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Research article

Effects of chronic aerobic exercise on attentional bias among women with methamphetamine addiction

Qi Zhao [a], Jianing Liu [b], Chenglin Zhou [c], Tianze Liu [d,*]

[a] Physical Education Institute, Jimei University, China
[b] Department of Physical Education, Tongji University, China
[c] School of Psychology, Shanghai University of Sport, China
[d] Department of Orthopedics, Changhai Hospital, Naval Medical University (Second Military Medical University), China

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ABSTRACT

Objective: To explore the effects of chronic exercise on attentional bias toward drug-related stimuli and on brain electrophysiological characteristics among women with methamphetamine addiction.

Methods: In total, 63 women with methamphetamine addiction were randomized to participate in a dance (n = 21; mean age, 32.16 ± 2.07 years), bicycle (n = 21; mean age, 32.59 ± 2.12 years), or control (maintained regular activities with little exercise; n = 21; mean age, 30.95 ± 2.81 years) group for 12 weeks. The participants in the three groups were not significantly different in terms of methamphetamine use or detoxification. Before and after the intervention, attentional bias was assessed using the dot-probe task, and event-related potentials were recorded during the task.

Results: The mean attentional bias scores decreased significantly after the intervention in both exercise groups but not in the control group. After 12 weeks of dance exercise, the amplitudes of the N170, N2, P2, and P3 components of the event-related potentials decreased significantly during attentional bias processing. In addition, differences in N170 amplitudes for congruent vs. incongruent conditions in the dot-probe task were no longer observed. After 12 weeks of cycling exercise, N2 and P2 amplitudes decreased significantly. By contrast, there were no significant differences in N170, N2, P2, and P3 amplitudes in the control group before vs. after the intervention.

Conclusions: Chronic (12 weeks of) aerobic exercise reduced attentional bias toward drug-related cues by improving attentional inhibition and reducing the maintenance of extra attention to drug-related cues among women with methamphetamine addiction. Both dance and bicycle exercise improved the early recognition of drug-related cues, weakened the influence of the memory of previous drug use, and improved attentional bias behavior by strengthening attention control. Dance exercise, but not bicycling, also regulated emotional control and improved the attention selection process. These results provide theoretical and empirical evidence that chronic aerobic exercise may reduce the attentional bias toward drug-related cues to assist in the recovery of women with methamphetamine addiction.

* Corresponding author. 168Changhai Road, Yangpu District, Shanghai, 200433, China.
E-mail address: ltz1214@sina.cn (T. Liu).

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1. Introduction

Drug addiction a relapsing brain disorder associated with damaged cognitive function [1,2]. Attentional bias toward drug-related cues is one of the most typical features of damaged cognitive function. Attentional bias among persons addicted to drugs is manifested primarily by an uncontrollable investment of attention resources in drug-related cues, with more attention being paid to drug-related cues than to neutral cues. Continuously paying more attention to drug-related cues may induce increased drug craving, which may make drug taking difficult to stop or lead to relapse [3–5].

Methamphetamine (MA), one of the most abused drugs in the world, causes substantial damage to cognitive function [6,7]. Persons addicted to MA have several impaired cognitive functions, primarily including inhibitory control, attention, and reward [8]. Attentional bias as a biomarker of impaired brain function. Aerobic exercise, as an effective supplementary therapy, has been widely used during abstinence treatment for persons with drug addiction [9]. Our group previously explored the effects of chronic exercise on attentional bias among males with MA addiction, finding that chronic exercise reduced their attentional bias by augmenting early identification of drug-related stimuli and diverting attention to reduce conflict processing [10]. However, whether chronic exercise would reduce attentional bias in females with MA addiction was not investigated. In addition, more effective methods aimed at specific physical and mental characteristics associated with MA addiction need to be explored among females.

