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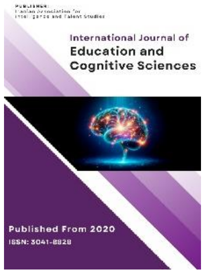

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Investigating the Effect of the Bigdeli Mind Simulation Technique on Psychological Status, Substance Craving, and Brain Activation Patterns (fMRI) in Substance-Dependent Individuals

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ABSTRACT

Purpose: The present study aimed to investigate the effectiveness of the Bigdeli mind simulation technique on psychological status, addiction tendency, substance craving, craving-related thoughts, and functional brain activation patterns in individuals with substance dependence.

Methods and Materials: This study employed a quasi-experimental one-group pretest–posttest design. The statistical population consisted of male individuals aged 30 to 55 years referred to addiction treatment clinics in Karaj who were receiving methadone maintenance therapy at a dosage of 40 mg. Fifteen participants were selected through purposive sampling. Data collection instruments included the Attitude Toward Addiction Questionnaire, Addiction Tendency Questionnaire, Substance Craving Questionnaire, Craving Beliefs Questionnaire (CBQ), Addiction Severity Index, and Post-Cessation Craving Questionnaire. The intervention consisted of eight structured 60-minute sessions based on the Bigdeli mind simulation technique. Psychological assessments and resting-state functional magnetic resonance imaging (Rest-fMRI) were conducted before and after the intervention. fMRI analyses focused on reward-system regions and cognitive control regions, including the dorsolateral prefrontal cortex (dlPFC), anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), nucleus accumbens, and basal ganglia. Behavioral data were analyzed using SPSS software through Wilcoxon and paired t-tests, while neuroimaging data were processed using CONN Toolbox Version 22a under MATLAB-2020b.

Findings: The findings demonstrated significant reductions in all examined psychological variables following the intervention. Attitude toward addiction decreased significantly ($p = 0.002$), addiction tendency showed a significant reduction ($p = 0.004$), substance craving decreased significantly ($p = 0.013$), and craving-related thoughts were also significantly reduced ($p = 0.001$). Resting-state fMRI analyses revealed increased functional connectivity in executive control regions, particularly the dlPFC and ACC, alongside reduced connectivity within reward-related and impulsivity-related pathways involving the orbitofrontal cortex and basal ganglia. These neural changes were associated with improvements in cognitive control, emotional regulation, and reduced craving-related processing.

Conclusion: The results indicate that the Bigdeli mind simulation technique may serve as an effective psychological intervention for reducing addiction-related cognitive and emotional processes while simultaneously modifying neural connectivity patterns associated with reward processing and executive control. The intervention appears capable of enhancing self-regulation and reducing vulnerability to substance craving among individuals with substance dependence.

Keywords: *Bigdeli mind simulation; substance dependence; addiction craving; craving-related thoughts; functional magnetic resonance imaging (fMRI); executive control; reward system.*

1. Introduction

Substance addiction remains one of the most complex and persistent public health challenges worldwide, affecting millions of individuals across diverse social, cultural, and economic contexts. Contemporary perspectives no longer conceptualize addiction solely as a behavioral weakness or moral failure; rather, it is understood as a chronic and relapsing brain disorder involving dysregulation in neurocognitive, emotional, and motivational systems (Franklin, 1995; Leshner, 1997). The evolution of addiction research over recent decades has substantially transformed scientific understanding of substance dependence, moving from purely behavioral interpretations toward integrated neurobiological and psychological models. This paradigm shift has enabled researchers and clinicians to investigate the mechanisms underlying craving, compulsive drug-seeking behavior, impaired executive functioning, and relapse vulnerability from a multidimensional perspective (Nathan et al., 2016; Volkow et al., 2016). Despite considerable advances in pharmacological and psychosocial interventions, relapse rates among individuals with substance use disorders remain alarmingly high, indicating the necessity of developing innovative therapeutic strategies capable of targeting both cognitive and neural processes associated with addiction (Roth et al., 2018; Volkow & Boyle, 2018).

Neuroscientific investigations have demonstrated that addictive substances profoundly alter the functioning of neural circuits involved in reward processing, emotional regulation, decision-making, and inhibitory control. In particular, repeated substance use disrupts dopaminergic pathways within the mesocorticolimbic system, leading to maladaptive reinforcement learning and compulsive patterns of behavior (Goldstein & Volkow, 2002; Hyman et al., 2006). The ventral tegmental area, nucleus accumbens, orbitofrontal cortex, amygdala, anterior cingulate cortex, and dorsolateral prefrontal cortex have been identified as central neural structures implicated in craving and addiction-related behaviors (Koob & Volkow, 2010; Morales & Margolis, 2017). Functional neuroimaging studies have consistently revealed abnormal activation and connectivity patterns in these regions among individuals with substance dependence, particularly during exposure to drug-related cues or stressful conditions (Parvaz et al., 2011; Volkow et al., 2019). Such findings support the view that addiction involves an imbalance between reward-driven motivational systems and executive control mechanisms responsible for self-regulation and behavioral inhibition (Everitt & Robbins, 2015; Koob & Volkow, 2016).

