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Comparison of the Effectiveness of Relapse Prevention Therapy Based on Neurofeedback and Cognitive Rehabilitation on Clinical Symptoms in Women Using Methamphetamine

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A B S T R A C T

Objective: This study aimed to compare the effectiveness of neurofeedback-based relapse prevention and cognitive rehabilitation on pain perception and momentary craving in women with a history of methamphetamine use.

Methods and Materials: The study employed a quasi-experimental design with a pre-test, post-test, and follow-up assessment. Participants included 86 women aged 20 to 40 years with a history of methamphetamine addiction who had undergone treatment and participated in recovery support programs. They were randomly assigned to the neurofeedback group (n = 43) or the cognitive rehabilitation group (n = 43). The interventions were conducted over five weeks, with neurofeedback training focusing on sensorimotor rhythm (SMR) and alpha-theta protocols, while cognitive rehabilitation targeted executive functions such as working memory, attention, and response inhibition. The McGill Pain Questionnaire (MPQ) and the Desire for Drug Questionnaire (DDQ) were administered at baseline, post-intervention, and follow-up. Data analysis was conducted using analysis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA).

Findings: The cognitive rehabilitation intervention significantly reduced total pain scores ($F = 4.57$, $p = 0.039$, $\eta^2 = 0.100$) and affective perception of pain ($F = 4.94$, $p = 0.032$, $\eta^2 = 0.115$), whereas the neurofeedback intervention did not show significant effects on pain ($p > 0.05$). Both interventions significantly reduced total momentary craving (Neurofeedback: $F = 98.68$, $p < 0.001$, $\eta^2 = 0.701$; Cognitive Rehabilitation: $F = 64.64$, $p < 0.001$, $\eta^2 = 0.612$) and its components, including desire and intention to use, negative reinforcement, and perceived control over substance use ($p < 0.05$). There was no significant difference in treatment effects between the two interventions ($p > 0.05$).

Conclusion: Cognitive rehabilitation was effective in reducing pain, particularly affective pain perception, while both neurofeedback and cognitive rehabilitation significantly reduced momentary craving. These findings suggest that cognitive rehabilitation may be a more suitable intervention for pain management, while both interventions can be effective for craving reduction in individuals recovering from methamphetamine addiction.

Keywords: *Neurofeedback, Cognitive Rehabilitation, Methamphetamine, Pain.*

1. Introduction

Methamphetamine use is considered one of the most serious health and social issues in many countries worldwide. This powerful stimulant rapidly induces dependence due to its intense psychological and physiological effects, placing users at significant physical and psychological risk. Methamphetamine, commonly known as "crystal meth," is highly potent and persistent compared to other narcotic substances, and its continued use can lead to central nervous system damage and numerous psychiatric disorders (Turan et al., 2023).

Substance use is generally understood as providing an immediate short-term reward. This acute positive effect (e.g., euphoria) can be observed behaviorally and in brain regions involved in reward processing, including the orbitofrontal cortex (OFC), the rostral anterior cingulate cortex (ACC), and the ventral striatum. When these positive emotional states outweigh the negative consequences and use continues, drug-seeking behavior is said to be positively reinforced. However, methamphetamine use may also be reinforced by alleviating or eliminating distressing or adverse bodily states (Hine et al., 2023; Stellern et al., 2023). This principle, known as negative reinforcement, suggests that individuals continue substance use despite negative consequences because it reduces unpleasant states or feelings, such as those associated with negative mood states, tension, arousal, craving, or withdrawal. For some individuals, these distressing states and situations emerge as withdrawal symptoms following prolonged substance use. For others, even initial use may serve as a maladaptive coping mechanism to reduce pre-existing negative states, such as depression, anxiety, or reduced responsiveness to reward (Alizadehgoradel et al., 2021; Nooripour et al., 2021; Siefried et al., 2020).

