A newly designed Cognitive Addiction Therapy (CAT) App improved cognition impairments and risk decision making for methamphetamine use disorder: A randomized clinical study

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Abstract

**Background:** Cognitive rehabilitation therapy have been found to improve cognitive deficits and impulse control problems in methamphetamine use disorder. However, there is limited research regarding their feasibility using mobile health technologies in supporting recovery from methamphetamine use disorders (SUDs) in China.

**Objective:** The main aim of this study was to test whether four weeks of newly designed Cognitive Addiction Therapy (CAT) App can repair cognitive impairments, and eliminate drug related attention bias and attenuate risk decision-making behaviors in participants with
methamphetamine use disorder (MUD).

**Method:** Forty moderate to severe MUD participants were assigned randomly to either CAT group in which they received four weeks of CAT plus treatment as usual or control group who only received the treatment as usual in drug rehabilitation centers in Shanghai. CAT was designed by combine methamphetamine (MA) use related pictures stimulus with computerized cognitive training with the aim to improving cognitive function and eliminate drug related attention bias. CogState Battery, delay discounting task (DDT), Iowa gambling task (IGT), and Balloon Analogue Risk Task (BART) were administrated to all participants before and after CCAT interventions.

**Results:** Compared to control group, CTA improved working memory in CAT group. Group-by-time interactions were observed among DDT, IGT and BART task, with rates of discounting of delayed rewards, IGT, and BART score reduced among those who received CAT, while no changes were found in control group.

**Conclusions:** The newly designed CAT can help to repair the cognitive impairment and impulsive control in MUD. Further study is needed to understand the underline brain mechanisms of the cognitive therapy.

**Trial Registration:** This study is a randomized, single blind controlled clinical trial which has been registered on the ClinicalTrials.gov (ID: NCT03318081).

**Key words:** Methamphetamine; Methamphetamine use disorder; cognitive addiction training; Cognitive function; impulse control; Risk-decision making; Attention bias

**1. Introduction**

Amphetamine-type stimulants (ATS) are the second most widely abused illicit drugs worldwide, with methamphetamine (MA) being one of the most dominated ATS, especially in East and South-East Asia, and parts of North America and Europe [1]. MA abuse has caused huge public health consequences all over the world [2]. Chronic methamphetamine (MA) use was associated with abnormalities in brain function and metabolism [3, 4], leading to many negative consequences such as cognitive impairments, high impulsivity, and poor psychological wellbeing [5, 6].
Cognitive impairments and high impulsivity could lead patients to one central paradox situation where individuals often desperately continued to consume MA despite fully aware the potential negative consequences.

According to dual-systems perspective of addiction, two unbalanced information processing mechanisms underlying methamphetamine use disorder (MUD) patients’ behaviors, namely automatic and reflective processes might address this paradox phenomenon. Automatic processes, which is over-activated in many SUD patients, is a fast, implicit and automatic impulsive process and often operates at the early stages of response selection when facing high-risk situation through drug related associative links between emotional and motivational associations[7]. A common feature of sensitized automatic impulsive process can result in drug related cognitive bias. On the contrary, reflective process which can help regulating individuals emotion and self-control, optimizing behavioral outcome and better exertion of these abilities in the suppression of automatic impulses. Reflective process is a much slower, relatively controlled processes and also often impaired in SUD patients [8]. With continuous drug use, damaged cognitive functions such as attention control, working memory and response inhibition might have negative effect on this process. Sensitized automatic impulsive process and over-slowed reflective process further deteriorated this paradox problem.