The transition from voluntary substance use to compulsive addiction has also been conceptualized through learning and habit-formation models. According to these perspectives, repeated exposure to psychoactive substances strengthens maladaptive associative learning processes and gradually shifts behavioral control from goal-directed systems toward habitual responding mediated by the basal ganglia (Belin et al., 2009; Everitt & Robbins, 2015). This transition contributes to persistent craving, impaired decision-making, and increased susceptibility to relapse even after prolonged abstinence. Emotional dysregulation further exacerbates this process by enhancing the salience of substance-related cues and weakening cognitive control capacities (Carmack et al., 2019). Consequently, addiction treatment requires interventions capable of simultaneously modifying maladaptive cognitive schemas, emotional responses, and neural activation patterns associated with substance use.

Traditional treatment approaches for addiction have included pharmacotherapy, detoxification programs, cognitive-behavioral therapy, motivational interviewing, contingency management, and relapse-prevention strategies. Although many of these interventions demonstrate moderate effectiveness, a substantial proportion of individuals continue to experience recurrent relapse and chronic psychological distress (Petry et al., 2018; Volkow & Boyle, 2018). Pharmacological interventions such as methadone maintenance therapy have proven beneficial in reducing withdrawal symptoms and stabilizing opioid-dependent individuals; however, these treatments do not fully address the underlying cognitive and emotional mechanisms associated with craving and compulsive drug-seeking behaviors (Nielsen et al., 2014). Similarly, emerging neurobiological interventions such as deep brain stimulation targeting the nucleus accumbens have shown promising results in severe cases of addiction, but such methods remain invasive, costly, and clinically limited (Kuhn et al., 2013; Muller et al., 2016). Therefore, there is a growing interest in developing psychologically informed interventions capable of influencing neural plasticity and improving self-regulation without requiring invasive procedures.

Recent advances in cognitive neuroscience and clinical psychology have highlighted the potential role of cognitive imagery, mental rehearsal, and simulation-based techniques in modifying maladaptive behavioral and emotional patterns. Mind simulation refers to the cognitive process through which individuals internally recreate experiences, scenarios, or behavioral sequences in the absence of direct sensory input (Kamarzerin et al., 2021). Through repeated mental rehearsal, individuals may strengthen adaptive neural pathways, enhance cognitive control, and reduce the emotional intensity of maladaptive thoughts and impulses. Simulation-based cognitive interventions have been applied in various psychological and behavioral domains, including sports performance, communication disorders, emotional regulation, and rehabilitation processes (Kamarzarin, Beygi, et al., 2021; Kamarzarin, Fallahi, et al., 2021). These approaches are grounded in the assumption that mental representations can activate neural systems similar to those engaged during actual behavioral experiences, thereby facilitating behavioral change and neurocognitive restructuring.

Evidence supporting the effectiveness of mind simulation interventions has expanded in recent years. Studies conducted by Kamarzarin and colleagues demonstrated that the mind simulation method significantly improved communication attitudes and reduced stuttering severity among individuals with speech disorders (Kamarzarin & Bigdeli Shamloo, 2025; Kamarzarin et al., 2023; Kamarzarin & Shamloo, 2024). Similar findings have been reported in adolescent populations, where mind simulation techniques enhanced skill acquisition, self-regulation, and adaptive cognitive processing (Kamarzarin, Fallahi, et al., 2021). These findings suggest that mind simulation interventions may facilitate neural and psychological flexibility by enabling individuals to cognitively rehearse adaptive responses before confronting real-world situations. Because addiction is strongly associated with dysfunctional anticipatory processing, craving imagery, and impaired self-regulation, mind simulation techniques may hold substantial therapeutic value for individuals with substance dependence.

One of the central psychological mechanisms involved in addiction is craving, which refers to the intense desire or urge to consume substances. Craving is not merely a subjective emotional state; rather, it involves complex interactions between memory systems, attentional biases, emotional regulation processes, and reward-related neural circuitry (Goldstein & Volkow, 2002; Volkow et al., 2019). Cue-induced craving has been linked to increased activation in the orbitofrontal cortex, amygdala, ventral striatum, and anterior cingulate cortex, regions associated with emotional salience and reward expectancy (Koob & Volkow, 2016; Parvaz et al., 2011). Consequently, interventions targeting craving-related cognitions and neural activation may contribute significantly to relapse prevention. Mind simulation may provide an opportunity for individuals to rehearse adaptive coping strategies, cognitively process high-risk situations, and reduce automatic emotional reactivity to substance-related cues.

In addition to craving, decision-making deficits represent another critical factor contributing to addiction maintenance and relapse vulnerability. Individuals with substance dependence often display impaired evaluation of long-term consequences, heightened impulsivity, and increased sensitivity to immediate rewards (Konova et al., 2020). Neurocognitive studies have indicated that these impairments are associated with dysfunction in prefrontal cortical regions responsible for executive functioning and inhibitory control (Volkow et al., 2016). Mind simulation techniques may improve decision-making processes by encouraging reflective cognitive processing and strengthening executive control systems. Through guided cognitive rehearsal, individuals may learn to anticipate negative outcomes associated with substance use and generate more adaptive behavioral alternatives in response to stress or craving-inducing situations.

The integration of neuroimaging methodologies into addiction research has substantially enhanced understanding of treatment-related neural changes. Functional magnetic resonance imaging (fMRI), particularly resting-state fMRI, enables researchers to examine functional connectivity patterns among brain regions implicated in addiction and self-regulation (Parvaz et al., 2011). Studies have shown that successful addiction treatment is often associated with increased connectivity within executive control networks and decreased activation in reward-related regions (Volkow

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& Boyle, 2018). Furthermore, interventions that reduce craving and improve emotional regulation may produce measurable changes in neural connectivity involving the dorsolateral prefrontal cortex, anterior cingulate cortex, orbitofrontal cortex, and limbic structures (Koob & Volkow, 2010; Morales & Margolis, 2017). Therefore, combining psychological interventions with neuroimaging assessment provides a valuable opportunity to investigate both behavioral and neural dimensions of treatment effectiveness.