Eugene Peniston first proposed the treatment of addictive disorders using neurofeedback in 1991. Research has demonstrated that this method effectively reduces psychological symptoms and the adverse effects of substance abuse. Recently, electroencephalography (EEG)-based neurofeedback has been identified as an efficient rehabilitation approach for substance use disorders (Nooripour et al., 2021). Neurofeedback provides patients with real-time feedback, enabling them to alter the rhythm and frequency of their brain waves. Neurophysiological studies indicate that EEG provides insights into the relationship between underlying brain mechanisms, cortical activity, and psychological states. Neurofeedback rehabilitation is a method that has recently been studied for its effectiveness in treating pathological psychiatric disorders such as stress and anxiety (Castro & Hill, 2002). The goal of this method is to help individuals modify their brain wave patterns without invasive techniques. Neurofeedback rehabilitation improves the electrical system of the brain by reinforcing well-functioning patterns and inhibiting undesirable activity. It is also believed to stimulate growth, alter neuronal efficiency, and enhance both brain function and cognitive-behavioral performance. During neurofeedback rehabilitation, individuals learn to change their brain wave patterns through conditioning. Neurofeedback rehabilitation has been shown to promote relaxation, reduce stress, and decrease psychiatric abnormalities in individuals with substance and alcohol use disorders (Nooripour et al., 2018; Sunder & Bohnen, 2017).

One of the neurofeedback rehabilitation methods involves alpha/theta wave conditioning. Alpha brain waves, with a frequency of 8–12 Hz, are associated with a state of well-being (Shojaei, 2024; Wu et al., 2024). Theta brain waves, with a frequency of 4–7 Hz, are linked to pre-sleep or dreamlike states, including anxiety-inducing traumatic events and spontaneous and/or fragmented hypnagogic imagery. Alpha-theta rehabilitation is primarily designed to enhance alpha and theta waves. An increase in these wave frequencies promotes relaxation and conscious awareness. This relaxed state, known as the twilight state, enables individuals to experience hypnagogic imagery or subjective perceptions of emotions and suppressed memories, which play a fundamental role in the therapeutic process. Few studies have explored neurofeedback rehabilitation for anxiety in substance use disorders (Castro & Hill, 2002; Nooripour et al., 2018; Nooripour et al., 2021; Sunder & Bohnen, 2017).

Methamphetamine abuse has significant public health consequences worldwide. Chronic methamphetamine use is associated with abnormalities in brain function and metabolism, leading to numerous negative outcomes, including cognitive impairments, high impulsivity, and poor psychological well-being (Barati et al., 2023; Pourasghar et al., 2022). Cognitive impairments and high impulsivity can create a paradoxical situation in which individuals, despite being fully aware of the negative consequences, continue using methamphetamine compulsively. According to the dual-process model of addiction, two imbalanced information processing mechanisms may contribute to this paradox in individuals with methamphetamine use disorder

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(MUD): automatic and reflective processes (Luikinga et al., 2018; Simons et al., 2018).

Automatic processes, which become excessively activated in many individuals with substance use disorders (SUDs), are rapid, impulsive, and automatic cognitive processes that often guide response selection in high-risk situations. A common feature of sensitized automatic processes is drug-related cognitive bias. Reflective processes, which are associated with cognitive control functions, are significantly slower and relatively controlled. With continued substance use, impairments in cognitive functions such as attentional control, working memory, and response inhibition may negatively affect this reflective process. The interaction between a sensitized automatic process and a slower reflective process further exacerbates the addiction paradox (Alizadehgoradel et al., 2021).

Studies have provided evidence that neuropsychological rehabilitation techniques targeting cognitive function and cognitive bias may effectively address this challenge. Cognitive rehabilitation therapy (CRT) is one such promising intervention and has demonstrated beneficial effects on cognitive deficits in several clinical populations, including schizophrenia, traumatic brain injury, and SUDs. Cognitive bias modification is another computerized treatment method that targets sensitized automatic processes. Previous evidence has shown that drug-related attentional bias can be retrained, leading to short-term benefits in reducing substance use (Nooripour et al., 2018).

However, to the best of our knowledge, no prior intervention has simultaneously addressed both neurofeedback and cognitive rehabilitation among individuals with MUD. Considering both processes in individuals with MUD, interventions that target both aspects may be more effective than singular approaches. Cognitive rehabilitation therapy (CRT), which involves training cognitive tasks such as memory, problem-solving, response inhibition, perception, and discrimination skills, is one of the strategies for preventing relapse. In recent years, technological advancements have facilitated the use of computerized CRT to improve neurocognitive deficits in patients. Bickel demonstrated that computerized memory training tasks modulated impulsivity and delayed discounting among stimulant users (Nooripour et al., 2018; Nooripour et al., 2021).