Longitudinal studies have provided evidence that the ability to stop one's actions can influence their including substance-related behaviors later in their lives [9]. Clinical neuropsychology-based rehabilitation techniques focused on cognitive function training as well as cognitive bias modification, maybe ideally suited to address this challenge. Computer-based cognitive rehabilitation therapies are one of these promising interventions and has shown beneficial effects for these cognitive deficits across several clinical groups, including patients with schizophrenia[10], brain injury[11], Alzheimer disease ( AD ) [12], anxiety[13] and substance use disorder ( SUD ) patients[14]. Cognitive bias modification is another computerized treatment technique which is targeting sensitized automatic impulsive process. Previous evidence have showed that drug related attention bias can be retrained, but along with favorable short-term effects in reducing substance abuse [15].
These modification therapies were mainly based on visual point task [16], modified Stroop task [17], or attention control training program [18]. Such bias modification methods have been applied to patients with alcohol and nicotine use disorder problems [19, 20], and effectively reduced substance intake and implicit impulsive control ability. However, to the best of our knowledge, no interventions had addressed both cognitive deficits and cognitive bias. Considering both processes are impaired in MUD patients [21] and uncontrolled cognitive mechanisms, either cognitive bias or cognitive deficits play an important role in substance use disorder [22, 23], interventions to address these two aspects may be more effective than single approaches [24]. Therefore, we designed a mobile-based App program called cognition addiction therapy (CAT) by combining cognitive training and cognitive bias modification. Furthermore, studies have showed that enhanced drug-related choice can be demonstrated even for pictorial stimuli [25], with simple passive pictures might induce stronger cognitive biases while active pictures presenting drug use related context might induce a stronger urge for drugs [26]. MA use related pictures were integrated into the App programs, aiming to address both cognitive impairment and cognitive bias in MUD patients. We hypothesized that the CAT would have beneficial effects for repairing cognition impairment as well as correct attention bias and risk decision-making behaviors in MUD patients.

2. Methods

2.1 Experimental design
This study is a randomized, single blind controlled clinical trial which has been registered on the ClinicalTrials.gov (ID: NCT03318081). All subjects were instructed to be treated by computerized cognitive rehabilitation therapies or treatments as usual. All outcome measures were assessed by blinded researchers. The study protocol was approved by the institutional IRB in Shanghai Mental Health Center.

2.2 The mobile based cognitive addiction therapy (CAT) App
The CAT is a mobile health-based cognitive intervention App, which is designed to help MUD patients overcome their and cognitive deficits, increased impulse control problems, and
enabling them to gain better control over MA related attentional bias. The CAT App consisted of cognitive training tasks, including two working memory training tasks and two MA related attention bias control training tasks. Each training task lasts about 6 minutes. In each training session, participants completed each of the four training programs twice. Thus far, it is the first mobile app designed for people with MUD in China.

2.2.1 Methamphetamine attention bias modification

During this part of training, patients were asked to decide whether the meaning of the word in the left box is consistent with the color of the word on the right (Fig. 1). Every session lasts about 8 minutes. An incorrect response resulted in a red cross, while a correct response resulted in a green check mark. The color of the words were limited to red, yellow, blue and green. Accuracy rate showed to the participant when finishing every training session.

![Image](image.png)

Fig. 1. MA related attention bias modification task. During this part of training, patients were asked to decide whether the meaning of the word in the left box is consistent with the color of the word on the right.

2.2.2 Attention control training
This training task was derived from Fadardi and Cox’ alcohol attention control training project (AACTP) used in training alcohol use disorder patients[27]. In our newly designed task, when there is only one picture, patients need to figure out the border color of MA related picture. However, if there are two pictures, one is MA related and another is neutral picture with a colored border, patients should ignore the MA related pictures and push the button representative the rightful color. Accuracy rate showed to the participant when finishing every training session. (Fig. 2).

![Fig. 2. MA related attention control training. In situation 1, the border of MA related image is red, and the patients need to push the “red” button. In situation 2, the border of neutral picture is yellow, and the patients need to push the “yellow” button as soon as possible.](image)

### 2.2.3 Working memory training (N-back task)

This part of working memory training task is originated from N-back task. The figures show on the right of the screen were target stimulus, patient were asked to judge that if the figure showed right now is consistent with the figure N prior earlier. MA related pictures on the left were served as distractions. Duration of each training session was set at 10 minutes. (Fig. 3).
Fig. 3. MA related working memory training task (N-back task). The above fig.2 was an example of 2-back task training. Patients in CCRT group were asked to decide the figure (both shape and color) on the right was consistent with the figure showed two pictures before, while ignoring the MA related picture on the left.

2.2.4 Working memory training (Memory matrix task)

MA related pictures were set as background (at the bottom of Fig. 4) or on the left as distraction (on the top of Fig. 4). A few blue figures were showed 3 seconds, then disappeared and turned to its original color. Patients were told to find these blue figures showed seconds before. An incorrect response resulted in a red cross, while a correct response resulted in a green checkmark. Three times were sat as response threshold. This program begins with recalling three figures. If successfully recalled or failed to remember the blue squares three times in succession, then the figures to be recalled are increased or decreased accordingly. Accuracy rate showed to the participant when finishing every training session.
Fig. 4. Memory matrix task. A few blue figures were showed 3 seconds, then disappeared and turned to its original color. Patients were told to find these blue figures showed seconds before. An incorrect response resulted in a red cross, while a correct response resulted in a green checkmark.

