Ji *et al. BMC Psychiatry* (2025) 25:559
https://doi.org/10.1186/s12888-025-07008-7

BMC Psychiatry

RESEARCH

Open Access

Effect of pilates on the physical and mental health of drug-dependent individuals — a randomized controlled trial

Feng Ji[1†], Ensong Zhou[1†], Peng Zhao[2†], Xinliang Chen[2], Hui Wang[1], Jiabin Zhong[1], Yi Zhang[3], Yunhang Lu[1*] and Qing Zhang[1*]

Abstract

Objective Drug-dependent individuals often face severe physical and mental health impairments, necessitating safe and adaptable rehabilitation strategies. This study aims to investigate the effects of Pilates exercise on the physical and mental health of drug-dependent individuals. Specifically, the study seeks to evaluate changes in body composition, physical fitness, blood biochemistry, and psychological outcomes following a structured Pilates intervention.

Methods This study was conducted as a double-blind, parallel-group, randomized controlled trial. A total of 43 substance-dependent individuals were recruited from the Judong Drug Rehabilitation Center and randomly assigned to either the Pilates intervention group ($n=22$) or the control group ($n=21$). The experimental group underwent Pilates program of two weekly sessions for 24 weeks, while the control group received conventional rehabilitation. We assessed physical and mental health indicators at baseline, 12, and 24 weeks. Repeated measures analysis of variance was employed to discern inter-group differences, and Spearman correlation analysis was applied to assess the relationship between fluctuations in scores on anxiety and depression scales and those of associated physiological metrics.

Results After 24 weeks of Pilates intervention, the intervention group showed significant improvements ($p<0.05$) in body fat percentage, skeletal muscle mass, sit-and-reach distance, push-up performance, one-leg standing with eyes closed, vital capacity, white blood cell count, and neutrophil count. Psychological assessments revealed significant differences in scores on the Self-Rating Depression Scale (SDS) and Self-Rating Anxiety Scale (SAS) between the experimental and control groups ($p<0.01$), with more pronounced effects in the experimental group. Additionally, changes in SDS scores were correlated with changes in sit-and-reach distance ($r=-0.657$, $p<0.001$), one-leg standing with eyes closed ($r=-0.734$, $p<0.001$), and vital capacity ($r=-0.490$, $p=0.001$). Changes in SAS scores were correlated with changes in the neutrophil-to-lymphocyte ratio ($r=-0.304$, $p=0.048$), platelet-to-lymphocyte ratio ($r=-0.320$, $p=0.037$), sit-and-reach distance ($r=-0.595$, $p<0.001$), one-leg standing with eyes closed ($r=-0.704$, $p<0.001$), and vital capacity ($r=-0.472$, $p=0.001$).

[†]Feng Ji, Ensong Zhou and Peng Zhao contributed equally to this work and share first authorship.

*Correspondence:
Yunhang Lu
yunhanglu@suda.edu.cn
Qing Zhang
zhangqing@suda.edu.cn
Full list of author information is available at the end of the article

Conclusion The Pilates intervention significantly enhanced participants' physical attributes—body composition, strength, endurance, flexibility, balance, lung function, and immune response—while alleviating anxiety and depression. Correlations were identified between mental health improvements and physical gains, indicating that tailored exercise, informed by ongoing health monitoring, could optimize drug rehabilitation outcomes.

Clinical trial registration ChiCTR-IPR-2400087067, Registered on: 18/7/2024.

Keywords Pilates, Exercise Intervention, Physical and Mental Health, Drug Addiction, Rehabilitation

Introduction

Drug addiction poses a global public health challenge, contributing to severe morbidity and mortality worldwide [1]. Beyond compromising both individual health [2] and societal stability [3], this disorder significantly reduces workforce productivity and burdens healthcare systems [4]. Current estimates indicate approximately 300 million individuals suffer from drug-related disorders, including addiction-induced dependence. Studies have shown that even short-term, low-level drug use can lead to severe physical and mental damage, manifesting symptoms such as arrhythmia, nausea, vomiting, sweating, fever, irritability, impulsiveness, mania, or aggressive behavior. Overdose can even lead to coma or death [5]. Long-term drug dependence can cause even more irreversible harm to the physical and mental health of drug users, characterized by extreme physical emaciation, unstable mental state, and a decline in the function of various internal organs [6]. These physiological declines substantially impair quality of life [7], while post-withdrawal mental health complications remain primary contributors to relapse [8]. These pathophysiological insights underscore the urgent need to develop comprehensive rehabilitation strategies targeting both the biological and psychological dimensions of addiction recovery.

Current therapeutic approaches for substance use disorders predominantly encompass pharmacotherapy [9], cognitive-behavioral interventions [10], and psychological counseling. However, these modalities present limitations including adverse effects, elevated implementation costs, and insufficient evaluation protocols [11]. Exercise therapy has emerged as a promising rehabilitation strategy owing to its multimodal benefits, operational feasibility, and safety profile [12], with established efficacy in addiction recovery [13–15]. Robertson et al. (2016) found that exercise can reduce dopaminergic neuronal damage induced by drugs, thereby reducing the drug cravings and relapse rates of drug users [16]. Cabral et al. (2018) found that high-intensity interval exercise may also be beneficial in improving the initial withdrawal symptoms of drug abusers [17]. In terms of physical condition improvement, Brown et al. (2010) found significant enhancement in the cardiopulmonary function of drug-dependent individuals after periodic moderate-intensity aerobic exercise intervention and maintained this good recovery benefit during the subsequent three-month follow-up period [18]. In subsequent research, Dolezal et al. (2013) confirmed that methamphetamine-dependent individuals significantly improved their maximum oxygen uptake and lower limb strength after a combination of endurance and resistance training intervention. They also effectively controlled body weight and reduced body fat percentage and fat mass [19]. Giménez-Meseguer et al. (2015) found that after implementing a group-based exercise program for drug-dependent patients, the incidence of injury and muscle pain decreased, obesity rates declined, and vitality was enhanced, greatly improving their quality of life [20]. Emerging evidence demonstrates exercise-induced mental health improvements in abstinent populations, particularly in alleviating anxiety and depression [21], enhancing self-esteem [22], and optimizing sleep architecture [23, 24]. Nevertheless, while extensive evidence supports exercise efficacy in addressing substance dependence, debate persists regarding optimal modality selection and intensity calibration for maximal therapeutic outcomes.

Janse Van Rensburg et al. (2013) found that compared with high-intensity and low-intensity acute aerobic exercise, moderate-intensity aerobic exercise is more effective at reducing withdrawal symptoms, alleviating negative emotions, and stress in drug-dependent individuals, and the intervention benefits are more long-lasting [25]. Ercan et al. (2016) also found in their research that moderate-intensity aerobic exercise and strength training are more helpful in reducing anxiety and depression in drug-dependent populations [26]. In contrast, Giménez-Meseguer et al. (2020) reported enhanced affective benefits from low-intensity mind–body therapies versus moderate-intensity protocols [15], corroborating behavioral evidence of inverse intensity-cognition correlations [27]. The choice of exercise intensity is also limited by the physical condition of individuals undergoing drug rehabilitation. Chronic substance abuse induces physical deconditioning characterized by asthenia, psychomotor retardation, and cardiometabolic impairment [5], rendering moderate-high intensity protocols potentially hazardous [28]. In addition, many studies have mentioned the issue of low compliance in individuals undergoing drug rehabilitation during exercise intervention [29, 30]. This may be due to the long-term single form of exercise practice leading to addiction to the feeling of boredom with exercise [31], and the unreasonable intensity setting making it difficult for the addicted population to make progress during the exercise process, which in turn leads to a loss of self-confidence and poor quality and completion of exercise [32]. These multifaceted limitations underscore the critical need for personalized exercise prescription strategies in addiction rehabilitation.

As a mind–body practice within the comprehensive exercise paradigm, Pilates shares core components with yoga and Tai Chi, including postural alignment, breath regulation, and cognitive integration during training [33–35]. These disciplines collectively demonstrate injury prevention capacity while conferring benefits in weight management, musculoskeletal optimization, flexibility enhancement, and cardiovascular adaptation [36, 37]. Notably, Pilates distinguishes itself through broader therapeutic scope and precise intensity modulability [38], exhibiting superior synergistic effects on holistic health outcomes [39]. Current evidence confirms yoga- and Tai Chi-based interventions effectively address substance use disorders via craving reduction, stress modulation, and physiological enhancement [40–42]. Nevertheless, the application of Pilates in addiction rehabilitation remains empirically uncharted, underscoring the imperative to investigate its therapeutic potential for diversifying evidence-based exercise interventions.

In the treatment of individuals undergoing drug rehabilitation, body composition detection and physical fitness testing can help monitor the physical recovery of individuals undergoing drug rehabilitation [43], and anxiety and depression scores are one of the core indicators to verify the degree of mental health [44], and hematology analysis can also provide objective physiological data [45]. Drug abuse has a direct impact on hematological parameters [45–47], among which the neutrophil-to-lymphocyte ratio (NLR) and the platelet-to-lymphocyte ratio (PLR) can be important prognostic factors for anxiety [48, 49]. Anxiety and the often accompanying depression can also affect body balance [50, 51], and the neurological basis supporting this connection lies in the convergence of vestibular information processing and somatic and visceral sensory information processing in the parabrachial nucleus [52]. These pathways are related to avoidance conditioning, anxiety, and conditional fear responses. Monoamines affect the regulation of these pathways, which may affect the alertness of balance control and the anxiety effect, as well as the development of anxiety [52]. In addition, higher levels of anxiety symptoms and depressive symptoms are associated with lower lung function [53, 54], and the improvement of flexibility is usually accompanied by the alleviation of anxiety symptoms [55, 56]. These psychophysiological linkages warrant rigorous investigation within exercise-based detoxification assessments, offering novel perspectives to elucidate intervention mechanisms while informing the development of precision exercise protocols.

To our knowledge, this is the first attempt to explore the impact of Pilates exercise therapy on the physical and mental health of individuals undergoing drug rehabilitation based on the logical connection between hematological indicators, physical fitness, and psychological state. Our dual-phase analysis aims to 1) elucidate Pilates' impacts on physiological-psychological health, and 2) develop evidence-based exercise protocols for addiction rehabilitation, thereby advancing personalized intervention strategies in substance use disorder management.

Methods

Study design

This study adhered to the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) Guidelines and was designed as a randomized controlled trial, with random group allocation and outcome assessment conducted by researchers not involved in the intervention. Participant recruitment and the trial were conducted at the Judong Compulsory Isolation Drug Rehabilitation Center in Zhenjiang City, Jiangsu Province, with the assistance of police officers within the center. After initial screening, eligible participants underwent baseline testing, followed by random assignment to either the Pilates group or the control group. Both groups underwent a standardized rehabilitation program during the 24-week study period. In addition, the Pilates group completed targeted Pilates training. To evaluate the intervention's effectiveness, interim assessments were conducted at the end of week 12, and final assessments were performed at the end of week 24. The health indicators studied included body composition, physical fitness, blood biochemistry, and psychological mood. The study was approved by the Ethics Committee of Soochow University (Approval No. SUDA20231211H03) and all procedures followed the guidelines of the Declaration of Helsinki [57]. All participants provided written informed consent. The current study has been registered on the platform of the China Trial Registration Center (Registration number: ChiCTR2400087067). The methodology and reporting of this research adhere to the principles outlined in the Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Sample size

The sample size was determined a priori using G*Power software (version 3.1.9.7; Heinrich-Heine-Universität

Düsseldorf, Germany). For the two-way repeated-measures Analysis of Variance (ANOVA), we adopted Cohen's convention for effect sizes: f= 0.1 (small), 0.25 (medium), and 0.4 (large). A medium effect size (f =0.25) was selected based on previous comparable interventions [58], with an alpha error probability of 0.05 and a power of 0.8. Input parameters included 2 groups, 3 repeated measurements, and an assumed correlation of 0.5 among repeated measures. The analysis indicated a required total sample size of 28 participants (14 per group) [59].

