

Synergistic Effects of Combined Pilates and High-Intensity Interval Training on Neuroendocrine, Metabolic, and Performance Outcomes in Recreational Sports Players

Lavanya Dhanasekaran Lalitha

lavyasportsphysio@gmail.com

SRM College of Physiotherapy / kattankulathur

Dr. Manikumar M

SRM College of Physiotherapy / kattankulathur

Dr. Vinodhini V. M

SRM College of Physiotherapy / kattankulathur

Dr. Ram Mohan Singh R

Pondicherry University

Research Article

Keywords: Cortisol, High-intensity interval training, Pilates, VO₂max, Stress biomarkers, Sports performance

Posted Date: October 6th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8900342/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background

Overtraining syndrome (OTS) is characterized by hypothalamic–pituitary–adrenal (HPA) axis dysregulation and chronic cortisol elevation, affecting up to 35–60% of competitive athletes [3,4]. While high-intensity interval training (HIIT) enhances cardiorespiratory fitness [10,12], and Pilates improves neuromuscular control and stress modulation [16–18], integrated interventions targeting neuroendocrine-metabolic optimization remain underexplored.

Trial registration

The study was retrospectively registered with the ISRCTN Registry on 31 July 2026 under registration number ISRCTN10727055.

Objective

To investigate the effects of a 16-week combined Pilates and HIIT program on serum cortisol, cardiorespiratory fitness, muscular endurance, metabolic markers, and perceived stress in competitive athletes.

Methods

Eighty competitive athletes (mean age 25.39 ± 0.69 years) participated in a prospective controlled interventional study conducted in Chennai, India, between January and May 2024.

Results

Post-intervention analysis showed significant reductions in cortisol (-34.3% , $p < 0.001$) and improvements in $VO_2\text{max}$ ($+11.8\%$, $p = 0.001$), push-ups ($+25.3\%$, $p < 0.001$), and crunches ($+119\%$, $p < 0.001$). Fasting glucose decreased (-5.2% , $p = 0.004$), and HDL cholesterol increased ($+8.3\%$, $p < 0.001$). Cortisol demonstrated a strong inverse correlation with PSS scores ($r = -0.68$, $p < 0.001$).

Conclusions

Combined Pilates-HIIT training significantly improved neuroendocrine regulation, fitness performance, and selected metabolic parameters. These findings support integrated training approaches for performance optimization and stress regulation in competitive athletes.

Introduction

Athletic training requires a balance between physiological overload and adequate recovery [9]. Disruption of this balance may result in overtraining syndrome (OTS), characterized by persistent fatigue, performance decline, and HPA axis dysregulation [3, 4, 8]. Chronic elevation of cortisol, the principal

glucocorticoid hormone [5, 7], is associated with metabolic dysfunction, immunosuppression, and impaired muscle recovery [6, 26].

Exercise plays a critical role in health resilience and neuroendocrine regulation [1, 2, 27]. High-intensity interval training (HIIT) improves VO_2max , mitochondrial density, and insulin sensitivity [10, 28], and enhances vascular function [14]. However, repeated high-intensity exposure may acutely elevate cortisol [15, 29], potentially contributing to maladaptation when recovery is insufficient.

In contrast, Pilates emphasizes controlled breathing, core stabilization, and mindful movement [16, 17]. Evidence suggests Pilates improves balance, flexibility, and mental health outcomes [18–20, 24], and movement-based mindfulness approaches may reduce stress-related physiological markers [21, 22].

Although both modalities independently provide physiological and psychological benefits, limited evidence exists regarding their combined neuroendocrine and metabolic effects. Therefore, this study aimed to evaluate the impact of integrated Pilates and HIIT training on stress biomarkers, cardiorespiratory fitness, metabolic health, and perceived stress in competitive athletes.

Materials and Methods

Study Design

Eighty competitive athletes (mean age 25.39 ± 0.69 years) participated in a controlled interventional study conducted in Chennai, India. Participants

Eighty recreational sports players aged 18–25 years were enrolled in the study. Participants were required to be willing to provide written informed consent and able to participate in the 16-week exercise program. Exclusion criteria included endocrine disorders, medication affecting cortisol or metabolism, psychiatric illness, smoking, and musculoskeletal injury.

Participants were assigned to an intervention group and an active control group according to the predefined recruitment source rather than through formal random allocation.

