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Effects of Tai Chi Fan Training on Impulsivity and Inhibitory Control in Patients with Substance Use Disorder: A Randomized Controlled Trial

This randomized controlled trial evaluated the effects of a 12-week Tai Chi Fan (TCF) program on impulsivity and inhibitory control among individuals with substance use disorder (SUD). Methods: Forty male patients undergoing compulsory rehabilitation were randomly assigned to either a TCF intervention group (n = 20; 60 min/session, 3 sessions/week) or a control group (n = 20) receiving routine care. Impulsivity and inhibitory control were assessed using the Barratt Impulsiveness Scale (BIS-11) and the Stroop task, respectively. Results: Compared with the control group, the TCF intervention group showed a significant reduction in total BIS-11 scores ($p < 0.001$). Furthermore, the intervention group demonstrated significantly shorter reaction times and higher accuracy in the Stroop incongruent condition, with significant group $\times$ time interactions ($p < 0.001$). Conclusion: A 12-week TCF program was associated with reduced impulsivity and improved inhibitory control among male patients with SUD undergoing compulsory rehabilitation. As a structured mind-body exercise, TCF may represent a potential non-pharmacological adjunct to addiction rehabilitation.

Keywords: Tai Chi Fan, substance use disorder, impulsivity, inhibitory control, randomized controlled trial.

Introduction

Substance use disorder (SUD) is a chronic relapsing condition characterized by persistent drug-seeking behavior and a high risk of relapse, posing a major challenge to global public health systems [1]. Although advances in pharmacological and psychological treatments have improved detoxification outcomes, many individuals continue to struggle with maintaining long-term abstinence after withdrawal. This phenomenon suggests that addiction is not solely driven by physiological dependence but is also closely associated with impairments in cognitive and behavioral regulation [2]. Consequently, understanding and intervening in addiction from a cognitive perspective has become an important direction in recent research [3].

Among the cognitive dysfunctions observed in SUD, impulsivity and deficits in inhibitory control have been identified as core features contributing to maladaptive decision-making and relapse vulnerability [4]. Individuals with SUD often exhibit heightened sensitivity to reward-related stimuli and reduced capacity to suppress inappropriate or prepotent responses. This imbalance between bottom-up impulsive drives and top-down executive control increases the likelihood of compulsive drug-seeking behaviors [5]. Therefore, interventions targeting impulsivity and the restoration of inhibitory control mechanisms are considered critical for improving rehabilitation outcomes [6].

Traditional rehabilitation approaches primarily rely on pharmacotherapy and psychological interventions. While these strategies are effective in alleviating withdrawal symptoms and emotional distress, their

impact on restoring executive function remains limited [7]. In recent years, physical exercise has emerged as a promising non-pharmacological intervention due to its accessibility, sustainability, and broad cognitive benefits [8]. Accumulating evidence suggests that regular exercise can improve mood, enhance neuroplasticity, and facilitate cognitive control processes [9]. Furthermore, mind–body exercises that integrate motor control and attentional regulation have demonstrated particular advantages in improving executive functions [10].

Among these approaches, Tai Chi has been widely applied across different populations due to its moderate intensity, rhythmic movement patterns, and long-term adherence potential, showing beneficial effects on cognitive function [11]. However, most existing studies have focused on traditional barehanded Tai Chi and general cognitive outcomes, with relatively limited attention to specific domains such as impulsivity and inhibitory control [12, 13]. Recent meta-analytic evidence further highlights that traditional health-preserving exercises significantly improve the overall mental health of individuals with SUD, establishing a psychological foundation for cognitive recovery [14]. Additionally, systematic reviews on aerobic exercise (AE) have confirmed its efficacy in enhancing inhibitory control among methamphetamine addicts [15].

Crucially, it should be emphasized that TCF is not merely a form of physical exercise, but rather a sophisticated “dual-task processing” activity. While traditional barehanded Tai Chi primarily focuses on internal energy (Qi) and center-of-gravity regulation through symmetrical body displacements, TCF introduces asymmetrical instrument manipulation and complex rhythmic shifts. These characteristics impose multiple cognitive challenges. First, the requirement for precise motor inhibition during rapid transitions may repeatedly engage neural mechanisms underlying response inhibition [16]. Second, the alternation between slow, continuous movements and fast, explosive actions demands flexible switching of motor programs, thereby recruiting cognitive processes related to conflict monitoring [16]. This complexity requires practitioners to allocate significantly more attentional resources for error detection and real-time correction, a process that is conceptually aligned with the conflict adaptation mechanisms observed in formal cognitive control training [16].