Participants

A total of 52 volunteers were initially recruited based on willingness to participate. After medical examination and basic information survey, 8 individuals who did not meet the inclusion and exclusion criteria were excluded, resulting in a final sample of 44 verified drug-dependent individuals.

Randomization was performed using a computer, with the IBM SPSS 26.0 statistical software employed to generate a series of random numbers. The sequence of random numbers was maintained by a third party not involved in the study to ensure impartiality. Participants were assigned to either the Pilates group (assigned by odd numbers) or the control group (assigned by even numbers). The randomization scheme was securely stored in an opaque, sealed envelope, which was opened only after the completion of baseline measurements for each study subject to determine their group assignment. Researchers responsible for outcome measurements were blinded to group assignments, minimizing selection and performance bias.

Inclusion and Exclusion Criteria:

1. Inclusion criteria included: (1) Male, meeting the diagnostic criteria for mental disorders caused by psychoactive substances according to the Chinese Classification and Diagnostic Criteria of Mental Disorders, 3rd Edition (CCMD-3); (2) Having completed physiological detoxification and entering the rehabilitation phase, with a remaining compulsory isolation and drug rehabilitation time of more than 6 months; (3) Willing to participate in the study and sign an informed consent form; (4) Not familiar with Pilates training to avoid or balance the interference of the training effect.
2. Exclusion criteria included: (1) Having infectious diseases or a history of mental illness; (2) Diagnosed with cardiovascular, respiratory, metabolic diseases, or contraindications to exercise by a hospital medical examination.

Basic information was collected from eligible participants, including age, height, weight, resting heart rate, systolic and diastolic blood pressure, duration of drug dependence, type of drug used, and duration of stay in the center. Participants were randomly divided into the Pilates group (n= 22) and the control group (n= 22) using a computer. During the intervention, one participant withdrew from the Pilates group due to non-compliance, resulting in a final sample size of 22 in the Pilates group and 21 in the routine treatment group for statistical analysis. Given that the proportion of missing data was minimal (< 5%) and assumed to be missing completely at random, we opted to exclude the missing data from the analysis. Recruitment, the randomization scheme, and final sample distributions group are presented in the consolidated standards of reporting trials diagram (Fig. 1).

Blinding

In this study, due to the nature of the exercise intervention, there were distinct differences between the Pilates group and the control group, making it challenging to implement blinding. However, randomization of participants and the assessment of outcome measures were conducted by researchers who were uninvolved in the intervention process, ensuring the integrity of the study's methodology.

Dietary standardization

To minimize dietary confounding effects on blood biomarkers, all participants received standardized meals designed by a certified nutritionist. Caloric intake was calculated as 25–30 kcal/kg/day, with macronutrient distribution set at 55% carbohydrates, 20% protein, and 25% fat. Meals were prepared and provided uniformly by the rehabilitation center's kitchen, and consumption was supervised by staff to ensure compliance. External food, caffeine, alcohol, dietary supplements, and smoking were strictly prohibited.

Exercise intervention

The exercise modality selected for this study was Pilates, which was divided into mat Pilates and reformer-based Pilates training. Considering the convenience and operability of group intervention within the drug rehabilitation center, mat Pilates was chosen. Given the remote location of the center and strict management of visitors, the Pilates intervention was conducted through video teaching by a professional Pilates instructor, and was supervised by the teaching assistant from the rehabilitation guidance department during each session. After a pilot experiment confirming the quality of the movements, the

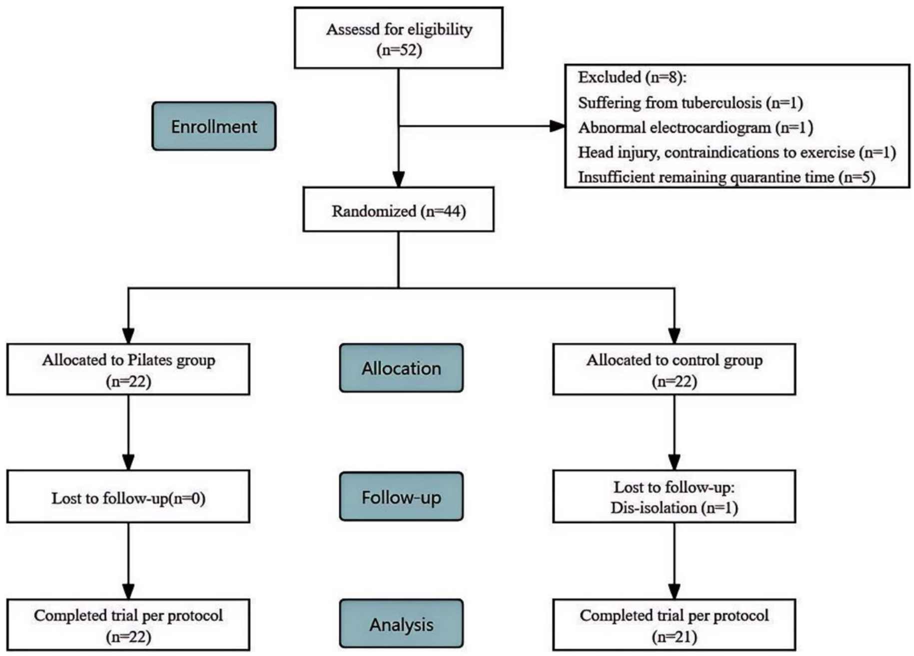

Fig. 1 Flow diagram of the study

participants were arranged to complete the exercises in a fixed area within the center every week.

The Pilates exercise program was designed based on the principles of progressiveness, appropriateness, and overload. Participants underwent appropriate training loads to induce adaptive changes in the body, and after mastering the basics, the load was gradually increased to improve the body's endurance and stimulate more significant beneficial changes [33, 34]. The Pilates group underwent two 1-h exercise interventions per week for a total of 24 weeks. The 24-week Pilates program (2 sessions/week, 1 h/session) was designed based on evidence from prior mind–body exercise studies in substance-dependent populations. For example, yoga interventions lasting 24 weeks with comparable frequency and session duration have demonstrated significant improvements in anxiety, depression, and physical function [40]. The selected protocol balances feasibility (to minimize dropout) and dose sufficiency to achieve cumulative physiological and psychological effects. The overall training plan was divided into four stages: adaptation, autonomy, proficiency, and mind–body unity. Control of exercise intensity was crucial throughout the program, considering the generally poor physical condition of the drug rehabilitation participants [5], with different intensities and densities at various stages (Table S1).

Participants' attendance and exercise fidelity were recorded in each session. Each training session was divided into a warm-up (5 min), main practice (45 min), rest intervals, and final relaxation meditation (10 min). The warm-up exercises were of low intensity, reaching 40–50% of the maximum heart rate (HRmax) to fully mobilize the body's functions. Movement selection and set configurations were dynamically adjusted based on phase-specific HRmax targets (Table S2). The final relaxation meditation allowed the heart rate to gradually return to normal. Specific movements were taught by a professional Pilates instructor through video, and the rehabilitation guidance police officers were responsible for supervision during training. The main practice movements included the supine spinal rotation, supine crunch, rolling abdominal twist, supine roll up, seated spinal extension, supine twist, rolling like a ball, swan dive, spear, and Seal clap flippers, among others [60] (Table S2). Participants in the Pilates group demonstrated high adherence to the intervention, completing 96% of scheduled sessions (46/48 sessions on average). No adverse events related to the exercise protocol were reported throughout the study. In accordance with the pre-specified per-protocol analysis, one participant was excluded from the final analysis due to attendance falling below the predefined compliance threshold (< 90% of sessions attended, equivalent to missing > 3 sessions).

Exercise intensity was controlled by the maximum heart rate, and the monitoring device was the domor smart armband produced by Beijing Oxygen Orange Company. The Pilates group wore the device during exercise, and heart rate data could be displayed in real-time on the screen. During the practice, the teaching assistant paid attention to the heart rate changes of each participant and urged them to meet the movement quality standards. The exercise density, a common indicator in physical education classes, represented the proportion of the main practice activity time of an individual in a training class to the total class time in this study (Table S1). The teaching assistant also guided and supervised the individuals undergoing drug rehabilitation according to the exercise density requirements of different training stages.

Both groups of participants underwent the same standardized rehabilitation program within the detoxification facility. This program included routine treatments and care, such as daily labor tasks, substance abuse education, and legal and ideological education. Routine labor activities (e.g., light gardening) were documented and balanced between groups. However, the control group did not receive specialized exercise interventions.

Outcome measurements

Physical health indicators included body composition, physical fitness, and blood biochemistry. Body composition indicators included Body Mass Index (BMI), body fat percentage, waist-hip ratio, protein content, skeletal muscle mass, mineral content, and fat-free mass, all measured by a body composition analyzer (produced by Jilin Donghuayuan, model: DBA-210), using contact electrodes to measure bioelectrical impedance and analyze relevant data. Before measurement, participants were required to fast and empty their bladders. Participants entered their personal information on the machine with a card, stood barefoot on the analyzer, held the handles with both hands, and saved personal data after the test. The specific indicators of physical fitness included vital capacity, grip strength, sit-and-reach, vertical jump, push-ups, choice reaction time, and one-leg standing with eyes closed. The testing equipment was all sourced from Shanghai Bangwen Equipment. Researchers supervised participants to ensure strict adherence to the physical fitness test standards. Blood biochemistry was tested before, during, and after the experiment, with blood routine tests, using the blood routine mode automatic-venous whole blood-Complete Blood Count (CBC) + DIFF. Specific indicators include the number of white blood cells (WBC), number of neutrophils, number of lymphocytes, number of red blood cells (RBC), hemoglobin (Hb), Packed cell volume (PCV), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), red blood cell distribution width (RDW), platelet count, mean platelet volume (MPV), platelet distribution width (PDW), and platelet pressure (PHV). Venous blood samples were collected after a 12-h overnight fast. The specific blood collection process and blood routine test were arranged by the medical staff within the compulsory isolation drug rehabilitation center, and the researchers then integrated and recorded the test results.

The psychological health indicators encompass subjective measures of depression and anxiety. The Self-Rating Depression Scale (SDS) [61] and the Self-Rating Anxiety Scale (SAS) [62] were utilized to assess the participants' levels of depression and anxiety, respectively. Both scales have been validated in Chinese populations [63, 64]. The SDS consisted of 20 items, with respondents selecting from four possible answers per question, each corresponding to a score of 1 to 4. Items 2, 5, 6, 11, 12, 14, 16, 17, 18, and 20 were reverse-scored, while the rest were scored directly. The sum of the item scores equated to the total score, which was then converted to a standard score by multiplying by 1.25 and rounding to the nearest whole number. A higher standard score indicated a more severe level of depression. The SAS, similarly composed of 20 items, employed a 4-point rating scale for each question, with responses scored from 1 to 4. It was assessed using a standard scoring method, with the exception that reverse scoring applied to items 5, 9, 13, 17, and 19. A higher standard score on the SAS reflects greater levels of anxiety.