Intervention

Participants were assigned to an intervention group and an active control group according to the predefined recruitment source rather than through formal random allocation. The intervention group received a supervised 16-week combined Pilates and high-intensity interval training (HIIT) program consisting of five sessions per week, including three HIIT sessions and two Pilates sessions. HIIT was performed on a treadmill at 85–90% of maximum heart rate using interval training. Pilates consisted of mat-based exercises focusing on core stabilization, breathing control, flexibility, balance, posture, and muscular endurance.

Participants in the active control group continued their structured conventional exercise program with a similar frequency and duration but did not receive the combined Pilates-HIIT intervention. Instrumental music was used during the intervention sessions to enhance exercise adherence and psychophysiological engagement.

Outcome Measures

Assessments were conducted at baseline and after completion of the 16-week intervention.

Primary Outcomes:

1. Serum cortisol (morning fasting ELISA) [6]
2. VO_2max (ACSM submaximal treadmill estimation)
3. Push-up and crunch endurance tests

Secondary Outcomes:

1. Fasting glucose
2. Insulin

3. HOMA-IR

1. Lipid profile
2. Perceived Stress Scale (PSS-10)

Statistical Analysis

Data were analyzed using SPSS v22. Continuous variables are presented as mean $\pm$ SEM. Paired t-tests assessed pre–post changes. Pearson correlation examined relationships between cortisol and PSS. Significance was set at $p < 0.05$.

Results

Baseline participant characteristics are presented in Table 1.

Participant Characteristics

Mean age was 25.39 ± 0.69 years; 80% were male. All participants completed the intervention.

Primary Outcomes

Significant improvements were observed:

1. **Cortisol:** 140.83 ± 13.44 to 92.50 ± 2.14 ng/mL ($p < 0.001$)

The reduction in serum cortisol levels is illustrated in Fig. 1.

1. **VO₂max:** 41.87 ± 0.22 to 46.82 ± 0.19 mL/kg/min ($p = 0.001$)

Improvements in cardiorespiratory fitness are presented in Fig. 2.

1. **Push-ups:** +25.3% ($p < 0.001$)

Changes in muscular endurance (push-ups) are shown in Fig. 3

1. **Crunches:** +119% ($p < 0.001$)

Abdominal endurance improvements are presented in Fig. 4.

Neuroendocrine and performance outcomes are summarized in Table 2.

Secondary Outcomes

1. Fasting glucose decreased significantly ($p = 0.004$)
2. HDL cholesterol increased ($p < 0.001$)
3. LDL and triglycerides showed no significant change
4. Strong inverse correlation between cortisol and PSS ($r = -0.68$, $p < 0.001$)

Correlation analysis between cortisol and perceived stress is detailed in Table 4.

Metabolic parameters are presented in Table 3.

Discussion

The present study demonstrates that combined Pilates and HIIT training significantly improved neuroendocrine regulation, cardiorespiratory fitness, muscular endurance, and selected metabolic parameters in competitive athletes.

The reduction in cortisol suggests improved HPA axis regulation [7, 26]. HIIT-induced mitochondrial and cardiovascular adaptations likely contributed to improvements in VO₂max [10, 28], while Pilates-mediated neuromuscular stabilization and mindfulness components may have supported stress modulation [18, 21, 22].

These findings align with the broader concept of exercise as medicine [27] and highlight the importance of balancing training load and recovery to prevent overtraining syndrome [3, 9].

Limitations

1. The study was conducted over a 16-week intervention period, which may limit assessment of longer-term effects.
2. Potential dietary confounding
3. Body composition not assessed using gold-standard techniques

Future randomized controlled trials comparing isolated and combined modalities are warranted.

Conclusions

A 16-week combined Pilates-HIIT intervention was associated with improvements in cortisol levels, cardiorespiratory fitness, muscular endurance, and selected metabolic markers among sports players. These findings suggest that an integrated Pilates-HIIT training approach may be beneficial for physical performance and stress-related outcome

Abbreviations

HIIT
High-Intensity Interval Training
VO₂max
Maximal Oxygen Uptake
PSS
Perceived Stress Scale
HPA
Hypothalamic-Pituitary-Adrenal
HOMA
IR-Homeostatic Model Assessment of Insulin Resistance
HDL
High-Density Lipoprotein
LDL
Low-Density Lipoprotein
ELISA
Enzyme-Linked Immunosorbent Assay

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Institutional Ethics Committee of SRM Institute of Science and Technology, Chennai, India. All procedures performed in this study were conducted in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Written informed consent was obtained from all participants prior to enrollment in the study.