Given the reviewed literature, it is crucial to emphasize that relapse prevention following substance cessation is of significant importance. However, an examination of previous studies indicates that no research in Iran has explored neurofeedback-based relapse prevention in conjunction with cognitive rehabilitation. This raises the question: Is neurofeedback-based relapse prevention combined with rehabilitation effective in reducing clinical symptoms among methamphetamine users?

2. Methods and Materials

2.1. Study design and Participant

The present study is fundamental in terms of its objective, survey-based in terms of data collection, and quantitative in terms of data analysis. The study population consisted of women with a history of methamphetamine addiction in Tehran who had undergone treatment and participated in recovery support groups at an addiction treatment center in northeastern Tehran (the name of the collaborating center is omitted due to ethical considerations). The participants were between 20 and 40 years old, forming a population of approximately 500 individuals. Data and participant information were collected in direct collaboration with this center. The participants were informed about the benefits of the study, assured of confidentiality, and given the option to establish direct communication with the researchers upon providing informed consent. Those who agreed to participate attended the intervention sessions, and written informed consent was obtained before their inclusion in the study.

Considering the interventional nature of the study, a sample size of 20 to 40 participants is generally deemed sufficient for such interventions. However, to increase precision, the GPower software was used to determine the required sample size. Based on the calculations using GPower, a minimum of 83 participants was needed across the two groups (intervention and control). To ensure adequate statistical power, the study aimed to recruit more than 43 participants in each group. Given that participants were selected from a specific center, convenience sampling was employed. Individuals who had received treatment at the center within the past two years were identified using their national identification numbers, and a random number generator was used to select participants to minimize selection bias. The final sample size was determined based on informed consent, and a larger sample would enhance the reliability of the results.

It was ensured that participants had the right to withdraw from the study at any stage. Additionally, individuals receiving other psychological interventions were excluded. Participants who failed to attend the sessions regularly were also removed from the study and replaced with new

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individuals. Fortunately, none of the participants withdrew from the study.

After obtaining written informed consent, participants received an ethical commitment form ensuring confidentiality, protection of personal data, and a guarantee that they would not be abandoned in case of complications. Subsequently, demographic information was collected using an initial demographic questionnaire. Participants completed study assessments at three points: at baseline, after the interventions, and two months later for follow-up.

Since cognitive rehabilitation sessions were relatively longer, efforts were made to increase the number of neurofeedback sessions to match the number of cognitive rehabilitation sessions so that both interventions were completed simultaneously. Upon completion of the interventions, post-test data were collected for both the intervention and control groups using the McGill Pain Questionnaire (MPQ) and the Desire for Drug Questionnaire (DDQ), which were then entered into statistical software for analysis. The validity and reliability of each instrument used in the study are presented in subsequent sections.

2.2. Measures

2.2.1. Pain

McGill Pain Questionnaire (MPQ) consists of 20 sets of statements designed to assess individuals' pain perception across multiple dimensions, including sensory perception of pain, affective perception of pain, evaluative perception of pain, and various types of pain (Melzack, 2017). The questionnaire includes three dimensions: sensory perception of pain, affective perception of pain, and evaluative perception of pain. The validity of this questionnaire was confirmed in a study by Dworkin et al. (2009). Its reliability was calculated using Cronbach's alpha, with coefficients ranging from .83 to .87. Khosravi et al. (2012) localized this questionnaire and reported a Cronbach's alpha of .85, with reliability coefficients above .80 for all subscales (Roshandel et al., 2022). The validity and reliability of the questionnaire were re-evaluated in the present study, and the results are provided in the final section of this methodology.

2.2.2. Drug Craving

Momentary Drug Craving Scale questionnaire was developed by Franken et al. (2002) to assess drug craving as a motivational state in the present moment (Franken, Hendriks, & van den Brink, 2002). The questionnaire consists of 14 items categorized into three main factors. The first factor, "desire and intention to use," includes items 1, 2, 12, and 14. The second factor, "desire for use and negative interpretation or belief in problem-solving through drug use," includes items 4, 5, 7, 9, and 11. The third factor, "pleasure and intensity of control," includes items 3, 6, 8, 10, and 13. Franken and Hendriks (2002) demonstrated high validity for this questionnaire, with factor loadings exceeding .60, indicating strong construct validity. The calculated Cronbach's alpha for the entire scale was .86. Internal consistency coefficients for opioid users (e.g., heroin and crack) were reported as .89, .79, and .40, respectively, by Mokri et al. (2010). For methamphetamine users, the coefficients were .78, .65, and .81. Pourseyedmousavi et al. (2013) evaluated the reliability of the questionnaire using Cronbach's alpha and found high internal consistency for different drug user groups: .96 for stimulant users, .95 for crack users, .90 for methamphetamine users, and .94 for heroin users (Baher Talari, 2022). The reliability assessment in the present study showed that the Cronbach's alpha for all research variables exceeded .70. Specifically, the Cronbach's alpha coefficient for the pain scale was .85, for the depression scale was .79, for the anxiety scale was .87, for the aggressive behavior scale was .92, and for the momentary drug craving scale was .77. These findings confirm the reliability of the study questionnaires.

