Neurology, Psychiatry and Brain Research 34 (2019) 13–21

Contents lists available at ScienceDirect

Neurology, Psychiatry and Brain Research

journal homepage: www.elsevier.com/locate/npbr

Mindfulness-based substance abuse treatment (MBSAT) improves executive functions in adolescents with substance use disorders

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ARTICLE INFO

Keywords:
Mindfulness
Executive function
Methamphetamine use disorders
Adolescence

ABSTRACT

Objective: Studies show promise for the treatment of substance abuse through mindfulness practice. However, the neural mechanisms of mindfulness practice for treating substance use disorders are still unclear. Evidence suggests that major deficits in executive functions such as inhibitory control, risky behavior and decision-making, psychological flexibility, and working memory are associated with a craving to use. The current study aims to investigate the efficacy of mindfulness practice on improving executive functions, assessed by neuroscientific tools, in a group of adolescents with methamphetamine use disorders.

Method: Forty adolescents (18–21 years old) with methamphetamine use disorders were selected and randomly assigned to experimental (n = 20) and control groups (n = 20). Subjects were assessed three times: before the intervention, immediately after and one month after treatment. Mindfulness-based substance abuse treatment (MBSAT) was administered for 12 sessions, two 50–60 minutes sessions per week.

Results: Results Mixed model ANOVAs analysis showed that mindfulness-based intervention improved executive functions in the experimental group compared to controls.

Conclusions: This study is the first to support the benefits of mindfulness-based practice in improving executive functions of adolescents with methamphetamine use disorders.

1. Introduction

In recent decades, research on the effectiveness of mindfulness on adolescents has rapidly increased (Quach, Mano, & Alexander, 2016). Mindfulness was brought to the spotlight mainly by Jon Kabat-Zinn in the early1970s. It is defined as an awareness of one's mental, physical, and emotional phenomena in the present moment, accompanied by awareness, nonjudgmental attitude, and grown acceptance (Kabat-Zinn, 1991, 2013).

Top-down and bottom-up neurological processes are the center of attention in many addiction treatment theories (McKim & Boettiger, 2015; Witkiewitz et al., 2014). The main models of addiction have focused on deficits or disruption in top-down executive function (EF) processes (Nichols, 2015). Cognitive processes are an important goal in the treatment of drug abuse disorder (Sofuoglu, DeVito, Waters, & Carroll, 2013). In particular, EF impairments are associated with substance use disorder (SUD) (Fernandez-Serrano, Pérez-García, & Verdejo-Garcia, 2011). Studies show that methamphetamine use leads to structural and functional changes in the brain of methamphetamine users (Scott et al., 2007). These changes have been related with deficits in diverse cognitive functions including attention control (Salo et al., 2009), memory (Rendell, Mazur, & Henry, 2009) and decision-making (Hoffman et al., 2008).

Recent research on treatments for substance use disorders focus on cognitive goals (for instance, Robinson, Waters, Kang, & Sofuoglu, 2017). Treatments that target deficits in executive functions or changes in automatic processing in people with substance abuse seem promising (Sofuoglu et al., 2013). An extensive body of research has linked deficits in executive functions to addiction, and this relationship has become the core of many addiction theories (Fernandez-Serrano et al., 2011; Meil, LaPorte, & Stewart, 2012). Executive function is defined as the ability to organize the sequence of future-directed or goal-directed behavior (Fuster, 2011). In adolescents, problems or deficits in executive functions are associated with an increased risk of tobacco use, alcohol consumption, and other potentially addicting behaviors such as excessive gaming and overeating (Riggs, Spruijt-Metz, Chou, & Pentz, 2012). Exposure to nicotine in adolescence can increase executive function problems by interrupting the development of neural

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https://doi.org/10.1016/j.npbr.2019.08.002
Received 18 July 2019; Received in revised form 16 August 2019; Accepted 19 August 2019
Available online 05 September 2019