Another important consideration in addiction treatment is the role of emotional distress and maladaptive coping strategies in relapse processes. Anxiety, depression, stress, and negative affective states are strongly associated with increased substance craving and diminished self-control (Carmack et al., 2019). Interventions such as mindfulness-based therapies have demonstrated effectiveness in improving emotional regulation and reducing addictive behaviors by modifying cognitive and physiological responses to stress (Garland et al., 2017). Mind simulation techniques may operate through similar mechanisms by promoting adaptive cognitive processing, emotional awareness, and self-regulatory capacity. By mentally rehearsing successful coping responses and emotionally challenging situations, individuals may strengthen neural pathways associated with resilience and executive control while reducing dependence on maladaptive reward-seeking behaviors.

Technological and digital innovations have also contributed to the development of novel interventions for addiction management. Mobile-based behavioral interventions, text-messaging systems, and digital therapeutic approaches have demonstrated moderate effectiveness in promoting treatment adherence and reducing relapse risk (Liao et al., 2018). Nevertheless, many existing interventions primarily target behavioral monitoring and motivational support without directly addressing the neural and cognitive processes underlying craving and compulsive substance use. Mind simulation techniques may complement these approaches by providing a structured cognitive framework through which individuals can actively reshape maladaptive mental representations associated with addiction.

Despite the growing body of literature on addiction neurobiology and psychological interventions, relatively limited research has specifically investigated the effects of Bigdeli mind simulation techniques on psychological status, craving intensity, and functional brain activation patterns among individuals with substance dependence. Most existing studies have focused either on pharmacological interventions or traditional psychotherapeutic methods, leaving a significant gap regarding cognitive simulation-based approaches and their neurobiological correlates. Moreover, few studies have simultaneously evaluated behavioral outcomes and resting-state fMRI connectivity changes following psychological interventions in addiction populations. Addressing this gap may contribute to the development of integrative treatment models capable of targeting both subjective psychological experiences and objective neural mechanisms associated with addiction.

Accordingly, the present study aimed to investigate the effect of the Bigdeli mind simulation technique on psychological status, substance craving, and brain activation patterns assessed through functional magnetic resonance imaging (fMRI) among individuals with substance dependence.

2. Methods and Materials

2.1. *Study Design and Participants*

The present study was quasi-experimental in nature and employed a one-group pretest–posttest design. The statistical population consisted of men aged 30 to 55 years who were referred to addiction treatment clinics in Karaj and were receiving methadone maintenance treatment at a dosage of 40 mg (syrup or tablet). The study sample included 15 individuals selected through purposive sampling. Inclusion criteria consisted of a diagnosis of substance dependence, methadone use at the specified dosage, absence of severe psychiatric disorders (e.g., schizophrenia), and provision of informed consent for participation in the study. Exclusion criteria included failure to complete the intervention sessions or withdrawal from the study.

2.2. *Measures*

The following standardized questionnaires, whose validity and reliability had been confirmed in previous studies, were used for data collection:

The Attitude Toward Addiction Questionnaire (Karimi, 2012), consisting of 35 items and two subscales, including positive attitude (16 items) and negative attitude (19 items) toward addiction, assesses individuals' attitudes based on a 5-point Likert scale ranging from "strongly agree" to "strongly disagree." Scores range from 39 to 199, with higher scores indicating a more favorable attitude toward

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addiction. Positive attitude items are scored directly (1 to 5), whereas negative attitude items are reverse-scored (5 to 1). The face, content, and criterion validity of this instrument were confirmed in the study by Ansari (Ansari, 2019), and its reliability was reported with a Cronbach's alpha coefficient of 0.79.

The Addiction Tendency Questionnaire (Farjad, 2006), consisting of 16 items and three dimensions including environmental (5 items), individual (4 items), and social (7 items) factors, evaluates tendency toward addiction based on a 5-point Likert scale ranging from "very low" to "very high." Scores range from 16 to 80, with higher scores indicating greater tendency toward addiction. The face validity of this instrument was confirmed in the study conducted by Mir Hosami (Mir Hosami, 2009), and its reliability was reported with a Cronbach's alpha coefficient of 0.97.

The Substance Craving Questionnaire (Fadardi et al., 2010) is a 20-item scale scored on a 6-point Likert scale ranging from 0 ("completely false") to 5 ("completely true") and assesses thoughts and cravings related to substance use following abstinence. The reliability of this instrument was reported with a Cronbach's alpha coefficient of 0.94, and its validity was confirmed through correlations with situational confidence scales ($r = 0.53$), psychological craving ($r = 0.58$), and positive and negative affect ($r = 0.32$ and $r = 0.55$, respectively).

The Craving Beliefs Questionnaire (CBQ) developed by Wright and Beck (Wright & Beck, 1993) is a 20-item instrument scored on a 7-point Likert scale ranging from 1 ("strongly disagree") to 7 ("strongly agree") and evaluates craving for substance use. Scores range from 20 to 140, with higher scores indicating greater craving. The reliability of this instrument was reported with a Cronbach's alpha coefficient of 0.95, and its face and content validity were confirmed in the study conducted by Chang et al. (Chang et al., 2011).