The collection and organization of research data were performed with rigorous verification by two researchers working in concert to ensure data accuracy.

Statistical methods

Data are presented as means (standard deviation, SD), medians (interquartile range, IQR), or frequencies (%). Differences in clinical baseline characteristics between the two participant groups were assessed using homogeneity chi-square tests for categorical variables, independent samples t-tests for normally distributed continuous variables, or non-parametric tests for non-normally distributed continuous variables. A 2 (group: exercise and control) × 3 (time points: baseline, 12 weeks, 24 weeks) repeated measures ANOVA was employed to evaluate the outcome parameters of physical and psychological health, as it accommodates correlated measurements across time points. Normality assumptions were verified via Shapiro–Wilk tests ($p > 0.05$ for all variables), and Greenhouse–Geisser corrections were applied if sphericity was violated. Post-hoc pairwise comparisons used Bonferroni-adjusted p-values to control for Type I error. When significant interactions were present, simple effects analyses were conducted; otherwise, main effects were considered. Correlation analyses for changes in relevant health indicators were preceded by normality tests; Pearson correlation was used for data conforming to a normal distribution, and Spearman correlation was applied otherwise. The level of statistical significance was set at $p< 0.05$. All statistical analyses were performed using IBM SPSS 26.0 (IBM Corp., Armonk, NY, USA). Graphical representations were created with GraphPad Prism 9.0.0 (GraphPad Software Inc., San Diego, CA, USA), adhering to consistent formatting guidelines for data visualization.

Table 1 Baseline characteristics of participants

Characteristic	Pilates group (*n* = 22)	Control group (*n* = 21)	*P*-value
Mean age (SD), y	29.50 (3.38)	31.52 (3.57)	0.063
Mean height (SD),cm	172.82 (5.10)	171.19 (4.00)	0.252
Mean body weight (SD), kg	68.65 (8.08)	70.58 (9.74)	0.483
Mean resting Heart Rate(SD), bpm	87.50 (15.23)	88.38 (8.43)	0.817
Mean SBP (SD), mmHg	131.41 (16.03)	125.05 (11.43)	0.143
Mean DBP (SD), mmHg	74.73 (9.98)	77.00 (9.21)	0.443
Mean years of drug use (SD), y	6.38 (3.15)	5.18 (2.25)	0.158
Type of Drug Used, n (%)			0.792
Methamphetamine	18(81.82)	18(85.71)	
Heroin and Other Drugs	4(18.18)	3(14.29)	
Mean duration of isolation (SD), y	1.04 (0.37)	1.09 (0.33)	0.651

SBP Systolic Blood Pressure, *DBP* Diastolic Blood Pressure, Data presented as the mean (SD) or count (%).; *$p < 0.05$; **$p < 0.01$

Results

The demographic data showed no statistically significant differences between the exercise group and the control group in terms of age, height, body weight, resting heart rate, systolic and diastolic blood pressure, years of drug dependence, types of drugs used, and duration of compulsory isolation for drug rehabilitation ($P> 0.05$) (Table 1).

The results of the repeated measures analysis of the physical health variance comparing the Pilates group with the control group at baseline, week 12, and week 24 are presented in Tables 2 and 3.

Body composition outcomes

Statistically significant time ×group interactions were observed after 24 weeks for the body fat [$F_{(2,82)}= 9.669$, $p< 0.01$, $\eta^2= 0.191$] and skeletal muscle mass [$F_{(2,82)}= 7.174$, $p< 0.01$, $\eta^2= 0.149$]. Upon further analysis through simple effects, it was found that the Pilates group showed a significant increase in body fat percentage from

Table 2 Primary outcomes: Body composition and Physical fitness

	Pilates group(*N=22*)			Control group (*N=21*)			Time*group(F)	Eta
	Week 0	Week 12	Week 24	Week 0	Week 12	Week 24		
Body Composition outcomes								
BMI(kg/m2)	22.92(1.99)	23.20(2.02)	23.09(2.19)	24.07(3.15)	24.34(3.30)	24.66(3.37)	0.209	0.005
Body fat (%)	18.48(5.38)	20.65(4.54)	17.48(4.76)	18.73(4.90)	19.28(4.95)	19.00(4.86)	9.669**	0.191
WHR	0.86(0.03)	0.87(0.03)	0.86(0.03)	0.87(0.03)	0.88(0.03)	0.88(0.03)	0.555	0.013
Protein Mass(kg)	10.91(0.81)	10.76(0.79)	11.30(0.86)	11.07(1.17)	11.12(1.18)	11.52(1.21)	1.550	0.036
Skeletal Muscle Mass(kg)	30.90(2.42)	30.38(2.42)	32.16(2.54)	31.30(3.50)	31.41(3.39)	31.90(3.64)	7.174**	0.149
Mineral Amount(kg)	3.91(0.28)	3.84(0.30)	3.99(0.30)	3.86(0.40)	3.84(0.37)	4.00(0.37)	1.588	0.037
Fat-Free Mass(kg)	55.33(4.11)	54.45(4.13)	57.19(4.30)	55.53(5.87)	55.60(5.69)	58.13(5.96)	2.023	0.047
Physical Fitness outcomes								
Sit and Reach(cm)	7.30(8.08)	10.38(7.48)	14.30(6.56)	7.30(3.93)	7.89(5.23)	7.94(4.76)	40.004**	0.494
Vertical Jump(cm)	34.78(6.73)	35.40(5.35)	35.40(4.74)	33.61(6.16)	36.13(6.59)	35.77(6.90)	1.048	0.025
Push-ups(count)	13.05(4.04)	17.64(4.92)	21.32(6.65)	16.81(6.45)	16.38(5.23)	16.48(7.65)	22.348**	0.353
Reaction Time(s)	0.51(0.06)	0.52(0.07)	0.50(0.08)	0.51(0.07)	0.52(0.05)	0.53(0.05)	1.255	0.030
One-Leg Stand with Eyes Closed(s)	13.13(2.67)	52.71(11.93)	35.02(9.95)	14.63(5.11)	14.64(6.37)	14.88(3.68)	65.656**	0.616
Grip Strength(kg)	45.28(7.12)	49.27(5.44)	53.91(7.58)	45.21(7.19)	49.61(6.06)	50.81(8.45)	40.000	0.077
Lung Capacity(cc)	3638.45(661.43)	3702.73(779.47)	3882.73(637.11)	3451.33(456.64)	3438.67(587.45)	3353.52(312.84)	5.455**	0.117

Data presented as the mean(SD); *$p < 0.05$; ** $p < 0.01$

Table 3 Primary outcomes:Complete blood count

	Pilates group(*N=22*)			Control group (*N=21*)			Time*group(F)	Eta
	Week 0	Week 12	Week 24	Week 0	Week 12	Week 24		
Complete Blood Count outcomes								
WBC Count(10^9/L)	6.14(1.09)	7.21(1.42)	7.27(0.91)	6.65(1.27)	6.80(1.42)	6.88(1.51)	4.027*	0.089
Neutrophil Count(10^9/L)	3.57(0.82)	4.12(0.94)	4.02(1.05)	3.97(0.96)	3.82(0.92)	3.66(1.22)	4.129*	0.091
Lymphocyte Count(10^9/L)	1.99(0.44)	2.46(0.58)	2.66(0.70)	2.05(0.43)	2.41(0.49)	2.60(0.40)	0.515	0.012
RBC Count(10^9/L)	5.03(0.26)	4.91(0.27)	4.95(0.26)	5.22(0.41)	5.19(0.36)	5.16(0.36)	0.890	0.021
Hb(g/L)	155.91(8.07)	154.82(8.17)	154.32(5.78)	160.29(8.73)	162.71(8.82)	160.14(8.88)	2.091	0.049
PCV(%)	45.98(2.18)	44.40(2.13)	44.64(1.74)	47.29(2.97)	46.88(2.49)	46.24(2.66)	2.698	0.062
MCV(fL)	91.33(2.65)	90.58(2.69)	90.43(2.75)	90.68(2.92)	90.32(2.51)	89.80(2.74)	0.698	0.017
MCH(pg)	30.90(1.07)	31.59(1.17)	31.24(1.24)	30.81(1.33)	31.40(1.14)	31.12(1.10)	0.049	0.001
MCHC(g/L)	338.59(4.64)	348.27(8.83)	345.55(6.88)	342.33(5.58)	347.52(6.50)	346.62(5.97)	2.638	0.060
RDW(fL)	41.22(1.33)	38.10(0.87)	39.05(1.20)	41.76(1.48)	38.30(1.20)	39.05(1.47)	1.535	0.036
Platelet Count(10^9/L)	225.05(38.34)	234.09(43.03)	238.73(51.67)	245.71(56.80)	235.33(47.11)	225.38(51.60)	7.491*	0.154
MPV(fL)	9.58(0.66)	9.19(0.60)	9.52(0.70)	9.37(0.71)	9.07(0.67)	9.51(0.68)	1.562	0.037
PDW(fL)	16.15(0.27)	16.10(0.25)	16.24(0.27)	16.12(0.33)	16.11(0.25)	16.21(0.26)	0.254	0.006
PHV(%)	0.21(0.03)	0.21(0.03)	0.223(0.04)	0.23(0.05)	0.21(0.04)	0.21(0.04)	5.916*	0.126

Data presented as the mean(SD); *$p < 0.05$; ** $p < 0.01$

baseline to 12 weeks, which was followed by a significant decrease from 12 to 24 weeks [$F_{(2,40)} = 24.999$, p< 0.01, $\eta^2 = 0.556$]. In contrast, the control group exhibited no significant differences in body fat percentage across all measured time points(Fig. 2A).

Additionally, the Pilates group demonstrated higher skeletal muscle mass at 24 weeks compared to both baseline and 12 weeks, with significant differences observed [$F_{(2,40)} = 29.968$, $p < 0.01$, $\eta^2 = 0.600$]. Conversely, no significant changes in skeletal muscle mass were noted for the control group at any of the assessed stages (Fig. 2B).

Physical fitness outcomes

Statistically significant time ×group interactions were observed after 24 weeks for various physical fitness parameters, including sit and reach [$F_{(2,82)} = 40.004$, $p < 0.01$, $\eta^2 = 0.494$], push-ups [$F_{(2,82)} = 22.348$, $p < 0.01$, $\eta^2 = 0.353$], one-leg stand with eyes closed [$F_{(2,82)} = 65.656$, $p < 0.01$, $\eta^2 = 0.616$], and lung capacity [$F_{(2,82)} = 5.455$, $p < 0.01$, $\eta^2 = 0.117$]. Subsequent simple effects analysis revealed that, at 24 weeks, the Pilates group exhibited significantly higher sit-and-reach values compared to the control group [$F_{(1,41)} = 13.113$, $p < 0.05$, $\eta^2 = 0.242$], with significant improvements from baseline observed at both 12 weeks [$F_{(2,40)} = 72.404$, $p < 0.05$, $\eta^2 = 0.784$] and 24 weeks, whereas the control group showed no significant changes (Fig. 2C).