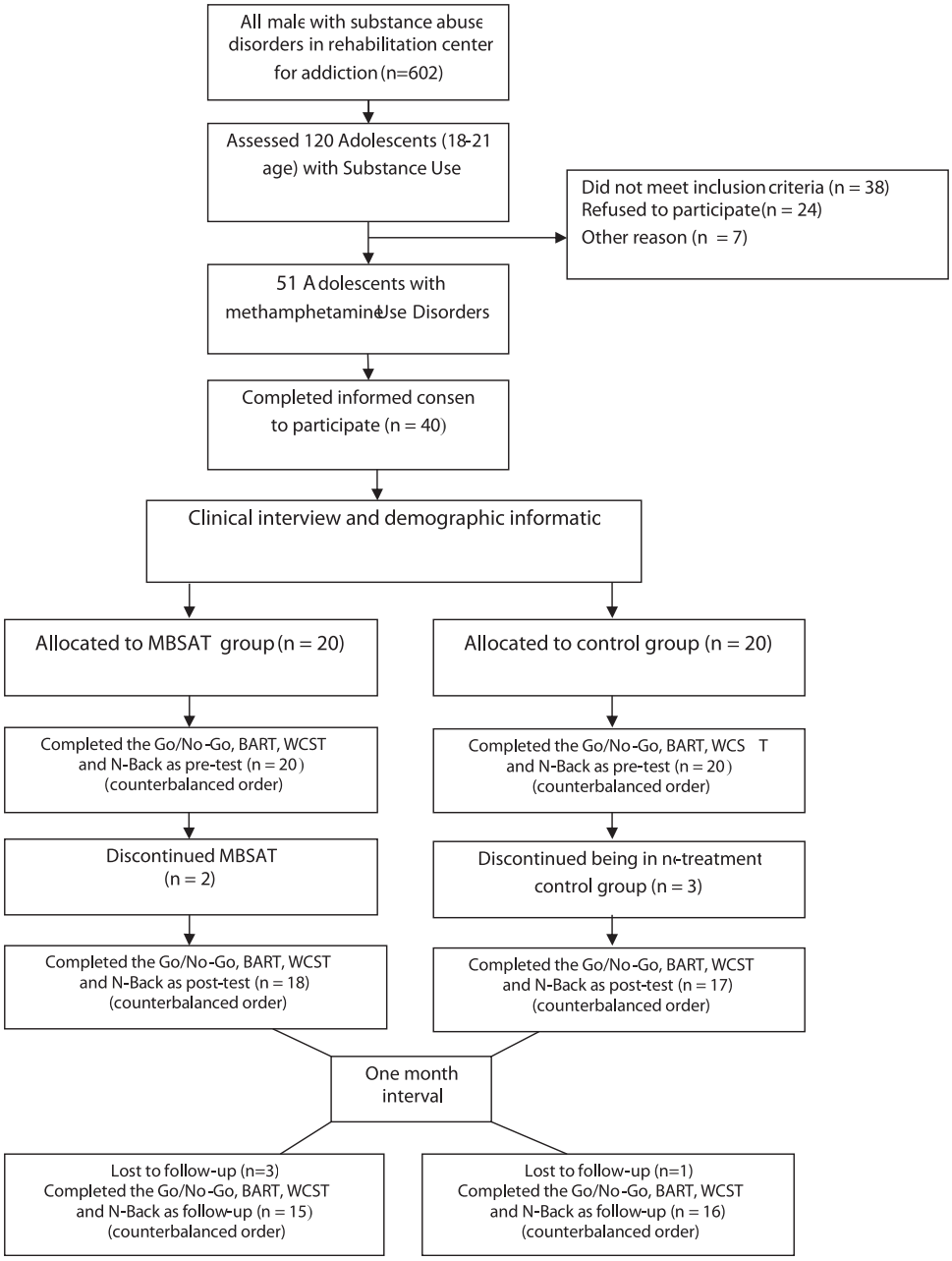

Fig. 1. Flowchart of study inclusion.

connections and preventing limbic signals that regulate impulsivity (Kandel & Kandel, 2014).

In the last decade, mindfulness-based interventions have become increasingly popular, so that they are developed and used for many different goals (Beattie, Hankonen, Salo, Knittle, & Volanen, 2019). Mindfulness treatment as an intervention method has proved to be effective both in the adolescent population (Himelstein, Hastings, Shapiro, & Heery, 2012) and substance abusers (Bowen, Chawla, & Marlatt, 2011). Hence, mindfulness is considered a key element in substance abuse treatment and prevention. Various studies have investigated the effect of mindfulness as an intervention for youth (Black, Milam, & Sussman, 2009), incarcerated adolescents (Himelstein et al., 2012; Leonard et al., 2013), and adolescents with substance abuse (Himelstein, 2011; Robinson, Ladd, & Anderson, 2014). Mindfulness-based intervention has also been administered experimentally on adolescents with substance use disorders (Himelstein, 2011; Himelstein, Saul, Garcia-Romeu, & Pinedo, 2014). These studies demonstrated that mindfulness has the potential and can be used as an intervention method for adolescents with substance abuse. In a study on the effect of mindfulness-based intervention on self-regulation, perceived drug risk, and impulsiveness of sixty incarcerated adolescents participating in substance abuse treatment, Himelstein (2011) demonstrated that impulsiveness significantly decreased post-intervention, while perceived drug risk increased significantly.

Mindfulness-based intervention is a promising approach for enhancing and expanding attention and executive functions; especially when executive functions are measured with computerized tools (Mak, Whittingham, Cunnington, & Boyd, 2018). However, Josefsson, Lindwall, and Broberg (2014) findings emphasize that there is a complex relationship between executive functions and cognitive processes. Also, while recent studies have proven that mindfulness practice positively affects executive functions, the main mechanism of this effect is not adequately explained (Teper & Inzlicht, 2012). Long-term cocaine use is associated with cognitive deterioration in most cognitive

Table 1
Structure and guideline of each MBSAT session.