Most previous studies have been focused on males with MA addiction, however, the number of females with MA addiction has been rising [11], increasing the burden to society and families. Aerobic exercise may have gender differences in the treatment effect of cognitive impairment in drug addicts, cause baseline and exercise fitness discrepancy in cognitive characteristics between male and female [12]. Aerobic dance training was found to diminish the functional connectivity between the frontal polar area and the right dorsolateral prefrontal cortex. This effect likely contributed to a decrease in female addicts' motivation for drug-related behavior and inhibition of drug craving [13]. In addition, exercise types for cognitive benefits also differ by sex, but higher benefits were found after coordinative exercise [14]. Power cycling is widely used in exercise detoxification because it is easy to learn and convenient to control the intensity [10,15]. Dance is increasingly being implemented as exercise intervention for rehabilitation, especially in women, and has been found to be more effective in modulating cognitive processes based on rhythmic and coordinated movements. While power cycling is suggested as an efficacious intervention for male drug addiction withdrawal, dance training comprises exercises targeting both fine and gross motor body coordination, and it has been widely recognized for its capacity to augment physical and cardiopulmonary function in individuals with substance dependence [13]. Therefore, it is necessary to explore women-specific exercise interventions to help female with drug addiction receive effective treatment.

The dot-probe task is an effective paradigm for testing attentional bias [16]. Attentional bias scores directly reflect the attentional bias of persons with MA addiction and assess whether they pay excessive attention to drug-related cues or have reasonable attention inhibition. The dot-probe task combined with event-related potential (ERP) methods—which assess relevant cognitive functions by recording spontaneous potentials of the brain at the scalp—can be used to measure attentional bias [17]. Indeed, ERP methods have been used to detect electrophysiological characteristics of attentional bias in persons with MA addiction [18,19]. In the dot-probe task, the ERP components N170, N2, P2, and P3 manifest sequentially in temporal succession. The N170 component serves a discriminatory function between addiction-related and neutral stimuli, while the N2 component is instrumental in appraising cognitive control. Furthermore, P2 indexes early stages of perceptual processing, while P3 is implicated in the modulation of attentional processes, encapsulating cognitive functions pertinent to attention allocation, memory encoding, and stimulus evaluation [10,20,21]. The abnormal performance on electroencephalogram (EEG) components N170, N2, P2, and P3 have been used to reflect the cognitive characteristics of attentional bias in persons with MA addiction and have indicated that they allocate too many attentional resources at the early stage of attention, maintaining excessive attention to drug-related cues, and may then lose self-control [10,21–24].

Because attentional bias toward drug-related cues is an important biomarker of MA addiction, reducing attentional bias may help to promote the rehabilitation of persons with MA addiction. Our previous work has shown that aerobic exercise is an effective treatment for MA addiction among men [10,15,25,26], but whether type of exercise may be effective among women was not assessed. Therefore, the present study recruited women with MA addiction to investigate their responses to two aerobic exercise interventions: dancing and bicycling. We used the dot-probe task in combination with recordings of ERP components N170, N2, P2, and P3 to explore the electrophysiological mechanisms underlying any exercise-induced changes in attentional bias among these women. We hypothesized that aerobic exercise would effectively reduce attentional bias toward drug-related cues among women with MA addiction with changes in ERP components, and while dance is a more effective exercise rehabilitation type for women addicts.

2. Methods

2.1. Participants

All procedures were approved by the Ethics Committee of Shanghai University of Sport.

The required sample size was determined using G*power [27]. With an effect size of 0.21, power (1-β) of 0.80, and α of 0.05 for the dot-probe task, 60 participants would be needed. Thus, we recruited 69 women with MA use disorder (all right-handed; mean age, 31.59 ± 2.32 years) living in a rehabilitation center located in Zhejiang, China. All participants detoxed, were required to be abstinent in the rehabilitation center, and were at low level of physical activity before the exercise intervention. The staff at the center helped recruit the participants. We explained the proposed study to potential participants, including their role in performing the dot-probe task and undergoing the EEG tests and the details regarding the exercise types, duration, and intensity. We also informed them that they could withdraw from the study at their discretion. We followed the Code of Ethics of Shanghai University of Sport to obtain written informed consent from each participant prior to conducting the study.

Among 69 participants who volunteered for the study, we excluded two each from the dance, bicycle, and control groups with exercise compliance rates <90 %. Thus, data from 63 participants were analyzed, and their demographic characteristics are provided in Table 1. No differences were observed across the three groups for MA use or detoxification.