At baseline, the Pilates group had a lower push-ups count compared to the control group [$F_{(1,41)} = 5.315$, $p = 0.026$, $\eta^2 = 0.115$]. However, by 24 weeks, the Pilates group's push-up count had significantly increased and was higher than the control group [$F_{(1,41)} = 4.923$, $p = 0.032$, $\eta^2 = 0.107$]. The Pilates group showed significant improvements in push-ups at both 12 weeks and 24 weeks [$F_{(2,40)} = 27.211$, $p < 0.01$, $\eta^2 = 0.576$], while the control group did not exhibit significant changes (Fig. 2D).

The Pilates group also demonstrated significantly longer times in the one-leg stand with eyes closed at both 12 weeks [$F_{(1,41)} = 14.210$, $p = 0.001$, $\eta^2 = 0.257$] and 24 weeks [$F_{(1,41)} = 76.067$, $p < 0.01$, $\eta^2 = 0.650$], with significant improvements in balance ability observed at each time point [$F_{(2,40)} = 159.012$, $p < 0.01$, $\eta^2 = 0.888$]. In contrast, the control group did not show significant changes throughout the study(Fig. 2E).

Finally, significant differences between groups were found at 24 weeks for lung capacity [$F_{(1,41)} = 11.770$, $p = 0.001$, $\eta^2 = 0.223$]. The Pilates group showed a continuous increase in lung capacity with significant differences between baseline, 12 weeks, and 24 weeks [$F_{(2,40)} = 6.537$, $p = 0.003$, $\eta^2 = 0.246$]. The control group's lung capacity changes were not statistically significant during the study period (Fig. 2F).

Complete blood count outcomes

Statistically significant interactions between time and group were observed after 24 weeks for the WBC Count [$F_{(2,82)} = 4.027$, $p < 0.05$, $\eta^2 = 0.089$], Neutrophil Count [$F_{(2,82)} = 4.129$, $p < 0.05$, $\eta^2 = 0.091$], Platelet Count [$F_{(2,82)} = 7.491$, $p < 0.05$, $\eta^2 = 0.154$], and PHV [$F_{(2,82)} = 5.916$, $p < 0.01$, $\eta^2 = 0.126$].

Following these findings, a simple effects analysis was conducted. It revealed that in the Pilates group, the WBC

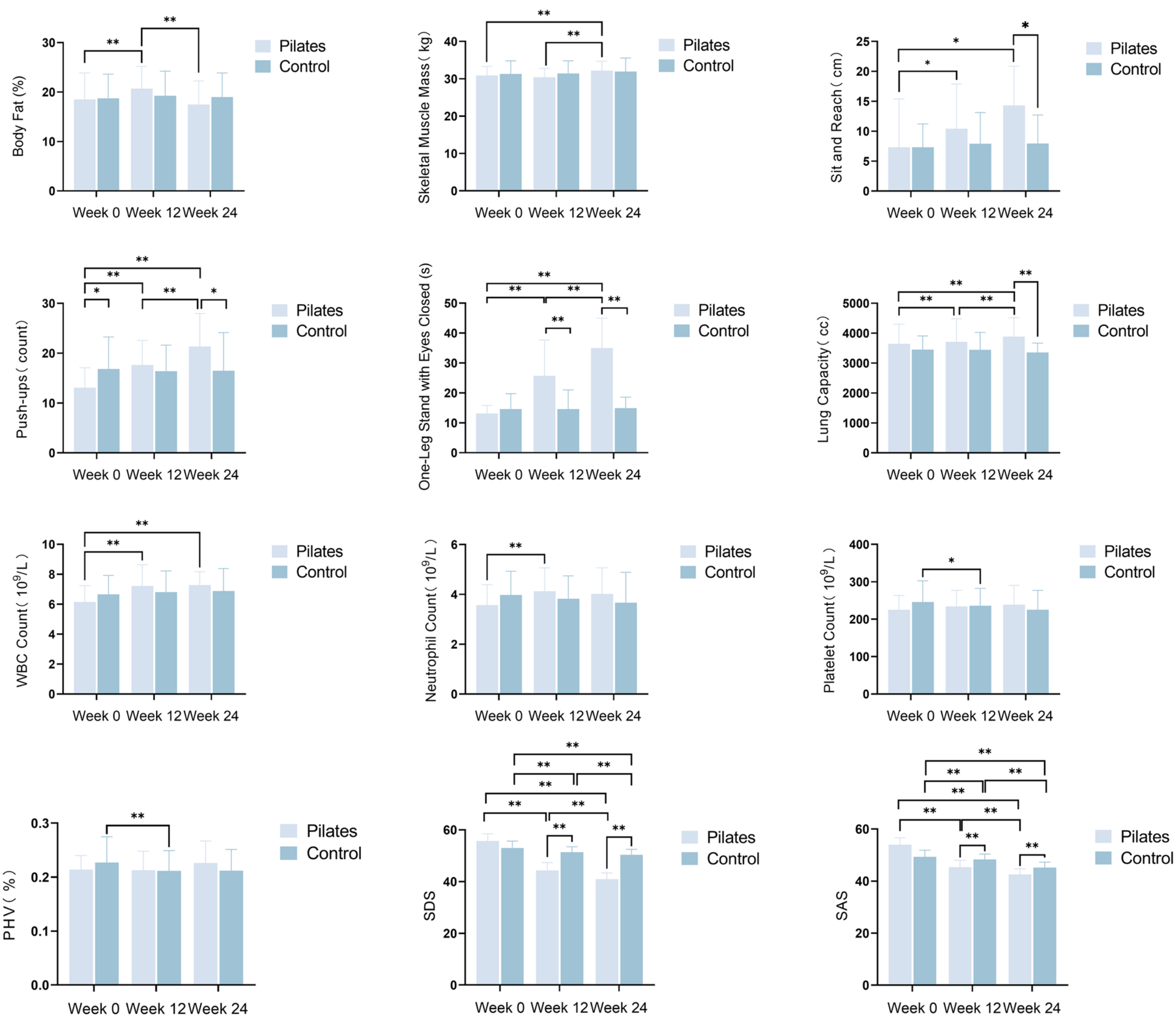

Fig.2 Comparative Analysis of the Two Groups at Baseline, 12, and 24 Weeks Using Two-Way ANOVA with Repeated Measures; (**A**-**L**): Results derived from simple effects analysis following the verification of interaction effects between the Pilates group and the control group for body fat percentage, skeletal muscle mass, sit-and-reach distance, push-up performance, one-leg stand with eyes closed, vital capacity, white blood cell count, neutrophil count, platelet count, plateletcrit, SDS, and SAS. * $p < 0.05$; ** $p < 0.01$

count significantly increased from baseline at both 12 weeks and 24 weeks [$F_{(2,40)} = 29.797$, $p < 0.01$, $\eta^2 = 0.598$], whereas the control group showed no significant changes (Fig. 2G). The Neutrophil Count in the Pilates group also demonstrated a statistically significant increase from weeks 0 to 12 [$F_{(2,40)} = 10.127$, $p < 0.01$, $\eta^2 = 0.336$] (Fig. 2H). Additionally, the simple effects analysis indicated that the changes in Platelet Count from baseline to 12 weeks [$F_{(2,40)} = 5.233$, $p < 0.05$, $\eta^2 = 0.207$] (Fig. 2I) and the changes in PHV from weeks 0 to 12 in the control group [$F_{(2,40)} = 6.910$, $p < 0.01$, $\eta^2 = 0.257$] were both statistically significant(Fig. 2J).

Mental outcomes

Statistically significant interactions between time and group were observed after 24 weeks for both SDS [$F_{(2,82)} = 9.669$, $p < 0.01$, $\eta^2 = 0.191$] and the SAS [$F_{(2,82)} = 7.174$, $p < 0.01$, $\eta^2 = 0.149$].

Subsequent simple effects analysis revealed that the SDS scores in the Pilates group were significantly lower than those in the control group at both 12 weeks (44.32 ± 3.01 vs. 51.33 ± 2.01; $p < 0.01$) and 24 weeks (40.82 ± 2.50 vs. 50.33 ± 2.10; $p < 0.01$). Similarly, SAS scores were significantly lower in the Pilates group compared to the control group at 12 weeks (45.32 ± 2.70 vs. 48.29

Table 4 Correlations between subjects' characteristics changes and the SDS and SAS scale changes

Variables	ΔSDS		ΔSAS	
	r	*P*	r	*P*
Inflammatory markers				
ΔNLR	−0.172	0.270	−0.304*	0.048
ΔPLR	−0.287	0.062	−0.320*	0.037
Physical fitness				
ΔSit and Reach, cm	−0.657**	0.000	−0.595*	0.000
ΔOne-Leg Stand with Eyes Closed, s	−0.734**	0.000	−0.704**	0.000
ΔLung Capacity, cc	−0.490**	0.001	−0.472**	0.001

* $p < 0.05$; ** $p < 0.01$

±2.12; $p < 0.01$) and 24 weeks (42.55 ±2.22 vs. 45.19 ±2.09; $p < 0.01$).

The SDS scores [$F_{(2,40)} = 283.103$, $p < 0.01$, $\eta^2 = 0.934$] and SAS scores [$F_{(2,40)} = 111.991$, $p < 0.01$, $\eta^2 = 0.848$] for the Pilates group displayed a continuous downward trend throughout the intervention period, with particularly notable reductions from weeks 0 to 12. The control group also demonstrated a downward trend in SDS [$F_{(2,40)} = 8.985$, $p < 0.01$, $\eta^2 = 0.310$] (Fig. 2K). and SAS scores [$F_{(2,40)} = 22.484$, $p < 0.01$, $\eta^2 = 0.529$] (Fig. 2L), although the overall decrease was less pronounced.

The correlations between inflammatory markers, physical fitness indicators, and the psychological scale scores of SDS and SAS among participants are detailed in Supplementary Table S3. A Spearman correlation analysis was conducted to investigate the relationships between changes in inflammatory markers, physical fitness indicators, and mental health scores as measured by the SDS and SAS. The results are detailed in Table 4.

The change in Neutrophil-to-Lymphocyte Ratio (ΔNLR) showed a non-significant trend with ΔSDS ($r = -0.172$, $p = 0.270$) and a significant negative correlation with ΔSAS ($r = -0.304$, $p = 0.048$). Similarly, the change in Platelet-to-Lymphocyte Ratio (ΔPLR) demonstrated a non-significant trend with ΔSDS ($r = -0.287$, $p = 0.062$) and a significant negative correlation with ΔSAS ($r = -0.320$, $p = 0.037$).

Significant negative correlations were observed between changes in physical fitness indicators and both ΔSDS and ΔSAS. Specifically, the change in sit-and-reach distance (ΔSit and Reach) showed a very strong significant negative correlation with both ΔSDS ($r = -0.657$, $p < 0.001$) and ΔSAS ($r = -0.595$, $p < 0.001$). The change in one-leg stand with eyes closed (ΔOne-Leg Stand with Eyes Closed) also displayed a very strong significant negative correlation with both ΔSDS ($r = -0.734$, $p < 0.001$) and ΔSAS ($r = -0.704$, $p < 0.001$). Additionally, the change in lung capacity (ΔLung Capacity) was significantly and negatively correlated with ΔSDS ($r = -0.490$, $p = 0.001$) and ΔSAS ($r = -0.472$, $p = 0.001$) (Figs. 3 and 4).