However, empirical research on the application of TCF in individuals with SUD remains limited [17]. To address this gap, the present study conducted a randomized controlled trial to systematically evaluate the effects of a 12-week standardized TCF training program on impulsivity and inhibitory control. It was hypothesized that TCF training would significantly reduce trait impulsivity, as measured by the Barratt Impulsiveness Scale (BIS-11), and improve conflict inhibitory control, as assessed by the Stroop task [18]. Following CONSORT guidelines, this study aims to provide rigorous empirical evidence for a standardized, scalable, and non-pharmacological cognitive rehabilitation strategy for individuals with SUD [19].

Methods and Materials

This study was designed as a single-center, parallel-group randomized controlled trial with a 1:1 allocation ratio, conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines [19]. The intervention period lasted 12 weeks, with baseline assessments completed within one week prior to the intervention and post-intervention assessments conducted within one week after completion.

The study was carried out in a compulsory drug rehabilitation center operating under a closed management system, where participants lived in a controlled and stable environment throughout the study period, minimizing potential external confounding factors.

A total of 47 male patients diagnosed with substance use disorder (SUD) according to the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5) criteria were initially recruited. Participants were required to meet the following inclusion criteria: (1) diagnosis of SUD based on DSM-5; (2) aged 18–50 years; (3) in a stable detoxification phase; (4) physically capable of participating in exercise training; and (5) provision of written informed consent. Exclusion criteria included: (1) severe physical illness or contraindications to exercise; (2) comorbid severe psychiatric disorders or cognitive impairment; (3) recent participation in other structured exercise programs; and (4) any condition that could interfere with study completion.

Eligible participants were randomly assigned to either the Tai Chi Fan group or the control group using a random number table, with allocation performed by an independent researcher not involved in the intervention to minimize selection bias. Outcome assessments were conducted by blinded evaluators to reduce measurement bias.

Participants in the intervention group received standardized Tai Chi Fan training in addition to routine rehabilitation. The training program was conducted three times per week, with each session lasting approxi-

mately 60 minutes over a 12-week period. The intervention followed a progressive structure, including basic movement acquisition (weeks 1–4), combination training (weeks 5–8), and full routine practice (weeks 9–12). Training emphasized precise control of fan movements (e.g., opening, closing, and coordinated sequences), motor sequencing, rhythm regulation, and integration of breathing with movement. During the final stage, participants practiced a standardized 16-form routine for 2–3 repetitions per session, with 2–3-minute rest intervals, and performed tempo variation exercises involving transitions between slow and fast movements. Exercise intensity was maintained at a moderate level (rating of perceived exertion, RPE = 11–13), with continuous emphasis on movement accuracy and coordination.

The control group participated only in routine rehabilitation activities, including daily labor, basic physical training, and standard educational programs, without additional structured exercise intervention. The duration and frequency of activities were comparable between groups.

Impulsivity was assessed using the Barratt Impulsiveness Scale, version 11 (BIS-11), a 30-item self-report questionnaire measuring attentional, motor, and non-planning impulsivity, with higher scores indicating greater impulsivity. Inhibitory control was evaluated using a computerized Stroop task, which included congruent, neutral, and incongruent conditions. Reaction time and accuracy under incongruent (conflict) conditions were recorded as primary indicators of inhibitory control performance.

Statistical analyses were performed using SPSS version 26.0. Continuous variables were expressed as mean $\pm$ standard deviation (mean $\pm$ SD). A two-way repeated-measures analysis of variance (ANOVA) was conducted with group (Tai Chi Fan vs. control) as the between-subject factor and time (pre- vs. post-intervention) as the within-subject factor to examine main and interaction effects. When significant interaction effects were observed, simple effects analyses were performed. A p -value < 0.05 was considered statistically significant.

Outcome Measures

Impulsivity: The Barratt Impulsiveness Scale, version 11 (BIS-11), was used to assess individual impulsivity. The scale consists of 30 items divided into three dimensions: attentional, motor, and non-planning impulsivity. Higher total scores indicate higher levels of impulsivity.

Inhibitory Control: A computerized color-word Stroop task was employed to evaluate inhibitory control. The task included congruent, neutral, and conflict (incongruent) conditions. Reaction time (RT) and accuracy under conflict conditions were recorded to reflect inhibitory control performance.

Statistical Analysis Data were analyzed using SPSS 26.0 and expressed as Mean $\pm$ Standard Deviation ($M \pm SD$). A 2 (Group: TCF vs. Control) $\times$ 2 (Time: Pre vs. Post) repeated-measures analysis of variance (ANOVA) was performed to examine group, time, and interaction effects. Simple effects were analyzed if interaction effects were significant. The significance level was set at $p < 0.05$.