The Addiction Severity Index and the Post-Cessation Craving Questionnaire were used to assess addiction severity and post-abstinence cravings. However, details regarding their structure and psychometric properties were not provided. It was assumed that standardized versions with acceptable validity and reliability were employed.

2.3. *Intervention*

The Bigdeli mind simulation intervention was implemented in eight structured 60-minute sessions. Pretest and posttest assessments were conducted using standardized questionnaires and resting-state functional magnetic resonance imaging (Rest-fMRI). fMRI was used to investigate changes in brain activity within reward-system regions (nucleus accumbens and orbitofrontal cortex) and cognitive control regions (dlPFC and ACC). fMRI data processing was performed using CONN Toolbox Version 22a under MATLAB-2020b, including analyses of brain region activation and functional connectivity. Informed consent was obtained from all participants, and confidentiality of data was guaranteed. The intervention was administered under the supervision of clinical specialists.

2.4. *Data Analysis*

Questionnaire data were coded and analyzed using SPSS software. Descriptive analyses (mean and standard deviation) and inferential analyses (Wilcoxon test for non-normal data and mean comparison tests) were conducted at a significance level of 0.05.

3. Findings and Results

The findings related to the demographic characteristics of the study sample indicate that, regarding employment status, the highest frequency belonged to self-employed individuals, accounting for 73.3% of respondents. In contrast, 20% of participants were employed in formal or administrative occupations, and only 6.7% were unemployed. This occupational distribution suggests that the majority of participants were engaged in informal occupations or self-employment, which may be associated with specific economic, social, and cultural characteristics.

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Table 1

Demographic Characteristics of Participants

Variable	Category	Frequency	Percentage
Employment Status	Self-employed	11	73.3%
	Employee	3	20.0%
	Unemployed	1	6.7%
Education Level	Below Diploma	7	46.7%
	Diploma	7	46.7%
	Master's Degree	1	6.7%

Regarding educational level, the data indicated that nearly half of the participants (46.7%) had education below the diploma level, while an equal proportion held a high school diploma. Only 6.7% of respondents possessed a master's degree. Therefore, it can be concluded that the majority of participants in the present study had low to moderate educational attainment, whereas individuals with higher education constituted only a very small proportion of the sample.

Table 2

Results of Hypothesis Testing (Pretest–Posttest Comparisons)

Variable	Statistical Test	Test Statistic	Standardized Statistic	Standard Deviation	Significance Level (p)	Result
Attitude Toward Addiction	Wilcoxon	5.000	-3.126	17.596	0.002	Significant
Addiction Tendency	Wilcoxon	63.000	0.170	6.000	0.004	Significant
Substance Craving	Paired t-test	71.500	0.654	17.596	0.013	Significant
Craving-Related Thoughts	Wilcoxon	0.000	-3.420	17.546	0.001	Significant

Inferential analysis of the psychometric data using Wilcoxon tests (for non-normal data) and paired t-tests demonstrated the significant effect of the Bigdeli mind simulation technique on the variables of attitude toward addiction, addiction tendency, substance craving, and craving-related thoughts. For the variable of attitude toward addiction, the Wilcoxon test yielded a test statistic of 5.000, a standardized statistic of -3.126, and a standard deviation of 17.596, indicating a significant reduction in positive attitudes toward addiction following the intervention.

Regarding addiction tendency, the Wilcoxon test produced a test statistic of 63.000, a standardized statistic of 0.170, and a standard deviation of 6.000, confirming a significant reduction in addiction tendency after the intervention. For substance craving, the paired t-test reported a test statistic of 71.500, a standardized statistic of 0.654, and a standard deviation of 17.596, confirming a significant reduction in substance craving. Finally, for craving-related thoughts, the Wilcoxon test yielded a test statistic of 0.000, a standardized statistic of -3.420, and a standard deviation of 17.546, indicating a significant reduction in craving-related thoughts following the intervention. Collectively, these findings support the effectiveness of the Bigdeli mind simulation technique in modifying psychological components associated with addiction.

Functional connectivity analysis of the resting-state fMRI pretest and posttest data was conducted using CONN-22a under MATLAB-2020b to examine the effects of the Bigdeli mind simulation technique on neural patterns. Using the Harvard–Oxford cortical atlas, 48 brain regions were initially selected; however, due to low signal-to-noise ratios, 9 regions (14, 15, 16, 27, 34, 35, 37, 38, and 41) were excluded, and analyses were performed on the remaining 39 regions. Preprocessed fMRI data were used to extract the mean time series of each region of interest (ROI), and a functional connectivity matrix (39 × 39) was computed using Pearson correlation coefficients.

The results demonstrated significant differences in connectivity patterns before and after the intervention. Prior to the intervention, abnormal activity was observed in reward-system regions (orbitofrontal cortex and basal ganglia), which was associated with intense craving for substance use. Following the intervention, increased functional connectivity was observed in self-regulation regions (dlPFC and ACC), along with decreased connectivity in impulsivity and addiction-craving pathways. These changes were consistent with the significant

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reductions in anxiety, depression, impulsivity, and craving for substance use observed in the behavioral data, indicating the positive effect of the intervention on cognitive processing, impulse control, and emotional regulation.

Figure 1

Harvard–Oxford cortical atlas overlaid on structural brain data (MNI 2 mm isotropic).