2.2. Aerobic exercise

We randomly assigned participants to one of three groups: dance, bicycle, or control. Each exercise included a total of 40 bouts, and participants were required to complete at least 36 bouts; otherwise, their data were excluded. Exercises were performed 3 times each week inside the gymnasium located at the rehabilitation center. Each bout of exercise was 40 min, and the duration of the program was 12 consecutive weeks. Groups of 10 participants each were randomized to exercise either in the morning or the afternoon. The participants in the dance group engaged in a supervised dance exercise program. The choreographed movements in the dance intervention program are customized by professional dance instructors to align with the specific traits of female addicts. The main training included basic dance moves based on the physical and mental characteristics of female MA users, with the flexibility, strength, speed, and other aspects needed for the dance moves taken into consideration. The bicycle group rode stationary bicycles, with a 5-min warm-up before power cycling for 30 min. They completed the bout with stretching exercises for 5 min. Both exercise groups wore SUUNTO heart rate belts to maintain moderate-intensity aerobic exercise. Based on our previous research [10], we defined moderate intensity as 65%–70 % of the maximum heart rate, using formula $206.9 - (0.67 \times \text{age in years})$ to define the maximum [28]. Two professional sports coaches supervised each group of participants and, for example, changed their cycling rate to the maintain appropriate heart rate.

The control group was instructed to continue with their typical activities and not to engage in increased physical activity during the 12-week study.

2.3. Dot-probe task

The dot-probe task was conducted as described in our previous study [10] prior to and following 12 weeks of exercise training (Fig. 1). Participants started the task either in the morning or afternoon at their assigned exercise time and completed the task in about 15 min.

2.4. EEG recording

While participants performed the dot-probe task, we recorded EEG data via 64 scalp electrodes (Ag/Ag–Cl; ActiCHamp, Brain Products) placed in accordance with the International 10–20 system. We used a sampling rate of 1000 Hz and impedances below 10 kΩ. Participants had electrodes attached to the outer canthus of their right eye so that the horizontal electrooculographic eye movements could be recorded and attached to the infraorbital region of the same eye so that the vertical electrooculographic eye movements could be recorded.

2.5. Data processing

2.5.1. Attentional bias index

We removed from further analyses any reaction time longer than three standard deviations from the mean. The attentional bias index was calculated using reaction times in the following formula: $[(DlPr - DrPr) + (DrPl - DlPl)]/2$, where D is a drug-related image; P is a probe; l is the left side of the screen; and r is the right side of the screen [29].

2.5.2. ERP components

The EEG data were assessed using BrainVision Analyzer 2.1. Major artifacts, such as a large drift, were deleted before the signal was re-referenced to the global average brain signal. We used a bandpass filter of 0.01–30 Hz (slope, 24 dB/octave) [30]. We removed any

Table 1
Demographics of participants by group.

Characteristic	Mean ± SD		
	Dance	Bicycle	Control
No. of participants	21	21	21
Age (y)	32.16 ± 2.07	32.59 ± 2.12	30.95 ± 2.81
BMI (kg/m^2)	23.96 ± 1.32	23.61 ± 1.82	22.33 ± 1.43
Educational level (y)	8.23 ± 1.27	8.63 ± 1.43	8.05 ± 1.32
MA use			
Usage (g/use)	0.48 ± 0.13	0.42 ± 0.15	0.42 ± 0.12
Frequency (days/week)	3.35 ± 1.12	3.08 ± 1.03	3.61 ± 1.16
Duration (mo)	62.32 ± 7.21	61.09 ± 7.33	59.25 ± 7.42
Detoxification (mo)	3.27 ± 0.42	3.65 ± 0.55	3.45 ± 0.50

Abbreviations: BMI, body mass index; MA, methamphetamine; SD, standard deviation.

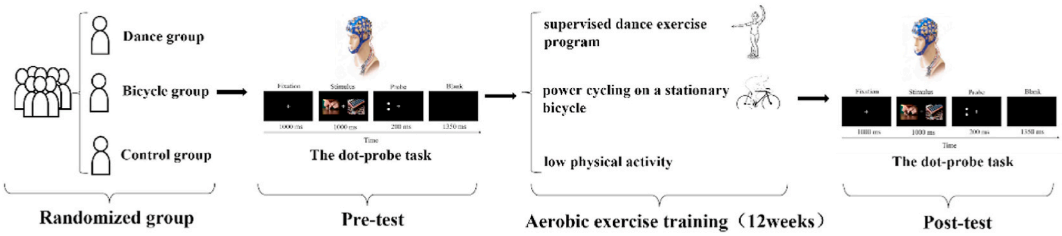

Fig. 1. Study protocol.