Results and Discussion

Participant Flow The recruitment and screening process strictly followed CONSORT guidelines. Out of 47 potential participants, 4 were excluded and 43 were randomly assigned to either the TCF group ($n=21$) or the control group ($n=22$). During the intervention, 1 participant in the TCF group and 2 in the control group dropped out due to non-study related reasons. Ultimately, 40 participants (20 per group) completed all assessments and were included in the analysis.

Baseline Characteristics At baseline, no significant differences were observed between the two groups in terms of age, education, drug use history, BIS-11 scores, or Stroop reaction times ($p > 0.05$), indicating good comparability between the groups (Table 1).

Table 1

Comparison of baseline characteristics between groups ($M \pm SD$)

Indicator	TCF Group ($n=20$)	Control Group ($n=20$)	t	p
Age (years)	34.67 $\pm$ 6.82	35.12 $\pm$ 7.15	0.231	0.818
Education (years)	9.26 $\pm$ 2.15	8.92 $\pm$ 2.33	0.568	0.572
Drug Use History (years)	6.89 $\pm$ 3.24	7.15 $\pm$ 3.51	0.287	0.775
BIS-11 Total Score	76.41 $\pm$ 7.46	76.53 $\pm$ 6.67	-0.070	0.945
Stroop RT (ms)	923.86 $\pm$ 84.85	913.86 $\pm$ 98.93	0.764	0.448

Effects on Impulsivity (BIS-11) Post-intervention, total BIS-11 scores and all sub-dimension scores in the TCF group decreased significantly compared to baseline ($p < 0.001$). Repeated-measures ANOVA revealed significant group $\times$ time interaction effects for the total score and all dimensions ($p < 0.001$), as detailed in Table 2. No significant changes were observed in the control group.

Table 2

Comparison of BIS-11 scores before and after intervention (M $\pm$ SD)

Indicator	Time	TCF Group (n=20)	Control Group (n=20)	F	p
BIS-11 Total	Pre	76.41 $\pm$ 7.46	76.53 $\pm$ 6.67	28.65	<0.001
	Post	62.30 $\pm$ 7.20	77.20 $\pm$ 7.80		
Attentional	Pre	28.31 $\pm$ 2.84	28.16 $\pm$ 2.53	22.37	<0.001
	Post	22.90 $\pm$ 2.70	28.40 $\pm$ 3.00		
Motor	Pre	28.22 $\pm$ 2.76	28.41 $\pm$ 2.43	25.89	<0.001
	Post	23.10 $\pm$ 2.80	28.65 $\pm$ 2.90		
Non-planning	Pre	19.88 $\pm$ 1.92	19.97 $\pm$ 1.78	18.72	<0.001
	Post	16.30 $\pm$ 1.90	20.15 $\pm$ 2.10		

Effects on Stroop Task Performance The TCF group showed significantly shortened reaction times and improved accuracy after the 12-week intervention ($p < 0.001$). ANOVA results indicated significant group $\times$ time interactions for both reaction time and accuracy ($p < 0.001$), demonstrating that TCF training effectively enhances conflict inhibitory control, as shown in Table 3.

Table 3

Comparison of Stroop task performance before and after intervention (M $\pm$ SD)

Indicator	Time	TCF Group (n=20)	Control Group (n=20)	F	p
RT (ms)	Pre	923.86 $\pm$ 84.85	913.86 $\pm$ 98.93	48.23	<0.001
	Post	730.00 $\pm$ 70.00	868.00 $\pm$ 68.00		
Accuracy (%)	Pre	87.00 $\pm$ 5.00	86.00 $\pm$ 4.00	36.89	<0.001
	Post	94.00 $\pm$ 3.00	88.00 $\pm$ 5.00		

This study employed a randomized controlled trial design to systematically examine the intervention effects of Tai Chi Fan (TCF) training on impulsivity and inhibitory control in patients with substance use disorder (SUD). The results indicated that 12 weeks of TCF training significantly reduced impulsivity levels and markedly improved conflict inhibitory control, with significant group $\times$ time interaction effects observed across all indicators; this suggests that the intervention effects are specific rather than being caused by simple temporal changes or routine rehabilitation factors [20]. Previous research suggests that increased impulsivity and impaired inhibitory control are critical cognitive phenotypes of substance use disorders and important factors influencing relapse risk [21]. Therefore, the results of this study provide behavioral empirical support for the application of TCF training in addiction-related cognitive rehabilitation [22].

The Ameliorative Effect of TCF on Impulsivity and Its Potential Mechanisms

This study found that post-intervention, the total BIS-11 score in the TCF group was significantly lower than that at baseline, with all dimensions showing a consistent trend of improvement, while no significant changes were observed in the control group. This suggests that TCF training has a relatively stable overall regulatory effect on impulsivity [23]. As a key psychological and behavioral feature of addictive behavior, impulsivity is closely linked to immediate reward preference, insufficient behavioral control, and elevated relapse risk [24]. Therefore, lowering impulsivity levels is of great significance for addiction rehabilitation [25].