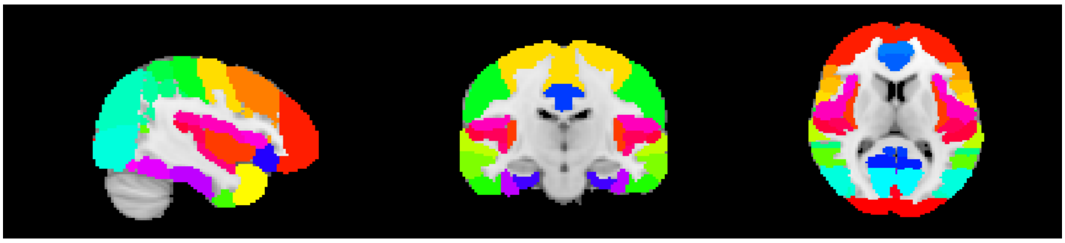

Figure 2

Transformation of the Harvard–Oxford cortical atlas into native fMRI space for connectivity matrix computation.

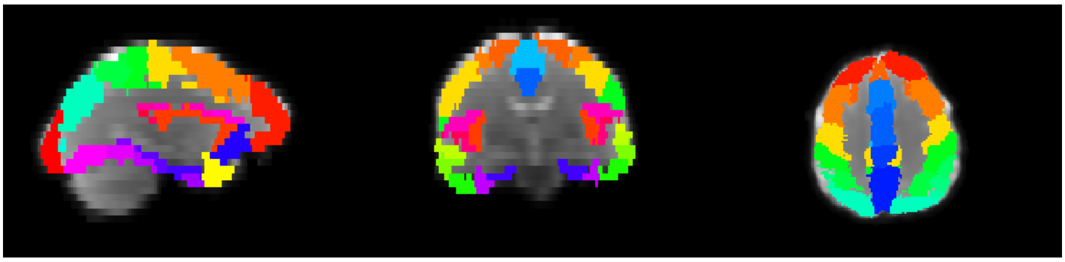

Figure 3

Connectivity matrix before fMRI intervention for 39 cortical brain regions.

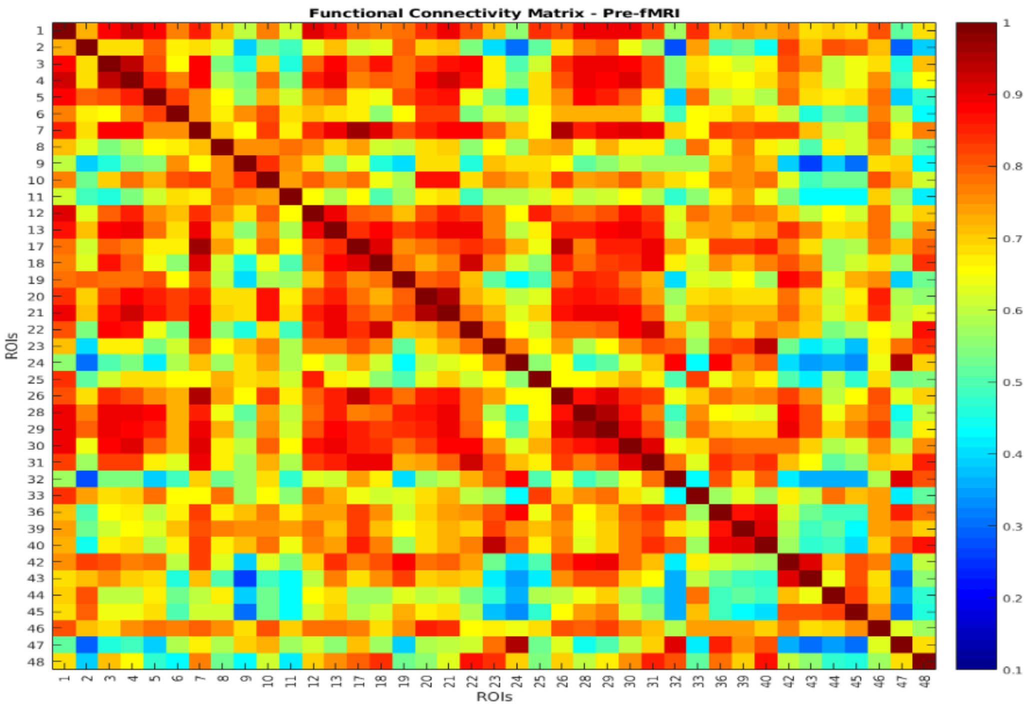

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Figure 4

Connectivity matrix after fMRI intervention for 39 cortical brain regions.

