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Imagine before you leap: Episodic future thinking combined with transcranial direct current stimulation training for impulsive choice in repetitive negative thinking

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A R T I C L E I N F O

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A B S T R A C T

Background: Immediate reward preference in repetitive negative thinking (RNT) has a high clinical correlation with a variety of maladaptive behaviors, whereas episodic future thinking (EFT) may be conducive to dealing with non-adaptive thinking and decision-making.
Objectives: This study aimed to evaluate the efficacy of EFT training combined with transcranial direct current stimulation (tDCS) stimulation over the ventromedial PFC (vmPFC) in inhibiting impulsive choice of RNT individuals.
Method: Study 1 explored the effects of EFT on immediate reward preference of participants with high and low RNT ($N = 48$). Study 2 conducted a randomized controlled trial (RCT) to examine the treatment effect of the EFT-neural training on impulsive choice of high RNT individuals ($N = 103$).
Results: In study 1, individuals with high RNT were more likely to choose smaller and sooner (SS) rewards, however, there were no significant differences between the high-RNT group and the low-RNT group under the positive EFT condition. In study 2, a significant decrease was shown in the proportion of choosing SS rewards under the 8-week EFT-neural training, and the effect was maintained at 1 month follow-up.
Conclusion: RNT is a vulnerability factor for short-sighted behaviors, and EFT-neural training could be suitable for reducing RNT and improving immediate reward preference.

Introduction

Discounting future outcomes underlies much of human intertemporal choice and figures prominently in much overlapping psychological functioning, such as impulse control or self-regulation (Amasino et al., 2019; Bulley & Schacter, 2020). Steeper delay discounting rate, or the preference for foregoing larger delayed rewards in pursuit of smaller immediate gratification, is found to be associated with an array of clinical disorders including addictive disorders, binge eating, and even attempted suicides (Amlung et al., 2019; Miranda-Olivos et al., 2021). Clarification of the related factors that affect this core process underlying psychological dysregulation, a pressing need given the paucity of empirically supported research, is essential as it might inform the development of future prevention and treatment strategies for clinical populations (Verdejo-García et al., 2019).

Notably, repetitive negative thinking (RNT) has been identified as a transdiagnostic and predictive cognition process, which refers to perseverative and verbal thinking about self-relevant distress (Hijne et al., 2020). RNT contributes not only to the development and maintenance of major depression disorder, generalized anxiety disorder and obsessive-compulsive disorder (Moulds et al., 2022; Raines et al., 2017), but rather to myriad co-occurring psychiatric disorders (Hartley et al., 2014). Building from growing literature associated with impulsive choice, RNT may represent an underlying cause for immediate rewards over long-term benefits (Elliott et al., 2023; Llera & Newman, 2020). Extensive evidence has demonstrated that high RNT is prospectively linked with limited working memory, and could increase self-control load associated with the preference for smaller immediate rewards (Park et al., 2022; van Oort et al., 2022). Also, when stuck in impending stressors, it is argued that heightened RNT makes individuals more immersed in negative cognition and stimuli, which could contribute to reduced cognitive flexibility and great loss aversions (Bell et al., 2023).

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As such, it could be harder to flexibly moderate self-control based on the perceived decision importance (Shenhav et al., 2013).

To date, most therapeutic approaches that were developed to moderate dysregulated behaviors are process-oriented (Kopf-Beck & Fietz, 2021; Lawental et al., 2021). While these interventions initially showed promise, some clients still reported challenges in freeing themselves from lingering negative feelings during the treatment (Johan et al., 2022). Recently, emerging attention has been given to the dual-emotion solution, which has been developed to counteract an unwanted decision effect by inducing another state (Lerner et al., 2015). For instance, negative feelings such as sadness are known to increase excessive discounting rates, whereas developing gratitude could reduce such rates (DeSteno et al., 2014; Lerner et al., 2013). Positive and pictorial episodic future thinking (EFT) reduces the negative effect of RNT at two levels: negative-positive valence modulation and verbal-imagery modulation. On the one hand, from the negative-positive perspective, the broaden-and-build theory in positive psychology has indicated that inducing positive emotions provides a strong association with situation modification, attentional deployment and decision response modulation in clinical individuals (Vanlessen et al., 2016). In the context of positive thinking, negatively-valanced cues with high RNT could be well inhibited, with the decrease of choosing smaller immediate rewards and the facilitation of problem-solving and goal attainment. On the other hand, from the verbal-imagery perspective, EFT acts as an ability to project into self-related future situations to pre-experience possible future events. The benefits of EFT training could derive from perceiving more control over future events and developing more constructive responses to negative situations (Hallford et al., 2020). Considering that building positive prospective thinking may be helpful to promote positive mood, this training could dynamically change selective attention processes and mediate widespread beneficial effects on mental and physical well-being and health. Also, this positive training is beneficial to decrease negative symptoms and avoid the re-experiencing and spreading of negative emotions during the training (Bolier et al., 2013; Stone & Schmidt, 2020).

When only receiving psychological treatment, ensuring whether individuals could benefit deeply is important to improve treatment efficiency (Xu et al., 2021). Admittedly, counteracted training has the potential to improve impulsive choice under heightened RNT, however, the development of high RNT over a long period may lead to rigid adaptation patterns, and disrupt the generation and flow of emotion modification, which poses great challenges when promoting treatment (Demnitz-King et al., 2021). Based on these features, a possible way to boost existing treatment effects may be combining with a complementary approach that targets “top-down” neural moderating processes (Chami et al., 2020). Specifically, brain stimulation could provide a more sophisticated understanding of the neural circuitry of moods and thoughts, and enhance cognitive control involved in EFT training, and transcranial direct cur-rent stimulation (tDCS) may play a role by enabling neuroplasticity (Yavari et al., 2018). In tDCS, a weak direct electrical current is delivered through two electrodes placed on the scalp (one anode, one cathode), subthreshold, polarity-dependent shifts in resting membrane potentials in underlying brain regions. The resulting net increase (predominantly under the anode) or decrease (pre-under the cathode) in neuronal excitability leads to dominantly modulation of the neuronal network (Tarnutzer et al., 2023). Establishing the underlying “future thinking path” targets in high RNT through neuromodulating could leverage EFT training to extend synergistic effects.

Currently, previous research has revealed the cumulative and longer-lasting effects of multiple-session tDCS combined with psychological treatment (Borrione et al., 2021; Norred et al., 2021). Improved therapeutic benefits of effectively reducing RNT and making longer-sighted choices may thus be realized by combining multiple tDCS with EFT training. Of note, the ventromedial prefrontal cortex (vmPFC) may be crucial in EFT and RNT moderation (Ciaramelli et al., 2021; Gao et al., 2023; Via et al., 2018). As a core component of the default network (Mayeli et al., 2020), vmPFC has been implicated in neural circuits for scene construction and imagining the future in neurological findings by consistent evidence. Activating vmPFC via neuromodulatory intervention might serve to enable pleasant, episodic and constructive processes, and assist EFT training to boost the importance of future rewards.

