physical activity. Therapeutic interventions like tDCS and MT improved movement-induced dopamine release in CP patients, reducing cortisol levels, promoting relaxation, potentially improving anxiety levels, and highlighting the therapeutic potential of targeted interventions [55]. Physical activity stimulates dopamine release, which helps to improve mood by interacting with serotonin, another mood-regulating neurotransmitter. This process enhances brain function, supports mental health, and reduces stress [56].

In support of this study, a study was conducted to investigate the effects of aerobic exercise at various intensities on neurotransmitter levels, including dopamine, norepinephrine, and serotonin metabolites, as well as oculomotor control in Parkinson's patients and found no significant effect on oculomotor control. However, the study found aerobic exercise alters brain neurotransmitters, particularly dopamine, norepinephrine, and serotonin metabolites [35]. In our study, a comparable effect on dopamine modulation was observed in response to a holistic intervention that included tDCS, MT, and RPT. This suggests that integrative approaches involving brain stimulation and movement-based therapies may have a broader impact on neurochemical modulation across different neurological disorders.

In support of this study, a study was conducted to examine the relationship between dopamine release and human movement. The study concludes that dopamine release depends on the type and intensity of physical activity. An intense activity level stimulates higher dopamine release while a low activity level lowers dopamine release. This highlights the significant impact of activity levels on dopamine [28]. In the current study, tDCS and MT are employed to catalyze the movement, which enhances dopamine release and its impact on mental health. This dopamine release is hypothesized to contribute to improved mental health, highlighting the potential of these interventions to enhance both physical and psychological well-being.

tDCS has demonstrated significant improvements in hormone imbalances, depression, anxiety, and overall mental wellness [57]. However, this study focused on individuals with spastic CP, categorized by the Gross Motor Function Classification System (GMFCS) as Levels I to III, each presenting varying mental ages. This diversity presents a significant challenge in addressing the mental health needs of this population. To gain a more comprehensive understanding, further research is needed to compare the mental health of individuals with spastic CP across all GMFCS levels, from I to V. In this study, tDCS was administered at 2 mA for 15 min per side, five times per week for two weeks, which could be adjusted in future investigations. tDCS can be used as an adjunct to other brain stimulation methods, such as repetitive transcranial magnetic stimulation and transcranial alternating current stimulation for depression and other coexisting neurological disorders. Future studies should be conducted to gain long-term release of dopamine by changes in frequency, intensity, and treatment doses of tDCS application. tDCS impact can be studied by combining it with other dopaminergic-stimulating pharmacological or neurostimulatory interventions.

Conclusion

This study concluded that the combination of tDCS and MT effectively improves mental health and elevates dopamine levels compared to either intervention alone. These findings suggested that integrating tDCS into clinical practice could significantly enhance patient care. While dopamine levels increased initially due to the treatment, they declined during follow-up, indicating that tDCS and MT actively stimulate dopamine release in the short term. This study emphasizes the necessity for further research to explore the long-term efficacy of tDCS and MT in promoting sustained dopamine release and its long-lasting impact on mental health.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12887-025-05793-4.

Supplementary Material 1

Acknowledgements
We acknowledge all the participants and their parents for their time and support.

Author contributions
Conceptualizationa: S.W, J.B.G Data curation: A.N, A.A Validation: A.H Writing – original draft: S.W, M.T Writing– review & editing: A.A, S.W, M.T.

Funding
Not availed.

Data availability
Study data is available from the corresponding author.

Declarations

Ethics approval and consent to participate
The ethics committee of the University of Lahore approved the study with reference number REC-UOL-273-08-2024 on 11-07-2024. Informed consent was obtained before the study from parents, guardians, and children who could provide it, ensuring they were fully informed about the study's purpose, procedures, and potential risks or benefits.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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Received: 8 July 2024 / Accepted: 21 May 2025
Published online: 11 July 2025

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