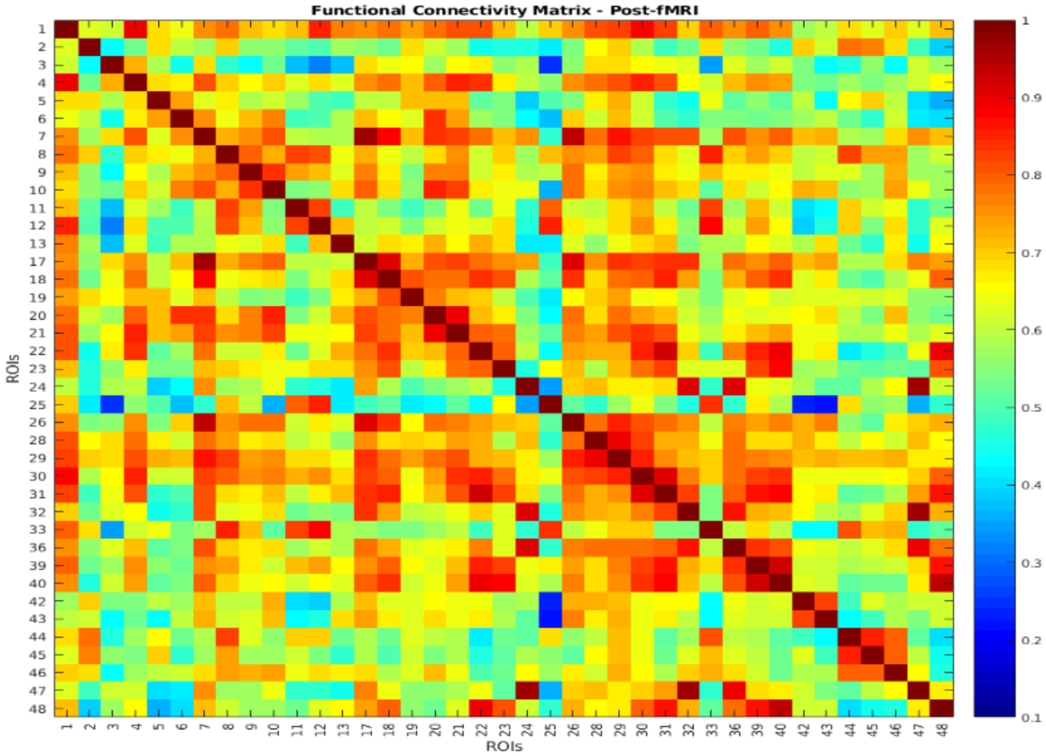
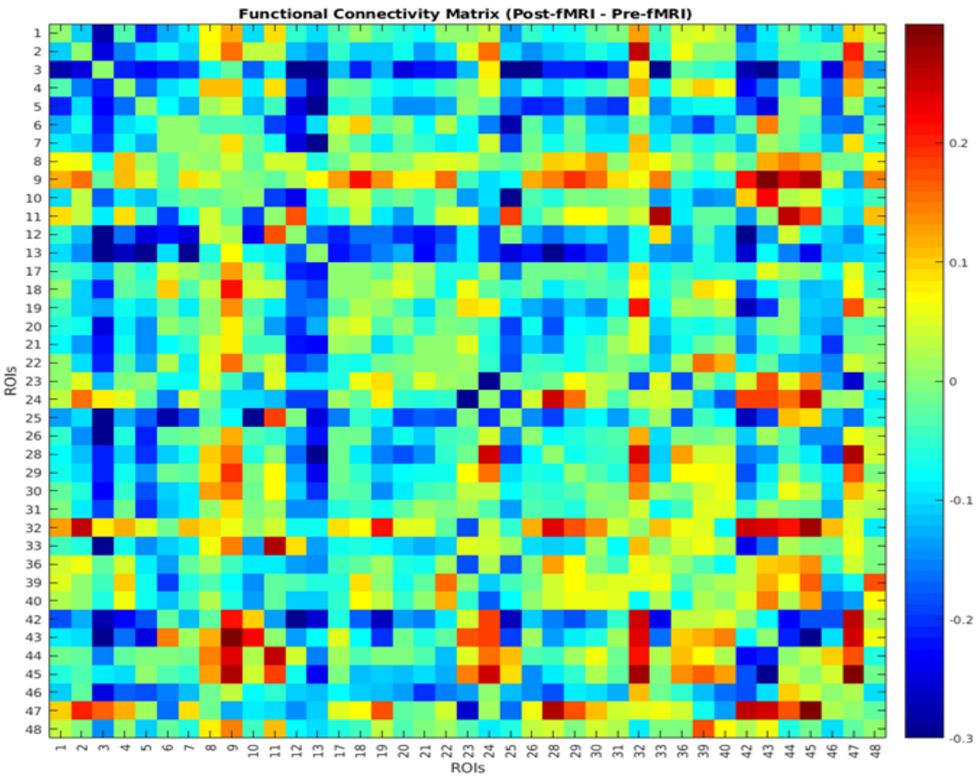


Figure 5

Subtraction results between post-fMRI and pre-fMRI connectivity matrices for 39 cortical brain regions.



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4. Discussion and Conclusion

The present study aimed to investigate the effectiveness of the Bigdeli mind simulation technique on psychological status, addiction craving, and functional brain activation patterns in individuals with substance dependence. The findings demonstrated that the intervention produced significant reductions in attitudes toward addiction, addiction tendency, substance craving, and craving-related thoughts. In addition, resting-state fMRI analyses revealed meaningful alterations in neural connectivity patterns, particularly increased functional connectivity in executive control regions such as the dorsolateral prefrontal cortex (dlPFC) and anterior cingulate cortex (ACC), alongside reduced connectivity in reward-related and impulsivity-related pathways. Collectively, these findings support the effectiveness of the Bigdeli mind simulation technique as a multidimensional intervention capable of influencing both psychological and neurobiological processes associated with addiction.

