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Behavioral Inhibition and Activation Systems in the Relationship Between Physical Exercise and Drug Craving in Individuals with Substance Use Disorders: A Cross-Sectional Mediation Analysis

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Abstract

Background: Physical exercise (PE) effectively alleviates drug cravings (DC) and improves withdrawal symptoms in individuals with substance use disorders (SUD). Nevertheless, the mechanistic pathways through which PE influences DC remain inadequately explored. Objective: This investigation examines how the Behavioral Inhibition System (BIS) and Behavioral Activation System (BAS) mediate PE effects on DC in individuals with SUD.

Methods: A total of 289 individuals receiving drug rehabilitation treatment at Masanjia Drug Rehabilitation Center underwent evaluation utilizing the Physical Activity Rating Scale (PARS-3), the BIS/BAS scale, and the DC Scale. Structural equation modeling methodology was employed to assess the mediating function of BIS and BAS within the link between physical activity levels and DC manifestations.

Results: (1) Physical activity levels demonstrated negative links to DC while showing positive links to BIS, which subsequently exhibited inverse links to cravings. (2) BIS mediated the relationship between physical activity and DC. (3) High-frequency PE and moderate to high exercise duration were linked to enhanced BIS and reduced DC relative to low-frequency and low-duration exercise.

Conclusion: BIS may mediate the link between PE and reduced DC, with exercise duration and frequency acting as potential dosage-related factors. Longer and more frequent physical activity was associated with higher behavioral inhibition and lower drug craving among individuals with SUD, which may strengthen behavioral control and support craving reduction.

Highlights

- BIS mediates the relationship between physical exercise and drug craving in SUD.
- Higher exercise frequency and duration reduce drug craving via enhanced BIS.
- Findings support exercise frequency/duration as key dosage factors for SUD rehab.

1. Introduction

Drug abuse represents a significant global public health challenge, jeopardizing individual health, family stability, and social order. The latest World Drug Report estimates that the number of drug users reached over 296 million globally. Worryingly, the number of people with substance use disorders (SUD) marked a 13% increase compared to the previous decade [1]. Drug craving (DC), characterized by an intense and compulsive urge to use drugs in response to drug-related cues or stress, is a core feature of addiction [2, 3]. It serves as a psychological motivator for relapse and is influenced by various factors at the neurobiological, psychological, and social levels [4]. Even after prolonged abstinence, individuals with drug dependence remain vulnerable to cravings and relapse when exposed to triggers. As such, DC is a key indicator of addiction in SUD [5] and a key target for intervention and relapse prevention [6]. Identifying effective strategies to reduce cravings is essential to improving the success rate of SUD rehabilitation.

Chronic drug abuse triggers structural and functional alterations in the brain, shifting the motivation for drug use from reward-seeking (pleasure) to avoiding withdrawal pain, thereby perpetuating addiction. The Behavioral Inhibition System (BIS) and Behavioral Activation System (BAS) represent fundamental components within addiction neurobiology [7, 8]. According to Gray's Reinforcement Sensitivity Theory (RST) [9], the BIS and BAS are two systems in personality theory that govern responses to reward and punishment stimuli, regulating motivation and behavior. The BIS is involved in avoiding punishment or danger, while the BAS drives behavior toward reward-seeking [10]. The BAS is associated with brain regions such as the dopamine (DA)system and the ventral tegmental area (VTA) of the midbrain [11], which play critical roles in addictive behaviors. In addition, the BAS acts as an "accelerator," motivating individuals to seek rewarding stimuli such as food, alcohol, and drugs, with these behaviors often linked to DA activation [12]. Conversely, the BIS is involved in behavioral inhibition, functioning through the serotonin system and structures like the hippocampus and amygdala. Researches indicate that drug-dependent individuals frequently exhibit an imbalance, characterized by excessive BAS activity and insufficient BIS function. This dysregulation weakens behavioral control and exacerbates addiction tendencies [13, 14]. Consequently, regulating the BIS/BAS balance may offer an effective intervention strategy for addiction treatment.