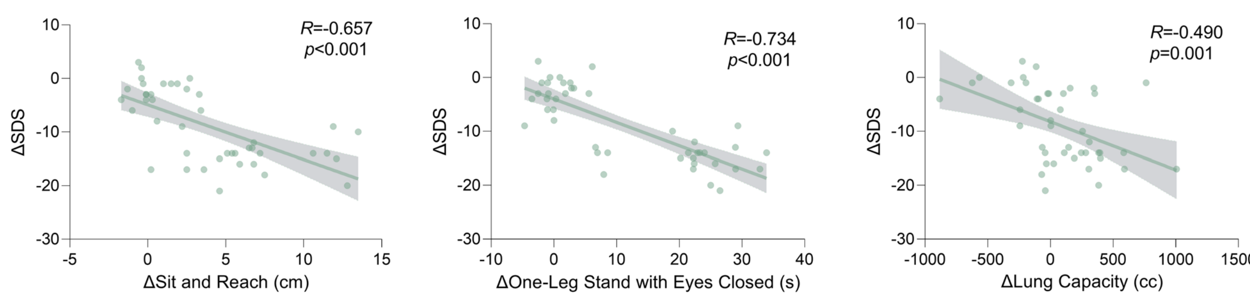

Fig. 3 Correlations Between Changes in Subject Characteristics and ΔSDS. **A**-**C** The results of Spearman correlation analyses between changes in sit-and-reach distance, one-leg stand with eyes closed, and vital capacity with changes in the SDS

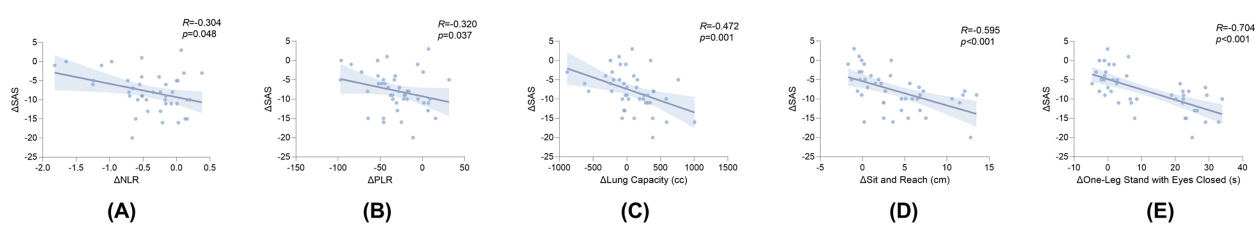

Fig. 4 Correlations Between Changes in Subject Characteristics and ΔSAS. **A**-**E** The results of Spearman correlation analyses between changes in NLR, PLR, sit-and-reach distance, one-leg stand with eyes closed, and vital capacity with ΔSAS

Discussion

In this randomized controlled trial, we compared the effects of a Pilates intervention versus conventional care on body composition, physical fitness, blood parameters, and mental health in male drug rehabilitation patients. The results indicated that the Pilates group showed greater improvements in body fat percentage, skeletal muscle mass, immune function, upper body and core strength, flexibility, balance, vital capacity, and symptoms of anxiety and depression compared to the conventional care group. Additionally, this study revealed correlations between the improvements in anxiety and depression and the enhancements in balance, flexibility, lung function, the NLR and the PLR, indicating that a Pilates intervention may contribute to the rehabilitation of drug users by providing complementary improvements in physical fitness and psychological health. However, further research is needed to confirm these findings.

Improvements in body composition and exercise performance

After 24 weeks of Pilates intervention, participants in the Pilates group exhibited a reduction in body fat percentage and an increase in skeletal muscle mass compared to baseline measurements. In contrast, the control group did not show significant changes in these parameters. Interestingly, unlike the continuous increase in skeletal muscle mass, the body fat percentage in the Pilates group exhibited an initial increase followed by a decrease. This could be attributed to drug abuse leading to nervous system disorders, causing states of extreme excitement and reduced appetite [65]. Drug use can also disrupt gastrointestinal function [66], affecting the digestion and absorption of food, resulting in long-term malnutrition among drug users [67]. Compared to healthy individuals, these users typically have lower body weight and skeletal muscle mass. After 12 weeks of Pilates training, participants' core muscle groups were frequently exercised, enhancing gastrointestinal motility and improving digestive function [68], leading to an increase in body fat percentage. The subsequent decrease in body fat percentage in the Pilates group between weeks 12 and 24 may be due to the fact that Pilates training achieved an improvement in body fat percentage as the intensity of the exercise progressed [69]. This also aptly prevents the increase in body fat percentage, obesity, and sub-health that is prone to occur after the subject's body functions and digestive system are restored. The continuous increase in skeletal muscle mass in the Pilates group, which became significantly higher than the control group at 24 weeks, is a cumulative effect of long-term Pilates training [70]. The increase in skeletal muscle mass and decrease in body fat percentage in the Pilates group resulted in minimal changes in body weight, which may explain the lack of significant changes in BMI. Previous studies on healthy individuals have indicated that a 12-week Pilates program does not significantly improve body composition [71, 72]. However, this study shows that a 24-week Pilates program positively affected the body composition of drug rehabilitation participants, albeit to a limited extent, confirming that regular long-term Pilates exercise can effectively increase skeletal muscle mass and improve body fat percentage.

The general decline in physical fitness among drug users is a prominent issue. However, good physical fitness is the cornerstone for individuals to reintegrate into society and enjoy a fulfilling life [5]. This study demonstrated significant improvements in the physical fitness of drug rehabilitation participants through Pilates intervention, including flexibility, upper limb and core strength, balance, and lung function.

After 24 weeks of Pilates intervention, the sit-and-reach performance of participants in the Pilates group increased to twice the baseline values and was significantly better than that of the control group. The improvement in flexibility is closely related to the design of this study's exercise protocol, which included a significant amount of stretching exercises such as "spine extension," "roll down," and "lateral stretch," effectively promoting the stretching of joint capsules and ligaments, increasing joint mobility. The strength training in Pilates also enhanced muscle elasticity and strength, as well as joint stability [73], leading to an improvement in flexibility. Although the average push-up performance of the Pilates group was lower than the control group at the beginning of the study, it significantly surpassed the control by week 24, due to the significant mobilization of the upper limb and core muscle groups and the improvement in muscle strength and endurance [74]. The balance quality of the Pilates group also showed a significant improvement, with the one-leg stand with eyes closed nearly doubling in duration, reflecting this enhancement. The mechanism behind the improvement in balance may be related to the increase in core strength. Through Pilates training, participants' core muscle group stability and control capabilities were enhanced, leading to positive changes in balance ability [75]. This is consistent with studies showing that similar exercises like Tai Chi can improve balance in drug rehabilitation populations [76, 77]. In the Pilates group, vital capacity showed a stable increasing trend throughout the study. At 24 weeks, it was significantly higher than in the control group, suggesting that long-term Pilates training may potentially benefit respiratory health in drug rehabilitation individuals. This benefit may be attributed to the mobilization of respiratory muscles, coordination between the chest and abdomen, improvement in breathing patterns, and optimization of thoracic morphology during Pilates exercises [78]. Moreover, it is worth noting that the improvements in body composition and physical fitness of the Pilates group are also closely linked. Lower body fat percentage reduces the burden of excess fat, making the transmission of muscle strength more effective, thereby improving the body's exercise efficiency and functional performance, and enhancing strength, flexibility, and balance [79]. The enhancement of upper limb and core strength also benefits from the increase in skeletal muscle mass in the corresponding body parts. The increase in skeletal muscle mass and the strengthening of the core muscle group improve the stability and control of the trunk, significantly improving balance [75]. The increased skeletal muscle mass and improved body fat percentage positively affect lung function by improving overall health [80].

In summary, Pilates has shown positive effects in enhancing flexibility, upper-body and core muscle endurance, balance, and lung function among drug rehabilitation participants, which aligns with prior studies observing similar benefits [81]. Clinically, these improvements may enhance participants' ability to engage in daily activities (e.g., bending, lifting), indirectly supporting rehabilitation goals such as vocational training.

Improvement in blood routine results

The ravages of drug abuse can severely disrupt physiological functions and inevitably lead to a decline in immune function [82]. Key indicators in routine blood tests, such as white blood cells, red blood cells, and platelets, provide important information about the immune status of the body. White blood cells play an essential role in defending against invasions by foreign bacteria [83], and platelets also have a significant defensive role [84]. Therefore, it is important to monitor the improvement in relevant indicators of drug addicts to assess their health status.

During the experimental intervention, the Pilates group exhibited significant increases in total white blood cell and neutrophil counts, likely reflecting exercise-induced immunomodulation. Previous research has shown that regular exercise can boost the number and activity of white blood cells and neutrophils in healthy individuals [85]. Thus, the significant rise in white blood cell and subtype counts from baseline to week 12 likely represents adaptive changes in the early to mid-intervention stages due to Pilates, indicating immune system activation. However, these adaptive changes gradually attenuated over time. The specific chronic adaptations (e.g., enhanced anti-pathogen capacity) still need to be further validated through functional immune assays. Future studies should integrate inflammatory biomarkers and pathogen challenge models to clarify whether Pilates can enhance immune competence in drug-dependent populations. Meanwhile, the control group showed a decrease in platelet count and PHV at 12 weeks, which may be related to the weaker physical constitution of the participants and the lack of stable support from routine daily activities for the recovery of immune function, leading to a decrease in platelet count and crit. This phenomenon has also been documented in patients with opioid and alcohol addiction [86, 87]. Gronesova et al. (2018) found that two weeks of Pilates intervention could affect specific blood parameters in healthy women [88], mainly manifesting in the reduction of pro-inflammatory cytokines and angiogenic chemokine levels, as well as the enhancement of NK cell activity. These could also be potential mechanisms by which Pilates exercise improves immune function. Overall, Pilates intervention appears to activate the immune system, but the specific chronic adaptations, underlying mechanisms, and relationships with other health factors require further exploration, the clinical significance of the improvements in these blood parameters is currently limited.

Improvement in psychological outcomes and the correlation analysis

The exacerbation of anxiety and depressive states in drug users is related to a conflict of internal emotions [89]. Although they recognize the harmful effects of drugs on health and society, the discomfort caused by drug use intensifies the craving for drugs. This accumulated conflict of emotions ultimately leads to anxiety and depression [90]. The worsening of anxiety and depressive symptoms can lead to a stronger dependence on drugs in addicts [43], forming a vicious cycle. Therefore, to break this cycle, effectively alleviating anxiety and depressive emotions caused by drug cravings is crucial for the recovery of individuals in drug rehabilitation.

At 12 weeks, the Pilates intervention reduced anxiety and depression scores by nearly 20%, with sustained improvements through follow-up. The participants in the conventional care group also showed a slight improvement in anxiety and depressive states, which may be due to the physical exercise and teamwork involved in daily labor, which to some extent increased their physical activity and social interaction, thereby promoting psychological health. Overall, compared to conventional care, Pilates intervention can achieve more significant results in the treatment of negative emotions in the short term, and long-term Pilates exercise intervention can further consolidate and strengthen the therapeutic effect.