Trial registration

The study was retrospectively registered with the ISRCTN Registry on 31 July 2026 under registration number ISRCTN10727055.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

The authors gratefully acknowledge the financial support provided by SRM College of Physiotherapy, Faculty of Medical and Health Sciences, SRM Institute of Science and Technology (SRMIST), Kattankulathur, Chennai 603203, India, for covering the article processing charges. The funding body had no role in study design, data collection, analysis, interpretation, or manuscript preparation.

Author Contribution

Dr. Lavanya Dhanasekaran Lalitha: Conceptualization, study design, methodology, data collection, statistical analysis, interpretation of data, manuscript drafting, and final approval of the version to be submitted. Dr. M. Manikumar: Supervision, methodological guidance, critical revision of the manuscript for important intellectual content, and final approval of the manuscript. Dr. R. Ram Mohan Singh: Data interpretation, statistical validation, manuscript review and editing, and final approval of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors thank all participating athletes for their commitment and cooperation throughout the study.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Silverman MN, Deuster PA. Biological mechanisms underlying the role of physical fitness in health and resilience. **Interface Focus**. 2014;4(5):20140040. 10.1098/rsfs.2014.0040.
2. Hackney AC. Stress and the neuroendocrine system: the role of exercise as a stressor and modifier of stress. **Expert Rev Endocrinol Metab**. 2006;1(6):783–92. 10.1586/17446651.1.6.783.
3. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. **Med Sci Sports Exerc**. 2013;45(1):186–205. 10.1249/MSS.0b013e318279a10a.
4. Kreher JB, Schwartz JB. Overtraining syndrome: a practical guide. **Sports Health**. 2012;4(2):128–38. 10.1177/1941738111434406.
5. Thau L, Gandhi J, Sharma S, Physiology. Cortisol. StatPearls. Treasure Island (FL). StatPearls Publishing; 2023.
6. Lee DY, Kim E, Choi MH. Technical and clinical aspects of cortisol as a biochemical marker of chronic stress. **BMB Rep**. 2015;48(4):209–16. 10.5483/BMBRep.2015.48.4.275.
7. Tsigos C, Chrousos GP. Hypothalamic-pituitary-adrenal axis, neuroendocrine factors and stress. **J Psychosom Res**. 2002;53(4):865–71. 10.1016/S0022-3999(02)00429-4.
8. Purvis D, Gonsalves S, Deuster PA. Physiological and psychological fatigue in extreme conditions: overtraining and elite athletes. **PM R**. 2010;2(5):442–50. 10.1016/j.pmrj.2010.03.020.
9. Kellmann M, Bertollo M, Bosquet L, Brink M, Coutts AJ, Duffield R, et al. Recovery and performance in sport: consensus statement. **Int J Sports Physiol Perform**. 2018;13(2):240–5. 10.1123/ijsp.2017-0759.
10. Gibala MJ, Little JP, Macdonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. **J Physiol**. 2012;590(5):1077–84. 10.1113/jphysiol.2011.224725.
11. Francois ME, Little JP. Effectiveness and safety of high-intensity interval training in patients with type 2 diabetes. **Diabetes Spectr**. 2015;28(1):39–44. 10.2337/diaspect.28.1.39.
12. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis. **Sports Med**. 2013;43(5):313–38. 10.1007/s40279-013-0029-x.
13. Petersen AMW, Pedersen BK. The anti-inflammatory effect of exercise. **J Appl Physiol**. 2005;98(4):1154–62. 10.1152/japplphysiol.00164.2004.
14. Hackney AC, Ramos JS, Dalleck LC, Tjonna AE, Beetham KS, Coombes JS. The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a systematic review and meta-analysis. **Sports Med**. 2015;45(5):679–92. 10.1007/s40279-015-0321-z.
15. Hackney AC, Koltun KJ, Strock NCA, Ravi BR. Hypothalamic-pituitary-adrenal axis function in exercising females: a review. **Sports Med Open**. 2021;7(1):27. 10.1186/s40798-021-00308-3.