MBSAT Session	The theme of MBSAT Session
Session 1	***Introduction to the Program***: The first session includes the following: 1) Informal Greeting. 2) Introduction to the Program. 3) Group Agreements: Step 1: Distinguishing Rules vs. Agreements, Step 2: Presenting and Agreeing to the Preferred Group Behaviors. 4) Defining Mindfulness: Step 1: Lion Mind vs. Dog Mind Metaphor, Step 2: Standard Definition of Mindfulness. 5) Meditation: Mindfulness of Deep Breathing: Step 1: Mindfulness of Deep Breathing, Step 2: Processing the Meditation. 6) Group Poll: Learning Interests of the Youth. 7) Homework and Close-Out.
Session 2	***Mindfulness of Drugs and Their Health Effects***: The session 2 includes the following:1) Centering Meditation. 2) Mindful Check-In: Step 1: The Mindful Check-In, Step 2: Processing the Deep Breath. 3) Drug Classifications Activity: Step 1: Brainstorming Session, Step 2: Major Drug Category Education, Step 3: Drug-Matching Competition. 4) Fatal Drug Combinations. 5) Meditation: Mindfulness of Deep Breathing. 6) Homework and Close-Out.
Session 3	***Reacting vs. Responding:*** The session 3 includes the following:1) Role Play: Mental vs. Physical Power: Step 1: Initial Skit, Step 2: Process Initial Skit, Step 3: Second Skit, Step 4: Processing of Second Skit. 2) Discussion: Reaction vs. Response: Step 1: Defining Reacting and Responding, Step 2: The Copy Machine Metaphor. 3) STIC (Stop, Take a breath, Imagine the future consequences, Choose) Contemplation. 4) STIC Role-Plays. 5) Meditation: Mindfulness of the Breath. 6) Mindful Check-In.7) Homework and Close-Out.
Session 4	***Mindfulness of Delusion***: The session 4 includes the following: 1) Centering Meditation. 2) Poem: "The Perfect High": Step 1: The Perfect High, Step 2: Processing the Underlying Meaning of "The Perfect High". 3) Mindful Check-In. 4) Debate: Pros and Cons of Substance Use: Step 1: Splitting Into Teams and Defining A Debate, Step 2: Brainstorming Session, Step 3: The Debate. 5) Personal Pros and Cons of Substance Use: Step 1: Personal Pros and Cons of Substance Use Contemplation, Step 2: Personal Pros and Cons Worksheet, Group Discussion. 6) Meditation: Bodyscan. 7) Homework and Close-Out.
Session 5	***Emotional Awareness***: The session 5 includes the following: 1) Centering Meditation: Bodyscan. 2) Emotional Categories: Step 1: Emotions Brainstorm, Step 2: Defining Emotional Categories, Step 3: Discussion on Emotional Categories. 3) Emotional Expression and Gender Norms: Step 1: The Gender Box ("Man" or "Woman" Box), Step 2: Tree of Emotions. 4) Stand If: Step 1: Stand If Instructions, Step 2: Facilitate Stand If, Step 3: Processing Stand If. 5) Deep Disclosure: Step 1: Prep, Step 2: Facilitate Deep Disclosure, Step 3: Brief Compassion Meditation. 6) Game: Concentration. 7) Homework and Close-Out.
Session 6	***The Brain and Drugs***: The session 6 includes the following: 1) Youth-Led Centering Meditation. 2) Mindful Check-In. 3) Brain Presentation I: Major Brain Areas and the Role of Pleasure: Slide 1: Four Brain Lobes, Slide 2: Frontal Lobe, Slide 3: Dopamine, Pleasure, and Substance Use. 4) Meditation Break. 5) Brain Presentation II: Substance Use, Trauma, and the Mindful Brain: Slides 1: Dopamine in Synapses, Slide2: Tolerance and Withdrawal, Slides 3: Drug Use and Bad Habits, Slide 4: Mindfulness and the Brain. 6) Meditation: Bodyscan. 7) Homework and Close-Out.
Session 7	***Mindfulness of Craving:*** The session 7 includes the following: 1) Youth-Led Centering Meditation. 2) Mindful Check-In. 3) Mindful Eating Activity: Step 1: Mindful Eating Instructions, Step 2: Mindful Eating Exercise. 4) The Role of Craving in Drug Use: Step 1: Discussion on Role of Craving in Drug Use, Step 2: Triggers and Urges Flow Chart. 5) Nonmoving Bodyscan. 6) Worksheet: Roots of Craving. 7) Homework and Close-Out.
Session 8	***Mindfulness of Triggers:*** The session 8 includes the following: 1) Youth-Led Centering Meditation. 2) Mindful Check-In. 3) Mindfulness of Triggers: Step 1: Triggers Visualization, Step 2: Defining Triggers. 4) Three Levels of Influence: Step 1: Presentation of the Three Levels of Influence on Drug Use, Step 2: Personal Trigger Worksheet, Step 3: Discussion on Personal Triggers Worksheet. 5) Meditation: Noting Awareness. 6) Homework and Close-Out.
Session 9	***The Family System and Drugs***: The session 9 includes the following: 1) Youth-Led Centering Meditation. 2) My Children Contemplation. 3) The Effect of Drug Use on Family Relationships: Step 1: Brainstorming Themes, Step 2: Highlighting the Core Relationship Theme. 4) Addiction and Intergenerational Trauma: Step 1: Introducing the Genogram, Step 2: Cycles of Addiction and Trauma, Step 3: Personal Genogram Worksheet. 5) Meditation: Compassion for Family Members. 6) Mindful Check-In. 7) Homework and Close-Out.
Session 10	***Mindfulness of the Peer System***: The session 10 includes the following: 1) Peer Pressure Role-Play. 2) Discussion: Friends vs. Accomplices. 3) Mindful Check-In With Prompt. 4) Mindful Communication: Step 1: Review STIC, Step 2: Mindful Communication Interventions. 5) Youth Developed Peer Pressure Role-Plays: Step 1: Peer Pressure Situation Brainstorm, Step 2: The Role-Play. 6) Meditation: Compassion for Friends and Accomplices. 7) Homework and Close-Out.
Session 11	***Mindfulness of the External Environment:*** The session 11 includes the following: 1) Youth-Led Centering. 2) Mindful Check-In. 3) Mindfulness of External Environment: Step 1: Three Levels of Influence Review, Step 2: Ecological Systems Theory and the Environmental Level of Influence, Step 3: Environmental Influences on Drug Use. 4) Transforming Systems of Influence: Step 1: Transforming Systems Worksheet, Step 2: Group Discussion. 5) Meditation: Compassion Meditation Toward Community. 6) Homework and Close-Out.
Session 12	***Closing Ceremony:*** The session 11 includes the following: 1) Meditation: Final Practice. 2) Mindful Check-In. 3) Focus Group: Step 1: Defining Focus Groups, Step 2: Facilitating the Focus Group. 4) Group Appreciations: Step 1: Explaining Group Appreciations, Step 2: Group Appreciations. 5) Pizza Party/Food Celebration. 6) Certificates of Completion. 7) Closing Dedication and Ceremony.

