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Keywords: Transcranial direct current stimulation, motor priming, mirror therapy, stroke, upper extremity, motor recovery

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Keywords: Transcranial direct current stimulation, motor priming, mirror therapy, stroke, upper extremity, motor recovery.

List of abbreviations

Abbreviation	Description
ARAT	Action Research Arm Test
BBT	Box and Block Test
FMA-UE	Fugl-Meyer Assessment-Upper Extremity
FTHUE	Functional Test for the Hemiplegic Upper Extremity
LTD	Long-term depression
LTP	Long-term potentiation
MAS	Modified Ashworth Scale
MCID	Minimal clinically important differences
MMSE	Mini-Mental State Examination
MT	Mirror therapy
tDCS	Transcranial direct current stimulation

1. Introduction

Neuroplasticity, which refers to the ability to rebuild anatomical and functional connectivity in order to react to external stimuli, is currently underpinning post-stroke functional recovery [1]. Researchers have explored hybrid or a combination of different modalities as possible ways to facilitate motor recovery after a stroke. Priming has been defined as a type of implicit learning wherein a change in behavior is induced by a stimulus [2]. In rehabilitation, motor priming has been reported in motor skill learning in order to facilitate the sensorimotor system to be more ready for sequential motor treatment, consequently enhancing behavioral outcomes [3]. Priming can be classified into prior or concurrent priming in terms of the time of application, and stimulation-based, mental based, movement based, pharmacological based and sensory-based in terms of the modalities used [2].

Transcranial direct current stimulation (tDCS) is commonly used as a form of stimulation-based priming. It is a safe and noninvasive therapeutic approach that causes a shift in membrane potential threshold which increases the probability of neurons in the cerebral cortex firing. The idea of tDCS is that it boosts subthreshold neuronal action potentials, thus may achieve stronger neurons firing than would occur without administering tDCS. The tDCS stimulator sends a low-level current from the anodal electrode to the cathodal electrode via surface electrodes attached to the scalp. With the application of anodal tDCS, the brain activity under the anodal electrode is likely to increase, whereas under the electrode in cathodal tDCS is likely be inhibited [4, 5]. The reasoning behind using tDCS for motor recovery in stroke is based on the interhemispheric competition theory that hemiplegia, due to a stroke, can lead to an imbalance between the two hemispheres, followed by the inhibition of the affected cerebral cortex and the excitation of the less affected hemisphere [4, 5]. Accordingly, tDCS can speed up motor recovery of the paretic upper limb, likely by rebalancing abnormal interhemispheric interactions, enhancing ipsilesional M1 excitability,

reducing contralesional excitability, or doing both [6]. There have been two recent meta-analyses regarding the effects of rTMS and tDCS on hemiplegic upper limb recovery after stroke [4, 7]. All three stimulation paradigms, including anodal, cathodal, and dual (applied bihemispherically) tDCS, have shown short-term benefits for chronic stroke patients with mild to moderate upper limb impairment [8].

Three studies have used tDCS as prior motor priming [9-11]. In those studies, one of them compared the three groups (anodal vs cathodal vs sham group) [11], and the other two only compared the anodal [10] or cathodal [9] groups with a sham group intervention, which was performed by using cathodal stimulation on the unaffected hemisphere or anodal electrode on the affected side or both of them together with 1.5-2mA of electric intensity and a duration of 10-25 minutes per session. All the studies used daily sessions and the number of total sessions varied from two to 10 sessions, according to different study designs. Four [12-15] studies chose tDCS as concurrent priming combined with other treatments, two of them [13-14] had a three-group design trial which consisted of an anodal group, a cathodal group, and a sham group. One study [15] only compared a cathodal group with a sham group. Another study used dual tDCS stimulation (with the anode over the affected side M1 and the cathode over the unaffected side M1) to compare results with a sham group [12].

tDCS can be combined with explicit motor training to enhance the effectiveness of motor learning. Two studies [13, 15] combined tDCS with virtual reality, and one study combined tDCS with robot-assisted arm training. The dual tDCS study combined tDCS with constraint-induced movement therapy (CIMT) [12]. Mirror therapy (MT) is a widely used motor training method and has also been demonstrated to be significantly beneficial for post-stroke upper limb motor recovery with a moderate effect size [16]. During the treatment, a mirror is placed in the subject's midsagittal plane. With the affected side behind the mirror, the subject can only see

the unaffected side and its reflection in the mirror, so that the affected side appears to be performing the same movement [17]. This combination of MT and tDCS has been demonstrated to be useful in the motor recovery of hemiplegic upper limbs in patients with chronic stroke [18].