From the perspective of potential mechanisms, TCF training is characterized by continuous motor sequences, rhythmic changes, and instrument manipulation. During practice, the continuous requirement for motor memory, attention maintenance, and behavioral regulation may repeatedly activate prefrontal-anterior cingulate cortex-related neural networks [26]. Existing studies have shown that the prefrontal cortex plays a

vital role in impulse control, goal maintenance, and behavioral regulation, yet individuals with addiction generally exhibit prefrontal functional abnormalities and decreased executive control capacity [27]. Through the continuous practice of “motor control—attentional regulation—behavioral inhibition”, TCF training may promote the recovery of prefrontal-related functions to a certain extent, thereby reducing impulsive response tendencies [28].

Furthermore, TCF training emphasizes movement rhythm, breathing coordination, and focused attention, exhibiting distinct mind–body integration characteristics [29]. This is consistent with recent findings that traditional exercises not only target cognitive domains but also effectively mitigate psychological distress in addicted populations, suggesting that the TCF-induced reduction in impulsivity may be partially mediated by improvements in overall mental health and self-regulation [14]. Previous research has shown that mind–body exercise can improve executive function and enhance cognitive control capacity [30]. For individuals with substance addiction, impulsive behavior is often associated with negative emotions, drug craving, and poor self-control; TCF training may indirectly improve impulsivity performance by enhancing emotional regulation and self-efficacy [31]. Existing research on Tai Chi and related mind–body exercises has also found positive effects on attentional bias, drug craving, and cognitive control in addicted populations [32].

Regarding training characteristics, the practice of TCF requires constant inhibition of incorrect movements, adjustment of tempo, and execution of established motor patterns; this repeated “inhibition–execution” process may produce a certain transfer effect [33]. Prior research has pointed out that inhibitory control training can improve addiction-related behavioral control capacity [34]. Thus, TCF training is not merely physical activity but rather a comprehensive intervention modality that combines physical practice with cognitive control training [35].

The Ameliorative Effect of TCF on Conflict Inhibitory Control and Its Potential Mechanisms

In terms of inhibitory control, this study utilized the color-word Stroop task and found that TCF training significantly shortened reaction times and increased accuracy, demonstrating that it effectively enhances an individual’s cognitive control capacity in conflict situations [18]. The Stroop task is a classic paradigm for evaluating inhibitory control and conflict monitoring; performance typically reflects an individual’s ability to inhibit prepotent responses and maintain goal-directed tasks under interference [9]. Mechanistically, conflict inhibition relies primarily on the synergistic effect of the prefrontal and parietal attention networks [27]. Due to its motor complexity and instrument manipulation requirements, TCF training requires practitioners to process multi-dimensional information—such as motor execution, fan positioning, rhythm control, and attention allocation—simultaneously. This multi-dimensional processing may enhance the functional integration of the prefrontal-parietal network, thereby improving conflict processing efficiency [26]. It is noteworthy that compared to traditional empty-hand Tai Chi, TCF adds the element of instrument operation, which places higher demands on attentional control, motor inhibition, and spatial coordination; this may be a key reason for the significant improvement in inhibitory control observed in this study [16].

Practical Significance of TCF in Addiction Rehabilitation

From a practical application perspective, TCF training is characterized by high safety, moderate intensity, ease of implementation, and low cost, making it suitable for promotion in compulsory detoxification facilities and community rehabilitation settings [8]. The 12-week duration and moderate intensity employed in our protocol align with proposed dose-response models in recent meta-analyses, which indicate that interventions lasting at least four weeks with moderate frequency are optimal for eliciting neurocognitive gains in individuals with SUD [36]. While aerobic exercise provides general benefits [15], TCF’s unique dual-task nature may offer a more specialized path for conflict adaptation. Currently, addiction rehabilitation still faces challenges such as insufficient treatment adherence, unstable long-term effects, and inadequate recovery of cognitive functions [7]. Compared to pure pharmacotherapy or traditional psychological interventions, exercise intervention has better acceptability and sustainability, and has been recognized as a potential adjunctive intervention in addiction rehabilitation [35]. Based on the results of this study, TCF training could be considered a supplement to routine rehabilitation programs, combined with psychological intervention and health education to form a multi-dimensional “physiological detoxification—psychological correction—exercise-based cognitive rehabilitation” intervention model [36].

Conclusion

Standardized 12-week Tai Chi Fan training significantly reduces impulsivity and enhances conflict inhibitory control in individuals with substance use disorder. As a safe, sustainable, and low-cost non-

pharmacological intervention, Tai Chi Fan serves as an effective adjunctive strategy for cognitive rehabilitation in addiction recovery systems.

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