Himelstein and Saul (2015)

processes, of which there is robust evidence on sustained attention, response inhibition, working memory, and decision-making. Opium, methamphetamine, and alcohol users have also shown lasting deficits in executive functions (Stavro, Pelletier, & Potvin, 2013).

Generally, neuroscientific studies have determined that two interacting neural circuits are affected by mindfulness (Zelazo & Lyons, 2012); the first is the top-down pathway, which is associated with self-regulation of thoughts, emotions, and behaviors, controlled by the prefrontal cortex, and includes inhibitory control and working memory (Riggs, Black, & Ritt-Olson, 2015). The second circuit is the bottom-up pathway, which directly controls stimulation and emotion. Mindfulness causes a decrease in the activity of brain regions involved in stimulation and emotion (amygdala and posterior putamen) (Taylor et al., 2011). Since the regions and circuits involved in substance abuse and mindfulness are similar, mindfulness-based approaches for treating substance abuse are promising. Studies have linked mindfulness to top-down and bottom-up neurological processes in adolescence, demonstrating that mindfulness practice can prevent substance uses before it becomes problematic (Riggs et al., 2015).

As mindfulness training is a promising treatment for substance abuse (Chiesa & Serretti, 2014) and as interest in mindful meditation as a practice for learning cognitive skills has increased (Tang, Hölzel, & Posner, 2015), the current study aims to determine the efficacy of mindfulness-based substance abuse treatment (MSAT) on improving executive functions in adolescents with substance use disorders. Himelstein and Saul (2015) designed and developed MBSAT specifically for adolescents with methamphetamine use disorders. We believe this is the first study to assess the effect of mindfulness-based treatment on executive functions of adolescent methamphetamine users.

2. Method

2.1. Participants

The sample consisted of forty adolescent boys who were methamphetamine addicts referred to the drug rehab centers in Ardabil (Mean age = 19.45, SD = 1.12). They were gathered through convenience sampling based on inclusion criteria: (1) age range of 18 to 21 years, (2) diagnosis a methamphetamine use disorder based on DSM-V criteria including at least 12 month history of methamphetamine use before beginning of the experiment, (3) lack of other substance related use disorders except for tobacco smoking, as verified by a urine drug screen, (4) lack of other psychiatric disorders except for substance use disorder assessed via a Structured Clinical Interview for DSM-5 Disorders by an experienced psychiatrist of rehabilitation center for addiction, (5) and not to be on psychotropic medications during the study. Participants were randomly assigned to experimental (mindfulness-based treatment; n = 20) and control (n = 20) groups. Five participants from the

experimental group and four from the control group withdrew before treatment was completed; thus the final analysis was conducted on15 members of the experimental and 16 members of the control group (Fig. 1).

2.2. Procedure

All participants completed the assessment tools in the pretest, posttest, and a one-month follow-up. The experimental group received MBSAT for 12 sessions consisting of two 50–60 minute-long sessions each week. The current study complied with the ethical principles set forth in the latest edition of the Declaration of Helsinki, and it is approved by the ethical committee of Shahid Beheshti University (IR.SBU.ICBS.97/1036). Subjects granted consent before participation and were free to withdraw at any point during the study. Participants in the control group just waiting without any intervention and received no interventions during the study however, they were recruited for MBSAT protocols by the end of the study.

2.3. Description of the MBSAT program

MBSAT for adolescents is a group-based training program that combines mindfulness, self-awareness, and substance abuse treatment strategies for adolescent substance users. It is an evidence-based program that provides an educational framework for professionals to pursue their interests by selecting the relevant sessions in aweekly manner. Each session includes clear guidelines, examples, points to discuss, dramatic scenarios to depict common types of resistance, and optional speeches. The various sessions of this method cover basic principles of working with adolescents (i.e., relationship building, working with resistance) as a comprehensive training program (Himelstein & Saul, 2015). One of MBSAT's distinguishing features is that it dedicates three sessions to the mutual effects of drugs and family, peers, and external environment. This training program includes all strategies and primary tools for relapse prevention along with mindfulness activities including mindful meditations and informal mindfulness techniques (Table 1).

2.4. Persian adaptation of MBSAT program

Two professionals translated the MBSAT protocol from English to Persian; one was a psychologist specialized in mindfulness, and the other was an English language specialist. The two translations were compared and the differences were discussed to ensure consistency between the translations. As a final confirmation, a committee of four psychologists evaluated each of the twelve sessions. All committee members deemed the MBSAT suitable for Iranian adolescents. After a pilot study on ten adolescents with substance use disorders, minor modifications were made to the protocol to ensure its suitability for the Iranian culture, and the final version of MBSAT was prepared for administration.

2.5. Measures

2.5.1. Go/No-Go task

Go/No-Go test is one of the most widely used neuropsychological tasks for assessing response inhibition. As one of the main components of executive functions, response inhibition is highly correlated with cognitive control (Peterson & Welsh, 2014). In the first part of this task, participants have to quickly give a stimulus-congruent response (Go, execute, or run). In the other part (No-Go, inhibit, stop), a second stimulus is presented after the first, upon seeing which the participant should withhold response. (See Fig. 2).