Recently, increasing evidence has demonstrated that the order of motor priming and training may influence the interaction effect between tDCS and behavioral tasks [1, 2, 19]. Given that most relevant studies were conducted in healthy populations and that different forms of tDCS have been used in motor priming, we would like to investigate the timing-dependent interaction effect of tDCS with MT in the stroke population. We hypothesize that dual tDCS applied simultaneously with MT would lead to a greater enhancement in motor performance than that of tDCS applied prior to MT, as well as sham tDCS applied before or simultaneously with MT.

2. Methods

2.1. Participants

Thirty participants with stroke were recruited from self-help stroke organizations in Hong Kong from January 2018 to May 2018, based on convenience sampling. Our study was performed in accordance with the principles of the Declaration of Helsinki and ethical approval was sought from the human ethics committee of the Hong Kong Polytechnic University before implementation (reference no. HSEARS20180118006). The study was retrospectively registered in the Chinese Clinical Trial Registry (no. ChiCTR180002008).

Only participants who had given informed written consent were included in the study. Participants were assessed for eligibility based on the following inclusion criteria: 1) adults (aged ≥ 18 years old) who had experienced their first stroke more than six months ago; 2) upper extremity impairment ≥ second level in the Functional Test for the Hemiparetic Upper Extremity (FTHUE) [20]; 3) medically stable; 4)

Mini-Mental State Examination (MMSE) score ≥ 21, to ensure the participant could understand the instructions and give consent; 5) not participating in other clinical, drug, or research studies at the same time; and 6) passed the safety screening for tDCS. Those who had severe health conditions that required intensive medical care, such as heart failure, pneumonia, a poor nutritional state, or contraindications of tDCS, such as a cardiac pacemaker, cancer, bleeding tendencies, pregnancy, metal implants, a history of seizures, etc., were excluded from the study.

2.2. Study design

A randomized, controlled pilot trial was conducted, wherein participants admitted consecutively were randomly allocated to one of the three training groups: 1) dual tDCS applied before MT (prior-tDCS group); 2) dual tDCS applied simultaneously with MT (concurrent-tDCS group); and 3) dual sham-tDCS applied before or simultaneously with MT (sham-tDCS group). Group allocations were sealed in opaque envelopes, which were kept by a third-party researcher. Once participants were enrolled, the researcher opened the envelopes and informed the study investigators of the group allocation.

2.3. Interventions

2.3.1. Transcranial direct current stimulation (tDCS)

The protocols of tDCS vary in the literature in terms of duration of stimulation, intensity, and density of current delivered. Some studies have reported that the duration typically ranges from 10 to 30 min [21-23] and even a 10-minute duration could present sufficient effects to elicit prolonged effects for more than one hour after the session [23]. In terms of density, the majority of studies have applied tDCS with a current density of 1mA/35 or 25cm2, without any reports of severe adverse effects [25]. Previous studies have demonstrated that patients who received a current

intensity over 2mA were more likely to perceive pain [26].

In this study, we used the Soterix Medical 1x1 tDCS Low-Intensity Stimulator, and a 1mA tDCS current was delivered through two 35cm × 35cm saline-soaked surface sponge electrodes for 30 minutes, 5 days per week, for 2 weeks. The cathodal electrode was placed over the primary motor cortex (M1) of the contralesional hemisphere (C3 position, according to the 10/20 EEG system), and with the anodal electrode placed above the ipsilateral M1 position. A head band was used to attach the electrodes. Initially, the current ramped up gradually to 1mA in 30 sec., in order to avoid adverse sensations. The 30-min training duration did not include the 30 sec. ramp up time at the start of stimulation and an approximately 30 sec. ramp down time at the end of stimulation. With regard to the sham condition, the sham button of the device was switched on so that only an approximately 30 sec. ramp up and an approximately 30 sec. ramp down was delivered. The experimental setup can be found in Fig. 1.