The reduction in positive attitudes toward addiction following the intervention suggests that Bigdeli mind simulation may contribute to restructuring maladaptive cognitive schemas related to substance use. Cognitive theories of addiction emphasize that individuals with substance dependence often maintain distorted beliefs regarding the perceived benefits of substance use, including emotional relief, social acceptance, and enhanced coping capacity (Goldstein & Volkow, 2002; Hyman et al., 2006). Such cognitive distortions reinforce substance-seeking behaviors and increase vulnerability to relapse. Through repeated mental rehearsal of adaptive coping strategies and anticipated consequences of substance use, the Bigdeli mind simulation technique may have facilitated cognitive reappraisal processes that weakened these maladaptive beliefs. This interpretation aligns with studies demonstrating that cognitive and imagery-based interventions can alter neural processing associated with reward expectancy and emotional valuation (Koob & Volkow, 2016; Volkow et al., 2019). Moreover, the present findings are consistent with previous investigations conducted by Kamarzarin and colleagues, which showed that mind simulation interventions effectively modified maladaptive attitudes and improved communication-related cognitions among individuals with stuttering and adjustment difficulties (Kamarzarin & Bigdeli Shamloo, 2025; Kamarzarin et al., 2023; Kamarzarin & Shamloo, 2024). These findings suggest that the Bigdeli mind simulation method may operate through generalizable cognitive restructuring mechanisms applicable across diverse psychological conditions.

The observed reduction in addiction tendency following the intervention further highlights the role of cognitive self-regulation in addiction treatment. Addiction tendency is influenced by multiple psychological and environmental factors, including impulsivity, emotional dysregulation, reward sensitivity, and maladaptive learning patterns (Belin et al., 2009; Everitt & Robbins, 2015). According to neurobehavioral models, repeated exposure to addictive substances gradually shifts behavioral control from voluntary decision-making systems toward automatic and habitual responding mediated by the basal ganglia and associated neural networks (Koob & Volkow, 2010, 2016). Mind simulation may counteract this process by strengthening reflective cognitive systems and increasing awareness of behavioral consequences. By repeatedly imagining adaptive responses and mentally rehearsing non-substance-related coping strategies, participants may have enhanced their capacity for inhibitory control and reduced automatic tendencies toward substance use. This interpretation is consistent with the brain disease model of addiction proposed by Leshner and later expanded by Volkow and colleagues, emphasizing the importance of restoring executive control mechanisms in addiction recovery (Leshner, 1997; Volkow et al., 2016).

Another important finding of the present study was the significant reduction in substance craving and craving-related thoughts following the intervention. Craving represents one of the strongest predictors of relapse and is closely linked to dysfunctional activation within reward-processing and emotional-regulation systems (Volkow & Boyle, 2018; Volkow et al., 2019). Neuroimaging studies have consistently shown that exposure to drug-related cues activates brain regions such as the orbitofrontal cortex, amygdala, ventral striatum, and anterior cingulate cortex, thereby intensifying urges for substance use (Morales & Margolis, 2017; Parvaz et al., 2011). In the present study, participants demonstrated reductions in craving-related cognitions after engaging in the Bigdeli mind simulation intervention, suggesting that this technique may reduce the salience and emotional impact of drug-related mental representations. These findings are theoretically consistent with models of reward-related learning and memory, which emphasize the role of cognitive rehearsal and associative processing in maintaining addictive behaviors (Hyman et al.,

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2006). Through repeated cognitive simulation of adaptive scenarios and coping responses, participants may have weakened maladaptive associative networks linked to substance craving.

The current findings are also congruent with previous research indicating that interventions targeting cognitive and emotional processing can reduce addictive behaviors and improve self-regulation. Garland and colleagues reported that mindfulness-based interventions significantly modified cognitive, affective, and physiological mechanisms associated with alcohol dependence (Garland et al., 2017). Although Bigdeli mind simulation differs conceptually from mindfulness training, both approaches appear to influence attentional control, emotional regulation, and cognitive flexibility. Similarly, studies examining behavioral interventions for smoking cessation and addiction management have demonstrated that psychologically oriented interventions can significantly reduce craving intensity and relapse vulnerability (Liao et al., 2018; Petry et al., 2018). The present findings extend this literature by demonstrating that Bigdeli mind simulation may represent an additional non-pharmacological strategy capable of reducing craving-related psychological processes among individuals with substance dependence.

One of the most important contributions of the present study lies in its integration of behavioral and neuroimaging findings. Resting-state fMRI analyses demonstrated increased functional connectivity in the dlPFC and ACC following the intervention. These regions are critically involved in executive functioning, attentional control, emotional regulation, conflict monitoring, and decision-making (Goldstein & Volkow, 2002; Koob & Volkow, 2016). Dysfunction in these cortical regions has frequently been associated with impaired inhibitory control and compulsive substance-seeking behavior among addicted individuals (Volkow et al., 2016). Therefore, the observed enhancement in connectivity within these areas may indicate improved cognitive control capacities and strengthened self-regulatory functioning following the Bigdeli mind simulation intervention.

At the same time, reductions in connectivity within impulsivity-related and reward-related pathways, particularly involving the orbitofrontal cortex and basal ganglia, suggest decreased sensitivity to substance-related reward processing. Previous neurobiological studies have shown that addiction is associated with hyperactivation of reward circuits and diminished prefrontal regulatory control (Koob & Volkow, 2010; Volkow et al., 2019). The current findings indicate that Bigdeli mind simulation may partially restore balance between these competing neural systems. Such changes are particularly meaningful because successful addiction recovery often depends on the ability to suppress automatic reward-driven impulses and engage reflective cognitive processes when confronted with craving-inducing stimuli. The findings are also consistent with studies demonstrating that therapeutic interventions capable of enhancing executive network functioning are associated with improved treatment outcomes and lower relapse rates (Konova et al., 2020).