2.3 Participants

40 male participants from one compulsory rehabilitation center in Shanghai who met Diagnostic and Statistical Manual of Mental Disorders criteria (DSM-5) criteria for moderate or severe MA use disorders were encouraged to participate in this study. Inclusion criteria were: (1) more than 9 years of education; (2) aged of 18-49 years old; (3) normal vision and audition; (4) receive no detoxification medications during treatment; (5) right handedness. The exclusion criteria included: (1) current medical diseases that required hospitalization or regular monitoring; (2) serious physical or neurological illness that required pharmacological treatment affecting cognitive function; (3) history of major psychiatric disorder such as bipolar disorder, schizophrenia, depression and disorders of high comorbidity with substance abuse/dependence; (4) neurological diseases such as stroke, seizure, migraine, head trauma (5) substance dependence other than nicotine, within the past 5 years; (6) intelligence quotient (IQ) < 70; (7) color blindness. (See CONSORT flowchart in Fig. 5). The study was approved by the institutional review board and the ethics committee of Shanghai Mental Health Center. Written consent was obtained from all subjects.
2.4 Data collection and measurements

2.4.1 Demographic and MA use information

Each subject was interviewed by one trained psychiatrist and completed a questionnaire, including socio-demographic characteristics and MA use histories.

2.4.2 Cognitive function

Cognitive functions were assessed by the Chinese version of CogState Battery, which has good validity (Cronbachα = 0.8) [28]. CogState Battery used including five cognitive tasks assessing verbal learning and memory, working memory, spatial working memory, problem
solving/error monitoring and social cognition. The total number of correct responses during International shopping list task (ISL) were used to reflect verbal learning and memory ability. Working memory were evaluated through the proportion of correct responses during two-back task (TWOB) performance. Spatial working memory function were reflected through total number of errors through Continuous paired association learning task (CPAL). Problem solving/error monitoring assessment index was the same as CPAL during Groton maze learning task. While for social cognition function, proportion of correct responses of social emotional cognition task (SEC) were applied.

2.4.3 Iowa-Gambling Task (IGT)
During the IGT test, subjects were asked to choose among four decks of cards (A, B, C, and D) and accumulate as much money as possible by picking one card at a time. Deck A and B are associated with high immediate wins but larger future penalties that results in a net loss over time (i.e., the disadvantageous decks). Deck C and D yields lower immediate wins but smaller future penalties, such that the participants gradually accumulate a profit by choosing these decks (i.e., the advantageous decks). There were totally 150 trials. Outcome is the net score (the number of cards from the disadvantageous decks subtracted from the advantageous decks). Positive score reflects the individual had a tendency to make good decision[29]. The index of individuals` decision-making performance was calculated through \[ (C+D) - (A+B) \], after subtracting the first 30 trials. Poor decision making can be indicated by a lower IGT scores.

2.4.4 Balloon Analogue Risk Task (BART)
Balloon Analogue Risk Task (BART) was an computerized evaluation measurement of individuals` risk taking behavioral[30]. On each single trial, a uninflated balloon appears on the screen, pressing button“1”means inflating the balloon and each successful trial the patients get 10 points and the balloon became much bigger. Because the balloon has the possibility of explosion on each inflation, participants needs to press button “5”to stop blowing the balloon and get benefit in time. There were totally 100 trials. Before the test started, participants were told to gain as many scores as possible, and total score were
present at the lower right corner of the monitor. BART scores (“Total number of balloon inflation”/“Total number of unexploded balloons”) were used to assess the impulsive risk decision making.

2.4.5 Delay Discounting Task (DDT)

In DDT test, delayed reward was set as 1000 Chinese yuan (approximately 158 $), delay time were 2-day, 1 week, 1 month, 3 month, 6 month and 1 year. The beginning immediate reward was 500 Chinese yuan (approximately 15.8 $). Participants were told to choose the smaller immediate reward over a larger but delayed reward. The larger delayed reward stays the same, while the immediate reward changed from trial to trial according to a decreasing-adjustment algorithm until an indifference point (an indifference point means the subject changed its choice between immediate and delayed rewards). The hyperbolic decay model

\[ V = \frac{A}{1+kd} \]

were used to calculate the discounting rate \( k \) to reflect individuals` risky decision making function[31]. A higher \( k \) means the subject had a much higher impulsiveness.