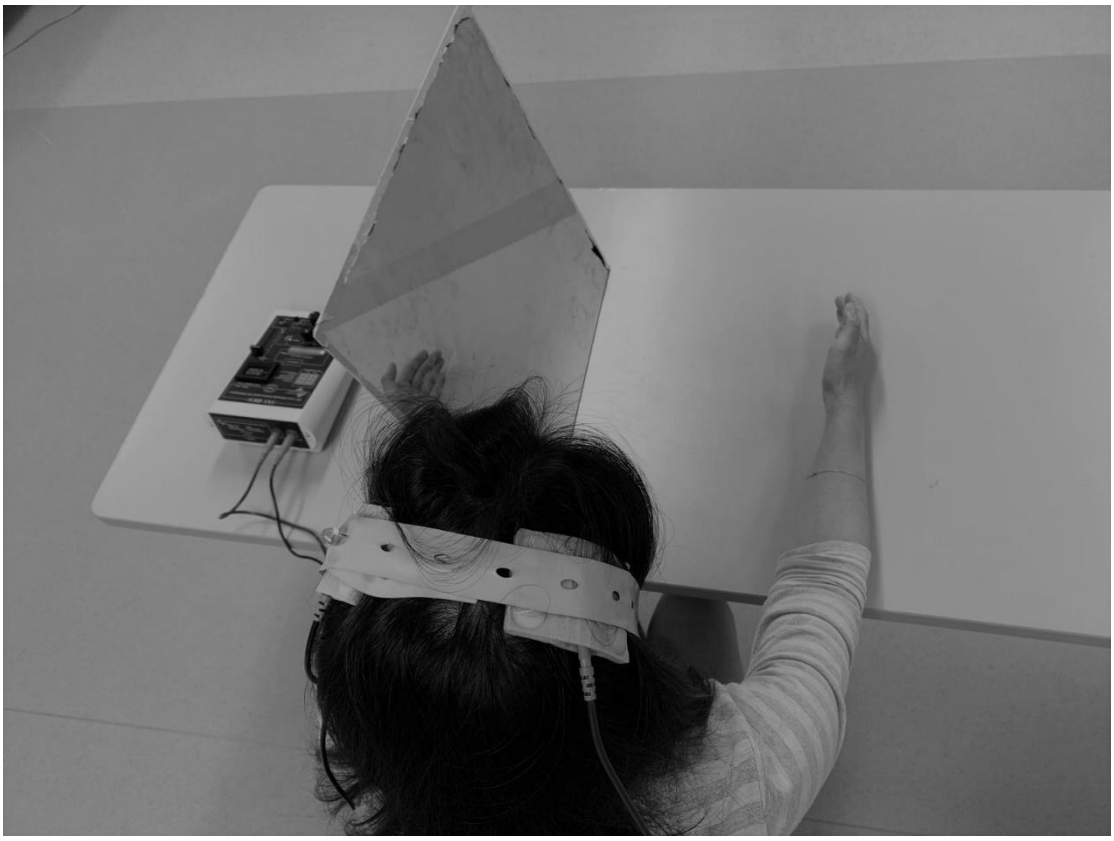

Fig. 1. Experimental setup of mirror therapy and tDCS stimulation

2.3.2. Mirror Therapy (MT)

The movement practice for each group involved five table-top tasks. The participants were instructed to perform as many trials as possible in each session, with a maximum of 30 trials per task, giving a total of 150 trials per session. Exercises were customized and based on the seven functional levels of the Functional Test for the Hemiplegic Upper Extremity (FTHUE) [20]. Examples of customized tasks are shown in the Appendix. The FTHUE was developed originally according to Brunnstrom's developmental stages of stroke recovery and has been validated and used extensively for stratification of hemiplegic upper extremities in recent studies [21].

During each session, participants in the prior-tDCS group received 30 minutes of stimulation prior to 30 minutes of MT training. In the concurrent-tDCS condition, tDCS was applied for 30 minutes at the same time as the 30 minutes of MT training. In the sham-tDCS group, in order to eliminate the effect of favoring either prior-tDCS or concurrent-tDCS conditions as well as providing similar dosage of MT in the sham, participants performed tasks with sham stimulation randomly prior to or concurrent with MT. The intervention was delivered five days per week for two weeks.

2.4. Outcome Measurements

The primary outcome was the motor function of the hemiplegic upper extremity. Three motor scales were used, including the Fugl-Meyer Assessment-Upper Extremity Subscore (FMA-UE) [22], the Action Research Arm Test (ARAT) [29], and the Box and Block Test (BBT) [30]. All of the assessments were evaluated before the first session (T0), at post-intervention (T1), and at the two-week follow-up (T2) by investigators who had received standard training.

The FMA is a classic motor measurement scale designed for the hemiplegic upper extremity. The FMA contains five domains and has better psychometric properties than most other assessments designed for clinical trials [31]. In the present study, only the upper extremity subscale (FMA-UE) was used. It includes 33 items, with each item rated from 0 to 2 (0 = cannot perform, 1 = can partially perform, and 2 = can fully perform). The FMA-UE scores range from 0 to 66. The ARAT is commonly used to measure upper extremity motor function after stroke, in a laboratory setting; it consists of four subtests: grasp, grip, pinch, and gross motor. Evidence demonstrates that the ARAT possesses satisfactory psychometric properties when used with stroke patients with mild to moderate motor severity [29]. The BBT counts the number of blocks that can be transported by participants from one compartment of a box to another compartment within one minute. It is a measure of

gross manual dexterity and demonstrates good inter-rater and test-retest reliability [30].