In recent years, physical exercise (PE), as a non-pharmacological intervention, has demonstrated significant potential in reducing DC and promoting withdrawal and rehabilitation. Its beneficial effects may be attributed to several mechanisms, including the promotion of endogenous opioid peptide release, improvement of emotional states, alleviation of stress and anxiety, and regulation of neurotransmitter systems involved in reward and impulse control, such as DA [15, 16]. However, the link between PE and DC remains complex and not fully understood. Further research is necessary to elucidate the underlying behavioral mechanisms. Notably, PE's impact on the BAS and BIS has gained increasing attention. Regular PE can regulate BAS and BIS through various neurobiological mechanisms. Exercise enhances the reward sensitivity of BAS by increasing neurotransmitters like DA [17], while improving BIS function through enhanced coordination and

inhibitory control of the nervous system[18]. Additionally, exercise may indirectly enhance BIS function by reducing inflammation and improving neuroinflammation [19]. Despite these effects, systematic empirical research examining the specific influence of PE on BIS/BAS functioning in individuals with SUD and its potential mediating role in DC improvement remains insufficient. Furthermore, the dose-effect relationship between the "dose" of PE (e.g., duration and intensity) and the degree of craving relief, as well as the mediating function of the BIS/BAS system, remains unclear.

This study investigated the mediating mechanisms by which PE influences DC using structural equation modeling. The goal is to explore the rehabilitation mechanisms associated with PE interventions for individuals with SUD and to enhance the framework for exercise-assisted drug rehabilitation. In addressing gaps identified in prior research, several hypotheses were proposed: Hypothesis 1 (H1): PE negatively affects DC; Hypothesis 2 (H2): BIS/BAS in individuals with SUD negatively affects DC; Hypothesis 3 (H3): PE positively affects BIS/BAS in individuals with SUD; Hypothesis 4 (H4): BIS/BAS mediates the link between PE and DC.

2. Methods

2.1 Research subjects

Cluster sampling was utilized to conduct a survey among individuals with SUD at the Masanjia Drug Rehabilitation Center for both male and female participants. Prior to completing the questionnaires, all participants furnished signed informed consent. The Medical Ethics Committee of Renhe Hospital, affiliated with China Three Gorges University, granted approval for this study (Approval No.: RHLL-2025-59). Sample size calculation: Referring to previous similar study [15], under the expected medium effect size (Cohen's $f^2 = 0.15$), statistical power ($1-\beta = 0.80$), and significance level ($\alpha = 0.05$), the G*Power 3.1 software was used to calculate that the minimum required sample size was N = 218. Considering a potential 10% sample loss rate, it was planned to survey a total of 240 individuals. Inclusion criteria: ▯ Meeting the diagnostic criteria for substance use disorder in the Diagnostic and Statistical Manual of Mental Disorders (Fifth Edition); ▯ Aged between 18 and 60 years; ▯ Having a drug rehabilitation time of ≥ 3 months; ▯ Voluntarily participating and signing the informed consent form. Exclusion criteria: ▯ Having severe mental disorders (e.g., schizophrenia, bipolar disorder) or cognitive impairment; ▯ Suffering from severe physical diseases (e.g., cardiovascular and cerebrovascular diseases, hepatic and renal insufficiency) and being unable to complete the questionnaire survey; ▯ Having received physical treatments such as electroconvulsive therapy or deep brain stimulation within the past 3 months. Among the 340 questionnaires distributed, 323 responses were gathered, achieving a response rate of 95%. 34 were deemed invalid and subsequently excluded. The specific reasons for exclusion included: insufficient completion time (n = 15), patterned responses (e.g., answering in a "Z" shape, n = 19). Consequently, the final number of valid samples was 289, resulting in an effective recovery rate of 89.47%. (See Figure 1)

Figure 1. Flow chart for sample inclusion.

2.2 Assessments

2.2.1 General information questionnaire: The study employed a structured questionnaire consisting of four primary components. The initial component collected fundamental demographic and substance use data, encompassing gender, age, drug categories utilized, substance use background, and relapse records. The subsequent three components utilized validated assessment instruments.

2.2.2 Physical Activity Rating Scale-3 (PARS-3): This scale was used to assess physical activity levels, considering exercise intensity, duration, and frequency. A five-point rating scale ranging from 1 to 5 was utilized to assess the degree of physical activity engagement. The PE score computation followed this formula: Physical exercise score = Intensity score × (Duration score - 1) × Frequency score, yielding a score range of 0 - 100. Physical activity levels were classified as low (≤ 19), moderate (20 - 42), and high (≥ 43) [20]. The pre-test reliability of the scale was strong, with a correlation coefficient of r = 0.82 [21].

2.2.3 DC Scale: This scale consists of 25 items. Responses were recorded employing a 5-point Likert scale: "Disagree completely," "Disagree," "Neutral," "Agree," and "Agree completely," with corresponding scores of 1 to 5. The total DC score represents the summation of the 25-item scores, with a range of 25 - 125 points. A higher score indicates a stronger craving for drugs. This scale exhibits excellent reliability and validity with a Cronbach's α coefficient of 0.96 [15].