2.5.2. Balloon analogue risk task (BART)

The BART test is one of the main neuroscientific tools for measuring the tendency toward risky behavior and decision-making (Lejuez et al., 2002). In the computerized version of the task, a balloon appears on the screen, which the participants can pump by pressing the button underneath. There are two boxes on the screen, one as a temporary safe and the other a permanent one. The amount of money in each box is displayed on it. With each pump to the balloon, an amount of money is added to the temporary box. Participants can either pump more or press the "claim money" button. If they choose to do the latter, a new balloon appears on the screen and the money in the temporary box is transferred to the permanent safe (the number of balloons is limited to 30). Risk-taking decision makers prefer to ignore the risk of popping the balloon, therefore trying to earn larger amounts of money by pumping further. In this task, the adjusted score (i.e., the average number of pumps for the balloons that did not pop) is the primary score of the test and the indicator for risk-taking. Moreover, the maximum and minimum number of balloon pumps is considered as test scores (See Fig. 2).

2.5.3. Wisconsin card sorting test (WCST)

Wisconsin Card Sorting Task (WCST) is one of the main tools that measure the performance of the prefrontal cortex (Romine et al., 2004), particularly dysfunction of the dorsolateral prefrontal cortex (Demakis, 2003). In the computerized version of this task, four sample cards appear on top of the screen, each showing different shapes (triangular, star, cross, and circle) in different numbers (one to four) and colors (green, blue, yellow). At the bottom of the screen, an additional deck of 64 cards is displayed with only the top card facing up. Participants have to guess the sorting rule and place the card facing up in one of the four sample categories on top of the screen (by typing the number of the category). (See Fig. 2).

2.5.4. N-Back test

This task is one of the most frequently used tools for working memory assessment (Brewin & Smart, 2005). A number of visual stimuli appear on the screen in a continuous manner, sequentially, and at a speed of 300 ms. If the stimulus on the screen is similar to the one that appeared before it, participants should press "1". If they believe it is different, "2" should be pressed. In this task, the participants need only to store the information for one stimulus (i.e., the one right before the present stimulus). Moreover, when a new stimulus replaces the last one, the working memory needs to update the information. We used the number of correct responses and reaction time as scores. Numerous clinical and empirical studies have demonstrated the test's high validity (Kane, Conway, Miura, & Colflesh, 2007). (See Fig. 2).

2.6. Data analyses

Data were analyzed with SPSS 24. This study utilized a randomized pretest, posttest, and follow-up design (Rausch, Maxwell, & Kelley, 2003). Shapiro-Wilk and Levene's tests were used to assess the normality of distribution and homogeneity of variance, respectively. Next, we ran a Mixed model ANOVAs to assess the effectiveness of MBSAT in improving executive functions in adolescents with substance use disorders. In this analysis, the within-subject factor was time (pretest, posttest, follow-up), while group (experimental, control) was the between-subject factor.

3. Results

The data overview including the means and standard deviations of executive functions pre-test, post-test and follow-up is presented in Table 3 and Fig. 3. No significant group differences were seen for the demographic variables (Table 2).

Mixed model ANOVAs for the EFs task showed that the main effect of the group is significant in all components, except for completed categories in WCST task and accuracy Go in GO/NO-GO task: For the GO/

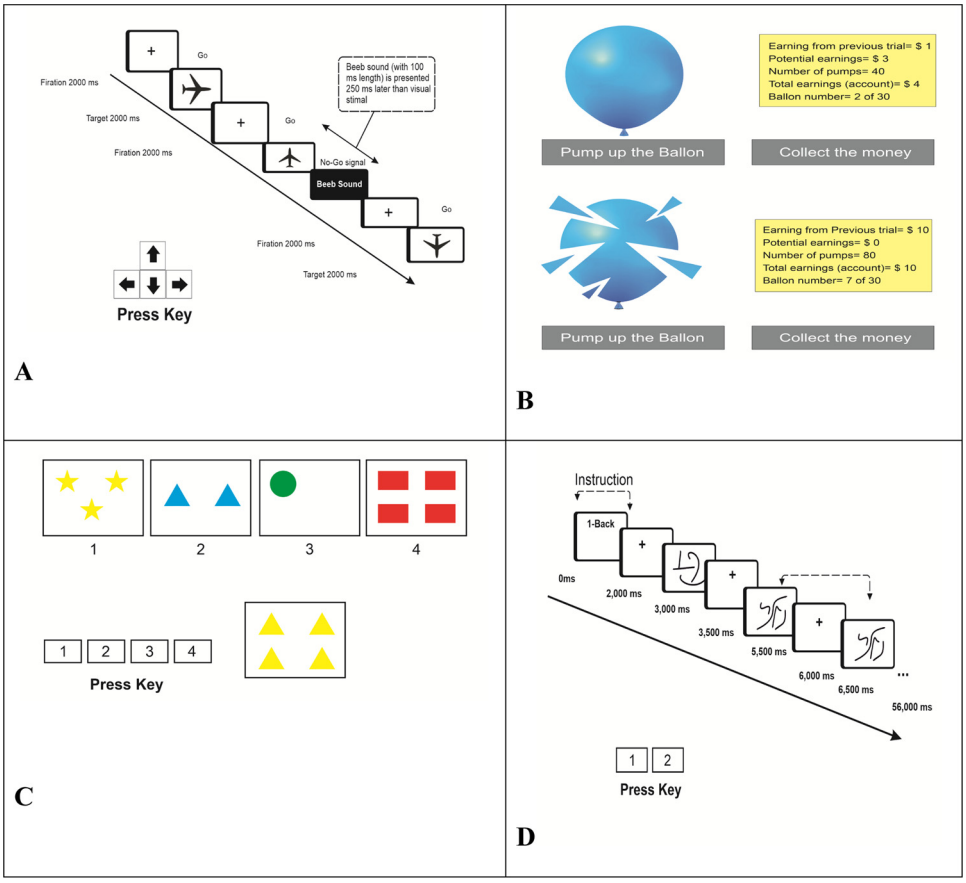

Fig. 2. Pictures of the executive function tasks: The Go-No-Go (A), BART (B), WCST (C) and 1-back (D).
All computerized tasks were presented on a 15.6" screen in counterbalanced order.