2.5. Statistical analysis

An intention-to-treat analysis was applied to deal with the missing data. Descriptive statistics were expressed as means and standard deviations (SDs) (Table 1). Due to the small sample size, non-parametric statistical methods were adopted. The baseline of the clinical and demographic data was compared across three groups using Fisher's exact test or the Kruskal-Wallis test for the categorical or continuous data, respectively. The Friedman Test was used to compare the within-group differences at T0, T1, and T2 (Table 2). Between-group differences for the Gain Score 1 (T1-T0) and Gain Score 2 (T2-T0) were evaluated by the Kruskal-Wallis Test (Table 2). The statistical significance level was set at 0.05. Significance values for post-hoc tests have been adjusted by the Bonferroni correction, so that $p = 0.05/n$, where n = number of variables; therefore, p was set at 0.017 in the between-group comparison. Minimal clinically important differences (MCID) were used to compare the results of the present study if significant differences were found. All statistics were calculated using SPSS version 20.

Table 1. Demographics and baseline characteristics

Variable	Groups[!]			
	Group 1 (n = 10)	Group 2 (n = 10)	Group 3 (n = 10)	*P**
Age (years)*	59.00 (9.80)	58.70 (7.92)	57.50 (7.08)	0.753[b]
Gender (female/male)	2/8	3/7	1/9	0.847[a]
Stroke onset (months)*	19.44 (8.25)	20.46 (11.13)	22.16 (8.15)	0.747[b]
Hemiparetic side (right/left)	4/6	8/2	7/3	0.249[a]
Stroke type (ischemic/hemorrhagic)	8/2	4/6	8/2	0.668[a]
Usual care (yes/no)	9/1	7/3	6/4	0.450[a]
FMA-UE*	52.70 (18.56)	45.80 (15.97)	49.30 (18.14)	0.426[b]
BBT*	28.60 (16.48)	19.00 (17.37)	22.80 (20.32)	0.570[b]
ARAT*	42.90 (22.02)	33.10 (18.86)	35.00 (22.18)	0.348[b]
FTHUE*	5.90 (2.08)	5.20 (1.81)	5.10 (2.18)	0.603[b]
Higher functioning (levels 5-7)	8	6	6	NA
Lower functioning (levels 1-4)	2	4	4	NA
MAS_arm*	0.65 (0.58)	0.90 (0.70)	0.95 (0.72)	0.493[b]
MAS_hand*	0.45 (0.60)	0.65 (0.71)	0.55 (0.90)	0.813[b]

*Data expressed as means (SDs); [!]Group 1 = prior-tDCS group, Group 2 = concurrent-tDCS group, Group 3 = sham-tDCS group; [a]Fisher's exact test was used to compare proportions for categorical variables; [b]the Kruskal-Wallis test was used to compare means; * $P \leq 0.05$; tDCS = transcranial direct current stimulation; MT = Mirror Therapy; FMA-UE = Fugl-Meyer Assessment-Upper Extremity Subscore; BBT = Box and Block Test; ARAT = Action Research Arm Test; FTHUE = Functional Test for the Hemiplegic Upper Extremity; MAS = Modified Ashworth Scale.

3. Results

Thirty patients were recruited, with 10 allocated to the prior-tDCS group, 10 to the concurrent-tDCS group, and 10 to the sham-tDCS group. The participants' flow charts can be found in Fig. 2. Two participants dropped out during the study, one from the prior-tDCS group and another from the sham-tDCS group. None of the patients reported discomfort or severe side effects.