The reduction in impulsivity-related neural connectivity observed in the present study may also be explained through the framework of emotional learning and negative reinforcement models of addiction. Carmack and colleagues demonstrated that addiction involves activation of negative emotional learning circuits, which reinforce substance use through avoidance of distress and negative affective states (Carmack et al., 2019). Mind simulation may reduce emotional reactivity by enabling individuals to mentally process stressful or craving-inducing scenarios in a controlled cognitive environment. Repeated exposure to simulated adaptive coping experiences may gradually reduce anxiety and emotional vulnerability associated with substance-related cues. This mechanism may explain the observed reductions in craving-related thoughts and the enhanced activation of cognitive control regions following the intervention.

The present findings further support contemporary perspectives emphasizing the plasticity of neural systems involved in addiction. Addiction-related neural pathways are not permanently fixed; rather, they remain responsive to behavioral, cognitive, and environmental interventions (Volkow & Boyle, 2018). Mind simulation techniques may facilitate adaptive neuroplasticity by repeatedly activating executive and self-regulatory neural networks. Similar mechanisms have been proposed in cognitive rehabilitation and motor imagery research, where repeated mental rehearsal has been shown to strengthen neural pathways associated with behavioral performance and cognitive functioning (Kamarzarin, Beygi, et al., 2021; Kamarzarin, Fallahi, et al., 2021). The present study extends this perspective into the domain of addiction treatment and suggests that cognitive simulation may serve as a practical and low-cost intervention capable of influencing both psychological symptoms and neural connectivity patterns.

The findings of the present study should also be interpreted within the broader context of contemporary

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addiction neuroscience. Modern conceptualizations of addiction emphasize the interaction between neurobiological vulnerability, environmental stressors, cognitive processes, and emotional dysregulation (Nathan et al., 2016; Volkow et al., 2016). Consequently, effective treatment approaches must address multiple dimensions simultaneously rather than focusing exclusively on detoxification or symptom suppression. The Bigdeli mind simulation technique appears particularly valuable in this regard because it combines cognitive rehearsal, emotional processing, anticipatory thinking, and self-regulatory practice within a unified therapeutic framework. By mentally simulating adaptive responses to high-risk situations, individuals may strengthen resilience against relapse and improve their capacity for behavioral self-management.

The current findings are also important because they contribute to the growing literature supporting psychologically informed neuroscience-based interventions. Although pharmacological treatments remain important components of addiction management, they are often insufficient for addressing the cognitive and emotional dimensions of addiction (Nielsen et al., 2014). Non-invasive psychological interventions capable of influencing neural connectivity patterns may therefore represent promising complementary approaches for long-term rehabilitation. Compared to invasive interventions such as deep brain stimulation (Kuhn et al., 2013; Muller et al., 2016), Bigdeli mind simulation offers a safer, more accessible, and potentially scalable therapeutic alternative.

Overall, the present study demonstrated that the Bigdeli mind simulation technique significantly improved psychological indicators associated with addiction and produced measurable alterations in neural connectivity patterns related to executive control and reward processing. These findings provide preliminary evidence supporting the integration of cognitive simulation-based interventions into addiction treatment programs and highlight the importance of addressing both psychological and neurobiological mechanisms in substance dependence rehabilitation.

One limitation of the present study was the relatively small sample size, which may reduce the generalizability of the findings to broader populations of individuals with substance dependence. In addition, the study employed a quasi-experimental one-group design without full randomization, limiting the ability to establish strong causal inferences. The exclusive inclusion of male participants receiving methadone maintenance therapy also restricts the applicability of the findings to female populations or individuals with different treatment conditions. Another limitation concerns the limited duration of follow-up assessment, as the long-term sustainability of the observed psychological and neural changes remains unclear. Furthermore, some psychometric instruments used in the study lacked detailed reporting regarding their structural and psychometric properties.

Future studies are recommended to employ larger and more diverse samples, including female participants and individuals from different cultural and clinical backgrounds. Randomized controlled trial designs with extended follow-up periods would provide stronger evidence regarding the long-term effectiveness of Bigdeli mind simulation interventions in addiction treatment. Future research may also investigate the comparative effectiveness of Bigdeli mind simulation relative to other cognitive and behavioral interventions such as mindfulness-based therapy, cognitive-behavioral therapy, and motivational interviewing. In addition, integrating multimodal neuroimaging techniques and computational analyses may provide deeper insight into the neural mechanisms underlying treatment-related changes. Examining the role of individual differences such as impulsivity, trauma history, emotional regulation capacity, and executive functioning may further clarify which individuals benefit most from Bigdeli mind simulation interventions.

From a practical perspective, the findings of the present study suggest that Bigdeli mind simulation techniques may be incorporated into addiction rehabilitation programs as a complementary therapeutic approach alongside pharmacological and psychosocial interventions. Mind simulation protocols may help individuals strengthen coping strategies, improve emotional regulation, and reduce vulnerability to craving and relapse. Clinical practitioners working in addiction treatment settings may benefit from integrating structured cognitive simulation exercises into group therapy or individualized rehabilitation programs. Moreover, because the intervention is non-invasive and relatively low-cost, it may be particularly useful in community-based treatment centers with limited access to advanced medical resources. The incorporation of neurocognitive training methods such as Bigdeli mind simulation into addiction treatment may ultimately contribute to more comprehensive and sustainable recovery outcomes.

Authors' Contributions

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All authors significantly contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

In this study, to observe ethical considerations, participants were informed about the goals and importance of the research before the start of the interview and participated in the research with informed consent.

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