In summary, this study aims to identify the vital role of RNT in the maintenance of impulsive choice and propose relevant promising treatments through two studies. We evaluated the effect of EFT training combined with tDCS activation over the vmPFC on reducing high RNT and investigated whether it would be associated with boosting the valuation of future rewards. We assumed that compared with tDCS alone or EFT alone, high RNT participants would make more long-term choices and get significant improvements in RNT and psychological well-being under the EFT-neural training condition, and the integrated EFT-neural training would have a stronger delay effect at 1 month follow-up. Based on the accumulating evidence (e.g., Hitchcock et al., 2022; Olatunji et al., 2023), the Perseverative Thinking Questionnaire (PTQ) could clearly identify the process and features of RNT, which has shown effectiveness in measuring RNT. Besides, the Ruminative Response Scale (RRS) and the Penn State Worry Questionnaire (PSWQ) have also been widely used in RNT assessment as the two scales focus on identifying the two typical and promising types of RNT (rumination and worry) (e.g., Favaretto et al., 2020). Thus, to provide a reliable and valid measure for the RNT level of participants, the PTQ, RRS and PSWQ scales were used to evaluate RNT in this study.

Study 1

Methods for study 1

Participants

Participants were screened using a two-stage method. Specifically, the Perseverative Thinking Questionnaire (PTQ), the Ruminative Response Scale (RRS) and the Penn State Worry Questionnaire (PSWQ) were administered for initial screening. Also, inclusion criteria included aged 16–25 years, fluency in Chinese, normal or corrected-to-normal vision and hearing. In the second step, participants were excluded from the study based on the following criteria: (a) had a Structured Clinical Interview for DSM–5 confirmed mental disorders diagnosis, such as major depression disorder and generalized anxiety disorder, (b) showed acute psychotic symptoms and (c) took psychotropic medications. Considering the need to perform RNT in a content-independent form (e.g., Heckendorf et al., 2019) and the positive association between RNT and depression and anxiety, depression and anxiety were excluded in this study. Also, these exclusion criteria were selected because they indicated the need for a higher level of care. To sum up, the criteria to define high and low RNT groups were: high-level RNT individuals: scored at least 25 on PTQ (Nota & Coles, 2018), and also scored in the upper range on RRS and PSWQ (total score $\geq$ 44; total score $\geq$ 45). Low-level RNT individuals: scored less than 18 on the PTQ, and also scored in the mid-low range on RRS and PSWQ (total scores $\leq$ 39; total scores $\leq$ 43). Sample size was determined using G*Power 3.1 (Faul et al., 2007). The estimated sample size for the detection of a significant small-to-medium effect of $f = 0.25$, at 0.95 power and $\alpha = 0.05$, in a repeated-measures interaction F test, was $N = 36$. All procedures involving human participants were consistent with the ethical standards of the Academic Board of XX University, and the 1964 Helsinki Declaration and its later amendments. Informed consent was obtained from all the participants. Handedness was assessed using the Edinburgh Handedness Inventory, and all the participants were right-handed.

Study design

A mixed design with 2 (group: high RNT vs. low RNT) × 4 (emotional valence of EFT: positive vs. negative vs. neutral vs. control) was performed to explore the effect of RNT and EFT on immediate reward preference. The emotional valence of EFT indicated the emotional value associated with EFT ranging from positive to negative.

Measures

Perseverative thinking questionnaire

PTQ was used to measure RNT (Ehring et al., 2011). The scale included 15 items (e.g., "The same thoughts keep going through my mind all the time"). All items were rated on a 5-point Likert scale from 0 (never) to 4 (almost always). Higher scores indicated higher levels of RNT. The Cronbach's α coefficient in this study was 0.95.

Ruminative response scale

The tendency to ruminate in response to negative mood was assessed with RRS (Nolen-Hoeksema & Morrow, 1991). The scale included 22 items (e.g., "Why can't I get going?"). All items were rated on a 4-point Likert scale ranging from 1 (almost never) to 4 (almost always). Higher scores indicated higher levels of rumination. The Cronbach's α coefficient in this study was 0.95.

Penn state worry questionnaire

The frequency and intensity of worry were assessed with PSWQ (Meyer et al., 1990). The scale included 16 items (e.g., "My worries overwhelm me"). All items were rated on a 5-point Likert scale ranging from 1 (not at all typical) to 5 (very typical). Higher scores indicated higher levels of worry. The Cronbach's α coefficient in this study was 0.94.

Procedure

Instruction

Before the experiment, participants were introduced to the concept of immediate reward preference and how to fully generate vivid mental images through structured interviews. The experimenter asked participants to visualize the future event presented, including the components of the future event (e.g., time, place, people), physical sensations about the event (e.g., seeing, hearing or smelling something), and the emotions and thoughts about the event (Snider et al., 2016). After that, participants were asked to orally describe the content of their imagination, and then the experimenter asked standardized questions to concretize the imagery, aiming at enabling participants to construct a clear, detail-rich picture of the event situation. After interviews, participants were instructed to complete sociodemographic questionnaires for the study.

Performance test

The modified delay discounting paradigm based on previous studies (Peters & Büchel, 2010; Wang et al., 2019) was conducted during study 1. In each trial, participants made repeated choices between a fixed immediate 20 RMB (which was not shown on the screen) and a larger but delayed reward (e.g., 25, 35, or 50 RMB; 1, 2, or 4 months) (Liu et al., 2013). Considering the consistent cognitive neural mechanisms between episodic future thinking and situational memory (Buckner & Carroll, 2007), the present study proposed the episodic future thinking task based on previous research (Levine et al., 2002). Each trial began with the presentation of a 500 ms "+". Under the control condition, participants did not engage in any imagery and only completed the delayed discounting task. Under the emotional episodic condition, participants needed to imagine specific events while completing the delayed discounting task. Specifically, positive, neutral and negative tags (e.g., accepted to your ideal school, taking a bus, make an ass of yourself in public) were displayed below the delayed options, indicating that participants needed to imagine the events which would happen on the respective day of delayed reward delivery (see Fig. 1). Responses were then performed by pressing the "F" key for the immediate benefit option and the "J" key for the delayed benefit option on the screen. The imagining events and delayed rewards were independent of each other. To avoid sequential effects, the presentation of the three episodic conditions was randomized.

Follow-up measures

After the experiment, participants rated the extent to which episodic tags evoked episodic associations (frequency), how vivid these associations were (vividness), and how they felt (pleasure) on a 7-point scale. Participants would be included if both the vividness and frequency scores were above 5, and there would be a significant difference in the pleasure scores for the emotional valences of EFT. In study 1, all the participants were included in the follow-up analysis.