Demographics and outcomes are summarized in Table 1. The distributions of age, gender, stroke onset, paralyzed side, types of stroke, usual care (which refers to regular clinical rehabilitation training), and the baselines of outcomes were comparable across groups. Regarding the within-group comparison, there was statistically significant improvement in the ARAT when tDCS was applied concurrently at both post-intervention ($P = 0.002$) and follow-up ($P = 0.030$), whereas a significant increase in the FMA-UE ($P = 0.022$) and the BBT ($P = 0.042$) were only found at post-intervention in the concurrent-tDCS condition (Table 2). Compared with the MCID for the FMA-UE in individuals with chronic stroke (MCID = 5.25) [32] and that for the ARAT (MCID = 5.7) [33] and the BBT (MCID = 6) [34], none of the gain scores achieved a clinical significance level. In regard to the between-group comparison, overall significant difference was found in Gain Score 1 in the ARAT ($p = 0.010$). The post-hoc comparison showed that there was significant improvement in the ARAT between the concurrent-tDCS group and the prior-tDCS group ($p = 0.022$), and between the concurrent-tDCS group and the sham-tDCS group ($p = 0.031$) (Table 3). Although the gain scores in the FMA-UE were higher for the concurrent-tDCS group than the prior-tDCS and sham groups, no statistically significant difference could be seen across the three groups in regard to the gain scores for the FMA-UE and the BBT (Fig. 3).

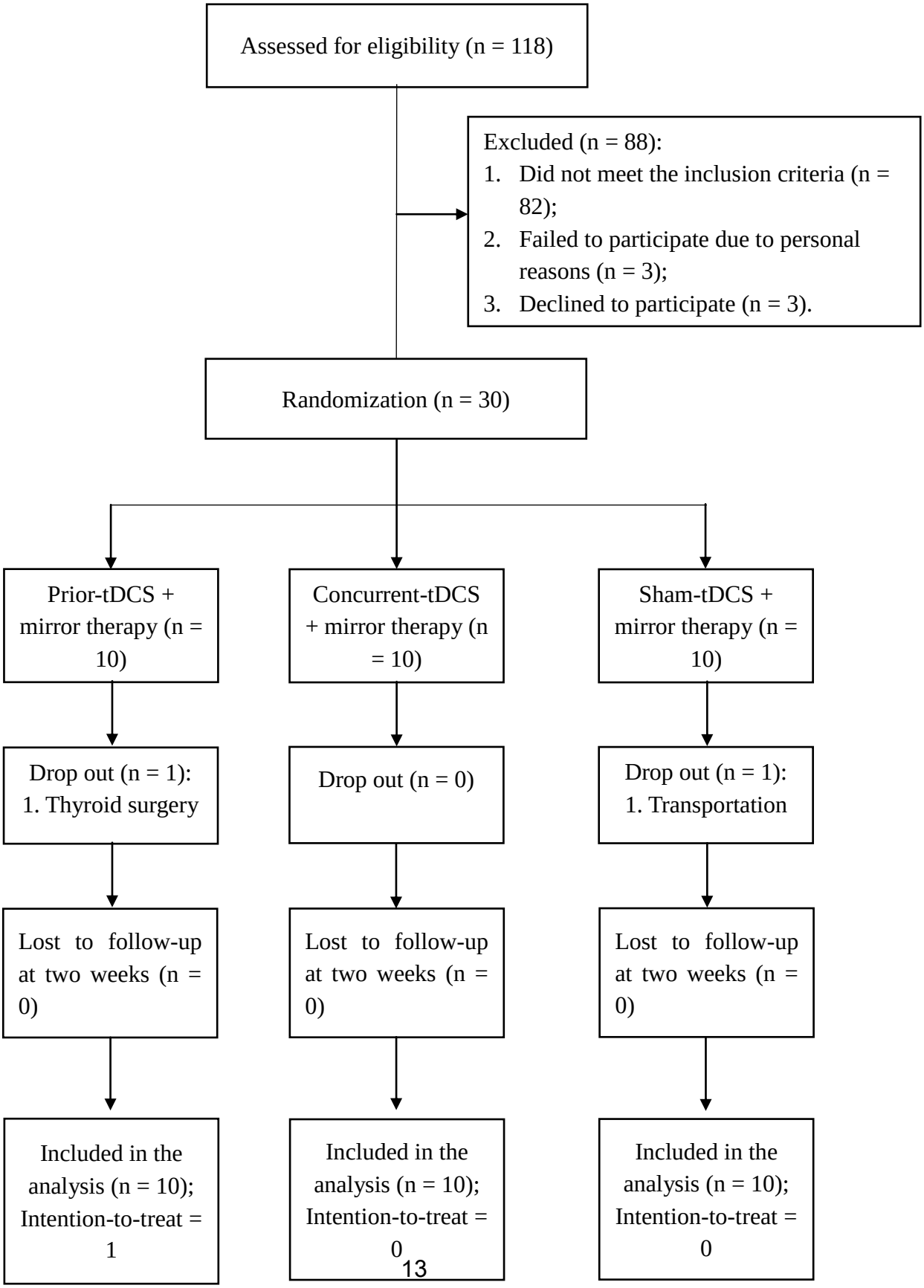
Assessed for eligibility (n = 118)
Excluded (n = 88):
1. Did not meet the inclusion criteria (n = 82);
2. Failed to participate due to personal reasons (n = 3);
3. Declined to participate (n = 3).
Randomization (n = 30)
Prior-tDCS + mirror therapy (n = 10)
Concurrent-tDCS + mirror therapy (n = 10)
Sham-tDCS + mirror therapy (n = 10)
Drop out (n = 1): 1. Thyroid surgery
Drop out (n = 0)
Drop out (n = 1): 1. Transportation
Lost to follow-up at two weeks (n = 0)
Lost to follow-up at two weeks (n = 0)
Lost to follow-up at two weeks (n = 0)
Included in the analysis (n = 10); Intention-to-treat = 1
Included in the analysis (n = 10); Intention-to-treat = 0
Included in the analysis (n = 10); Intention-to-treat = 0