The mind–body integration characteristic of Pilates played a key role in this process. Pilates emphasizes body awareness and breath control [60], which helps to improve individuals' awareness of their bodily state. Deep breathing can activate the body's relaxation response, reduce the levels of stress hormones such as cortisol, and promote the production of neurotransmitters in the brain (such as endorphins, serotonin, and dopamine) [91, 92], thereby achieving the effect of relieving symptoms of depression and anxiety. As a form of mind–body exercise, Pilates can also regulate the neural activity and functional connectivity of brain structures such as the prefrontal cortex, hippocampus/medial temporal lobe, lateral temporal lobe, insula, and cingulate cortex, as well as cognitive control and the default mode network [93], thereby repairing and protecting the damaged dopamine system [94]. Fleming et al. (2018) also explored the impact of Pilates on psychological health outcomes in a meta-analysis, and the results showed that Pilates exercise can significantly reduce depression, anxiety, and fatigue [95]. These findings further support the positive role of Pilates exercise in improving psychological health.

From a clinical perspective, Pilates training, as a non-pharmacological intervention, offers a safe, sustainable, and cost-effective adjunctive approach for substance rehabilitation through its demonstrated efficacy in alleviating anxiety and depressive symptoms. This therapeutic strategy holds particular relevance for patient populations exhibiting contraindications or suboptimal tolerability to conventional pharmacotherapy.

Our study yielded some intriguing findings, including a strong negative correlation between improvements in balance, flexibility, and lung function and the increased scores on the SAS and the SDS. Additionally, the increases in the NLR and the PLR showed a similar negative correlation with the rise in SAS scores. These findings may provide a new perspective and theoretical basis for selecting exercise interventions that can effectively improve the physical and mental health of individuals in drug rehabilitation.

NLR and PLR, as reliable indicators of inflammatory status [96, 97], have been linked by researchers such as Furtado et al. to the pathogenesis of psychological disorders like anxiety and depression. A recent study also supports a mild to moderate positive correlation between NLR and PLR and anxiety levels [98]. Notably, in individuals dependent on opioids, NLR and PLR are lower than in healthy controls but significantly elevated in those with long-term dependence or active use [86]. In our study, changes in NLR and PLR showed a mild negative correlation with changes in anxiety scores. However, due to the variability in the duration of drug dependence and the diversity of drug types used by the participants, the measurements may be subject to various interfering factors, which may limit the reference significance of the research findings.

Significant positive correlations were observed between improvements in flexibility, balance, and lung capacity, and the alleviation of anxiety and depression. Previous studies have noted that enhanced personal flexibility often parallels the alleviation of anxiety and depressive symptoms [55, 56], likely because practices that improve flexibility typically include increased body awareness and control, which enhance body perception and self-awareness, thereby aiding in easing symptoms of depression and anxiety [91, 92]. In terms of balance control, patients with anxiety and depression exhibit balance disorders reliant on proprioception [99, 100]. The neurological link between anxiety and panic and balance control is that motor responses modulate brainstem circuits through descending commands and indirectly through the locus coeruleus and the raphe nuclei. Monoaminergic inputs seem to increase the sensitivity of vestibular reflex pathways to vestibular inputs, and with heightened alertness and anxiety, the activation of these pathways may lead to postural sway and spatial motion discomfort [52]. These research findings provide theoretical support for the observations in our study. The significant correlation between improved lung function and the alleviation of anxiety and depressive symptoms may be attributed to the emphasis on deep breathing and breath control in Pilates exercises, which not only optimize the brain's oxygen supply but also serve as an effective means of anxiety relief [60]. Furthermore, enhanced lung function is closely associated with an individual's positive perception of physical health and overall well-being [101], which in turn promotes the improvement of psychological health [102]. Previous research has also indicated a link between higher levels of anxiety and depression and lower levels of lung function [53]. Therefore, our findings further emphasize the positive role of exercise interventions like Pilates in improving lung function to promote psychological health.The analysis results suggest that we may be able to design more individualized exercise intervention plans based on the weaknesses of individuals in drug rehabilitation in aspects such as flexibility, balance, and lung function, thereby more efficiently improving their physical and mental health. However, further research is needed to clarify the exact impact mechanisms of these indicators.

Compared to prior studies in exercise-based rehabilitation, long-term Pilates training showed greater benefits in improving balance and reducing body fat [44], whereas moderate-intensity training was more effective in enhancing reaction speed [23]. Additionally, long-term Pilates intervention demonstrated similar effects on alleviating negative emotions as long-term yoga or moderate-intensity exercise [40].

Limitations

This study has several limitations that warrant consideration. First, the small sample size and single-center design may reduce statistical power and increase the risk of Type II errors, particularly in detecting subtle effects of Pilates on hematological parameters. Second, the exclusive inclusion of male participants undergoing compulsory rehabilitation in Zhenjiang, China, limits the generalizability of the findings to females, voluntary rehabilitation populations, or individuals in other cultural contexts. For instance, females with substance use disorders often exhibit distinct comorbidities [103] that may modulate intervention responses. Third, the control group received routine care without structured exercise, which precludes direct comparisons between Pilates and other exercise modalities. Fourth, the reliance on video-based Pilates instruction, despite supervision by rehabilitation staff, introduces potential variability in exercise fidelity. While a pilot study ensured baseline movement accuracy, real-time feedback from certified instructors could further standardize practice. Finally, the absence of long-term follow-up data limits our understanding of whether the observed benefits persist beyond the 24-week intervention period.

Future research

Future research should aim to address the limitations of the current study and further advance the field by enhancing population diversity, conducting comparative intervention trials, investigating mechanisms, and evaluating long-term outcomes. To enhance population diversity, future studies should also recruit larger, gender-balanced cohorts across both voluntary and compulsory rehabilitation settings, including participants from diverse geographic, cultural, and socioeconomic backgrounds. This would allow for comparative analyses to explore whether factors such as gender, drug type, or legal status modulate the efficacy of Pilates interventions. Direct comparative trials are also needed to evaluate the relative benefits of Pilates compared to other evidence-based exercise modalities, such as yoga or aerobic training. A three-arm randomized controlled trial design (Pilates vs. yoga vs. control) could help clarify whether observed outcomes are driven by mind–body integration, physical intensity, or other modality-specific mechanisms. Furthermore, future research should integrate neuroimaging techniques (e.g., Functional Magnetic Resonance Imaging to assess dopaminergic pathway activation) and biomarker analysis (e.g., inflammatory cytokines, Brain-Derived Neurotrophic Factor levels) to elucidate the neurobiological and immunological mechanisms underlying Pilates' effects on addiction recovery and neuroplasticity. Additionally, post-intervention follow-up periods of 6–12 months are necessary to evaluate the durability of physical and mental health improvements, including relapse rates, quality of life metrics, and social reintegration outcomes. This will provide critical insights into the long-term sustainability of Pilates-based interventions. Finally, systematic dose–response studies should investigate the impact of varying Pilates intensities, frequencies, and intervention durations on rehabilitation outcomes, which could inform evidence-based exercise prescriptions tailored to clinical guidelines for addiction treatment. By addressing these priorities, future research can strengthen the scientific rigor of Pilates interventions and clarify their role in addiction recovery protocols.

Conclusion

The results of this study indicated that Pilates exercise, with its progressive intensity, is an effective therapeutic method for improving the physical and mental health of individuals in drug rehabilitation. After 24 weeks of Pilates intervention, participants showed significant improvements in body fat percentage, skeletal muscle mass, endurance of the upper limbs and core muscle groups, flexibility, balance, and lung function, with moderate activation of the immune system and effective alleviation of anxiety and depressive symptoms. Moreover, this study also found that improvements in anxiety and depressive states in the drug rehabilitation population may be associated with enhanced physical fitness, such as balance, flexibility, and lung function. This suggested that we may be able to design more targeted exercise interventions for the drug rehabilitation population by monitoring changes in relevant physiological and psychological indicators, thereby enhancing the overall effectiveness of exercise-based drug withdrawal.

Abbreviations

ANOVA	Analysis of Variance
BMI	Body Mass Index
CCMD-3	Chinese Classification and Diagnostic Criteria of Mental Disorders, 3rd Edition
CBC	Complete Blood Count
CONSORT	Consolidated Standards of Reporting Trials
Hb	Hemoglobin
HRmax	Maximum Heart Rate
IQR	Interquartile Range
MCH	Mean Corpuscular Hemoglobin
MCHC	Mean Corpuscular Hemoglobin Concentration
MCV	Mean Corpuscular Volume
MPV	Mean Platelet Volume
NLR	Neutrophil-to-Lymphocyte Ratio
PCV	Packed Cell Volume
PDW	Platelet Distribution Width
PHV	Platelet Hematocrit Volume
PLR	Platelet-to-Lymphocyte Ratio
RBC	Red Blood Cell
RDW	Red Blood Cell Distribution Width
SAS	Self-Rating Anxiety Scale
SD	Standard Deviation

SDS Self-Rating Depression Scale
SPIRIT Standard Protocol Items: Recommendations for Interventional Trials
WBC White Blood Cell

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12888-025-07008-7.

Supplementary Material 1.

Supplementary Material 2.

Acknowledgements
We extend our gratitude to the Judong Compulsory Isolation Drug Rehabilitation Center in Zhenjiang City, Jiangsu Province,China for their assistance in this project.

Authors' contributions
FJ, ESZ, PZ, YHL, and QZ participated in the design, conducted the statistical analyses, interpreted the data, and drafted the manuscript. HW, XLC, and JBZ supervised the study, assisted in data interpretation, critically reviewed the manuscript, and helped conduct and revise the manuscript. YZ helped to manage and analyze the data. All authors read and approved the final manuscript.

Funding
This study was financially supported by Judong Compulsory Isolation Drug Rehabilitation Center (AS10601221).

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

Declarations

Ethics approval and consent to participate
The studies involving human participants were reviewed and approved by the Ethics Committee of Soochow University (Approval NO. SUDA20231211H03). The current study has been registered on the platform of the China Trial Registration Center (Registration number: ChiCTR2400087067). This study was conducted in accordance with the Declaration of Helsinki, and all participants provided written informed consent 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.

Competing interests
The authors declare no competing interests.

Author details
[1]School of Physical Education and Sports Science, Soochow University, Suzhou 215021, China. [2]Judong Compulsory Isolation Drug Rehabilitation Center, Zhenjiang, Jiangsu 212400, China. [3]Department of Physical Education, Kyungpook National University, Daegu 41566, Republic of Korea.