Data analysis

Variables were examined for normality by analyzing frequency histograms and normality plots. All analyses were conducted using SPSS

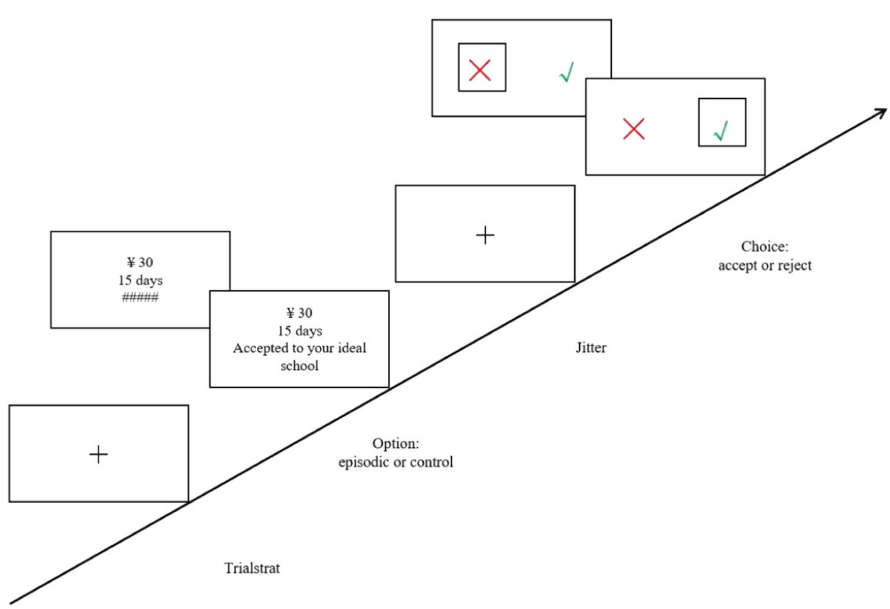

Fig. 1. Episodic modulation of immediate reward preference.

26.0. Pearson chi-square test was used to test for differences in gender. Independent sample *t*-test was used to test for differences in age, self-report PTQ, RRS, PWSQ and money demand scores between the high and low-RNT groups. One-way ANOVAs was used to test for differences in scores on frequency, pleasure and vividness under the positive, negative and neutral episodic condition. Rates of SS options was submitted to the 2 (group: high RNT vs. low RNT) × 4 (emotional valence of EFT: positive vs. negative vs. neutral vs. control) RM-ANOVAs. Adjustments for multiple comparisons were realized using Bonferroni correction, and the effect size was calculated as partial eta squared ($\eta^2 p$; ≥ 0.01, small effect; ≥ 0.06, moderate effect; ≥ 0.14, large effect; Cohen, 2013).

Results for study 1

Preliminary analysis (see Table 1)

A sample of 48 participants (40 females) aged 17–22 years old ($M = 19.27$, $SD = 1.14$) were recruited from a college in Shandong, China. The differences in gender distribution were not significant between the two groups, $\chi^2(1) = 0.6$, $p > 0.05$. There were no differences in age between the two groups, $t\,(46) = 1.14$, $p > 0.05$. There were significant differences in scores on PTQ, RRS, and PWSQ between the two groups, $t_{PTQ}\,(46) = -18.30$, $p < 0.001$, $t_{RRS}\,(46) = -16.18$, $p < 0.001$, $t_{PSWQ}\,(46) = -11.28$, $p < 0.001$. Concerned with the validity of manipulation, statistical analyses of the frequency, pleasure and imagery vividness in each episodic condition were conducted. There were no differences in the frequency scores between the three conditions, $F\,(2, 143) = 1.63$, $p = 0.20$, $\eta_p^2 = 0.023$. There were significant differences in pleasure scores under the three episodic conditions, $F\,(2, 143) = 138.85$, $p < 0.001$, $\eta_p^2 = 0.663$. There were no differences in vividness ratings under the three episodic conditions, $F\,(2, 143) = 0.84$, $p = 0.44$, $\eta_p^2 = 0.01$. The control variable, money demand scores was statistically analyzed in an independent sample *t*-test between the high and low RNT groups. The results indicated that ratings on money demand did not differ significantly between the two groups, $t\,(46) = -0.49$, $p = 0.63$. Thus, the control variable was not discussed later in the analysis.

Main findings

The main effect of group was significant, $F\,(1, 46) = 18.20$, $p < 0.001$, $\eta_p^2 = 0.28$. The main effect of the emotional valence of EFT was significant, $F\,(3, 44) = 20.25$, $p < 0.001$, $\eta_p^2 = 0.58$. The interaction between group and emotional valence of EFT was significant, $F\,(3, 44) = 4.07$, $p < 0.05$, $\eta_p^2 = 0.22$. Simple effect analysis found that in the negative episodic condition, participants in high RNT group preferred more immediate rewards compared to participants in low RNT group ($M_h = 0.72$, $SD = 0.031$; $M_l = 0.49$, $SD = 0.031$; $p < 0.001$). However, in the positive episodic condition, the rates of smaller and sooner (SS) options in high RNT group were similar to low RNT group ($M_h = 0.42$, $SD = 0.034$; $M_l = 0.36$, $SD = 0.034$; $p = 0.28$). Also, participants in high RNT group preferred more immediate rewards compared to participants in low RNT group in the neutral episodic condition ($M_h = 0.56$, $SD = 0.028$; $M_l = 0.38$, $SD = 0.028$; $p < 0.001$). Participants in high RNT group preferred more immediate rewards compared to participants in low RNT group in the control condition ($M_h = 0.55$, $SD = 0.031$; $M_l = 0.42$, $SD = 0.031$; $p < 0.01$). The results were shown in Table 1 and Fig. 2.

Study 2

Methods for study 2

Participants

Sample size was determined using G*Power 3.1 (Faul et al., 2007). The estimated sample size for the detection of a significant small-to-medium effect of $f = 0.25$, at 0.95 power and $\alpha = 0.05$, in a repeated-measures (group-by-time) interaction F test with four groups and three repeated-measurements, was $N = 60$. Participants in study 2 were recruited from college school counseling centers, and were recruited screened using a two-stage method. The inclusion criteria and exclusion criteria were the same as in study 1. These exclusion criteria were selected because they indicated the need for a higher level of care than would be provided during this intervention. Also, the further exclusion criteria were contraindications to tDCS (e.g., metallic implants, previous neurosurgical procedures, history of migraine, diseased/damaged skin on the scalp and history of seizures). We had 110 participants met the eligibility criteria, and 5 participants withdrew from the study. 105 participants were randomized to participate in the EFT-neural group, the EFT-sham tDCS group, the Control EFT-activation tDCS group and the control group, and 2 participants dropped out during the intervention. Finally, 103 participants (90 females) aged from 16 to 24 years old ($M = 20.13$, $SD = 1.55$) completed all the assessments (see Fig. 3) and were included for the later analyses. In the EFT-neural group, participants were treated with positive EFT training and tDCS activation. In the EFT-sham tDCS group, participants were

Table 1
Baseline characteristics of the participants and results in study 1 ($N = 48$).