NO-GO task results showed a significant main effect of group on accuracy No-Go ($F_(1,29_) = 13.00$, $p < 0.042$, $\eta p2 = 0.13$). For the BART task, results showed a significant main effect of group on both adjusted value ($F_(1,29_) = 11.59$, $p < 0.002$, $\eta p2 = 0.28$) and max pumping ($F_(1,29_) = 5.02$, $p < 0.030$, $\eta p2 = 0.15$). Similarly, in the WCST task, results showed a significant main effect of group on perseverative errors ($F_(1,29_) = 4.61$, $p < 0.040$, $\eta p2 = 0.13$). In the WM task, showed a significant main effect of group on both on accuracy ($F_(1,29_) = 9.04$, $p < 0.005$, $\eta p2 = 0.23$) and response time ($F(1,29) = 12.29$, $p < 0.001$, $\eta p2 = 0.30$). (See Table 4). The interaction effect suggests that executive functions significantly improved in the experimental group compared to controls.

4. Discussion

The present study aimed to determine the effect of mindfulness-based substance abuse treatment (MBSAT) on improving executive functions in adolescents with methamphetamine use disorders. The findings suggest that MBSAT successfully improved response inhibition, risky decision-making, working memory, and cognitive flexibility in the experimental group. A few studies have investigated the effectiveness of mindfulness on executive functions in adolescence. For instance, in Quach et al. (2016) study, mindfulness meditation led to improved working memory capacity in the experimental group. According to Oberle, Schonert-Reichl, Lawlor, and Thomson (2012) findings, mindfulness is correlated with the main aspects of executive function, such as response inhibition. Andreu, Cosmelli, Slagter, and Franken (2018) also found that mindfulness practice improves response inhibition in smokers. In Upton and Renshaw study (2019), mindfulness had a small effect on risky behavior, while Broderick and Jennings (2012) reported mindfulness to be effective in reducing risky behaviors in adolescents. Finally, Dick, Niles, Street, DiMartino, and Mitchell (2014) showed that mindfulness practice improved PTSD symptoms by increasing psychological flexibility.

There is some evidence that heavy alcohol consumption along with other substance use in adolescence can cause dysfunction in the brain. Evidence from animal studies suggests that substance use strongly affects brain development, which in turn influences both cognitive and emotional processes. For example, in mice, exposure to alcohol in adolescence increases risky or impulsive decision-making in adulthood (Silveri, Dager, Cohen-Gilbert, & Sneider, 2016). Although addiction is a social concern, cognitive and emotional discoveries of cognitive neuroscience have given us a deeper understanding of this agonizing and deadly phenomenon. In the new perspectives emerging from several different fields, addiction is considered a compulsory cycle of substance-seeking behaviors, which results from unregulated neurological processes (Garland, Froeliger, & Howard, 2014). The key processes related to addiction include attention stimulation, automaticity, reward processing, emotion regulation, stress reactivity, and inhibitory control. Studies have shown that these processes stem from a wide array of individual differences in functional, anatomical, cortico-limbic, and striatal circuits. These differences lead to acquirement, preservation, and return of addictive behaviors (George & Koob, 2010). Since addiction is a habit, people who try to fight it struggle with behavioral and cognitive control. Cognitive control deficit includes inhibitory control, and cognitive regulation deficit consists of emotion and stress regulation (Garland, Boettiger, Gaylord, Chanon, & Howard, 2012). Neuroanatomical correlations of substance abuse include changes in the cingulate and prefrontal cortex, which have a key role in self-regulation and inhibitory control (Hester & Garavan, 2009). Studies have shown