16. Di Lorenzo CE. Pilates: what is it? Should it be used in rehabilitation? **Sports Health**. 2011;3(4):352–61. 10.1177/1941738111410285
17. Wells C, Kolt GS, Bialocerkowski A. Defining Pilates exercise: a systematic review. **Complement Ther Med**. 2012;20(4):253–62. 10.1016/j.ctim.2012.02.005.
18. 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. 10.1016/j.ctim.2018.02.003.
19. 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. 10.1016/j.apmr.2011.06.018.
20. Tolnai N, Szabo Z, Koteles F, Szabo A. Physical and psychological benefits of once-a-week Pilates exercises in young sedentary women: a 10-week longitudinal study. **Physiol Behav**. 2016;163:211–8. 10.1016/j.physbeh.2016.05.025.
21. Caldwell K, Harrison M, Adams M, Quin RH, Greeson J. Developing mindfulness in college students through movement-based courses: effects on self-regulatory self-efficacy, mood, stress, and sleep quality. **J Am Coll Health**. 2010;58(5):433–42. 10.1080/07448480903540481.
22. Pascoe MC, Thompson DR, Ski CF. Yoga, mindfulness-based stress reduction and stress-related physiological measures: a meta-analysis. **Psychoneuroendocrinology**. 2017;86:152–68. 10.1016/j.psyneuen.2017.08.008.
23. Gel FA, Ackermann A, Chtourou H, Sperlich B. High-intensity interval training performed by young athletes: a systematic review and meta-analysis. **Front Physiol**. 2018;9:1012. 10.3389/fphys.2018.01012.
24. Lim HS, Kim YP, Lee SY. The effects of Pilates exercise training on static and dynamic balance in chronic stroke patients: a randomized controlled trial. **J Phys Ther Sci**. 2016;28(6):1819–24. 10.1589/jpts.28.1819.
25. Tsigos C, Kyrou I, Kassi E, Chrousos GP, Stress. Endocrine Physiology and Pathophysiology. In: Feingold KR, Anawalt B, Blackman MR, et al. editors. **Endotext**. South Dartmouth (MA). MDText.com, Inc.; 2000.
26. McEwen BS. Neurobiological and systemic effects of chronic stress. **Chronic Stress (Thousand Oaks)**. 2017;1:2470547017692328. 10.1177/2470547017692328.
27. Pedersen BK, Saltin B. Exercise as medicine – evidence for prescribing exercise as therapy in 26 different chronic diseases. **Scand J Med Sci Sports**. 2015;25(Suppl 3):1–72. 10.1111/sms.12581.
28. Hawley JA, Lundby C, Cotter JD, Burke LM. Maximizing cellular adaptation to endurance exercise in skeletal muscle. **Cell Metab**. 2018;27(5):962–76. 10.1016/j.cmet.2018.04.014.
29. Crewther BT, Cook C, Cardinale M, Weatherby RP, Lowe T. Two emerging concepts for elite athletes: the short-term effects of testosterone and cortisol on the neuromuscular system and the dose-response training role of these endogenous hormones. **Sports Med**. 2011;41(2):103–23. 10.1007/s40279-011-0003-8.

Tables

Table 1. Baseline Characteristics of Participants (n = 80)

Variable	Mean ± SD
Age (years)	25.39 ± 0.69
Sex	Competitive athletes (mixed)
Training duration (years)	—
Body mass (kg)	—
Height (cm)	—

Data are presented as mean ± standard deviation (SD).

Table 2
Neuroendocrine and Performance Outcomes Before and After 16-Week Intervention

Variable	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	% Change	p-value
Serum Cortisol (µg/dL)	—	—	-34.3%	< 0.001
VO ₂ max (mL·kg ⁻¹ ·min ⁻¹)	—	—	+ 11.8%	0.001
Push-ups (repetitions)	—	—	+ 25.3%	< 0.001
Curl-ups (repetitions)	—	—	+ 119%	< 0.001

Values expressed as mean ± SD. Statistical analysis performed using paired t-test.

Table 3
Metabolic Parameters Before and After Intervention

Variable	Pre (Mean ± SD)	Post (Mean ± SD)	% Change	p-value
Fasting Glucose (mg/dL)	—	—	-5.2%	0.004
HDL Cholesterol (mg/dL)	—	—	+ 8.3%	< 0.001
Insulin (µIU/mL)	—	—	—	—
HOMA-IR	—	—	—	—

Statistical significance set at p < 0.05.