	Group			
	Low-RNT ($N = 24$)	High-RNT ($N = 24$)		
Gender (n,%)			$\chi^2(1) = 0.60$	$p > 0.05$
female	19, 79.17 %	21, 87.50 %		
male	5, 20.83 %	3, 12.50 %		
Age (M ± *SD*)	19.46 ± 1.10	19.08 ± 1.18	$t\,(46) = 1.14$	$p = 0.26$
PTQ	11.67 ± 3.69	34.63 ± 4.92	$t\,(46) = -18.30$	$p < 0.001$***
RRS	32.46 ± 4.41	56.04 ± 5.61	$t\,(46) = -16.18$	$p < 0.001$***
PSWQ	35.30 ± 6.24	55.54 ± 6.20	$t\,(46) = -11.28$	$p < 0.001$***
Rates of SS options (M ± *SD*)				
positive episodic condition	0.36 ± 0.034	0.42 ± 0.034	$p = 0.28$	
negative episodic condition	0.49 ± 0.031	0.72 ± 0.031	$p < 0.001$***	
neutral episodic condition	0.38 ± 0.028	0.56 ± 0.028	$p < 0.001$***	
Control condition	0.42 ± 0.031	0.55 ± 0.031	$p < 0.01$**	

** $p < 0.01$.
*** $p < 0.001$.

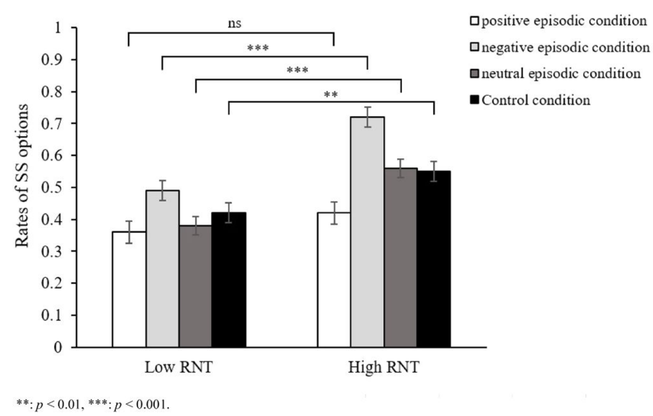

Fig. 2. Rates of SS options in high and low RNT groups. **: $p < 0.01$, ***: $p < 0.001$.

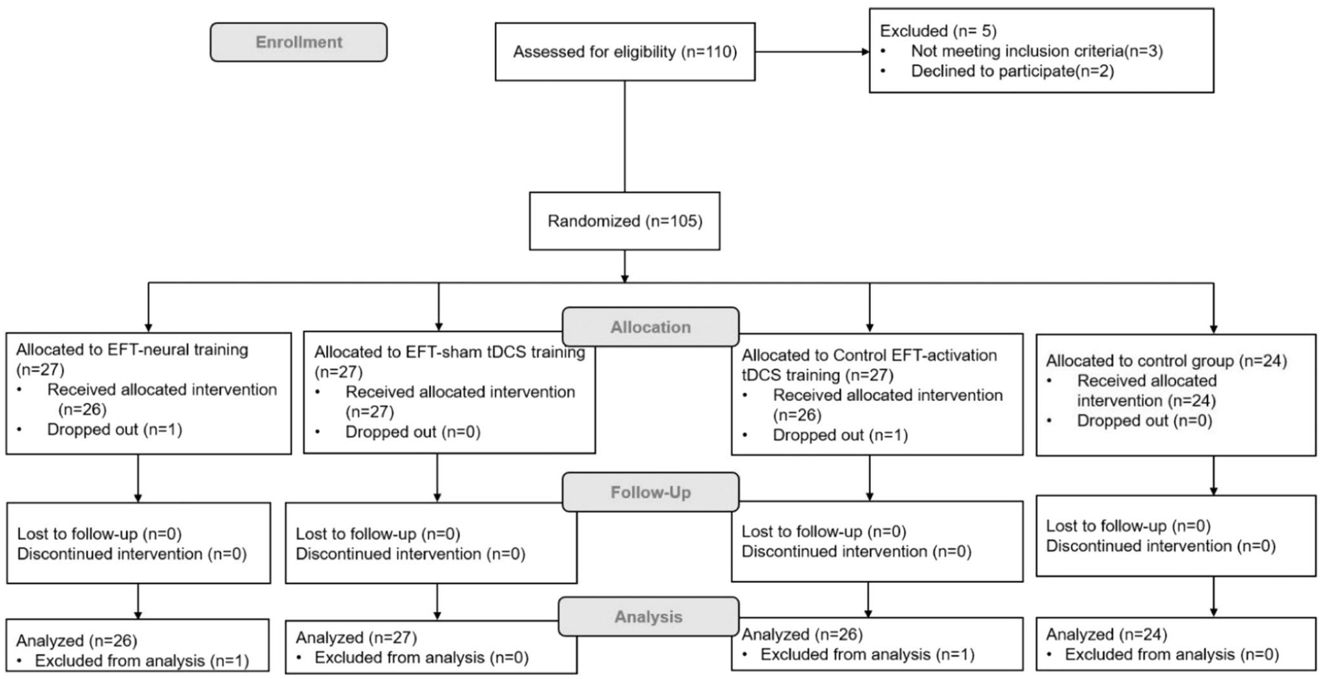

Fig. 3. CONSORT diagram illustrating participant flow through the EFT-neural trial.

treated with positive EFT training and sham tDCS activation. In the Control EFT-activation tDCS group, participants were treated with control EFT training and tDCS activation. In the control group, participants were treated with control EFT training and sham tDCS activation. There were at least 25 participants in each group, which ensured a statistical power near 100 % (Li et al., 2023). The demographic and clinical characteristics of participants are included in Table 2.

Study design

A randomized controlled trial with pre-treatment, 8-week post-treatment and 1 month follow-up measures was designed to explore the intervention effect of EFT training combined with tDCS activation for immediate reward preference of high-level RNT individuals. A 4 (group: EFT-neural vs. EFT-sham tDCS vs. Control EFT-activation tDCS vs. Control) × 3 (time: pre vs. post vs. 1 month follow-up) mixed design was performed. The trial was pre-registered on the Chinese Clinical Trial Registry (ChiCTR2200066327). All procedures involving human participants were consistent with the ethical standards of the Academic Board of xx University, and the 1964 Helsinki Declaration and its later amendments. Informed consent was obtained from all the participants.