Fig.2.CONSORT diagram of subjects throughout the study

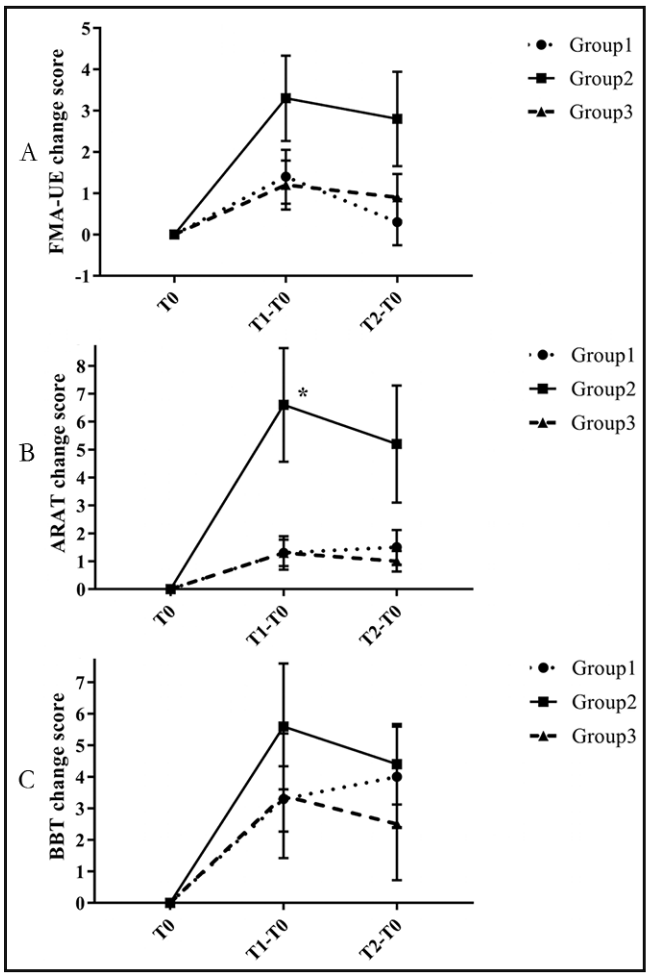

Fig. 3. T1-T0, T2-T0 change scores for the FMA-UE, ARAT, BBT among three groups.

Note: Error bars represent (SEM). *$P < 0.05$ when compared with the sham group; Group 1 = prior-tDCS group, Group 2 = concurrent-tDCS group, Group 3 = sham-tDCS group.

Table 2. Within-group (pretest, posttest, and follow-up) and between-group comparisons (Group 1, Group 2, and Group 3)

Variable	Group 1 (n = 10)						Group 2 (n = 10)						Group 3 (n = 10)								
	T0 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	p¶	Gain Score 1 Mean (SD)	Gain Score 2 Mean (SD)	T0 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	p¶	Gain Score 1 Mean (SD)	Gain Score 2 Mean (SD)	T0 Mean (SD)	T1 Mean (SD)	T2 Mean (SD)	p¶	Gain Score 1 Mean (SD)	Gain Score 2 Mean (SD)	p1	p2	Multiple comparison@
FMA-UE	52.70 (18.56)	54.10 (18.02)	53.00 (18.51)	0.047*	1.40 (2.07)	0.30 (1.77)	45.80 (15.97)	49.10 (15.61) #	48.60 (16.10)	0.007*	3.30 (3.27)	2.80 (3.61)	49.30 (18.14)	50.50 (17.30)	50.20 (18.33)	0.157	1.20 (1.87)	0.90 (1.79)	0.154	0.238	
ARAT	42.90 (22.02)	44.20 (22.43)	44.40 (21.38)	0.003*	1.30 (1.89)	1.50 (1.96)	33.10 (18.86)	39.70 (18.19) #	38.30 (18.01) #	0.001*	6.60 (6.43)	5.20 (6.63)	35.00 (22.18)	36.30 (22.71)	36.00 (22.53)	0.015*	1.30 (1.49)	1.00 (1.15)	0.010*	0.172	1, 2; 2, 3
BBT	28.60 (16.48)	31.90 (18.35)	32.60 (17.98)	0.004*	3.30 (3.27)	4.00 (5.06)	19.00 (17.37)	24.60 (19.30) #	23.40 (18.66)	0.007*	5.60 (6.31)	4.40 (4.03)	22.80 (20.32)	26.20 (23.82)	25.30 (22.69)	0.276	3.40 (6.26)	2.50 (5.62)	0.426	0.278	