ocular artifacts through independent component analysis. To acquire the ERPs, we assessed epochs that were locked to the stimuli from −200 to 800 ms. The period 200 ms before any stimulus was presented was used for baseline corrections. We excluded EEG artifacts, defined as epochs having amplitudes exceeding ±100 μV. The N170 component was defined as the average peak amplitude at electrodes P7 and P8 150–200 ms after the stimulus image was presented, prior to the probe image presentation. The N2 component was defined as the average peak amplitude at 150–250 ms for electrodes FC1, FC2, FC3, FC4, FCz, C1, C2, C3, C4, and Cz. The P2 component was defined as the average peak amplitude 200–300 ms after stimulus presentation at electrodes O1, O2, Oz, PO3, PO4, PO7, and PO8. The P3 component was defined as the average peak amplitude 300–400 ms after stimulus presentation at electrodes CP1, CP2, CP3, CP4, CPz, P1, P2, P3, P4, and Pz.

2.5.3. Statistical analysis

We assessed differences in attentional bias indexes through the use of 3 (group: dance, bicycle, control) × 2 (time: pre-exercise, post-exercise) repeat-measures analyses of variance (ANOVAs). ERP component differences were assessed using 3 (group: dance, bicycle, and control) × 2 (time: pre-exercise, post-exercise) × 2 (congruent, incongruent) repeated-measures ANOVAs. All statistical analyses were performed using SPSS, version 26.0. A two-sided $p < 0.05$ was considered statistically significant. All parameters underwent Shapiro-Wilk tests, with $p > 0.05$ indicating that the data followed a normal distribution. If needed, we applied the Greenhouse-Geisser correction for non-sphericity. For multiple post hoc comparisons, we used Bonferroni tests. We assessed significant interactions using simple effects models. We also reported partial eta-squared (η^2) to provide effect sizes.

3. Results

3.1. Attentional bias index

The repeated-measures ANOVA indicated a significant interaction between the main effects of group and time: $F_{(2,60)} = 16.692$, $p < 0.001$, $\eta^2 = 0.357$. Our simple effects analysis indicated significantly lower attentional bias indexes after exercise in both the dance ($p < 0.001$) and bicycle ($p < 0.001$) groups compared with those before exercise (Table 2). Attentional bias indexes remained unchanged after 12 weeks in the control group ($p = 0.182$).

3.2. ERP results

3.2.1. N170 component

A repeated-measures ANOVA assessment of a 3 (group: dance, bicycle, control) × 2 (condition: congruent, incongruent) × 2 (time: pre-exercise, post-exercise) analysis for the amplitude of the N170 component indicated that the interaction of group, condition, and time was statistically significant ($F_{(2,60)} = 3.652$, $p = 0.032$, $\eta^2 = 0.109$). Our simple effects analysis of baseline data (before any exercise was performed) indicated a significantly higher amplitude for the N170 component in the congruent compared with the incongruent condition for all three groups. Assessments after 12 weeks indicated that the amplitude of the N170 component remained significantly higher in the congruent condition (vs. the incongruent condition) for the bicycling and control groups but not for the dance group (Fig. 2, Table 3).

3.2.2. N2 component

A repeated-measures ANOVA assessment of peak N2 amplitudes indicated a lack of a significant interaction among group, condition, and time. However, the interaction between group and time was significant: $F_{(2,60)} = 3.971$, $p = 0.024$, $\eta^2 = 0.119$. Our simple

Table 2
Attentional bias indexes for the three groups prior to and after 12 weeks of exercise.