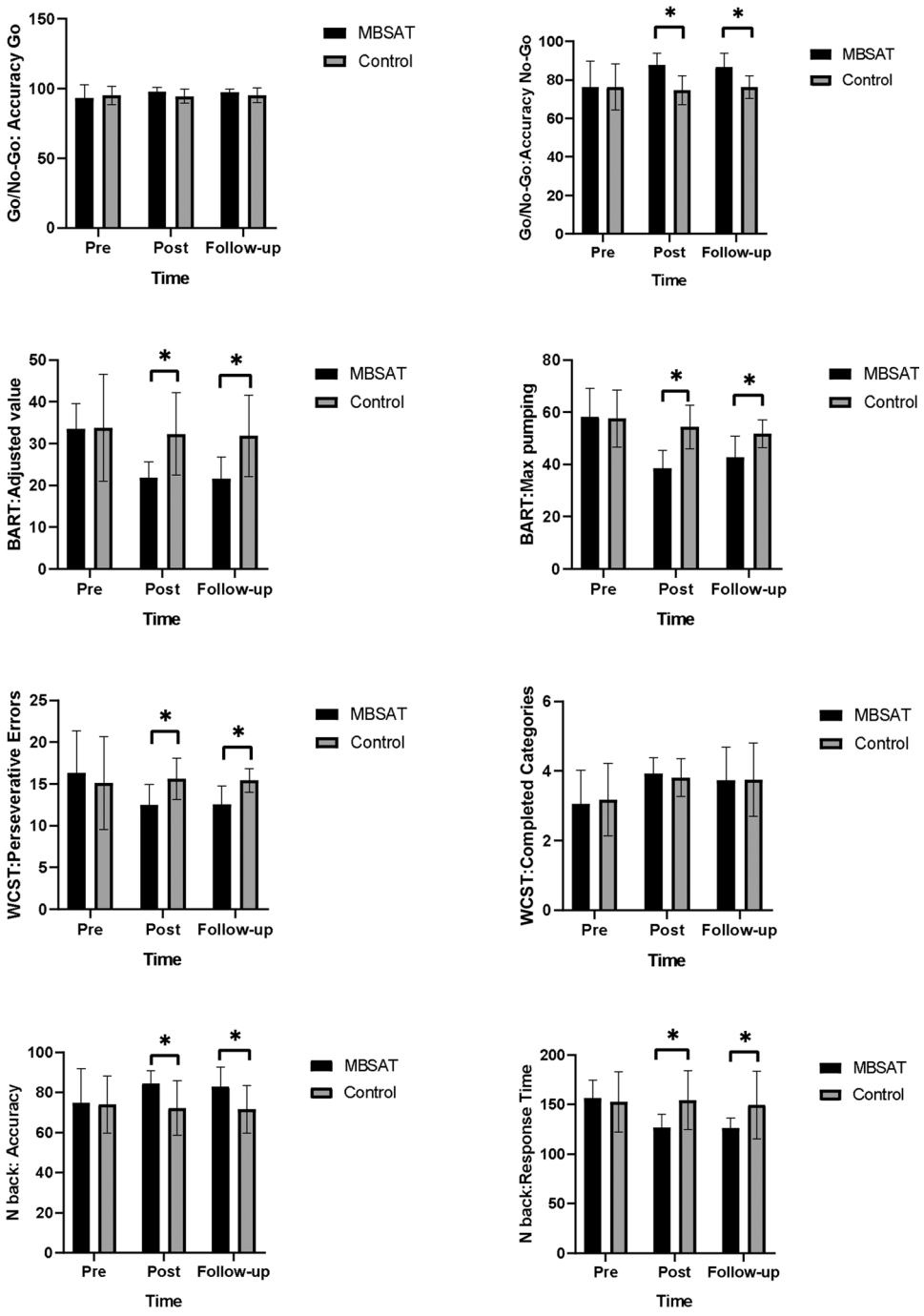

Fig. 3. Effects of intervention (MBSAT) on executive functions scores of participants in three-time points (pre-intervention, post-intervention, and follow-up). MBSAT = Mindfulness-Based Substance Abuse Treatment; WCST = Wisconsin Card Sorting Test; BART = Balloon Analog Risk Task.

that heavy alcohol and marijuana use in adolescence is associated with changes in the brain, including functional changes (e.g., deficits in executive functions), changes in white matter structure, and decreased gray matter (Bava et al., 2009).

Consistent mindfulness practice may stimulate neural and cognitive flexibility (Garland, Gaylord, Boettiger, & Howard, 2010). Functional Magnetic Resonance Imaging (fMRI) studies have demonstrated that mindfulness meditation regulates ACC and prefrontal activity, leading to increased activity and stronger connections in these regions (Etkin, Egner, & Kalisch, 2011; Froeliger, Garland, Modlin, & McClernon, 2012). Many studies suggest that mindfulness practice can change major risk mechanisms of addictive behaviors, craving, and relapse. Mindfulness practice can increase metacognitive awareness about the automatic processes related to craving, searching for drugs, using and triggers; therefore, the cycle of cognitive, emotional and bio-psychological mechanism can be stopped by using positive coping strategies (Garland et al., 2014). In addition, recent evidence suggests mindfulness can have beneficial effects on neurocognitive functions of upper brain regions; for instance, processes supported by the prefrontal cortex, and brain regions involved in self-regulation of behavior, cognition, and emotion (Lyvers, Makin, Toms, Thorberg, & Samios, 2014). Mindfulness practice and training is associated with amplified connections in the posterior attention network (Froeliger, Garland, Kozink et al., 2012). Mindfulness-based interventions can increase the capacity of shifting attention, i.e., the ability of posterior attention networks for becoming occupied or not occupied, and directing attention effectively

Table 2
Demographic data.

		experimental group	control group	p-value*
Sample size (*n*)		15	16	
Age – Mean (SD)		19.46 (1.12)	19.43 (1.15)	0.831
Sex – Male (female)		15 (0)	16 (0)	
Marital Status – Single (married)		11 (4)	13 (3)	0.278
Length of methamphetamine use		3.13	2.87	0.324
Age of onset of substance use – mean (SD)		15.46 (1.45)	15.25 (1.52)	0.612
Substance use by family members- Yes (No)		6 (9)	9(7)	0.479
Education	under the diploma	9	11	
	diploma	6	5	0.447

Note: M = Mean; SD = Standard Deviation; * = To analyze the differences between groups in the demographic variables, chi-square analysis or Fisher's exact test for categorical variables and t tests for continuous variables were used.

from one object to another (van den Hurk, Giommi, Gielen, Speckens, & Barendregt, 2010).

Changes in executive functions after mindfulness practice may be due to neurological flexibility or structural and functional changes that have occurred in the brain due to mindfulness practices (Tang & Posner, 2012). Many studies on mindfulness have demonstrated changes in brain regions that involve executive functions; e.g. regions related to the prefrontal cortex. For instance, the anterior cingulate cortex (ACC) has been shown to be more intensely activated during mindfulness practice (Hölzel et al., 2007). The activation of ACC, in particular, may be related to attention preservation and persistent occupancy during mindfulness practice, since this region often plays a role in directing attention and identifying conflicting information (Treadway & Lazar, 2010). In addition to ACC, studies have shown that prefrontal cortex, which is involved in complex cognitive behavior, is affected by mindfulness practice. For instance, Hölzel et al. (2007) it has been demonstrated that in participants who received mindfulness practice, the medial prefrontal cortex was much more intensely activated than in the control group who were solving math problems. Scholars have also observed an increase in gray matter in the hippocampus and frontal cortex (Luders, Toga, Lepore, & Gaser, 2009).