2.3. Interventions

2.3.1. Neurofeedback

Neurofeedback sessions were conducted over five weeks, with two 40-minute sessions per week. Neurofeedback training was based on therapeutic paradigms involving sensorimotor rhythm (SMR) training at the Cz region and alpha-theta training at the Pz region (located in the temporal cortex), each lasting 20 minutes, using the ProComp device. This device functions as an amplifier, receiving brain waves from electrodes attached to the scalp and transmitting them to a computer-based software system. Since brain-generated waves received through scalp electrodes are extremely weak and imperceptible, the device amplifies them into stronger electronic signals for analysis. The waves are then processed through neurofeedback software, converted into sinusoidal waves, and analyzed based on the current neurofeedback treatment protocol.

In the Cz region, feedback was provided through both auditory and visual modalities. Thresholds were set so that

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if the participant maintained the enhanced band above the threshold for at least 0.5 seconds in 80% of instances and the suppressed band remained below the threshold in 20% of instances, reinforcement (feedback) was given. If the participant maintained the enhanced band above the threshold in 90% of instances and did so consecutively in two attempts, the threshold was adjusted to approach the optimal level. In the Pz region, feedback was auditory-only. During this protocol, participants closed their eyes and listened to the auditory stimuli. The three primary parameters assessed were theta, alpha, and beta waves, with an additional parameter for delta wave control. The thresholds were set so that alpha and theta waves exceeded the threshold in at least 60% of instances, while theta waves exceeded the threshold in 20% of instances.

2.3.2. Cognitive Rehabilitation

The cognitive rehabilitation training package used in this study was based on the Najati (2010) computerized cognitive rehabilitation program, which focuses on enhancing working memory, selective attention, sustained attention, and shifting attention. This program consists of a structured hierarchy of tasks designed to strengthen various aspects of working memory, including storage, transfer, and information control. The working memory tasks included updating, maintenance, and transfer tasks, along with a home stimulus search task for selective attention enhancement, an image-matching task for sustained attention improvement, and a facial sorting task based on emotional expressions to enhance shifting attention. This program was implemented over 14 sessions, each lasting 30 minutes, conducted twice weekly.

2.4. Data Analysis

To test the research hypotheses and compare the groups, one-way analysis of covariance (ANCOVA) and multivariate analysis of covariance (MANCOVA) were employed. Assumptions for parametric ANCOVA analysis were examined, including the absence of outliers (assessed using box plots), normality of variable distribution (assessed using the Shapiro-Wilk test and skewness-kurtosis statistics), homogeneity of variances (assessed using Levene's test), homogeneity of regression slopes (assessed through the interaction effect of the pre-test variable and group variable on the post-test variable), and homogeneity of variance-covariance matrices (assessed using Box's M test). Data analysis was performed using SPSS 28 statistical software.

3. Findings and Results

The demographic analysis of the study indicated that most respondents in all three groups had an education level of less than a high school diploma, followed by those with a high school diploma. The results showed no significant difference in the mean age and duration of substance use among the groups. According to the independent samples t-test, the intervention and control groups were homogeneous in terms of age and duration of substance use ($p > .05$).

The descriptive statistics for the study variables and their components are presented in Table 1.