Group	Pre-exercise (Mean ± SD)	Post-exercise (Mean ± SD)
Dance	4.03 ± 1.38	- 7.58 ± 5.23
Bicycle	4.09 ± 1.51	- 7.28 ± 4.57
Control	3.32 ± 1.45	1.48 ± 2.51

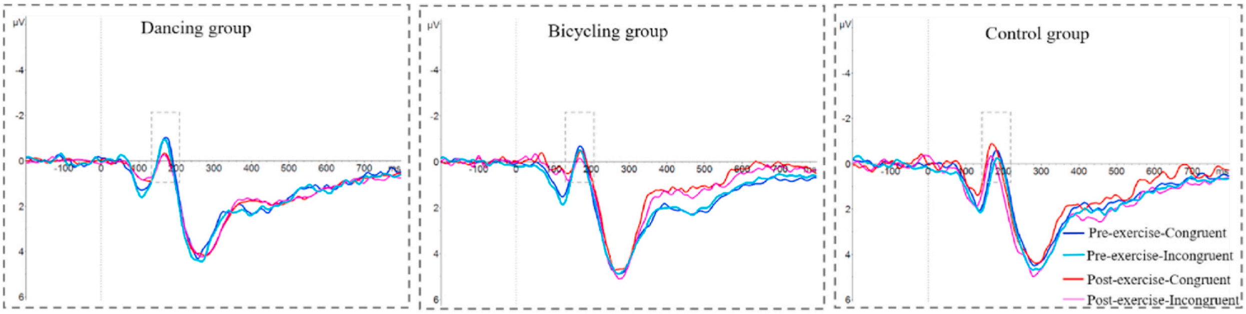

Fig. 2. Average N170 amplitudes recorded in each group during the dot-probe task performed prior to and after 12 weeks (electrodes: P7 and P8).

Table 3
Peak N170 amplitudes recorded during the dot-probe task for each group prior to and following 12 weeks of exercise.

Group	Pre-exercise		Post-exercise	
	Congruent Mean ± SD, µV	Incongruent Mean ± SD, µV	Congruent Mean ± SD, µV	Incongruent Mean ± SD, µV
Dance	- 1.73 ± 0.46	- 1.30 ± 0.43	- 0.81 ± 0.42	- 0.89 ± 0.39
Bicycle	- 1.52 ± 0.46	- 1.21 ± 0.43	- 1.49 ± 0.42	- 1.08 ± 0.39
Control	- 1.50 ± 0.46	- 0.95 ± 0.43	- 1.56 ± 0.42	- 0.87 ± 0.39

effects analysis suggested that following 12 weeks' intervention, N2 amplitudes in the dance ($p = 0.002$) and bicycle ($p = 0.001$) groups, but not the control group, were significantly smaller than those before the exercise program (Fig. 3, Table 4).

3.2.3. P2 component

A repeated-measures ANOVA assessment of peak P2 amplitudes indicated no significant interaction across group, condition, and time. However, a significant interaction was identified between group and time: $F_{(2,60)} = 3.460$, $p = 0.038$, $\eta^2 = 0.103$. Our simple effects analysis showed smaller P2 amplitudes after 12 weeks of exercise vs. before the intervention in the dance ($p < 0.001$) and the bicycle ($p = 0.22$) groups but not in the control group (Fig. 4, Table 5).

3.2.4. P3 component

A repeated-measures ANOVA analysis of the P3 peak amplitudes found no significant interaction for group, condition, and time; however, a significant interaction between group and time was identified: $F_{(2,60)} = 2.947$, $p = 0.060$, $\eta^2 = 0.089$. Our simple effects analysis showed smaller P3 amplitudes after vs. before 12 weeks of exercise only in the dance group ($p = 0.002$), with no significant change in the bicycling and control groups (Fig. 5, Table 6).

4. Discussion

This study investigated the impact of two types of aerobic exercise on attentional bias toward drug-related cues and brain electrophysiological indexes among women with MA addiction. Attentional bias was assessed in the dot-probe task while electrophysiological indexes were assessed by recording ERP components. The results indicated that after 12 weeks of either dancing or bicycling aerobic exercise, the attentional bias index in both groups decreased significantly, with positive values changing to negative values. In