2.2.4 Behavioral Inhibition/Activation System Scale (BIS/BAS Scale): The BIS/BAS Scale encompasses two primary dimensions: BIS and BAS. For the present investigation, the scale was structured into four levels, comprising Behavioral Inhibition (BIS) and three BAS sub-dimensions: Reward Responsiveness, Drive, and Fun Seeking. Participants provided responses utilizing a 4-point Likert scale (1-4), spanning from "Strongly Agree" to "Strongly Disagree." The Cronbach's α coefficient for this scale reached 0.76 [22].

2.3 Research procedure

The research commenced with obtaining permission from the management department. Following this, drug rehabilitation patients who met the inclusion criteria were identified through the information system. Prior to questionnaire administration, all participants underwent a preliminary medical assessment conducted by the medical staff at the drug rehabilitation center. This assessment included the evaluation of vital signs, acute withdrawal symptoms, and mental status to ensure that participants were physically and mentally capable of comprehending the questionnaire items and completing the survey safely. The participants were briefed on the research objectives, procedures, precautions, and confidentiality principles. Upon voluntary agreement by signing informed consent forms, they were allocated to complete questionnaires in a serene setting. The questionnaires encompassed a general information survey, the Physical Activity Rating Scale-3, the Behavioral Inhibition/Activation System Scale, and the Drug Craving Scale. Questionnaire completion took about 30 minutes, with researchers available for inquiries. Subsequently, the researchers assessed the questionnaires for completeness, discarding any deemed invalid (refer to Figure 1). All data were anonymized and solely utilized for academic purposes.

2.4 Statistical method

Statistical analysis for this investigation was executed utilizing SPSS 29.0 software. To thoroughly examine the effects of PE on BIS/BAS and DC in individuals with SUD, exercise intensity was categorized into three levels based on established criteria [15]: low-intensity, moderate-intensity, and high-intensity exercise. The following methods were employed for inter-group comparisons: Continuous variables were presented as Mean ± SD. Initially, the Shapiro-Wilk test was employed to examine data normality, while the Levene test was utilized to assess variance homogeneity. When data satisfied normality and variance homogeneity assumptions, one-way analysis of variance (ANOVA) was conducted for overall comparisons across the three groups. When these assumptions were not satisfied, or when variance was heterogeneous, the non-parametric Kruskal-Wallis H test was applied for comparison purposes. Categorical variables (e.g., gender, type of drug use) were expressed as n (%), with chi-square testing used for comparisons. When any expected frequency fell below 5, Fisher's exact test was implemented. Pearson correlation analysis was conducted to examine relationships among exercise amount, BIS/BAS, and DC. Amos 21.0 and JASP software were employed to develop the structural equation model and examine the mediating effect. Research hypothesis testing adhered to the mediating effect process outlined by Wen et al. [23]. One-way ANOVA was used to investigate differences in behavioral inhibition and DC under the influence of different levels of sub-dimensions of PE. All analyses adopted a significance level of p= 0.05.

3. Results

3.1 Differences in demographic variables, BIS/BAS, and DC scores among individuals with SUD with different levels of PE.

A total of 289 individuals with SUD were incorporated in this investigation, with a mean age of 43.58 ± 10.14 years. Among the participants, 131(45.3%) were male, and 158 (54.7%) were female. The main types of drugs used by the subjects included methamphetamine, heroin, morphine and mix drug. The average number of years of drug use was 12.75±7.42 years. Statistically significant differences were observed in BIS/BAS and DC levels among individuals with different levels of physical activity (p< 0.05). Nevertheless, other demographic variables showed no statistically significant differences (p> 0.05) (Table 1).

Table 1. Participants' demographic characteristic (mean ± SD/n+%).

3.2 Relationship among PE level, BIS/BAS, and DC in individuals with SUD.

The Pearson correlation coefficient was utilized to assess the links among PE level, DC, and the behavioral inhibition and activation systems. The findings (Figure 2) demonstrated significant negative links between PE level and craving (r = -0.18, p= 0.003) and significant positive links between PE level and reward responsiveness (r = 0.16, p= 0.006), drive (r = 0.15, p= 0.009), and fun seeking (r = 0.26, p< 0.001). DC exhibited significant negative links to reward responsiveness (r = -0.13, p= 0.030) and behavioral inhibition (r = -0.23, p< 0.001), while showing no link to drive (r = -0.05, p= 0.440) or fun seeking (r = 0.00, p= 0.950).

Figure 2. Relationship among PE, BIS/BAS, and DC in individuals with SUD.