Intervention

EFT training

The purpose of EFT training was to reduce RNT and prevent participants from being short-sighted in respect to their decisions. Based on prior studies (Aonso-Diego et al., 2021; Mellis et al., 2019), the present study for EFT training included three components. Prior to the first EFT session, participants were encouraged to discusses with therapists about future positive events that they were looking forward to, and complete a list of future positive events (e.g., an outdoor activity). Participants completed EFT training instruction in the consulting room during the 3–6 sessions. During each EFT session, therapists randomly presented participants with an event from a list of future positive events and asked them to construct clear and vivid mental images and detail the emotional and sensorial sensations of the moment, which was recorded by the therapist with the participant's consent. Besides, therapists asked standardized questions about details based on the description of the event to help participants associate more relevant details which may facilitate and motivate the visualization of the scenario, such as "Where did you have dinner with your friends", "What did you eat when you had dinner with your friends", "How did you feel when you had dinner with your friends". Notably, if participants had difficulty detailing events, therapists needed to work in a collaborative manner with them to identify the difficulties and find solutions. Finally, participants were asked to re-practice visualizing this event and dictate it. Notably, therapists showed participants how to engage in positive EFT to adjust feelings after experiencing negative events in daily life during the counseling session. Meanwhile, Participants were encouraged to practice positive prospective imagery once or twice daily and recorded relevant feelings (e.g., experiencing pleasurable emotions and a sense of accomplishment) as instructed in the consulting room. Appropriate use of EFT activities in daily life could improve the activity level and positive self-awareness of the participants.

tDCS

A battery-driven stimulator (DC-Stimulator Plus, neuroConn GmbH) delivered direct current with a pair of saline-soaked (0.9%) surface sponge electrodes (5 cm × 7 cm; 35 cm^2). Based on previous studies (e.g., Nord et al., 2019; Smits et al., 2021), participants received one tDCS session per week, which was applied for 20 min depending on the participant's availability. The anode was positioned over Fpz of the 10–20 EEG system to modulate vmPFC, and the cathodal return electrode was placed over Oz. For the active stimulation group, current stimulation was 2 mA, lasting for 20 min; for the sham stimulation group, to optimize blinding, current stimulation was ramped up to 2 mA over the first 30 s and ramped down over the next 30 s. There was no current during the rest of the session and all participants were blinded to the condition they were allocated for the entire duration of the study.

Procedure

The therapists involved in the current treatment were professionals with PhD degree in clinical psychology. All therapists had previous clinical experience at least 6 years in the treatment of many psychological disorders in adolescents and adults, and they were previously

Table 2
Baseline characteristics of the participants ($N = 103$).

	Total (N = 103)	EFT-neural (N = 26)	EFT-sham tDCS (N = 27)	Control EFT-activation tDCS (N = 26)	Control (N = 24)
Age, years					
Mean (*SD*)	20.13 (1.55)	19.77 (1.51)	19.96 (1.40)	20.58 (1.65)	20.21 (1.61)
Range	8 (16, 24)	7 (16, 23)	6 (18, 24)	6 (18, 24)	5 (18, 23)
Gender, *n* (%)					
Male	12.62	11.54	11.11	19.23	8.33
Female	87.38	88.46	88.89	80.77	91.67
Initial scale score (RNT)					
Mean (*SD*)	32.42 (9.43)	32.46 (9.68)	33.93 (10.61)	31.42 (8.59)	31.75 (8.99)
Range	39 (21, 60)	35 (21, 56)	39 (21, 60)	34 (21, 55)	31 (21, 52)
Initial scale score (Rumination)					
Mean (*SD*)	51.25 (12.99)	50.35 (13.18)	53.56 (13.66)	49.04 (10.61)	52.04 (14.61)
Range	58 (30, 88)	51 (30, 81)	55 (33, 88)	46 (35, 81)	50 (30, 80)
Initial scale score (Worry)					
Mean (*SD*)	53.02 (9.12)	52.46 (10.27)	53.33 (10.50)	52.96 (6.55)	53.33 (9.06)
Range	43 (36, 79)	43 (36, 79)	42 (36, 78)	23 (42, 65)	26 (42, 68)
Initial level (Rates of SS options)					
Mean (SD)	0.46 (0.21)	0.43 (0.21)	0.47 (0.25)	0.46 (0.19)	0.46 (0.20)
Range	0.91 (0.00, 0.91)	0.78 (0.11, 0.89)	0.80 (0.00, 0.80)	0.91 (0.00, 0.91)	0.71 (0.13, 0.84)
Initial level (Psychological well-being)					
Mean (SD)	7.67 (0.64)	7.60 (0.53)	7.64 (0.58)	7.53 (0.57)	7.95 (0.81)
Range	4.40 (6.10, 10.50)	2.43 (6.10, 8.53)	2.58 (6.30, 8.88)	2.43 (6.35, 8.78)	3.8 (6.70, 10.50)

trained and were systematically supervised to ensure delivering the same intervention. Eight weekly sessions, lasting approximately 40 min each, were conducted for participants in the four groups, which aimed to help individuals with high RNT to manage their negative feelings effectively and thereby make farsighted decisions (see Fig. 4). The EFT training exercises took approximately 20 min in the 3–6 sessions where relevant feelings of participants during in-sessions and out-of-sessions were also recorded and shared. For the control EFT condition, the contents were similar to the EFT training condition, except that the EFT component was replaced by regular emotion management strategies, which aimed to reveal the effects of EFT moderation. Participants in the EFT-neural group were allocated with positive EFT training and tDCS activation. Participants in the EFT-sham tDCS group were allocated with positive EFT training and sham tDCS activation. By contrast, participants in the Control EFT-activation tDCS group were allocated with control EFT training and tDCS activation. Participants in the control group completed regular intervention including control EFT and sham tDCS training. All the participants were blinded to the intervention condition.

Assessments

For the primary intervention indicators, RNT was assessed by PTQ, RRS, and PSWQ, and immediate reward preference was examined in the delay discounting tasks. The secondary intervention measure was the Index of Well-Being (Campbell, 1976), which mainly measured the happiness levels of participants, consisting of the following two parts: eight items with a weight of 1 measuring the Index of general affect and one item with a weight of 1.1 measuring the Index of life satisfaction.

Statistical analysis

Variables were examined for normality by analyzing frequency histograms and normality plots. All analyses were conducted using SPSS 26.0. Pearson chi-square test was used to test for differences in gender. One-way ANOVAs was used to test for differences in age between the four groups. All the scales of the RNT, rumination, worry, rates of SS options and psychological well-being were submitted to the 4 (Group: EFT-neural, EFT-sham tDCS, Control EFT-activation tDCS, Control) × 3 (time: pre, post and 1 month follow-up) RM-ANOVAs. Adjustments for multiple comparisons were realized using Bonferroni correction, and the effect size was calculated as partial eta squared (η^2p; ≥ 0.01, small effect; ≥ 0.06, moderate effect; ≥ 0.14, large effect; Cohen, 2013).