2.4.6 MA-Stroop Task

A Chinese version of MA Addiction Stroop Task was applied to measure MA related attentional bias. The words used involved eight MA-related words and neutral words. These words were matched for stroke number of Chinese characters and frequency based on searching results using the corpus of Beijing Language and Culture University (http://www.dwhyyjzx.com/cgi-bin/yuliao/). Each of the 16 words was presented eight times in four different colors (red, green, yellow, and blue). Every word was shown on the screen for 3000 ms. Participants were asked to ignore the meaning of the words by pressing the buttons corresponding to the color of the word presented as quickly as possible. Stimuli were presented in a pseudo-randomized non-stationary probabilistic sequence. Reaction time and errors of each participates were recorded. Attention bias was calculated through subtracted the time needed to name the color of the neutral words from the time taken to complete the MA related words.

All computerized cognitive tasks were programmed using the software “E-prime 2.0”
2.5 Procedures
Eligible participants were randomly assigned into CAT group and control group by researchers who did not involve in other parts of this research by using the simple random sampling method (random number table). Pre- and post-training assessments were conducted by another two trained doctors. During the treatment, patients in control group only received standard treatment in compulsory rehabilitation center. Participants included in the CAT group were also undergoing standard treatment, in addition, they received the CAT training program last for 4 weeks, 20 sessions, five times a week, 60 min duration at a time. The study was approved by the Ethics Committee for Human Research of the Shanghai Mental health center and all participants had already provide a signed informed consent before inclusion.

During each training session, participants in CAT group completed each of the four training programs twice, which last about 60 min in 4 consecutive weeks. Along with the patients in the control group, they also receive health education programs including behavioral therapy, judicial education, cultural and sports activities.

2.6 Safety
Safety was assessed at every treatment session by a self-administrated CAT training form by recording spontaneous adverse events such as craving, headache, and dizziness.

2.7 Statistical analyses
Data were analyzed using SPSS, version 21.0. Group differences were compared using Student t-test or analysis of variance (ANOVA) for continuous variables and chi-square test for categorical variables. Generalized Estimating Equations (GEE) was used to assess the main effects of groups (Treatments: CAT vs. sham ST), time (Time: Pre vs. Post-treatment), and group-by-time interactions for all cognitive tests variables. The alpha level were reported with p < 0.05 (two-sided tests). Bonferroni test were used to resolve significant interactions for post hoc analysis.
3. Results

3.1 Demographic and MA use information

Participants’ demographic characteristics and drug use histories were shown in Table 1. There were no differences between the CAT group and control group in terms of average age, education, marriage, onset age of first MA use, abstinence time, duration of MA use, dose and frequency. (Table 1).

Table 1. Demographic and drug use characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CAT group</th>
<th>F/</th>
<th>p</th>
<th>Control group</th>
<th>F/</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>32.70±5.27</td>
<td>1.200</td>
<td>0.280</td>
<td>35.05±8.02</td>
<td>0.474</td>
<td>0.280</td>
</tr>
<tr>
<td>Education (year)</td>
<td>10.00±2.43</td>
<td>0.525</td>
<td>0.474</td>
<td>9.55±1.36</td>
<td>0.773</td>
<td>0.474</td>
</tr>
<tr>
<td>Age of onset (years)</td>
<td>24.45±6.54</td>
<td>0.084</td>
<td>0.773</td>
<td>25.15±8.56</td>
<td>0.639</td>
<td>0.773</td>
</tr>
<tr>
<td>Abstinence (months)</td>
<td>4.30±1.17</td>
<td>0.224</td>
<td>0.639</td>
<td>4.10±1.18</td>
<td>0.891</td>
<td>0.639</td>
</tr>
<tr>
<td>Duration of MA use (year)</td>
<td>7.00±2.73</td>
<td>0.351</td>
<td></td>
<td>0.891</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dose of MA use (g/day)</td>
<td>0.60±0.31</td>
<td>0.294</td>
<td>0.591</td>
<td>0.66±0.39</td>
<td>0.555</td>
<td>0.591</td>
</tr>
<tr>
<td>Frequency of MA use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Everyday</td>
<td>14 (70%)</td>
<td>2.424</td>
<td>0.555</td>
<td>10 (50%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3–5 times a week</td>
<td>4 (20%)</td>
<td>8 (40%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once a week</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–3 times a month</td>
<td>1 (5%)</td>
<td>1 (5%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M = mean, SD = standard deviation.