3.3 Development and validation of a structural model of PE, DC, behavioral inhibition, and reward responsiveness among individuals with SUD.

A structural model was established based on the relationships between PE, DC, reward responsiveness, and behavioral inhibition in individuals with SUD. PE served as the independent variable, with craving functioning as the dependent variable, while reward responsiveness and behavioral inhibition acted as mediating variables. The structural equation model appears in Figure 3, demonstrating the following fitting indices: CMIN/df = 2.346, RMR = 0.038, RMSEA = 0.068, GFI = 0.978, NFI = 0.978, CFI = 0.987. These indices satisfy the reference criteria [24,25] for adequate fit (CMIN/df < 3, RMR < 0.05, RMSEA < 0.08, GFI, NFI, CFI > 0.90), demonstrating high reliability. Table 2 presents the mediation analysis outcomes. The pathway from reward responsiveness to craving showed no significance (95% confidence interval encompassing 0, p= 0.640). The mediating effect via reward responsiveness also lacked significance (95% confidence interval encompassing 0, p= 0.645). Nevertheless, the mediating effect via behavioral inhibition demonstrated significance, with the 95% confidence interval for this pathway ranging from [-0.107, -0.010] and p= 0.018. Therefore, behavioral inhibition serves as a mediator in the relationship between PE and DC among individuals with SUD.

Table 2. Test equations for PE, reward response, behavioral inhibition, and DC.

Figure 3. Mediating relationship among PE, reward response, behavioral inhibition, and DC. Solid arrows = statistically significant paths; dashed arrows = non-significant paths.

3.4 Differences in behavioral inhibition and craving levels under the influence of different levels of the sub - dimensions of PE

Behavioral inhibition functions as a mediator in the association between PE and DC, as evidenced above. Nevertheless, prior investigations have indicated that PE amount represents a multifaceted variable, frequently exhibiting a dose-response relationship. To better elucidate the influence of different levels within PE sub-dimensions on behavioral inhibition and DC, this investigation performed a comparative analysis across varying levels (1-2 points representing low level, 3 points representing medium level, and 4-5 points representing high level) [20]. The findings indicated: 1) In the exercise duration dimension, the high-level group exhibited stronger behavioral inhibition than both the low- and medium-level groups. 2) No significant differences were observed in the exercise intensity dimension. 3) Regarding exercise frequency, the medium- and high-level groups showed greater behavioral inhibition than the low-level group.

Table 3. Differences in behavioral inhibition and DC under the influence of different levels of sub-dimensions of PE.

4. Discussion

This research investigated the mediating function of the BIS/BAS in the association between physical activity and DC, testing the previously proposed hypotheses. The primary findings include the following: A notable negative association was identified between PE levels and DC among individuals with SUD. PE demonstrated positive effects on the BIS of these participants. The structural equation model revealed the mediating function of BIS in the association between exercise and DC, where exercise duration and frequency exhibited differential impacts on BIS and DC. These findings offer novel empirical evidence for comprehending the behavioral and neural mechanisms by which exercise reduces drug dependence.

The findings suggest that BIS may modulate the association between PE and DC in individuals with SUD. Engaging in physical activity may enhance the inhibitory functions of brain regions by activating the anterior cingulate gyrus [26], thereby suppressing DC. Previous research has shown that positive aerobic exercise effectively stimulates the brain circuits of methamphetamine users, improving their performance in inhibitory tasks. This exercise also enhances the function of brain areas involved in inhibition, significantly reducing methamphetamine cravings and relapse tendencies [27, 28]. Another potential neurobiological mechanism could be that BIS is primarily associated with the septum-hippocampus system [29], which is sensitive to punishment, non-reward, novelty, and fear stimuli. This system inhibits current activities to avoid potential threats or punishments [30]. BIS regulates inappropriate behaviors by assessing potential losses and gains during decision-making [31], which could influence choices between physical activity and DC in individuals with SUD. Additionally, BIS interacts complexly with the DA system. Research indicates that the functional state of the DA system, including DA release, metabolism, and transport, is regulated by BIS-related brain regions (such as the amygdala, prefrontal cortex, and VTA) [32]. DA is recognized as a key neurotransmitter in relapse behavior [33]. PE promotes DA synthesis, secretion, and release, while also accelerating its breakdown and metabolism, which increases DA turnover rate [34, 35]. By regulating BIS and influencing DA levels, PE may help prevent drug relapse and reduce cravings. In essence, PE is hypothesized to modulate BIS in individuals with SUD, enhance behavioral inhibition, and thereby mitigate DC.