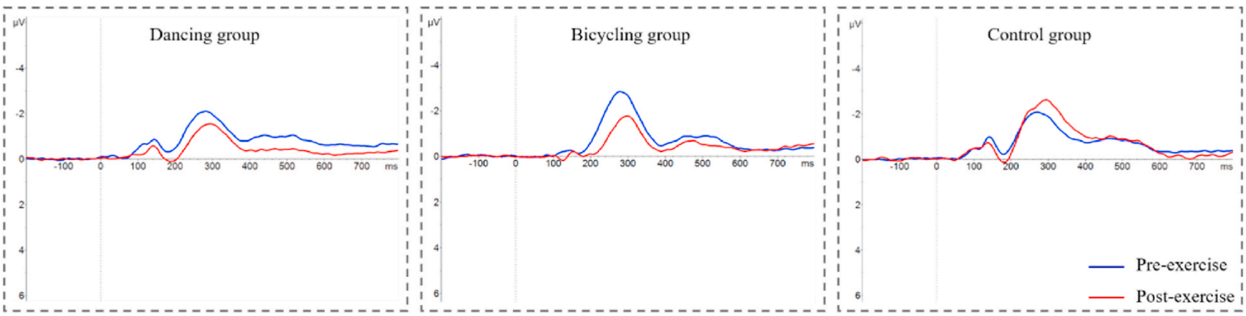

Fig. 3. Average N2 amplitudes recorded in each group during the dot-probe task performed prior to and following 12 weeks of exercise (electrodes: FC1, FC2, FC3, FC4, FCz, C1, C2, C3, C4, and Cz).

Table 4
Peak N2 amplitudes recorded in each group during the dot-probe task performed prior to and following 12 weeks of exercise.

Group	Pre-exercise Mean ± SD, μV	Post-exercise Mean ± SD, μV
Dance	- 2.44 ± 0.34	- 1.32 ± 0.18
Bicycle	- 2.56 ± 0.34	- 1.33 ± 0.18
Control	- 2.12 ± 0.35	- 2.18 ± 0.18

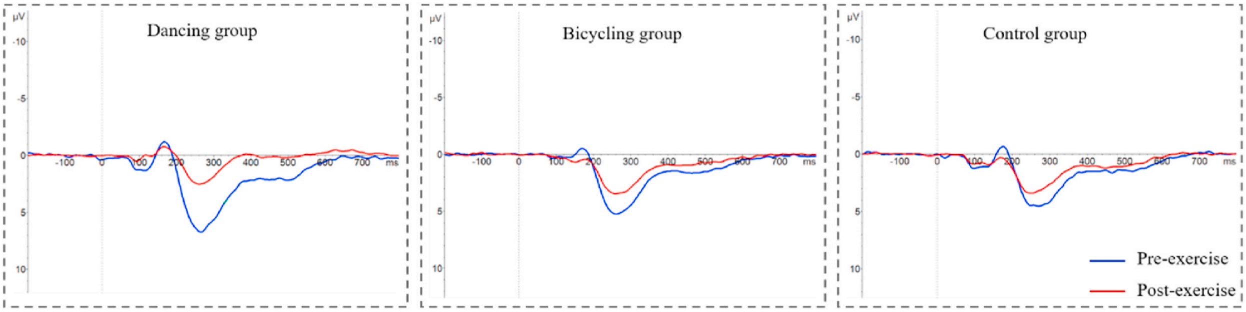

Fig. 4. Average P2 amplitudes recorded in each group during the dot-probe task performed prior to and following 12 weeks of exercise (electrodes: O1, O2, Oz, PO3, PO4, PO7, and PO8).

Table 5
Peak P2 amplitudes recorded in each group during the dot-probe task performed prior to and following 12 weeks of exercise.

Group	Pre-exercise Mean ± SD, μV	Post-exercise Mean ± SD, μV
Dance	7.28 ± 0.73	3.39 ± 0.60
Bicycle	6.21 ± 0.70	4.55 ± 0.57
Control	5.67 ± 0.77	4.32 ± 0.63