3.2 Effect of CAT on cognitive functions

In the test of CogState Battery, ISL scores, CPAL scores increased significantly in CAT group, while the control group patients did not reported this significant changes. Significant time*group effect (F = 31.78, p = 0.00), group effect (F = 4.53, p = 0.03) and time effect (F = 9.37, p = 0.00) were observed in ISL scores. Group effect (F = 5.95, p = 0.02) and time effect (F = 5.45, p = 0.02) in CPAL scores also reach significant level. Although group*time effect (F = 6.68, p = 0.01) were significant in SEC scores, patients in control group decreased significantly compared to CAT group. GML and TWOB scores did not show significant change between groups (Figs. 7, 8 and 9).
**Fig. 7.** ISL before and after invention

**Fig. 8.** CPAL before and after invention
3.3 Effect of CAT on impulsive risk decision-making

An effect of training were observed in CAT group in three of these risk decision-making tasks. First, those undergoing CAT training significantly decreased their discounting rate while there were not significant in control group. The group*time interaction effect was significant at each of the delayed time. (Fig. 10). Training effect was also observed with measures of IGT (Table 2 and Fig. 11). The treatment-by-time effect, group effect (F = 4.84, p = 0.03) and time effect (F = 214.60, p = 0.00) were significant (F = 49.07, p = 0.00).

In BART test, significant group-by-time interaction (F = 22.75, p = 0.00) and time effect (F = 5.16, p = 0.02) had reached significant level. Further comparison showed CAT group had a better performance than control group after CAT invention.
**Fig. 10.** The discounting change before and after CCRT training. Change in discounting ln (k) for CCAT and control groups, calculated as post-training minus pertaining. Negative values indicate a decrease in discounting. 2, 7, 30, 90, 180, 360 were delayed time in DDT test.

**Fig. 11.** The IGT score after CCAT or control training. The CCAT group reported significant changes after 20 sessions training compared to control group (p = 0.00).

3.4 Effect of CAT on attention bias

There were no significant differences between the two groups in attention bias. The treatment-by-time effect did not reach significant level (F = 0.92, p = 0.34). Only time effect (F = 6.23, p = 0.01) was observed.
<table>
<thead>
<tr>
<th>Task</th>
<th>CRT group (M ± SD)</th>
<th>Control group (M ± SD)</th>
<th>Time (F, p)</th>
<th>Group (F, p)</th>
<th>Time*Group (F, p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGT</td>
<td>-47.45 ± 25.48</td>
<td>-2.40±25.83</td>
<td>-47.80±19.14</td>
<td>-31.90±18.17</td>
<td>4.84, 0.03*</td>
</tr>
<tr>
<td>BART</td>
<td>10.68 ± 5.08</td>
<td>6.95 ± 2.31</td>
<td>9.34 ± 3.47</td>
<td>8.03 ± 2.08</td>
<td>5.16, 0.02*</td>
</tr>
<tr>
<td>Attention bias</td>
<td>5.19 ± 2.52</td>
<td>3.08 ± 1.49</td>
<td>5.17 ± 2.85</td>
<td>4.23 ± 2.97</td>
<td>6.23, 0.01*</td>
</tr>
</tbody>
</table>

* p < 0.05, M = mean, SD = standard deviation
3.5 Safety

No patients reported any discomfort during the whole training session.

4. Discussion

To the best of knowledge, this is the first pilot study that combined cognitive training and cognitive bias treatments adding MA related stimulants in MUD treatment programs. The results support our hypotheses that CAT can repair cognitive impairment and correct cognitive bias. As expected, compared to control group, MUD patients in CAT group showed improvement on cognitive function measures of CogState Battery. Impulsive risk decision-making, measured by DDT, IGT and BART also improved in CAT group after 20 sessions of CAT training.

Previous studies have proved that computerized cognitive related training showed promising treatment effect and even brain plasticity in substance use disorder patients, such as stimulants, cocaine, methamphetamine, alcohol and nicotine [32, 33]. However, these researches either only used cognitive training such as working memory training or cognitive bias modification training. While this research has provided primary evidence that of combining general cognitive training and attentional bias retraining may further enhancing treatment prognosis.