Note: ¶The Friedman Test was used to compare within-group differences; [1]the Kruskal-Wallis test was used to compare between-group differences for Gain Score 1 (T1-T0); [2]the Kruskal-Wallis test was used to compare between-group differences for Gain Score 2 (T2-T0); [@]post hoc analysis had not been carried out, as there was no overall significant difference among the three groups; Group 1 = prior-tDCS group, Group 2 = concurrent-tDCS group, Group 3 = sham-tDCS group; *$p \leq 0.05$; #adjusted $p \leq 0.05$ compared with T0; FMA-UE = Fugl-Meyer Assessment-Upper Extremity Subscore; BBT = Box and Block Test; ARAT = Action Research Arm Test.

4. Discussion

This study aimed to explore the time-dependent effect of dual tDCS with MT on the motor recovery of upper limbs in individuals with chronic stroke, compared to a combination of sham-tDCS and MT. The results demonstrated a significantly greater improvement in the ARAT at post-intervention when tDCS was applied concurrently with MT than prior to MT, as well as the sham condition. The results might imply that there was a motor priming effect of concurrent-tDCS in combination with MT when compared to the sham condition.

Our results regarding the robust improvements in behavioral measures in the concurrent tDCS application are partially in line with previous studies [1, 19]. The results might be attributed to the way in which motor learning in human M1 was associated with an increase in the synaptic strength in the form of long-term potentiation (LTP) like or long-term depression (LTD) like changes [35-37]. For motor priming, the underlying theory is that priming could increase neural activity and facilitate the subsequent induction of LTP or LTD-like plasticity, which would induce a change in the process of motor learning [38]. Thus, our results imply that the application of tDCS over M1 during motor practice is more likely to facilitate corticospinal excitability and consequently enhance the effects of the accompanying training. A study using a similar paradigm regarding lower limbs found that the concurrent application of tDCS resulted in a trend toward greater increases in corticospinal excitability (recorded by motor-evoked potential from the Tibialis muscle) than tDCS applied prior to motor training [1]. This superiority resulting from the concurrent-tDCS protocol may be explained by the Gating theory, which can be induced instantaneously from tDCS with motor practice and occurs by cortical disinhibition (i.e., anodal to the ipsilateral hemisphere and cathodal to the contralesional hemisphere). Any intervention that leads to an acute disinhibition of intracortical inhibitory circuits may gate the effects of a conditioning protocol [38],

consequently enhancing the effectiveness of MT when it is applied simultaneously. In contrast, compared to the sham condition, our results regarding tDCS applied before MT did not show any significant improvement on motor learning, which is consistent with several previous studies [1, 10, 39]. When tDCS is used in conjunction with another intervention successively, it is likely that the time course between the priming stimulation and motor training is considered as essential to the magnitude of boosting neuronal action potentials to induce plasticity [40].

When comparing the two-week follow-up results among the three groups, no significant difference in any of the three outcome measurements was observed. These findings are opposed to some previous studies. According to a recent review of the long-term maintenance effect of tDCS in facilitating motor learning post-stroke [4], dual (bihemispheric) tDCS could induce significant long-term motor learning retention in chronic stroke patients. There are three possible reasons for our discrepant results. The first is that the priming effect of tDCS could not be adequate to lead to acquired motor skills improvement, compared with sham tDCS. In the present study, improvements from the short intervention period of tDCS (i.e., 10 sessions, with 30 minutes per session) were relatively limited. The second reason is related to the heterogeneity and chronicity of recruited patients with stroke. As demonstrated in Table 1, some patients received extra rehabilitation training at varied intensities and recovery was slow due to chronic stroke.