Results for study 2

Baseline characteristics (see Table 2)

The distribution of gender between the four groups was not significant, $\chi^2(3) = 1.51$, $p > 0.05$. There were no differences in age between the four groups, F (3, 102) = 1.33, $p > 0.05$.

Primary outcomes

For RNT, there was a significant main effect in time, F (2, 98) = 58.71, $p < 0.001$, $\eta^2 = 0.55$. There was a significant main effect in group, F (3, 99) = 9.27, $p < 0.001$, $\eta^2 = 0.22$. The interaction of time × group was significant, F (6, 198) = 5.14, $p < 0.001$, $\eta^2 = 0.14$. Before intervention, the differences between the four groups were not significant, F (3, 99) = 0.36, $p > 0.05$, $\eta^2 = 0.01$. After intervention, the differences between the four groups were significant, F (3, 99) = 5.30, $p < 0.01$, $\eta^2 =$ 0.14. PTQ scores of the EFT-neural group were significantly lower than the control group ($p < 0.01$). The differences between the EFT-sham tDCS group and the control group were significant ($p < 0.05$). At 1 month follow-up, the differences between the four groups were significant, F (3, 99) = 12.89, $p < 0.001$, $\eta^2 = 0.28$. PTQ scores of the EFT-neural group were significantly lower than those of the EFT-sham tDCS group ($p < 0.05$), and significantly lower than those of the control EFT-activation tDCS group ($p < 0.001$), and significantly lower than those of the control group ($p < 0.001$). PTQ scores of the EFT-sham tDCS group were significantly lower than those of the control group ($p <$ 0.01). The results were shown in Fig. 5.

For rumination, there was a significant main effect in time, F (2, 198) = 32.25, $p < 0.001$, $\eta^2 = 0.25$. There was a significant main effect in group, F (3, 99) = 9.81, $p < 0.001$, $\eta^2 = 0.23$. The interaction of time × group was significant, F (6, 198) = 5.03, $p < 0.001$, $\eta^2 = 0.13$. Before intervention, the differences between the four groups were not significant, F (3, 99) = 0.60, $p > 0.05$, $\eta^2 = 0.02$. After intervention, the differences between the four groups were significant, F (3, 99) = 9.04, $p <$ 0.001, $\eta^2 = 0.22$. RRS scores of the EFT-neural group were significantly lower than those of the control EFT-activation tDCS group ($p < 0.01$), and significantly lower than the control group ($p < 0.001$). The differences between the EFT-sham tDCS group and the control group were significant ($p < 0.05$). At 1 month follow-up, the differences between the four groups were significant, F (3, 99) = 18.71, $p < 0.001$, $\eta^2 = 0.36$. RRS scores of the EFT-neural group were significantly lower than those of the EFT-sham tDCS group ($p < 0.05$), and significantly lower than those of the control EFT-activation tDCS group ($p < 0.01$), and significantly lower than those of the control group ($p < 0.001$). RRS scores of the EFT-sham tDCS group were significantly lower than those of the control group ($p < 0.001$). The differences in RRS scores between the control EFT-activation tDCS group and the control group were significant ($p <$

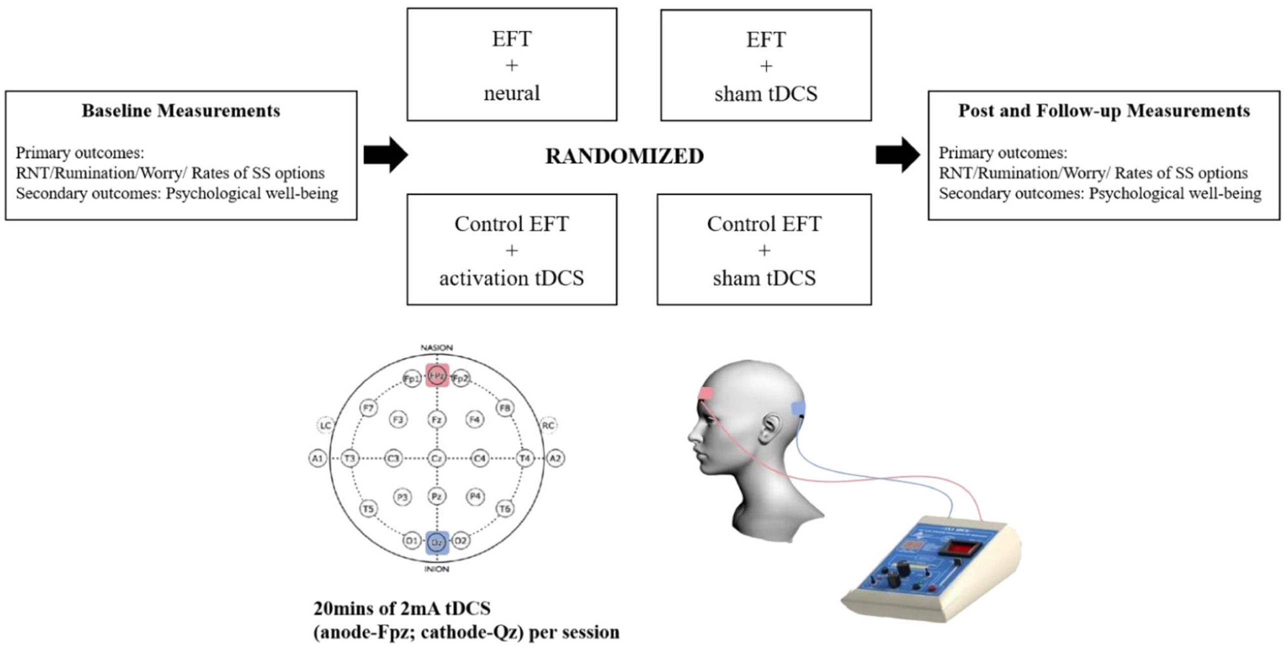

Fig. 4. The assemblies for the intervention.