Table 1

Descriptive Statistics for Study Variables and Their Components

Variable	Time	Neurofeedback Group M (SD)	Cognitive Rehabilitation Group M (SD)	Control Group M (SD)
Sensory Perception of Pain	Pre-test	23.00 (7.44)	24.33 (7.07)	25.39 (6.29)
	Post-test	21.82 (7.05)	22.86 (6.54)	24.39 (5.52)
Affective Perception of Pain	Pre-test	8.68 (2.40)	9.71 (2.28)	8.74 (2.09)
	Post-test	8.05 (2.04)	8.52 (2.34)	8.52 (2.06)
Evaluative Perception of Pain	Pre-test	3.23 (1.27)	3.19 (1.21)	3.70 (1.15)
	Post-test	2.91 (0.87)	2.71 (1.01)	3.35 (0.98)
Various Types of Pain	Pre-test	8.77 (3.01)	9.52 (2.20)	9.61 (2.94)
	Post-test	8.27 (2.57)	8.62 (1.94)	9.17 (2.71)
Total Pain	Pre-test	43.68 (8.58)	46.76 (8.98)	47.43 (7.13)
	Post-test	41.05 (8.14)	42.71 (8.91)	45.43 (6.65)
Desire and Intention to Use	Pre-test	27.36 (5.43)	27.24 (5.71)	26.09 (6.11)
	Post-test	20.73 (4.72)	22.19 (4.32)	26.13 (6.12)
Negative Reinforcement	Pre-test	16.68 (4.10)	15.90 (4.08)	16.22 (3.92)
	Post-test	13.00 (2.93)	12.90 (4.15)	15.65 (3.37)
Perceived Control over Substance Use	Pre-test	8.73 (3.20)	8.14 (2.41)	7.74 (3.25)
	Post-test	7.50 (2.92)	6.48 (2.14)	7.96 (3.34)
Total Momentary Craving	Pre-test	52.77 (8.11)	51.29 (6.99)	50.04 (6.34)

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Post-test	41.23 (6.75)	41.57 (5.96)	49.74 (6.17)

The results presented in Table 1 indicated that the mean total pain score in the neurofeedback group was 43.68 (8.58) in the pre-test, which decreased by 2.63 points to 41.05 (8.14) in the post-test. In the cognitive rehabilitation group, the mean decreased from 46.76 (8.98) in the pre-test to 42.71 (8.91) in the post-test, reflecting a reduction of 4.05 points. In the control group, only minor changes in mean scores were observed. The mean values of all pain components decreased in the post-test in both the neurofeedback and cognitive rehabilitation groups.

Additionally, the results showed that the mean total momentary craving score in the neurofeedback group was 52.77 (8.11) in the pre-test, which decreased by 11.54 points to 41.23 (6.75) in the post-test. In the cognitive rehabilitation group, the mean decreased from 51.29 (6.99) in the pre-test to 41.57 (5.96) in the post-test, reflecting a reduction of 9.72 points. In the control group, the mean decreased from 50.04 (6.34) to 49.74 (6.17), showing only a minor reduction of 0.30 points. The mean values of all momentary craving components decreased in the post-test in both the neurofeedback and cognitive rehabilitation groups.

The results of the analysis of covariance (ANCOVA) to assess the effectiveness of neurofeedback-based relapse prevention on total pain score and its components are presented in Table 2.

Table 2

ANCOVA for the Effectiveness of Neurofeedback-Based Relapse Prevention on Total Pain Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Sensory Perception of Pain	3.45	1	3.45	0.462	0.501	0.012
Affective Perception of Pain	1.58	1	1.58	1.39	0.245	0.034
Evaluative Perception of Pain	1.66	1	1.66	2.12	0.154	0.051
Various Types of Pain	0.225	1	0.225	0.076	0.784	0.002
Total Pain	18.68	1	18.68	1.34	0.254	0.031

The results in Table 2 showed that the effectiveness of the neurofeedback intervention on the pain variable and its components was not confirmed ($p > .05$). The obtained significance level for the pain variable and its components was greater than the alpha error threshold of .05, indicating that the neurofeedback intervention was not effective in reducing pain among participants.

The results of the ANCOVA to assess the effectiveness of cognitive rehabilitation on total pain score and its components are presented in Table 3.

Table 3

ANCOVA for the Effectiveness of Cognitive Rehabilitation on Total Pain Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Sensory Perception of Pain	6.18	1	6.18	1.89	0.177	0.047
Affective Perception of Pain	6.92	1	6.92	4.94	0.032	0.115
Evaluative Perception of Pain	2.29	1	2.29	2.67	0.111	0.066
Various Types of Pain	0.741	1	0.741	0.280	0.600	0.007
Total Pain	49.65	1	49.65	4.57	0.039	0.100

The results in Table 3 indicated that the effectiveness of the cognitive rehabilitation intervention on the total pain score and one of its components, namely affective perception of pain, was confirmed ($p < .05$). The effect size index (partial eta squared) suggested that the intervention had the highest effectiveness on the affective perception of pain component (0.115), followed by the total pain score (0.100), suggesting a moderate effect.