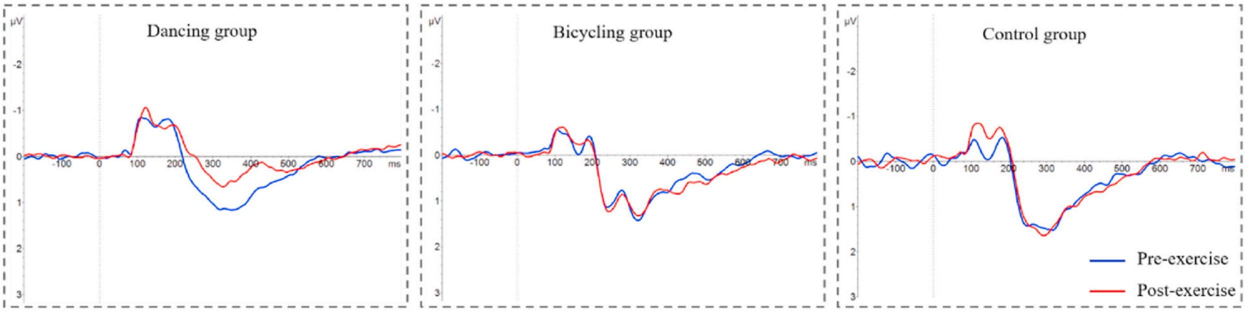

Fig. 5. Average P3 amplitudes recorded in each group during the dot-probe task performed prior to and following 12 weeks of exercise (electrodes: CP1, CP2, CP3, CP4, CPz, P1, P2, P3, P4, and Pz).

Table 6
Peak P3 amplitudes recorded in each group during the dot-probe task performed prior to and following 12 weeks of exercise.

Group	Pre-exercise Mean ± SD, μV	Post-exercise Mean ± SD, μV
Dance	1.52 ± 0.33	0.83 ± 0.29
Bicycle	1.57 ± 0.32	1.50 ± 0.28
Control	1.63 ± 0.34	1.61 ± 0.30

the dancers, the amplitudes of the N170, N2, P2 and P3 components decreased significantly, and the difference in the N170 components between the congruent and incongruent conditions was no longer observed. For the cyclists, the amplitudes of the N2 and P2 components decreased significantly. By contrast, there was no significant change in the attentional bias indexes in the control group. These results indicated that 12 weeks of dance or bicycle aerobic exercise may positively impact the health of women with MA addiction, reducing the excessive resource allocation to drug-related cues in the early stage of attention to more appropriate attentional control. Dancing appeared to be more effect than bicycling with regard to regulating emotions and drug-related memories among these women.

The stimulus duration was set to 1000 ms in the dot-probe task to investigate both the maintenance and disengagement of attention [31,32]. Calculating the difference in attentional bias scores before and after the exercise intervention enabled us to observed the change in attentional bias to drug-related cues among women with MA addiction. Consistent with previous studies [10,33], the results of the present study revealed that the attentional bias scores of participants in both the dance and bicycle groups were positive before the exercise intervention but were negative after the exercise intervention. A positive attentional bias score indicates that attentional maintenance exist, whereas a negative score indicates an inhibition of attentional maintenance [29,34]. Therefore, the results of this study showed that women with MA addiction continued to focus on drug-related cues before the exercise intervention but could divert their attention from drug-related cues through attention inhibition after the exercise intervention. Studies have shown that aerobic exercise has a positive impact on attentional processes, especially for selective attention [35,36]. In the present study after chronic aerobic exercise, women with MA addiction regulated attention resource allocation and selection, turning excessive maintenance of attention to drug-related cues into attention inhibition and diverting attention from drug-related cues. We explored the underlying cognitive neural mechanisms through assessment of ERP components.

N170 is a typical ERP component in visual recognition [37]. In the early stage of attentional bias processing, N170 may reflect the individual's classification of stimuli [38]. N170 is significantly affected by emotional factors. When facing negative or threatening stimuli, the amplitude of the N170 component is greater than when facing a neutral stimulus [34,39]. Before the exercise intervention in the present study, the N170 amplitude induced by drug-related cues was higher than that induced by neutral cues in women with MA addiction, indicating that drug-related cues, as negative stimuli, would have a negative impact on their emotions. After dance exercise, the N170 amplitude induced by drug-related cues decreased, indicating that the early recognition and classification of the drug-related cues were more accurate, and the emotional contribution of the drug-related cues was reduced. Interestingly, this effect was not observed in the bicycle group, indicating that dance exercise may be a better exercise choice for regulating emotional control to assist in the recovery of women with MA addiction.

In the present study, the change in the amplitude of the N2 component in the prefrontal cortex was related to attention control and error processing [18,40]. During early conflict monitoring, a larger N2 amplitude indicates that more attention is being allocated to drug-related stimuli [21,41]. Thus, the decrease observed in the N2 amplitude after the aerobic exercise intervention in the present study indicated that women with MA addiction paid less attention to drug-related cues. The N2 component may also represent attention transformation and conflict handling [22,24]. Consistent with prior research findings, aerobic exercise has been demonstrated to decrease the amplitude of N2, suggesting attentional allocation [10]. Aerobic exercise may divert attention from drug-related cues and reduce the conflict between attentional bias and cognitive control caused by drug-related cues to enable women with MA addiction to better regulate their attention.