Received: 24 July 2024 Accepted: 20 May 2025
Published online: 02 June 2025

References

1. Kim S, Lee H, Woo S, Lee H, Park J, Kim T, et al. Global, regional, and national trends in drug use disorder mortality rates across 73 countries from 1990 to 2021, with projections up to 2040: a global time-series analysis and modelling study. EClinicalMedicine. 2025;79:102985.
2. Castaldelli-Maia JM, Wang YP, Brunoni AR, Faro A, Guimarães RA, Lucchetti G, et al. Burden of disease due to amphetamines, cannabis, cocaine, and opioid use disorders in South America, 1990–2019: a systematic analysis of the Global Burden of Disease Study 2019. Lancet Psychiatry. 2023;10(2):85–97.
3. Pierce M, Hayhurst K, Bird SM, Hickman M, Seddon T, Dunn G, et al. Insights into the link between drug use and criminality: Lifetime offending of criminally-active opiate users. Drug Alcohol Depend. 2017;179:309–16.
4. Das P, Horton R. The global drug problem: change but not progression. Lancet. 2019;394(10208):1488–90.
5. Hall W, Degenhardt L. Adverse health effects of non-medical cannabis use. Lancet. 2009;374(9698):1383–91.
6. Koob GF, Volkow ND. Neurocircuitry of addiction. Neuropsychopharmacology. 2010;35(1):217–38.
7. Dowla R, Sinmaz H, Mavros Y, Murnion B, Cayanan E, Rooney K. The effectiveness of exercise as an adjunct intervention to improve quality of life and mood in substance use disorder: a systematic review. Subst Use Misuse. 2022;57(6):911–28.
8. Smith JP, Book SW. Anxiety and Substance Use Disorders: A Review. Psychiatr Times. 2008;25(10):19–23.
9. Peles E, Schreiber S, Adelson M. Factors predicting retention in treatment: 10-year experience of a methadone maintenance treatment (MMT) clinic in Israel. Drug Alcohol Depend. 2006;82(3):211–7.
10. Carroll KM, Kiluk BD. Cognitive behavioral interventions for alcohol and drug use disorders: Through the stage model and back again. Psychol Addict Behav. 2017;31(8):847–61.
11. Somkuwar SS, Staples MC, Fannon MJ, Ghofranian A, Mandyam CD. Evaluating exercise as a therapeutic intervention for methamphetamine addiction-like behavior. Brain plasticity. 2015;1(1):63–81.
12. Ashdown-Franks G, Firth J, Carney R, Carvalho AF, Hallgren M, Koyanagi A, et al. Exercise as Medicine for Mental and Substance Use Disorders: A Meta-review of the Benefits for Neuropsychiatric and Cognitive Outcomes. Sports Med. 2020;50(1):151–70.
13. Patterson MS, Spadine MN, Graves Boswell T, Prochnow T, Amo C, Francis AN, et al. Exercise in the treatment of addiction: a systematic literature review. Health Educ Behav. 2022;49(5):801–19.
14. Huang J, Zheng Y, Gao D, Hu M, Yuan T. Effects of Exercise on Depression, Anxiety, Cognitive Control, Craving, Physical Fitness and Quality of Life in Methamphetamine-Dependent Patients. Front Psychiatry. 2019;10:999.
15. Giménez-Meseguer J, Tortosa-Martínez J, Cortell-Tormo JM. The Benefits of Physical Exercise on Mental Disorders and Quality of Life in Substance Use Disorders Patients. Systematic Review and Meta-Analysis. Int J Environ Res Public Health. 2020;17(10):3680.
16. Robertson CL, Ishibashi K, Chudzynski J, Mooney LJ, Rawson RA, Dolezal BA, et al. Effect of Exercise Training on Striatal Dopamine D2/D3 Receptors in Methamphetamine Users during Behavioral Treatment. Neuropsychopharmacology. 2016;41(6):1629–36.
17. Cabral DA, Tavares VD, da Costa KG, Nascimento PH, Faro HK, Elsangedy HM, et al. The benefits of high intensity exercise on the brain of a drug abuser. Global J Health Sci. 2018;10(6):123.
18. Brown RA, Abrantes AM, Read JP, Marcus BH, Jakicic J, Strong DR, et al. A Pilot Study of Aerobic Exercise as an Adjunctive Treatment for Drug Dependence. Ment Health Phys Act. 2010;3(1):27–34.
19. Dolezal BA, Chudzynski J, Storer TW, Abrazado M, Penate J, Mooney L, et al. Eight weeks of exercise training improves fitness measures in methamphetamine-dependent individuals in residential treatment. J Addict Med. 2013;7(2):122–8.
20. Giménez-Meseguer J, Tortosa-Martínez J, Remedios Fernández-Valenciano MdI. Benefits of exercise for the quality of life of drug-dependent patients. J Psychoactive Drugs. 2015;47(5):409–16.
21. Liu F, Cui J, Liu X, Chen KW, Chen X, Li R. The effect of tai chi and Qigong exercise on depression and anxiety of individuals with substance use disorders: a systematic review and meta-analysis. BMC Complement Med Ther. 2020;20:1–11.

22. Ellingsen MM, Clausen T, Johannesen SL, Martinsen EW, Hallgren M. Effects of Acute Exercise on Affect, Anxiety, and Self-Esteem in Poly-Substance Dependent Inpatients. Eur Addict Res. 2023;29(4):285–93.
23. Xu J, Zhu Z, Liang X, Huang Q, Zheng T, Li X. Effects of moderate-intensity exercise on social health and physical and mental health of methamphetamine-dependent individuals: A randomized controlled trial. Front Psychiatry. 2022;13:997960.
24. Zhang Z, Zhu D. Effect of Taijiquan Exercise on Rehabilitation of Male Amphetamine-Type Addicts. Evid Based Complement Alternat Med. 2020;2020:8886562.
25. Janse Van Rensburg K, Elibero A, Kilpatrick M, Drobes DJ. Impact of aerobic exercise intensity on craving and reactivity to smoking cues. Exp Clin Psychopharmacol. 2013;21(3):196–203.
26. Ercan HY, Yargic IL, Karagozoglu C. The effects of regular exercise on anxiety, depression and quality of life in adult alcohol and drug dependents in addiction treatment/Alkol ve madde bagimliligi tedavisi goren yetiskinlerde duzenli egzersizin kaygi, depresyon ve yasam kalitesine etkisi. Anadolu Psikiyatri Dergisi. 2016;17(1):33–42.
27. Yanagisawa H, Dan I, Tsuzuki D, Kato M, Okamoto M, Kyutoku Y, et al. Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves cognitive performance with Stroop test. Neuroimage. 2010;50(4):1702–10.
28. Zhang Z, Liu X. A Systematic Review of Exercise Intervention Program for People With Substance Use Disorder. Front Psych. 2022;13:817927.
29. Weinstock J, Farney MR, Elrod NM, Henderson CE, Weiss EP. Exercise as an Adjunctive Treatment for Substance Use Disorders: Rationale and Intervention Description. J Subst Abuse Treat. 2017;72:40–7.
30. Linke SE, Ussher M. Exercise-based treatments for substance use disorders: evidence, theory, and practicality. Am J Drug Alcohol Abuse. 2015;41(1):7–15.
31. Kim H, Kim J, Woo M, Kim T. Changes in inhibitory control, craving and affect after yoga vs. aerobic exercise among smokers with nicotine dependence. Front Psychiatry. 2022;13:940415.
32. Santos CP, Proença M, Gouveia TDS, Soares de Oliveira CB, Tacao GY, Trevisan IB, et al. Effectiveness of Aerobic Exercise on Smoking Cessation in Adults: A Systematic Review and Meta-Analysis. J Phys Act Health. 2021;18(2):230–42.
33. Cruz-Ferreira A, Fernandes J, Laranjo L, Bernardo LM, Silva A. A systematic review of the effects of pilates method of exercise in healthy people. Arch Phys Med Rehabil. 2011;92(12):2071–81.
34. Bullo V, Bergamin M, Gobbo S, Sieverdes JC, Zaccaria M, Neunhaeuserer D, et al. The effects of Pilates exercise training on physical fitness and wellbeing in the elderly: A systematic review for future exercise prescription. Prev Med. 2015;75:1–11.
35. Vergeer I, Bennie JA, Charity MJ, Harvey JT, van Uffelen JGZ, Biddle SJH, et al. Participation trends in holistic movement practices: a 10-year comparison of yoga/Pilates and t'ai chi/qigong use among a national sample of 195,926 Australians. BMC Complement Altern Med. 2017;17(1):296.
36. Wehner C, Blank C, Arvandi M, Wehner C, Schobersberger W. Effect of Tai Chi on muscle strength, physical endurance, postural balance and flexibility: a systematic review and meta-analysis. BMJ Open Sport Exerc Med. 2021;7(1):e000817.
37. Campelo G, de Araújo JR, Aristizabal JP, de Souza W, de Castilho GM. Long-term effects of yoga-based practices on neural, cognitive, psychological, and physiological outcomes in adults: a scoping review and evidence map. BMC Complement Med Ther. 2025;25(1):92.
38. Fernández-Rodríguez R, Alvarez-Bueno C, Reina-Gutiérrez S, Torres-Costoso A, Nunez de Arenas-Arroyo S, Martínez-Vizcaíno V. Effectiveness of Pilates and Yoga to improve bone density in adult women: A systematic review and meta-analysis. PloS one. 2021;16(5):e0251391.
39. Qi F, Soh KG, Mohd Nasirudddin NJ, Mai Y. Effects of taichi on physical and psychological health of college students: A systematic review. Front Physiol. 2022;13:1008604.
40. Sarkar S, Varshney M. Yoga and substance use disorders: A narrative review. Asian J Psychiatr. 2017;25:191–6.
41. Walia N, Matas J, Turner A, Gonzalez S, Zoorob R. Yoga for substance use: A systematic review. J Am Board Fam Med. 2021;34(5):964–73.
42. Cui J, Liu F, Liu X, Li R, Chen X, Zeng H. The impact of Qigong and Tai Chi exercise on drug addiction: a systematic review and meta-analysis. Front Psych. 2022;13:826187.
43. Ye X, Liu R. Intervention effect of aerobic exercise on physical fitness, emotional state and mental health of drug addicts: a systematic review and meta-analysis. Int J Environ Res Public Health. 2023;20(3):2272.
44. Zhu D, Jiang M, Xu D, Schöllhorn WI. Long-Term Effects of Mind-Body Exercises on the Physical Fitness and Quality of Life of Individuals With Substance Use Disorder-A Randomized Trial. Front Psychiatry. 2020;11:528373.
45. Reece AS. Evidence of accelerated ageing in clinical drug addiction from immune, hepatic and metabolic biomarkers. Immun Ageing. 2007;4:6.
46. Savov Y, Antonova N, Zvetkova E, Gluhcheva Y, Ivanov I, Sainova I. Whole blood viscosity and erythrocyte hematometric indices in chronic heroin addicts. Clin Hemorheol Microcirc. 2006;35:129–33.
47. Guzel D, Yazici AB, Yazici E, Erol A. Evaluation of Immunomodulatory and Hematologic Cell Outcome in Heroin/Opioid Addicts. J Addict. 2018;2018:2036145.
48. Yaprak M, Turan MN, Dayanan R, Akın S, Değirmen E, Yıldırım M, et al. Platelet-to-lymphocyte ratio predicts mortality better than neutrophil-to-lymphocyte ratio in hemodialysis patients. Int Urol Nephrol. 2016;48(8):1343–8.
49. Ahbap E, Sakaci T, Kara E, Sahutoglu T, Koc Y, Basturk T, et al. Neutrophil-to-lymphocyte ratio and platelet-tolymphocyte ratio in evaluation of inflammation in end-stage renal disease. Clin Nephrol. 2016;85(4):199–208.
50. Elkjær E, Mikkelsen MB, Michalak J, Mennin DS, O'Toole MS. Motor alterations in depression and anxiety disorders: A systematic review and meta-analysis. J Affect Disord. 2022;317:373–87.
51. Feldman R, Schreiber S, Pick CG, Been E. Gait, balance, mobility and muscle strength in people with anxiety compared to healthy individuals. Hum Mov Sci. 2019;67:102513.
52. Balaban CD, Thayer JF. Neurological bases for balance-anxiety links. J Anxiety Disord. 2001;15(1–2):53–79.
53. Li Y, Jiang Q, Ji Y, Cao C. Anxiety and depression may associate with poorer control and quality of life in adults with asthma. Allergy. 2020;75(7):1759–62.
54. Rahi MS, Thilagar B, Balaji S, Prabhakaran SY, Mudgal M, Rajoo S, et al. The Impact of Anxiety and Depression in Chronic Obstructive Pulmonary Disease. Adv Respir Med. 2023;91(2):123–34.
55. Diehl K. A program for improving health and stress management for adolescents from low-income families: Integrating behavioral coping skills, nutrition education and yoga. J Adolesc Health. 2014;54(2):S73.
56. Kavuri V, Selvan P, Malamud A, Raghuram N, Selvan SR. Remedial yoga module remarkably improves symptoms in irritable bowel syndrome patients: A 12-week randomized controlled trial. Eur J Integr Med. 2015;7(6):595–608.
57. World Medical Association Declaration of Helsinki. ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191–4.
58. Cohen J. Statistical power analysis for the behavioral sciences: routledge; 2013.
59. Kang H. Sample size determination and power analysis using the G*Power software. J Educ Eval Health Prof. 2021;18:17.
60. Pilates JH, Miller WJ. Return to life through contrology: Ravenio Books; 2011.
61. Zung WW. A self-rating depression scale. Arch Gen Psychiatry. 1965;12(1):63–70.
62. Zung WW. Self-rating anxiety scale. BMC Psychiatry. 1971;12(6):371–9.
63. Zhang Y, Rui L, Guohong L, Shengqin M, Yuan Y. The reliability and validity of a Chinese-version Short Health Anxiety Inventory: an investigation of university students. Neuropsychiatr Dis Treat. 2015;11:1739–47.
64. Sun XY, Li YX, Yu CQ, Li LM. Reliability and validity of depression scales of Chinese version: a systematic review. Zhonghua Liu Xing Bing Xue Za Zhi. 2017;38(1):110–6.
65. Ciucă Anghel D-M, Nițescu GV, Tiron A-T, Guțu CM, Baconi DL. Understanding the Mechanisms of Action and Effects of Drugs of Abuse. Molecules. 2023;28(13):4969.
66. Jung K, Kim J, Park HY, Jung WS, Lim K. Hypoxic Pilates Intervention for Obesity: A Randomized Controlled Trial. Int J Environ Res Public Health. 2020;17(19).