Table 4

Analysis of Covariance (ANCOVA) to Assess the Effectiveness of the Intervention on Total Pain Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Sensory Perception of Pain	6.18	1	6.18	1.89	0.177	0.047

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Affective Perception of Pain	6.92	1	6.92	4.94	0.032	0.115
Evaluative Perception of Pain	2.29	1	2.29	2.67	0.111	0.066
Various Types of Pain	0.741	1	0.741	0.280	0.600	0.007
Total Pain	49.65	1	49.65	4.57	0.039	0.100

The results in Table 4 showed that the effectiveness of the cognitive rehabilitation intervention on the total pain score and one of its components, namely affective perception of pain, was confirmed (p < .05). The obtained significance level for the total pain score and the affective perception of pain component was below the alpha error threshold of .05, demonstrating the effectiveness of the cognitive rehabilitation intervention in improving pain and affective perception of pain.

However, the results indicated that the effectiveness of the cognitive rehabilitation intervention on the sensory perception of pain, evaluative perception of pain, and various types of pain was not confirmed (p > .05). The effect size index (partial eta squared) indicated that the intervention had the highest effectiveness on the affective perception of pain component (0.115), followed by the total pain score (0.100), suggesting a moderate effect.

Table 5

Analysis of Covariance (ANCOVA) to Assess the Effectiveness of the Intervention on Total Pain Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Sensory Perception of Pain	0.860	1	0.860	0.090	0.766	0.002
Affective Perception of Pain	1.44	1	1.44	0.994	0.325	0.026
Evaluative Perception of Pain	0.396	1	0.396	0.574	0.454	0.015
Various Types of Pain	0.949	1	0.949	0.431	0.516	0.012
Total Pain	10.57	1	10.57	0.715	0.403	0.018

The results in Table 5 showed no significant difference in the effectiveness of neurofeedback and cognitive rehabilitation interventions on pain and its components (p > .05). The obtained significance level for the pain variable and its components was greater than the alpha error threshold of .05, indicating that the effectiveness of the neurofeedback and cognitive rehabilitation interventions on pain was similar.

Table 6

Analysis of Covariance (ANCOVA) to Assess the Effectiveness of the Neurofeedback Intervention on Total Momentary Craving Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Desire and Intention to Use	436.45	1	436.45	62.89	<0.001	0.611
Negative Reinforcement	86.08	1	86.08	29.12	<0.001	0.421
Perceived Control over Substance Use	20.30	1	20.30	8.48	0.006	0.175
Total Momentary Craving	1210.06	1	1210.06	98.68	<0.001	0.701

The results in Table 6 indicated that the effectiveness of the neurofeedback intervention on momentary craving and all three of its components—desire and intention to use, negative reinforcement, and perceived control over substance use—was confirmed (p < .05). The obtained significance level for momentary craving and its components was below the alpha error threshold of .05, demonstrating the effectiveness of the neurofeedback intervention in reducing momentary craving and its components.

The effect size index (partial eta squared) indicated that the intervention had the highest effectiveness on total momentary craving (0.701), followed by the desire and intention to use component (0.611), the negative reinforcement component (0.421), and the perceived control over substance use component (0.175). These results suggest that the neurofeedback intervention had a significant impact on momentary craving and its components.

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Table 7

Analysis of Covariance (ANCOVA) to Assess the Effectiveness of the Cognitive Rehabilitation Intervention on Total Momentary Craving Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Desire and Intention to Use	255.35	1	255.35	56.90	<0.001	0.593
Negative Reinforcement	71.21	1	71.21	12.23	<0.001	0.239
Perceived Control over Substance Use	34.54	1	34.54	12.36	<0.001	0.241
Total Momentary Craving	894.81	1	894.81	64.64	<0.001	0.612

The results in Table 7 indicated that the effectiveness of the cognitive rehabilitation intervention on momentary craving and all three of its components—desire and intention to use, negative reinforcement, and perceived control over substance use—was confirmed ($p < .05$). The obtained significance level for momentary craving and its components was below the alpha error threshold of .05, demonstrating the effectiveness of the cognitive rehabilitation intervention in reducing momentary craving and its components.