BAS did not emerge as a significant mediator in the relationship between PE and DC. BAS, often referred to as the "reward-seeking system", may exhibit functional dissociation in individuals with SUD [36, 37]. In this study, reward responsiveness was significantly negatively correlated with DC, whereas drive and fun seeking showed no significant correlation with DC. This suggests that, among individuals in protracted abstinence, distinct BAS components relate differentially to craving. Specifically, reward responsiveness—reflecting pleasure derived from daily activities—may be inversely associated with craving, while drive (the pursuit of novel stimuli) and fun seeking (the tendency to seek new and exciting experiences) appear unrelated to DC. Furthermore, participants in this study had been abstinent for at least three months, representing a neural adaptation state distinct from acute withdrawal. Research indicates that during protracted abstinence, dopamine D2 receptor expression in the nucleus accumbens is upregulated, leading to a gradual recovery from reward system hyposensitivity [38, 39]. Under these conditions, the impact of PE on BAS may manifest as “normalization”—restoring healthy reward processing—rather than “activation” in the sense of amplifying reward-seeking tendencies. This distinction may explain the non-significant mediating effect of BAS, as PE appears to modulate reward function in a regulatory rather than excitatory manner.

To investigate the links between PE, behavioral inhibition, and DC in individuals with SUD more comprehensively, exercise duration, frequency, and intensity were categorized into low, medium, and high levels. The findings revealed that patients who engaged in longer exercise durations and higher frequencies experienced significantly lower DC levels. This suggests a "dose-effect" relationship in exercise intervention, where increasing exercise frequency or duration can enhance the inhibitory effect on cravings, aligning with previous recommendations (e.g., at least three sessions per week, 30-minute moderate-intensity exercise per session yields positive results) [40, 41]. However, no significant differences were observed in the effects of varying exercise intensities on behavioral inhibition and DC, consistent with studies indicating that PE of different intensities can effectively reduce DC [42–44]. Different intensities of exercise may exert their effects through distinct mechanisms. Low-intensity exercise primarily alleviates drug craving by modulating autonomic nervous system balance and reducing stress responses [45, 46], whereas moderate-to-high-intensity exercise predominantly operates via neurotransmitter regulation and the release of neurotrophic factors [47, 48]. These converging pathways may explain the non-significant differences observed between intensity groups. This suggests that maintaining a consistent exercise duration and frequency may be more critical than pursuing high-intensity exercise when designing an exercise prescription.

Limitations and Future Directions

This study elucidates the mediating role of BIS in the relationship between PE and DC. However, several limitations characterize this study. First, this study examined BIS/BAS as the primary mediating variable, yet the emergence and alleviation of DC could be influenced by a broader range of psychological factors. Future studies could incorporate negative emotional states such as anxiety and depression into the model, and explore their regulatory or mediating role in the "movement-BIS/BAS-craving" pathway, so as to construct a more comprehensive theoretical model. Second, the current research predominantly relies on self-reported questionnaires. Future investigations should integrate neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and near-infrared spectroscopy (NIRS), to assess exercise-induced changes in the functional connectivity and activation patterns of BIS-related brain regions. Moreover, Biochemical indicators, including dopamine, serotonin, and cortisol, could further elucidate the neurobiochemical pathways through which PE influences BIS/BAS and DC. Third, this study is a cross-sectional design and cannot infer causality. Future research should employ randomized controlled trials with varying exercise doses (intensity, frequency, duration) to track dynamic changes in BIS/BAS and craving over time. Combining such designs with ecological momentary assessment would enable real-time monitoring of daily PE and DC fluctuations, thereby clarifying the causal pathways and dose-response relationships underlying exercise-induced craving reduction. Collectively, these future directions will contribute to a more comprehensive understanding of exercise-based interventions for SUD and facilitate the development of precision-oriented rehabilitation strategies.

5. Conclusion

This study employed a structural equation model to examine the associations between PE, BIS/BAS, and DC. The findings suggest that BIS may play a mediating role in the association between PE and DC, with exercise duration and frequency showing particularly salient associations with craving. These findings provide empirical support for the behavioral mechanisms through which exercise may support withdrawal and recovery, offering guidance for tailoring exercise interventions that aim to enhance behavioral inhibition. Future research could focus on: 1) conducting randomized controlled trials to explore the causal link between PE, BIS, and DC; 2) incorporating multidimensional variables such as neurobiological markers, cognitive functions, and psychosocial factors to develop a more comprehensive model; and 3) investigating personalized exercise regimens to examine the dose-response relationship across various exercise modalities and demographic profiles.