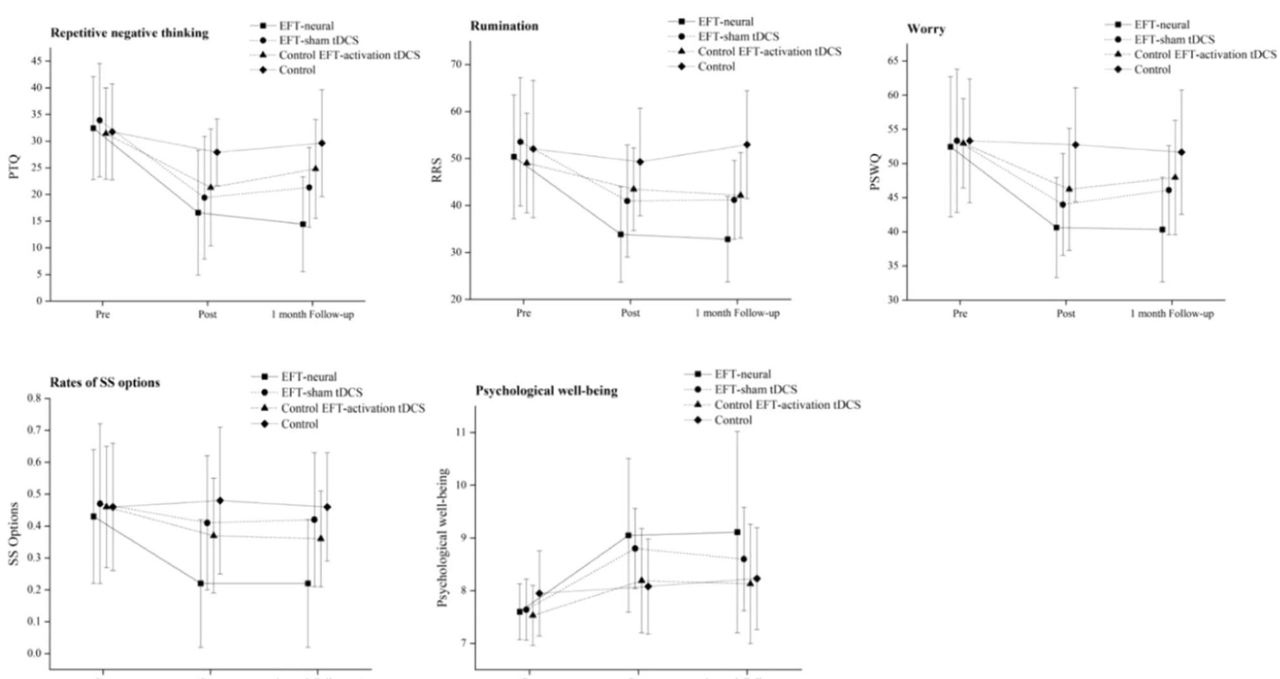

Fig. 5. Intervention results.

0.01). The results were shown in Fig. 5.

For worry, there was a significant main effect in time, F (2, 198) = 30.76, $p < 0.001$, $\eta^2 = 0.24$. There was a significant main effect in group, F (3, 99) = 7.72, $p < 0.001$, $\eta^2 = 0.19$. The interaction of time × group was significant, F (6, 198) = 3.60, $p < 0.01$, $\eta^2 = 0.10$. Before intervention, the differences between the four groups were not significant, F (3, 99) = 0.05, $p > 0.05$, $\eta^2 = 0.01$. After intervention, the differences between the four groups were significant, F (3, 99) = 10.07, $p < 0.001$, $\eta^2 = 0.23$. PSWQ scores of the EFT-neural group were significantly lower than the control group ($p < 0.001$). The differences between the EFT-sham tDCS group and the control group were significant ($p < 0.01$). The differences between the control EFT-activation tDCS group and the control group were significant ($p < 0.05$). At 1 month follow-up, the differences between the four groups were significant, F (3, 99) = 8.91, $p < 0.001$, $\eta^2 = 0.21$. PSWQ scores of the EFT-neural group were significantly lower than those of the control EFT-activation tDCS group ($p < 0.01$), and significantly lower than those of the control group ($p < 0.001$). The results were shown in Fig. 5.

For rates of SS options, there was a significant main effect in time, F (2, 198) = 9.73, $p < 0.001$, $\eta^2 = 0.09$. There was a significant main effect in group, F (3, 99) = 6.72, $p < 0.001$, $\eta^2 = 0.17$. The interaction of time × group was significant, F (6, 198) = 2.53, $p < 0.05$, $\eta^2 = 0.07$. Before intervention, the differences between the four groups were not significant, F (3, 99) = 0.22, $p > 0.05$, $\eta^2 = 0.01$. After intervention, the differences between the four groups were significant, F (3, 99) = 7.35, $p < 0.001$, $\eta^2 = 0.18$. Rates of SS options of the EFT-neural group were significantly lower than those of the EFT-sham tDCS group ($p < 0.01$), and significantly lower than those of the control EFT-activation tDCS group ($p < 0.05$), and significantly lower than the control group ($p < 0.001$). At 1 month follow-up, the differences between the four groups were significant, F (3, 99) = 8.08, $p < 0.001$, $\eta^2 = 0.20$. PSWQ scores of the EFT-neural group were significantly lower than those of the EFT-sham tDCS group ($p < 0.01$), and significantly lower than those of the control group ($p < 0.001$). The results were shown in Fig. 5.

Secondary outcomes

For psychological well-being, there was a significant main effect in time, F (2, 198) = 35.01, $p < 0.001$, $\eta^2 = 0.26$. There was a significant main effect in group, F (3, 99) = 3.38, $p < 0.05$, $\eta^2 = 0.09$. The interaction of time × group was significant, F (6, 198) = 3.87, $p = 0.001$, $\eta^2 = 0.11$. Before intervention, the differences between the four groups were not significant, F (3, 99) = 2.18, $p > 0.05$, $\eta^2 = 0.06$. After intervention, the differences between the four groups were significant, F (3, 99) = 5.01, $p < 0.01$, $\eta^2 = 0.13$. Psychological well-being scores of the EFT-neural group were significantly higher than those of the control EFT-activation tDCS group ($p < 0.05$), and significantly higher than the control group ($p < 0.05$). At 1 month follow-up, the differences between the four groups were significant, F (3, 99) = 2.98, $p < 0.05$, $\eta^2 = 0.08$. Psychological well-being scores of the EFT-neural group were significantly higher than those of the control EFT-activation tDCS group ($p < 0.05$). The results were shown in Fig. 5. All the intervention outcomes across time and groups were shown in Table 3.

Discussion

The present study is a relatively systematical trial that evaluated the effect of EFT combined with neural modulation over vmPFC on improving immediate reward preference under high RNT. In study 1, we found that high-level RNT individuals have more difficulties than low-level RNT individuals in inhibiting impulsive choice, and positive EFT had a significant modifying effect on it. As the combination with neuromodulation could be a potentially powerful approach for EFT training, we created the EFT-neural training in study 2 and hypothesized that engaging in the combined training could ameliorate more adverse effects of RNT on impulsive choice than the other treatment conditions, which provided a novel and effective method to intervene in tendencies for immediate gratification and potential adverse behaviors under high-level RNT.