The effect size index (partial eta squared) indicated that the intervention had the highest effectiveness on total momentary craving (0.612), followed by the desire and intention to use component (0.593), the perceived control over substance use component (0.241), and the negative reinforcement component (0.239). These results suggest that the cognitive rehabilitation intervention had a significant impact on momentary craving and its components.

Table 8

Analysis of Covariance (ANCOVA) to Assess the Effectiveness of the Intervention on Total Momentary Craving Score and Its Components

Dependent Variable	Sum of Squares	df	Mean Squares	F	p	Effect Size
Desire and Intention to Use	24.94	1	24.94	3.20	0.082	0.078
Negative Reinforcement	1.61	1	1.61	0.232	0.633	0.006
Perceived Control over Substance Use	3.07	1	3.07	1.36	0.251	0.035
Total Momentary Craving	18.58	1	18.58	1.14	0.292	0.028

The results in Table 8 showed that the effectiveness of the neurofeedback and cognitive rehabilitation interventions on momentary craving and its components was not confirmed ($p > .05$). The obtained significance level for momentary craving and its components was greater than the alpha error threshold of .05, indicating that no significant difference was observed between the two interventions regarding their effect on momentary craving.

4. Discussion and Conclusion

The present study aimed to compare the effectiveness of neurofeedback-based relapse prevention and cognitive rehabilitation on pain perception and momentary craving in women with a history of methamphetamine use. The findings indicated that while neurofeedback did not significantly reduce pain perception, cognitive rehabilitation was effective in decreasing total pain scores and the affective perception of pain. Additionally, both neurofeedback and cognitive rehabilitation significantly reduced momentary craving and its components, including desire and intention to use, negative reinforcement, and perceived control over substance use. These findings align with previous studies that have explored the effects of neurofeedback and cognitive rehabilitation on substance use disorders.

The lack of a significant effect of neurofeedback on pain perception contrasts with some prior studies that have suggested neurofeedback training can modulate pain-related neural activity and improve pain symptoms in clinical populations. However, research on the effectiveness of neurofeedback in pain management among individuals with a history of substance use remains inconclusive. One possible explanation for this finding is that chronic methamphetamine use alters pain processing pathways, making pain less responsive to neurofeedback interventions (DosSantos et al., 2012). Methamphetamine-induced neurotoxicity affects brain regions involved in pain perception, such as the anterior cingulate cortex and the insula, which might reduce the efficacy of neurofeedback-

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based interventions targeting these neural circuits. Additionally, the specific neurofeedback protocol used in this study, focusing on SMR and alpha-theta training, may not have directly targeted the pain-processing regions, thereby limiting its effectiveness in reducing pain symptoms.

Conversely, cognitive rehabilitation demonstrated a significant impact on pain reduction, particularly in the affective perception of pain. This finding is consistent with previous research suggesting that cognitive rehabilitation techniques, such as attention and memory training, can enhance cognitive control over pain perception and decrease the emotional distress associated with pain (Cascarilla, 2009; Christie et al., 2006). The affective dimension of pain is closely linked to cognitive appraisal and emotional regulation, which are often impaired in individuals with a history of substance use disorders. Cognitive rehabilitation may have improved these cognitive and emotional processes, thereby reducing the emotional intensity of pain. Moreover, studies have demonstrated that cognitive training interventions can strengthen prefrontal cortical function, which plays a critical role in modulating pain perception and emotional distress (Behroozi et al., 2018). This may explain why participants in the cognitive rehabilitation group experienced greater improvements in affective pain perception compared to the neurofeedback group.

The results also showed that both neurofeedback and cognitive rehabilitation significantly reduced momentary craving. These findings align with prior studies demonstrating that neurofeedback can effectively modulate neural circuits associated with craving and self-regulation in individuals with substance use disorders. Neurofeedback training has been shown to enhance functional connectivity between prefrontal regulatory regions and limbic structures, thereby improving inhibitory control over craving-related responses (Nooripour et al., 2021). The reduction in momentary craving observed in the neurofeedback group supports the notion that neurofeedback training can help regulate neural mechanisms underlying compulsive drug-seeking behaviors. Specifically, the significant reductions in desire and intention to use, negative reinforcement, and perceived control over substance use indicate that neurofeedback may have improved participants' ability to resist craving by strengthening top-down regulatory mechanisms.