Abbreviations

PE	Physical Exercise
DC	Drug Craving
SUD	Substance Use Disorders
BIS	Behavioral Inhibition System
BAS	Behavioral Activation System
PARS-3	Physical Activity Rating Scale-3
RST	Reinforcement Sensitivity Theory
DA	Dopamine
VTA	Ventral Tegmental Area
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition
ANOVA	Analysis of Variance
SEM	Structural Equation Modeling
LSD	Least Significant Difference
fMRI	Functional Magnetic Resonance Imaging
NIRS	Near-Infrared Spectroscopy

Declarations

Ethics approval and consent to participate

The studies involving human participants were reviewed and approved by Medical Ethics Committee of Renhe Hospital, affiliated with China Three Gorges University, granted approval for this study (Approval No.: RHLL-2025-59). This study was conducted in accordance with the Declaration of Helsinki, and written informed consent was obtained from all adult participants (aged 18–60) prior to their inclusion in the study. The consent form clearly stated that the data collected would be used for research purposes and that the results might be published in a scientific journal.

Consent for publication

The participants gave written informed consent for their personal or clinical details along with any identifying images (in the supplementary material) to be published in this study.

Availability of data and materials

All data generated or analyzed during this study are included in this article or are available from the corresponding author on reasonable request.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Author contributions

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Tables

Table 1. Participants' demographic characteristic (mean ± SD/n+%).

Variables	low (N=175)	medium (N=100)	high (N=14)	*P*
Age (years)	43.16 ± 10.34	44.02 ± 9.54	45.57 ± 12.20	0.604
Sex				
Male	76 (43.4%)	46 (46%)	9 (64.3%)	0.316
Female	99 (56.6%)	54 (54%)	5 (35.7%)	
Drugs				0.951
Methamphetamine	112 (64%)	69 (69.7%)	8 (57.1%)	
Heroin	33 (18.9%)	17 (17.2%)	3 (21.4%)	
Morphine	12 (6.9%)	5 (5.1%)	1 (7.1%)	
Mix	18 (10.3%)	8 (8.1%)	2 (14.3%)	
drug use (years)	12.46 ± 7.44	13.41 ± 7.47	11.93 ± 4.94	0.542
Number of drug rehabilitation	1.59 ± 0.87	1.61 ± 0.74	1.43 ± 0.85	0.751
BIS/BAS (scores)				
Behavioral inhibition	12.07 ± 2.53	13.30 ± 2.52	13.93 ± 2.27	<0.001***
Reward Responsiveness	12.95 ± 2.36	13.45 ± 2.40	14.29 ± 2.09	0.049*
Fun seeking	14.53 ± 2.79	15.43 ± 3.03	17.14 ± 2.60	<0.001***
Drive	13.59 ± 2.90	14.15 ± 2.66	15.39± 1.76	0.032*
PARS-3	9.42 ± 4.63	28.11 ± 6.50	53.71 ± 11.17	<0.001***
Drug craving	51.58 ± 12.94	47.94 ± 14.76	42.71 ± 20.93	0.018*

BIS/BAS, Behavioral Inhibition/Activation System Scale. PARS-3, Physical Activity Rating Scale-3. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 2. Test equations for exercise, reward responsiveness, behavioral inhibition, and DC.						
Path	Estimate	Std. error	*z*-value	*P*	95% Confidence Interval	
					Lower	Upper
PARS-3 → DC	-0.136	0.063	-2.168	0.030*	-0.260	-0.013
PARS-3 → Reward responsiveness	0.029	0.010	2.765	0.006**	0.008	0.049
PARS-3 → Behavioral inhibition	0.049	0.011	4.394	< 0.001***	0.027	0.071
Reward responsiveness → DC	0.213	0.455	0.467	0.640	-0.680	1.105
Behavioral inhibition → DC	-1.194	0.427	-2.796	0.005**	-2.030	-0.357
PARS-3 → Reward responsiveness → DC	0.006	0.013	0.461	0.645	-0.020	0.032
PARS-3 → Behavioral inhibition → DC	-0.058	0.025	-2.359	0.018*	-0.107	-0.010
PARS-3, Physical Activity Rating Scale-3. DC, Drug craving. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.						

Table 3. Differences in behavioral inhibition and DC under the influence of different levels of sub-dimensions of PE.