67. Mahboub N, Rizk R, Karavetian M, de Vries N. Nutritional status and eating habits of people who use drugs and/or are undergoing treatment for recovery: a narrative review. Nutr Rev. 2021;79(6):627–35.
68. Song BK, Han D, Brellenthin AG, Kim YS. Effects of core strengthening exercise on colon transit time in young adult women. J Exerc Sci Fit. 2021;19(3):158–65.
69. Wang Y, Chen Z, Wu Z, Ye X, Xu X. Pilates for Overweight or Obesity: A Meta-Analysis. Front Physiol. 2021;12:643455.
70. Silva LL, Mendes da Silva KB, Sousa Ld, Pinhata Rocha C. Is the Pilates method efficient to cause changes in the body composition of healthy individuals? A systematic review. J Bodywork Mov Ther. 2022;32:51–9.
71. Bergamin M, Gobbo S, Bullo V, Zanotto T, Vendramin B, Duregon F, et al. Effects of a Pilates exercise program on muscle strength, postural control and body composition: results from a pilot study in a group of post-menopausal women. Age (Dordr). 2015;37(6):118.
72. Aibar-Almazán A, Martínez-Amat A, Cruz-Díaz D, Jesús de la Torre-Cruz M, Jiménez-García JD, Zagalaz-Anula N, et al. The Influence of Pilates Exercises on Body Composition, Muscle Strength, and Gait Speed in Community-Dwelling Older Women: A Randomized Controlled Trial. J Strength Cond Res. 2022;36(8):2298–305.
73. Bertoli J, Bezerra ES, Winters-Stone KM, Alberto Gobbo L, Freitas IFJ. Mat Pilates improves lower and upper body strength and flexibility in breast cancer survivors undergoing hormone therapy: a randomized controlled trial (HAPiMat study). Disabil Rehabil. 2023;45(3):494–503.
74. Amin WM, Ali OI, Malik S, Draj SAI, Masoud FAM, Sohel AMI, et al. Effects of Pilates Exercises on Core Stability After Recovery from COVID-19: A Randomized Controlled Trial. J Multidiscip Healthc. 2024;17:753–63.
75. Amiri B, Sahebozamani M, Sedighi B. The effects of 10-week core stability training on balance in women with multiple sclerosis according to Expanded Disability Status Scale: a single-blinded randomized controlled trial. Eur J Phys Rehabil Med. 2019;55(2):199–208.
76. Zhu D, Xu D, Dai G, Wang F, Xu X, Zhou D. Beneficial effects of Tai Chi for amphetamine-type stimulant dependence: a pilot study. Am J Drug Alcohol Abuse. 2016;42(4):469–78.
77. Dunlap E, Lambeck J, Ku P-H, Gobert D. Ai Chi for Balance, Pain, Functional Mobility, and Quality of Life in Adults: A Scoping Review. The Journal of Aquatic Physical Therapy. 2021;29(1):14–8.
78. Cancelliero-Gaiad KM, Ike D, Pantoni CB, Borghi-Silva A, Costa D. Respiratory pattern of diaphragmatic breathing and pilates breathing in COPD subjects. Braz J Phys Ther. 2014;18(4):291–9.
79. Fogelholm M. Effects of Bodyweight Reduction on Sports Performance. Sports Med. 1994;18(4):249–67.
80. Park HK, Lee SH, Lee SY, Kim SS, Park HW. Relationships between lung function decline and skeletal muscle and fat mass changes: a longitudinal study in healthy individuals. J Cachexia Sarcopenia Muscle. 2021;12(6):2145–53.
81. Metz VR, Scapini KB, Dias Gomes AL, Andrade RM, Brech GC, Alonso AC. Effects of pilates on physical-functional performance, quality of life and mood in older adults: Systematic review and meta-analysis of randomized clinical trials. J Bodyw Mov Ther. 2021;28:502–12.
82. Ersche KD, Döffinger R. Inflammation and infection in human cocaine addiction. Curr Opin Behav Sci. 2017;13:203–9.
83. Bain BJ. Structure and function of red and white blood cells and platelets. Medicine. 2025;53(4):175–80.
84. Sonmez O, Sonmez M. Role of platelets in immune system and inflammation. Porto Biomed J. 2017;2(6):311–4.
85. Sand KL, Flatebo T, Andersen MB, Maghazachi AA. Effects of exercise on leukocytosis and blood hemostasis in 800 healthy young females and males. World J Exp Med. 2013;3(1):11–20.
86. Quraishi R, Kathiresan P, Verma K, Rao R, Jain R. Effect of chronic opioid use on the hematological and inflammatory markers: A retrospective study from North India. Indian Journal of Psychiatry. 2022;64(3):252-6.
87. Silczuk A, Habrat B. Alcohol-induced thrombocytopenia: Current review. Alcohol. 2020;86:9–16.
88. Gronesova P, Cholujova D, Kozic K, Korbuly M, Vlcek M, Penesova A, et al. Effects of short-term Pilates exercise on selected blood parameters. Gen Physiol Biophys. 2018;37(4):443–51.
89. Rogers AH, Zvolensky MJ, Ditre JW, Buckner JD, Asmundson GJG. Association of opioid misuse with anxiety and depression: A systematic review of the literature. Clin Psychol Rev. 2021;84:101978.
90. Gu W, Yang X, Liu X, Xu W. Mindfulness and Negative Emotions Among Females Who Inject Drugs: the Mediating Role of Social Support and Resilience. Int J Ment Heal Addict. 2023;21(6):3627–40.
91. Vancini RL, Rayes ABR, Lira CAB, Sarro KJ, Andrade MS. Pilates and aerobic training improve levels of depression, anxiety and quality of life in overweight and obese individuals. Arq Neuropsiquiatr. 2017;75(12):850–7.
92. Nowacka-Chmielewska M, Grabowska K, Grabowski M, Meybohm P, Burek M, Małecki A. Running from Stress: Neurobiological Mechanisms of Exercise-Induced Stress Resilience. Int J Mol Sci. 2022;23(21):13348.
93. Zhang X, Zong B, Zhao W, Li L. Effects of Mind-Body Exercise on Brain Structure and Function: A Systematic Review on MRI Studies. Brain Sci. 2021;11(2):205
94. Xu J, Zhu Z, Liang X, Huang Q, Zheng T, Li X. Effects of moderate-intensity exercise on social health and physical and mental health of methamphetamine-dependent individuals: a randomized controlled trial. Front Psych. 2022;13:997960.
95. Fleming KM, Herring MP. The effects of pilates on mental health outcomes: A meta-analysis of controlled trials. Complement Ther Med. 2018;37:80–95.
96. Turkmen K, Erdur FM, Ozcicek F, Ozcicek A, Akbas EM, Ozbicer A, et al. Platelet-to-lymphocyte ratio better predicts inflammation than neutrophil-to-lymphocyte ratio in end-stage renal disease patients. Hemodial Int. 2013;17(3):391–6.
97. Munkholm K, Jacoby AS, Lenskjold T, Bruunsgaard H, Vinberg M, Kessing LV. Leukocytes in peripheral blood in patients with bipolar disorder - Trait and state alterations and association with levels of cytokines and C-reactive protein. Psychiatry Res. 2018;261:383–90.
98. Melo MCA, Garcia RF, de Araújo CFC, Abreu RLC, de Bruin PFC, de Bruin VMS. Clinical significance of neutrophil-lymphocyte and platelet-lymphocyte ratios in bipolar patients: An 18-month prospective study. Psychiatry Res. 2019;271:8–14.
99. Bolmont Bt, Gangloff P, Vouriot A, Perrin PP. Mood states and anxiety influence abilities to maintain balance control in healthy human subjects. Neurosci Letters. 2002;329(1):96–100.
100. Jacobs E, Rolnick N, Wezenbeek E, Stroobant L, Capelleman R, Arnout N, et al. Investigating the autoregulation of applied blood flow restriction training pressures in healthy, physically active adults: an intervention study evaluating acute training responses and safety. Br J Sports Med. 2023;57(14):914–20.
101. Moreira JBN, Wohlwend M, Wisløff U. Exercise and cardiac health: physiological and molecular insights. Nat Metab. 2020;2(9):829–39.
102. Ma S, Xu Y, Xu S, Guo Z. The effect of physical fitness on psychological health: evidence from Chinese university students. BMC Public Health. 2024;24(1):1365.
103. Zilberman ML, Tavares H, Blume SB, el-Guebaly N. Substance use disorders: sex differences and psychiatric comorbidities. Can J Psychiatry. 2003;48(1):5–13.

Publisher's Note