Similarly, cognitive rehabilitation also produced significant reductions in momentary craving and its components. This finding is in line with previous research indicating that cognitive training can enhance executive functioning and cognitive flexibility, thereby reducing the intensity of craving episodes (Behroozi et al., 2018; Safikhani, 2022). Cognitive rehabilitation interventions often focus on improving attentional control, working memory, and response inhibition, which are crucial cognitive domains for regulating substance-related impulses (Pourjaberi et al., 2023). By strengthening these cognitive capacities, participants in the cognitive rehabilitation group may have developed better self-regulatory strategies to manage craving episodes. Additionally, studies have suggested that cognitive rehabilitation can help restructure maladaptive beliefs about substance use, reducing the perceived benefits of drug consumption. This may explain why participants in the cognitive rehabilitation group reported lower levels of negative reinforcement and perceived control over substance use in the post-test assessment.

The comparison between neurofeedback and cognitive rehabilitation revealed no significant difference in their effectiveness in reducing pain or craving. This suggests that while these interventions operate through distinct mechanisms, they may yield comparable benefits in terms of reducing craving-related behaviors. Neurofeedback primarily targets neurophysiological processes by enhancing self-regulation of brain activity, whereas cognitive rehabilitation focuses on strengthening cognitive control and executive functioning. The absence of a significant difference in treatment effects suggests that both approaches may be viable options for addressing craving in individuals recovering from methamphetamine addiction. However, future research should further explore whether combining these interventions could yield additive benefits by simultaneously targeting neural and cognitive mechanisms underlying addiction.

5. Limitations and Suggestions

Despite its valuable contributions, the present study has several limitations. First, the study relied on self-report measures for pain perception and craving, which may be subject to response biases. Future research should incorporate objective neurophysiological or behavioral measures to corroborate self-reported outcomes. Second, the sample consisted exclusively of women with a history of methamphetamine use, limiting the generalizability of the findings to other populations, including men and individuals with different substance use histories. Third, the study did

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not include a long-term follow-up assessment to examine whether the observed effects of neurofeedback and cognitive rehabilitation were maintained over time. Given the chronic nature of addiction, future studies should include follow-up assessments to determine the durability of treatment effects. Fourth, the study was conducted in a single treatment center, which may introduce site-specific factors that could influence outcomes. Future research should replicate these findings in diverse settings to enhance external validity.

Future research should explore whether integrating neurofeedback with cognitive rehabilitation could enhance treatment outcomes by addressing both neural and cognitive deficits associated with addiction. Additionally, studies should investigate the neural mechanisms underlying the effects of these interventions using neuroimaging techniques such as functional magnetic resonance imaging (fMRI) or electroencephalography (EEG) to better understand how neurofeedback and cognitive rehabilitation modulate brain activity related to craving and pain perception. Another important avenue for research is examining the effects of these interventions in individuals with polysubstance use, as different substances may have distinct neurobiological and cognitive consequences. Moreover, future studies should evaluate the potential moderating effects of individual differences, such as baseline cognitive functioning or severity of addiction, to identify which subgroups may benefit most from each intervention. Finally, expanding research to include community-based samples and real-world clinical settings would enhance the ecological validity of findings and inform the development of more effective, scalable interventions.

Given the demonstrated effectiveness of cognitive rehabilitation in reducing pain perception, treatment programs for individuals recovering from methamphetamine addiction should incorporate cognitive training exercises focused on improving emotional regulation and cognitive control over pain. Additionally, the significant reductions in craving observed in both neurofeedback and cognitive rehabilitation suggest that these interventions could be integrated into relapse prevention programs to enhance self-regulation and reduce the risk of relapse. Clinicians should consider tailoring neurofeedback protocols to target brain regions specifically involved in pain processing to maximize therapeutic benefits. Furthermore, cognitive rehabilitation programs should include personalized training modules that address the unique cognitive deficits of each individual to optimize treatment outcomes. Finally, treatment centers should consider providing combined neurofeedback and cognitive rehabilitation interventions to offer a comprehensive approach that addresses both the neurophysiological and cognitive aspects of addiction recovery.

Authors' Contributions

Authors contributed equally to this article.

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

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants. The present study was registered with the ethics committee under the code IR.IAU.K.REC.1403.104.

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