	Variables	low (N=162)	medium (N=76)	high (N=51)	*P*	LSD Multiple Comparisons
Exercise duration	DC	50.37 ± 13.46	49.64 ± 14.77	48.75 ± 15.71	0.764	-
	Behavioral inhibition	12.12 ± 2.65	13.03 ± 2.52	13.41 ± 2.21	0.002**	Low < medium; low < high
	Variables	low (N=88)	medium (N=32)	high (N=169)	*P*	LSD Multiple Comparisons
Exercise frequency	DC	53.94 ± 14.07	47.12 ± 12.23	48.31 ± 14.23	0.005**	Low > medium; low > high
	Behavioral inhibition	12.27 ± 2.50	11.97 ± 2.86	12.86 ± 2.56	0.080	-
	Variables	low (N=186)	medium (N=72)	high (N=31)	*P*	LSD Multiple Comparisons
Exercise intensity	DC	50.08 ± 13.71	51.19 ± 14.99	45.74 ± 14.82	0.193	-
	Behavioral inhibition	12.47 ± 2.65	12.64 ± 2.43	13.13 ± 2.59	0.420	-

DC, Drug craving. ** $P < 0.01$.

Figures

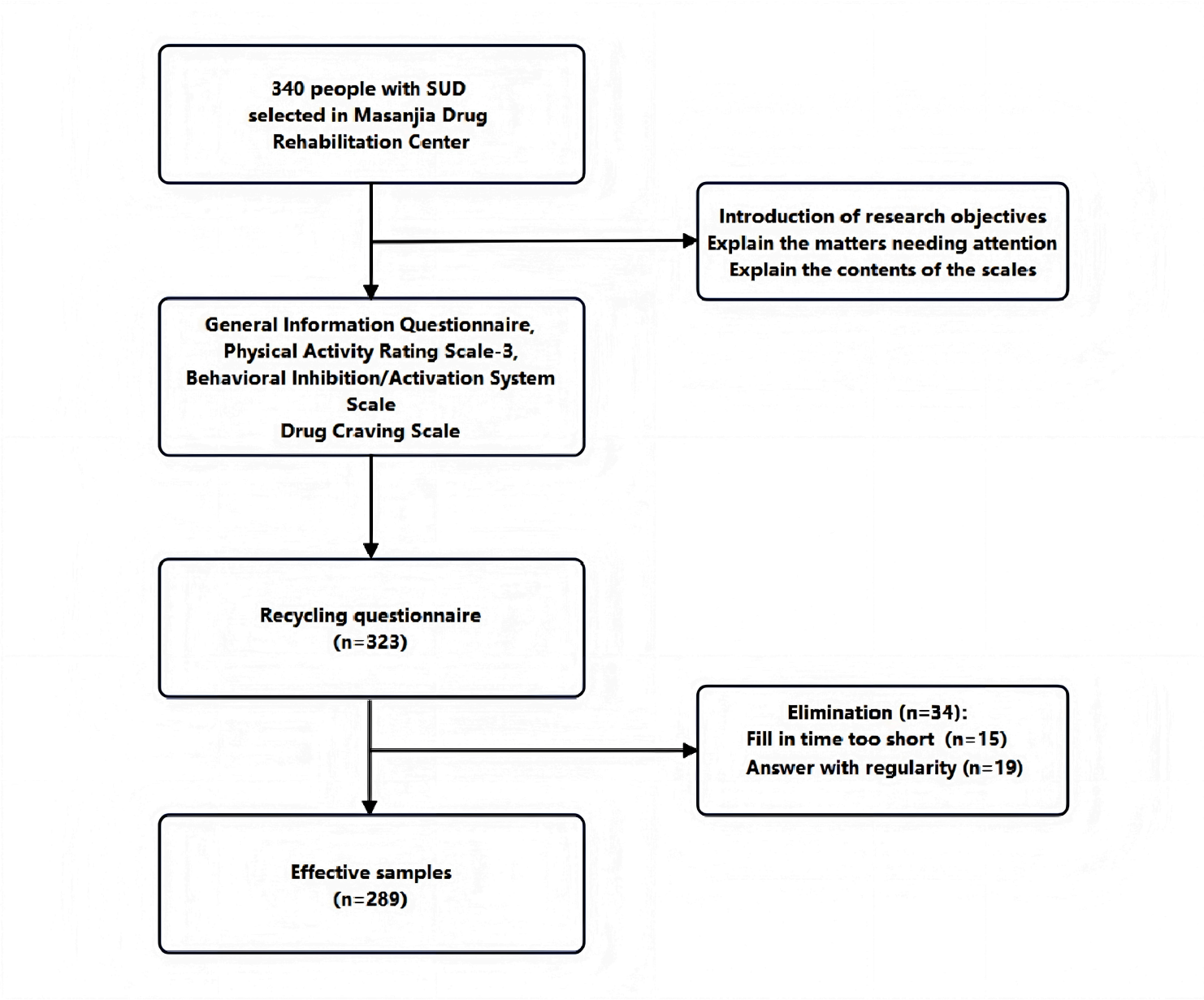


Figure 1

Flow chart of participant recruitment and inclusion.