One notable finding is that the along with cognitive function improvement, patients in CAT group also showed better performance of impulsive control abilities tasks, which is in line with previous studies. These researches have already indicated the underlining relationship between cognitive training and impulsive control enhancement, either measure by cognitive tasks or self-report measures [32, 34]. In this study, our results not only revealed the similar trend, but also in cognitive tasks such as DDT and IGT. Importantly, previous study either included people with stimulant dependence including cocaine and MA, or self-report measures. However, as in our study, we only recruited patients with moderate to severe MUD, and these patients also had a better performance in cognitive task. Thus, while our findings are small and preliminary, our pilot study have provided further evidence that cognitive training can affects impulsive control rehabilitation in SUD patients.

Unexpectedly, CAT training did not show improvement in social cognition. However, pre-
and post-evaluations of SEC task revealed that, patients in control group showed a trend of deterioration. Our previous study found that social cognitive also showed dysfunction in individuals with MUD [35]. Other researches have proved that enhancing working memory capacity could better help patients dealing with negative social emotional events[36]. Therefore, our research may indicating that 4 weeks CAT are not enough to facilitate the recovery of social cognitive but could serve as protective factors.

A growing body of researches indicating that substance related attention bias can be retrained directly [37], with favorable short-term effects and clinical effectiveness in alcohol abuse patients [38]. While in this research, attention bias did not show significant changes after CAT training. Other researches also suggested home environments and mobile technology may promote robust reductions in bias and clinical effectiveness [39]. Our previous study on MA related attention bias also showed that although there was also no significant difference in behavioral performance between MUD and health controls, increased P300 amplitudes by MA-related words were observed among MUD patients compared to health controls [40]. However, this was a small pilot study, well-powered clinical trials combined event related potentials (ERPs) is required to obtain a more conclusive answer on the potential clinical effectiveness of attention bias modification.

This study has several limitations. First, the relatively small sample (20 each group) limited us to further highlight the difference of clinical efficacy between the two groups. Given various constraints, we were unable to increase the number of participants to be recruited, however, considering our baseline data showed normal distribution and homogeneity of variance, which can still increasing the credibility of our findings. Another limitation is that, in order to make the task more engaging and relevant, we added MA related pictures during training. But we did not have enough sufficient trials to explore stimulus effects in these patients. However, to keep the training as effective as possible, we have invited these patients rating these pictures (valance, arousal, dominance and craving) and only used pictures that exceeds five points. Importantly, even drug related pictures can also induce a strong attention bias and craving[41]. Thirdly, given the increased risk of induced craving during CAT training, we were careful about the side-effect CAT may bring.
Relaxation training was conducted at the end of each training session and no patients had reported discomfort after invention.

In conclusion, results from our study support the fundamental dual process theory underlying cognitive-based treatments for SUD individuals. Four weeks (20 sessions) of CAT training could both better facilitating cognitive function rehabilitation and reducing impulsivity-related decision-making in MUD subjects. Future studies will focus on fMRI as well as electroencephalogram to find the underlying mechanisms of CAT.

**Ethics approval and consent to participate**
All procedures followed were in accordance with the ethical standards of the Norwegian National Committee for Research Ethics in the Social Sciences and the Humanities and with the Helsinki Declaration of 1975, as revised in 2000.

**Consent for publication**
All participants signed consent forms.

**Availability of data and material**
Please contact the author for data requests.

**Declarations of interest**
The authors declare that there are no known conflicts of interest associated with this publication.

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**Authors’ contributions**
All authors contributed to the design and execution of this study. Min Zhao was in charge of the initial research design and the randomized controlled trial. Na Zhong, Hang Su, Tianzhen Chen, Haoye Tan, Haifeng Jiang, Ding Xu, Huan Yan and Dawen Chen acquired the clinical
data. Xiaotong Li was in charge of programming the cognitive tasks used during the study. Youwei Zhu did the CCAT intervention. Together with help of Jiang Du, conducted the data analysis and drafted the manuscript. All authors provided critical revision of the manuscript for important intellectual content. All authors critically reviewed content and approved final version for publication.

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Abbreviations:
ATS: amphetamine-type stimulant
MA: methamphetamine
mHealth: mobile health
SDT: self-determination theory
SUD: substance use disorder
MUD: methamphetamine use disorder
CAT: cognitive addiction therapy

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