5. Conclusion

While applying mindfulness-based treatment to adolescents is on the increase, this study is the first to support the efficacy and benefits of mindfulness practice in improving executive functions in adolescents with methamphetamine use disorders. For this reason, more studies should be conducted to provide a deeper understanding of the effects of mindfulness practice on treating addiction in adolescents. Our findings add to the optimism regarding the effectiveness of mindfulness practice for adolescents. Moreover, this study confirms the efficacy of MBSAT protocol and suggests that researchers use it in future studies on different adolescent populations with various kinds of substance use disorders. One limitation of this study was the short follow-up period, and we recommend that studies with longer follow-up periods be conducted. Another limitation to mention is that there is no tool to measure brain changes after intervention, so future research can better describe brain changes using brain imaging techniques. This study was conducted on adolescents referred to drug rehab centers; therefore, it is also recommended that future studies investigate adolescent populations in other settings, such as incarcerated youth, etc.

Table 3
Means and SDs of EF tasks before and after interventions in groups.

Task	Outcome measures	Time	MBSAT M (SD)	Control M (SD)
Go/No-Go	Accuracy Go	Pre-intervention	93.13(9.37)	95.18(6.56)
		Post-intervention	97.73(3.19)	94.62(5.07)
		Follow-up	97.46(2.26)	95.31(5.30)
	Accuracy No-Go	Pre-intervention	76.26(13.41)	76.37(12.02)
		Post-intervention	87.93(6.19)	74.68(6.61)
		Follow-up	86.13(4.93)	76.31(5.74)
BART	Adjusted value	Pre-intervention	33.53(6.02)	33.75(12.81)
		Post-intervention	21.86(3.73)	32.18(9.84)
		Follow-up	21.66(5.13)	31.75(9.98)
	Max pumping	Pre-intervention	58.26(10.93)	57.62(10.95)
		Post-intervention	38.66(6.70)	54.43(8.35)
		Follow-up	42.93(7.85)	51.75(5.80)
WCST	Perseverative errors	Pre-intervention	16.33(4.99)	15.12(5.56)
		Post-intervention	12.46(2.50)	15.62(2.47)
		Follow-up	12.60(2.13)	15.43(1.41)
	Completed Categories	Pre-intervention	3.06(0.96)	3.18(1.04)
		Post-intervention	3.93(0.45)	3.81(0.54)
		Follow-up	3.73(0.96)	3.75(1.06)
N-back	Accuracy	Pre-intervention	74.80(16.98)	73.93(14.34)
		Post-intervention	84.66(6.25)	72.31(13.68)
		Follow-up	82.93(9.61)	71.62(11.88)
	Response Time	Pre-intervention	156.33(18.16)	152.68(30.31)
		Post-intervention	126.73(13.16)	154.43(29.68)
		Follow-up	126.46(9.75)	149.62(34.21)

MBSAT = Mindfulness-Based Substance Abuse Treatment; WCST = Wisconsin Card Sorting Test; BART = Balloon Analouge Risk Task; M = Mean; SD = Standard Deviation.

Table 4
Results Mixed model ANOVAs for effects of interventions to improve executive functions after interventions and follow-up.

Task	Measures		df	f	P	*eta2*
Go/No-Go	Accuracy Go	Time	2,58	1.38	0.259	0.04
		Group	1,29	1.74	0.197	0.05
		Time*group	2,58	1.72	0.188	0.05
	Accuracy No-Go	Time	2,58	3.50	**0.048**	0.10
		Group	1,29	13.00	**0.042**	0.13
		Time*group	2,58	5.17	**0.009**	0.15
BART	Adjusted value	Time	2,58	15.56	**0.001**	0.34
		Group	1,29	11.59	**0.002**	0.28
		Time*group	2,58	8.44	**0.021**	0.22
	Max pumping	Time	2,58	19.09	**0.001**	0.39
		Group	1,29	5.02	**0.030**	0.15
		Time*group	2,58	8.00	**0.001**	0.21
WCST	Perseverative errors	Time	2,58	2.59	0.107	0.08
		Group	1,29	4.61	**0.040**	0.13
		Time*group	2,58	3.99	**0.043**	0.12
	Completed Categories	Time	2,58	4.90	**0.002**	0.18
		Group	1,29	0.048	0.82	0.002
		Time*group	2,58	0.155	0.85	0.005
N-back	Accuracy	Time	2,58	3.57	**0.034**	0.11
		Group	1,29	9.04	**0.005**	0.23
		Time*group	2,58	8.03	**0.001**	0.21
	Response Time	Time	2,58	13.71	**0.001**	0.32
		Group	1,29	12.29	**0.001**	0.29
		Time*group	2,58	12.50	**0.001**	0.30

MBSAT = Mindfulness-Based Substance Abuse Treatment; WCST = Wisconsin Card Sorting Test; BART = Balloon Analog Risk Task; Significant results are highlighted ($p \leq 0.05$) in bold.

Authors' contributions

JAG, SI and VN the study and wrote the protocol and performed the experiments. JAG and JFA analyzed the data. SI and VN contributed to interpretation of data. JAG wrote the first draft of the manuscript and all authors contributed to and have approved the final manuscript.

Compliance with ethical standards

All procedures were approved by the ethics committee at the University of Shahid Beheshti and were in accordance with the Helsinki Declaration and its later amendments.

Role of funding source

Nothing declared.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Acknowledgments

The authors sincerely thank the Welfare Organization of Ardabil Province for introducing the participants, and express their heartfelt gratitude to the Research Center for Behavioral Cognitive Neurosciences for providing the neuroscientific measurement tools used in this study.

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