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Figure 2

Relationship among PE, BIS/BAS, and DC in individuals with SUD. respectively.

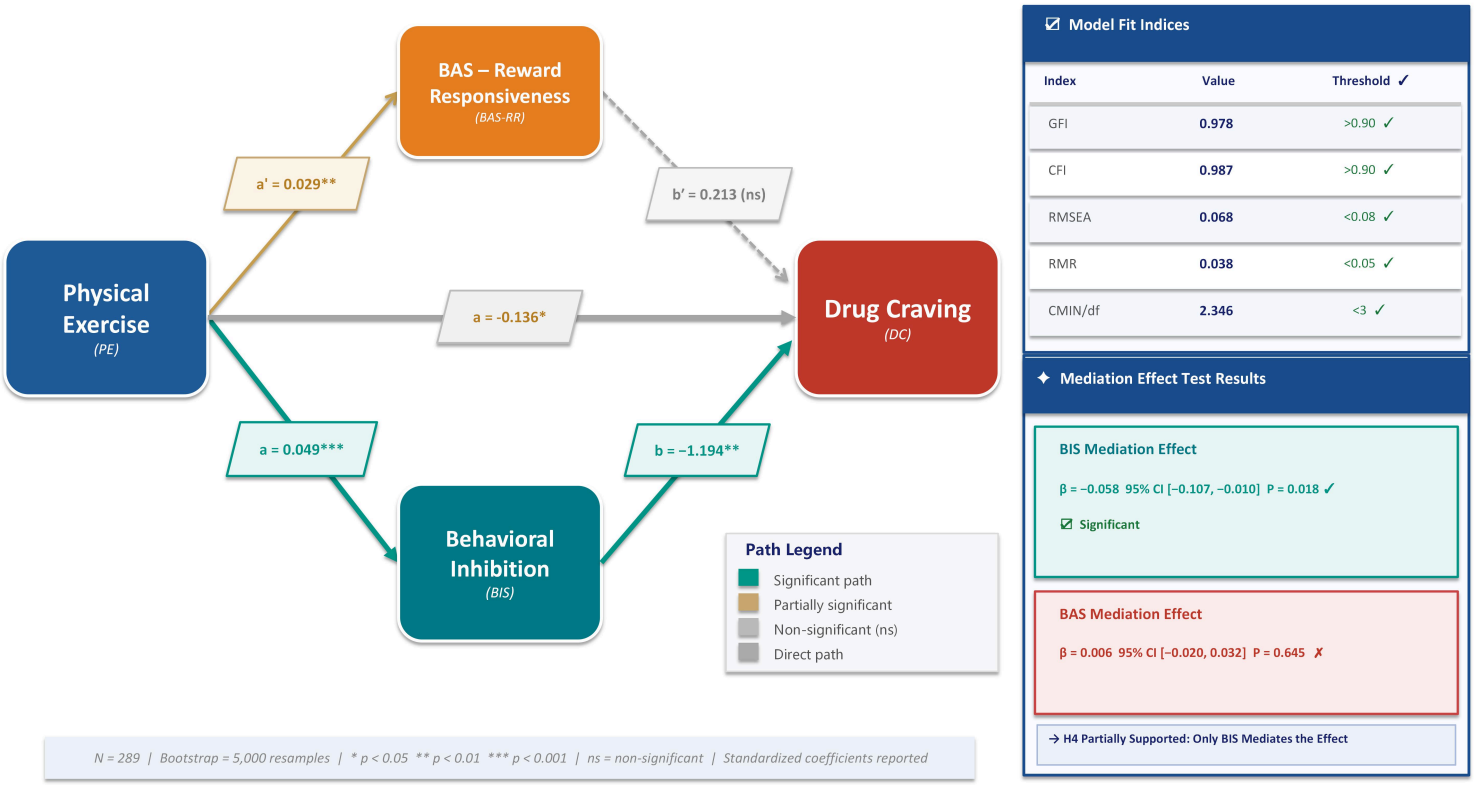


Figure 3

Mediating relationship among PE, reward response, behavioral inhibition, and DC. Solid arrows = statistically significant paths; dashed arrows = non-significant paths.