The P2 component is also an early component of attention. It is related to the initial recognition and evaluation of stimuli [19], reflects the bias of attention toward negative stimuli [21], and can feed back previous memory experiences to some extent [42,43]. In the dot-probe task results in the present study, the decrease in the P2 amplitude indicated that women with MA addiction invested more attention resources in the initial processing of drug-related cues before the exercise intervention than after it, suggesting that the early attentional bias had been corrected. Thus, the impact of the memory of previous drug use was reduced, enabling more accurate identification and classification of drug-related stimuli and providing favorable preparation for subsequent cognitive regulation.

The P3 component is related to the selection of stimuli for attention [44]. When persons with drug addiction are exposed to drug-related stimuli or environments, the P3 amplitude is large, indicating enhanced cognitive processing and greater attention to drug-related cues [43]. Aerobic exercise has the potential to regulate the abnormal amplitude of P3. Prior studies have indicated that aerobic exercise frequently leads to an increase in P3 amplitude during inhibitory tasks. However, the present study reveals that dance exercise is capable of reducing the abnormally high P3 amplitude in females with addiction [45]. Therefore, the decrease in the P3 amplitude observed in the present study after 12 weeks of dance exercise indicated that this exercise diverted attention from drug-related stimuli and reduced the conflict between attentional bias and cognitive control caused by the drug-related cues [46,47], enabling better regulation of attention in women with MA addiction. In addition, compared with bicycling, dancing was more conducive to improving attention selection among these women, making it easier for them to make appropriate decisions in the face of negative conflict.

This study had some limitations. Testing with the dot-probe task combined with ERP recording was limited in the present study to before the exercise intervention and 12 weeks after the intervention. In future research, additional time points should be selected for testing during the exercise intervention to follow the time course for the observed changes. In addition, the length of the overall exercise intervention should be extended to enable exploration of the duration of exercise benefits, and several levels of exercise intensity should be assessed. Regarding sports types, this study compared only dance and bicycle aerobic exercises. Future research should include resistance and anaerobic sports. The spatial resolution of the ERP method did not allow for accurately locating specific regions of the cerebral cortex. Future studies show consider using functional magnetic resonance imaging to increase spatial resolution.

5. Conclusions

The results of this study indicated that engaging in 12 weeks of aerobic cycling or dance exercise enhanced attentional inhibition in women with MA addiction, reducing their excessive attention to drug-related cues and thus reducing their attentional bias toward drug-related cues. Electrophysiological analyses showed that both dance and bicycle exercise improved the early recognition of drug-related cues, weakened the influence of the memory of previous drug use, and improved attention bias behavior by strengthening attention control. Dance, but not bicycle, exercise also helped to regulate the emotional control of women with MA addiction, improving their attention selection processes; thus, dance exercise may be better than bicycling to assist in the recovery of women with MA addiction. These study results provide theoretical and empirical bases for the use of chronic aerobic exercise to reduce attentional bias toward drug-related cues among women with MA addiction.

Ethics statement

All procedures were approved by the Ethics Committee of Shanghai University of Sport (Approval number: 102772019RT044, Year: 2019).

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Role of the funder

The funding mainly supported the purchase of equipment, such as EEG supplies and heart rate belts. The funder had no role in the design of the study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

Data availability statement

The data were obtained from a compulsory isolation drug rehabilitation center. Due to confidentiality reasons, the data cannot be publicly available. However, researchers interested in this study can contact the corresponding author. Upon approval from the rehabilitation center, the data can be provided.

CRediT authorship contribution statement

Qi Zhao: Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jianing Liu:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Chenglin Zhou:** Writing – review & editing, Writing – original draft, Resources, Funding acquisition, Conceptualization. **Tianze Liu:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Tianze Liu reports financial support was provided by National Natural Science Foundation of China. Qi Zhao reports financial support was provided by MOE (Ministry of Education in China) Youth Foundation of Humanities and Social Science. Qi Zhao reports financial support was provided by Scientific Research Foundation of Jimei University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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