Broadening previous research, the results in study 1 are in line with studies of behavioral impulsivity (Valderrama et al., 2016) and negative urgency (Valderrama et al., 2022) in rumination or worrisome and intrusive thoughts. Consistent with the impaired disengagement hypothesis, when experiencing heightened levels of rumination and worry, the inability to disengage from negative self-related information could narrow attention and reduce the effectiveness of executive function (Koster et al., 2011). Gradually, individuals who ruminate tend to continuously use perseverative thinking as a “useful” strategy to regulate their negative affect, and fail to make decisions with longer-term benefits. As previous research revealed that positive future thinking could shift the process of negative thinking (Annabelle & Ayelet, 2022), vivid and positive mental imagery with intense emotional experiences may interrupt RNT and facilitate decision-making with a long-term perspective.

At 1 month follow-up, high RNT individuals in the EFT-neural group continually showed significant reductions in impulsive preference and negative emotions, whereas in the other two treatment groups, the changes were flat. A possible explanation for the significant integrated effect may be that the “top-down” tDCS over vmPFC amplified beneficial effects to cognition and emotion shifts of rigid negative thinking, which made it more promising for high RNT individuals to strengthen prefrontal mechanisms of impulsivity inhibition. These findings are in line with recent literature, supporting the combined intervention effect by revealing that the neuroplastic effects of tDCS could be promoted with psychological interventions (Dedoncker et al., 2021).

Not surprisingly, impulsive preferences decreased in the positive EFT condition and increased in the negative EFT condition. However, it is worth considering that in the neutral EFT condition, high RNT individuals selected more short-term rewards. The reason may be that imaging neutral events cannot evoke any pleasant feelings, but may additionally occupy more cognitive resources, which largely results in impatient decision-making. EFT encouraged participants to project themselves into positive future scenarios in a narrative manner, replace their verbally dominated abstract thinking and enable them to effectively confront emotional problems and fully experience positive emotions. In fact, previous clinical and pre-clinical research has indicated deficient positive affectivity in addiction (Garland, 2021; Koob & Schulkin, 2019). In this sense, an increased focus on participants’ positive future thinking may optimize prevention available of mental and addictive disorders.

Consistent with the association between negative information immersion and maladaptive neural processing over vmPFC (Tsuchiyagaito et al., 2019), the application of tDCS in this study strongly elicited a clinically meaningful additive and long-lasting effect in moderating impulsive choice with EFT. Previous findings found that compared to the healthy group, patients with high rumination and worry showed

Table 3
Intervention outcomes across time and groups (N = 103).

Measures		EFT-neural		EFT-sham tDCS		Control EFT-activation tDCS		Control		
		Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	F/χ^2, p-value
Pre-Intervention	RNT	32.46	9.68	33.93	10.61	31.42	8.59	31.75	8.99	0.36, 0.78
	Worry	52.46	10.27	53.33	10.50	52.96	6.55	53.33	9.06	0.05, 0.98
	Rumination	50.35	13.18	53.56	13.66	49.04	10.61	52.04	14.61	0.60, 0.62
	Rates of SS options	0.43	0.21	0.47	0.25	0.46	0.19	0.46	0.20	0.22, 0.89
	Psychological well-being	7.60	0.53	7.64	0.58	7.53	0.57	7.95	0.81	2.18, 0.095
Post-Intervention	RNT	16.58	11.69	19.41	11.49	21.31	10.96	27.92	6.25	5.30, 0.002
	Worry	40.62	7.33	44.00	7.45	46.23	8.94	52.75	8.36	10.08, <0.001
	Rumination	33.85	10.16	40.96	11.94	43.46	8.81	49.29	11.46	9.04, <0.001
	Rates of SS options	0.22	0.20	0.41	0.21	0.37	0.18	0.48	0.23	7.35, <0.001
	Psychological well-being	9.05	1.46	8.80	0.76	8.19	0.99	8.08	0.90	5.01, 0.003
1 month Follow-up	RNT	14.42	8.89	21.33	7.48	24.81	9.28	29.63	10.06	12.89, <0.001
	Worry	40.35	7.67	46.11	6.52	47.96	8.37	51.67	9.11	8.91, <0.001
	Rumination	32.81	9.09	41.19	8.36	42.15	9.10	52.96	11.50	18.71, <0.001
	Rates of SS options	0.22	0.20	0.42	0.21	0.36	0.15	0.46	0.17	8.08, <0.001
	Psychological well-being	9.11	1.91	8.60	0.98	8.13	1.13	8.23	0.97	2.98, 0.035

dysregulated activation in vmPFC (Finnerty et al., 2017), and inhibitory vmPFC during impulsivity tasks processing has also been reported in depressed individuals (Brown et al., 2020). The association between heightened vmPFC activity and reduced self-referential negative processing might be due to the role of vmPFC as the structure enabling future narrative construction and working memory maintenance (Elena et al., 2017).

Clinical implications

Through performing multiple sessions of positive imagery training, participants produced a more positive future outlook, gradually promoting more positive changes in their daily activities. During the training sessions, therapists should discuss in depth to make sure that the positive future events were highly anticipated by clients and would elicit a pleasurable emotional experience. Besides, given the low compliance revealed by Aonso-Diego's work (2021), the EFT training also emphasized flexibility during treatment. Participants could do this training at any time of the day, making brief notes and giving feedback to therapists next session, which greatly improved their cooperation during these sessions. Also, the successful attempts to enhance the effects of EFT training with vmPFC stimulation suggest that tDCS interventions might be further developed in existing clinical applications. To find more effective ways to consolidate EFT training effect with tDCS, next steps should further determine the parameter conditions for tDCS (e.g., 2 mA, 20 min each time) that could effectively modulate targeted symptoms-related brain processes.

Strengths and limitations

This study was the first to investigate the effect of a change in impulsive preference in high RNT. Further, we created the EFT-neural training as a treatment project for moderating impulsivity under high RNT and thereby examining the possible neural mechanism of the activation in vmPFC. Despite these promising findings, the research should be interpreted with respect to several limitations. Firstly, although the form of self-report in the experiments is considered reliable, the investigations involving physiological indicators (e.g., heart rate and skin conductance) and neural changes indicators would provide more objective and convincing evidence. The combination with neuroimaging methods can help to better study brain state change effect of tDCS stimulation (e.g., Nord et al., 2019). Secondly, given that the conclusions derived from this study were focused on Chinese, whether the results of this study can be generalized to samples in different cultural backgrounds should be further explored. Moreover, given that the sample in this study consists of relatively young age individuals, it remains uncertain whether the findings could be generalized to broader samples.

Conclusion

In conclusion, this study is a new extension that revealed the impulsive preference in high RNT and the moderating effect of EFT on it. Based on this, we assessed the effectiveness of the EFT-neural project for impulsive choice under high RNT, supporting the idea that this integrated training could be promising in enriching emotional management strategies and improving delayed gratification. The current study comprehensively considered the features of high RNT and proposed the emotional counteracting and psychological-neural integrated intervention, which had significant implications for helping high RNT individuals attain meaningful abilities supporting their long-term development.

Data availability

Research data are not shared.

Declaration of competing interest

The authors declare no conflicts of interest associated with this manuscript.

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