Several limitations were identified in the present study. First, although significant pre-post improvements were found in the FMA-UE, ARAT, and BBT in the prior-tDCS and concurrent-tDCS groups at post-intervention, compared with the MCID for the FMA-UE in individuals with chronic stroke (MCID = 5.25) [32] and that for the ARAT (MCID = 5.7) [33] for the BBT (MCID = 6) [34], none of the gain scores demonstrated clinical significance due to the intervention. A possible explanation for this could rely on the comparatively small quantity of total

intervention sessions. A previous study that explored the interaction effect on chronic patients of tDCS, accompanied by MT and delivered over 18 sessions across six weeks, showed significantly positive results [18]. Another study that focused on the effectiveness of the combination of tDCS and virtual reality in chronic stroke patients conducted 15 sessions, which resulted in more than 50% of the participants achieving the MCID in the experimental group [41]. Future studies may increase the number of intervention sessions to achieve more persuasive results. Second, although the current intensity of using 1mA was referenced in another study of dual tDCS [6], it could be too low and might be for this reason we did not detect any persistent effects of the treatment at the follow-up visit. Third, our patients were quite varied in terms of stroke characteristics, whereas stroke severity and location were suggested as potential covariates to modify the effects of a combination protocol of tDCS and explicit motor training [42]. Moreover, MT itself could be considered as a movement-based priming that would induce a positive effect to motor learning and could be beneficial to all groups. The follow-up evaluation after 2 weeks was also relatively short in duration. Future studies could be to recruit more subjects and reduce heterogeneity when recruiting cases, limit the age and the FTHUE level to control the potential covariates.

5. Conclusion

This study investigated the timing-dependent interaction effects of tDCS in conjunction with MT in the chronic stroke population. We found that the priming effect of tDCS was important to facilitate motor recovery in MT. Significant improvements after concurrent-tDCS and MT in only one motor function test were found when compared with prior-tDCS or sham-tDCS and MT but could not be seen in other outcomes. The concurrent-tDCS seems to be more advantageous and time-efficient in the context of clinical trials combining with other kinds of motor

rehabilitation training which should be considered in future application.

DECLARATIONS

Consent for publication:

None.

Availability of data and material:

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations of interest:

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Legends

Fig. 1 Experimental setup of mirror therapy and tDCS stimulation.

Fig. 2 CONSORT diagram of subjects throughout the study.

Fig. 3 T1-T0, T2-T0 change scores for the FMA-UE, ARAT, and BBT among three groups.

Table 1 Demographics and baseline characteristics.

Table 2 Within-group (pretest, posttest, and follow-up) and between-group comparisons (Group 1, Group 2, and Group 3).

Appendix. Customary Mirror Therapy Training Tasks for the Upper Extremity

Corresponding levels in FTHUE-HK	Principles of movement	Examples of tasks recommended[#]
Two	1. Passive range of motion movement; 2. Balance the strength of flexors and extensors	- Passive shoulder flexion and extension with elbow extension Passive elbow exercise with forearm supported on table Passive wrist flexion and extension with forearm pronation and supported on table - Passive forearm pronation and supination
Three	3. Improve the control of shoulder and elbow 4. Facilitate functional synergy	- Shoulder circular motion - Elbow extension and flexion - Passive forearm pronation and active-assistive supination with elbow flexion at 90° - Passive wrist flexion and active extension with forearm supination - Passive finger flexion and extension
Four	1. Isolated limb segments control training 2. Grasp and release training	- Shoulder flexion at 90° with elbow in full extension and shoulder extension with elbow flexion - Active/active-assistive forearm pronation and supination - Wrist circumduction with elbow flexion or extension - Grasp and release exercise
Five	1. Shoulder, elbow, and wrist coordinated movement 2. Coordinating mild grasp and release in shoulder, elbow, and wrist control training	- Grasping a bottle and putting it on the box ahead with shoulder flexion and elbow extension - Wrist movement in all directions - Turning over a block with forearm supination and pronation - Grasping three blocks in hand and release - Finger opposition to index and middle fingers
Six	1. Fine motor skills training	- Finger opposition to ring and little

	2.	Individual finger movement		fingers
	3.	Grasp and release training	-	Reaching out and clipping clothes pegs
	4.	Endurance training	-	Small ball shifting in hand
			-	Coin shifting using radial three fingers
Seven	1.	Finger motor skills training	-	Finger opposition in a fast manner
	2.	Endurance, speed, and	-	Pen shifting using fingers
		coordination in arm use	-	Card translation between fingers

[#]FTHUE = Functional Test for the Hemiplegic Upper Extremity