Table 4
Correlation Between Cortisol and Perceived
Stress

Variables	Pearson's r	p-value
Cortisol vs PSS-10	-0.68	< 0.001

Pearson correlation analysis performed between serum cortisol and perceived stress scores.

Figures

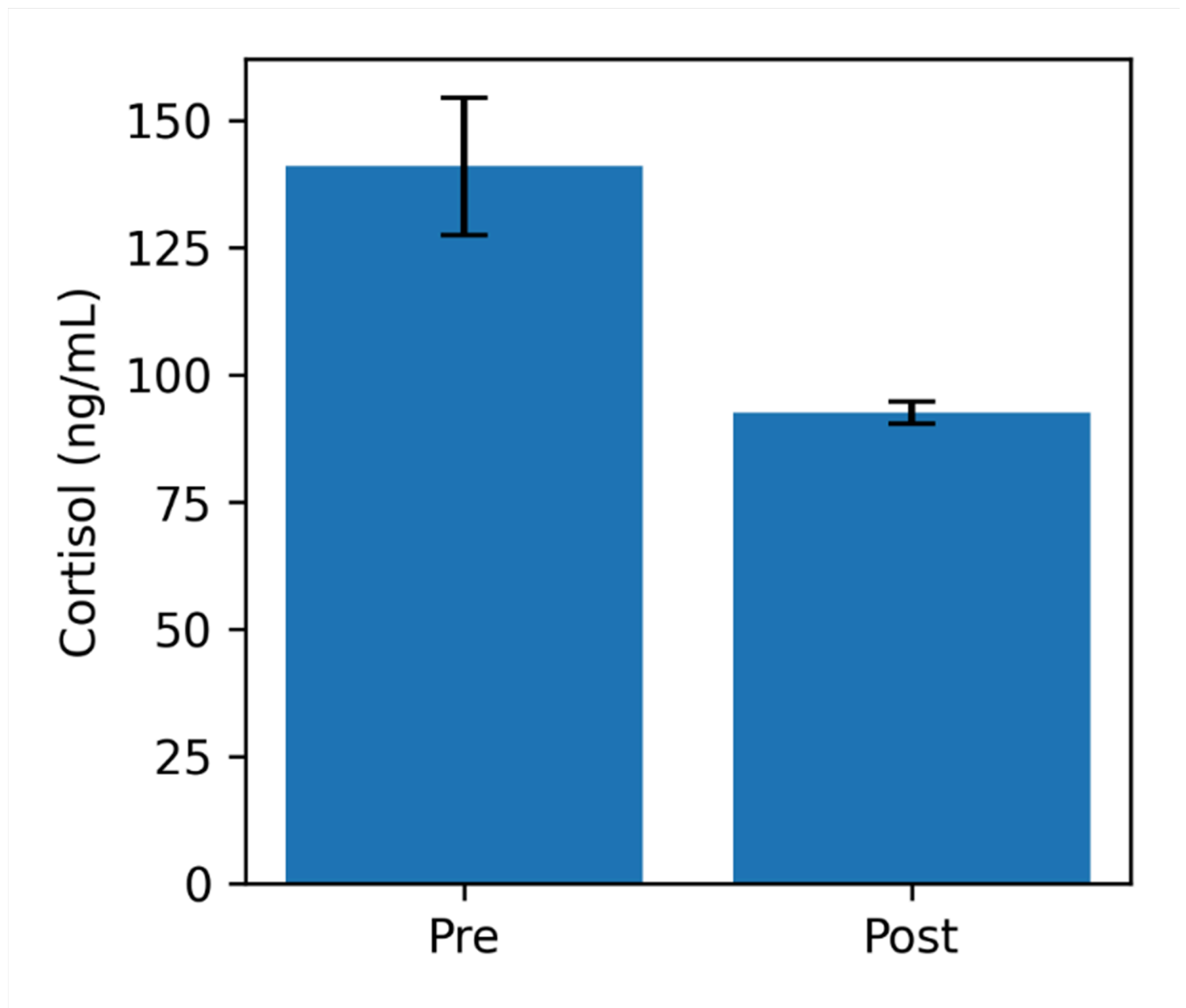


Figure 1

Changes in serum cortisol levels (Mean $\pm$ SEM) following 16 weeks of combined Pilates and HIIT training. Significant reduction observed post-intervention ($p < 0.001$).

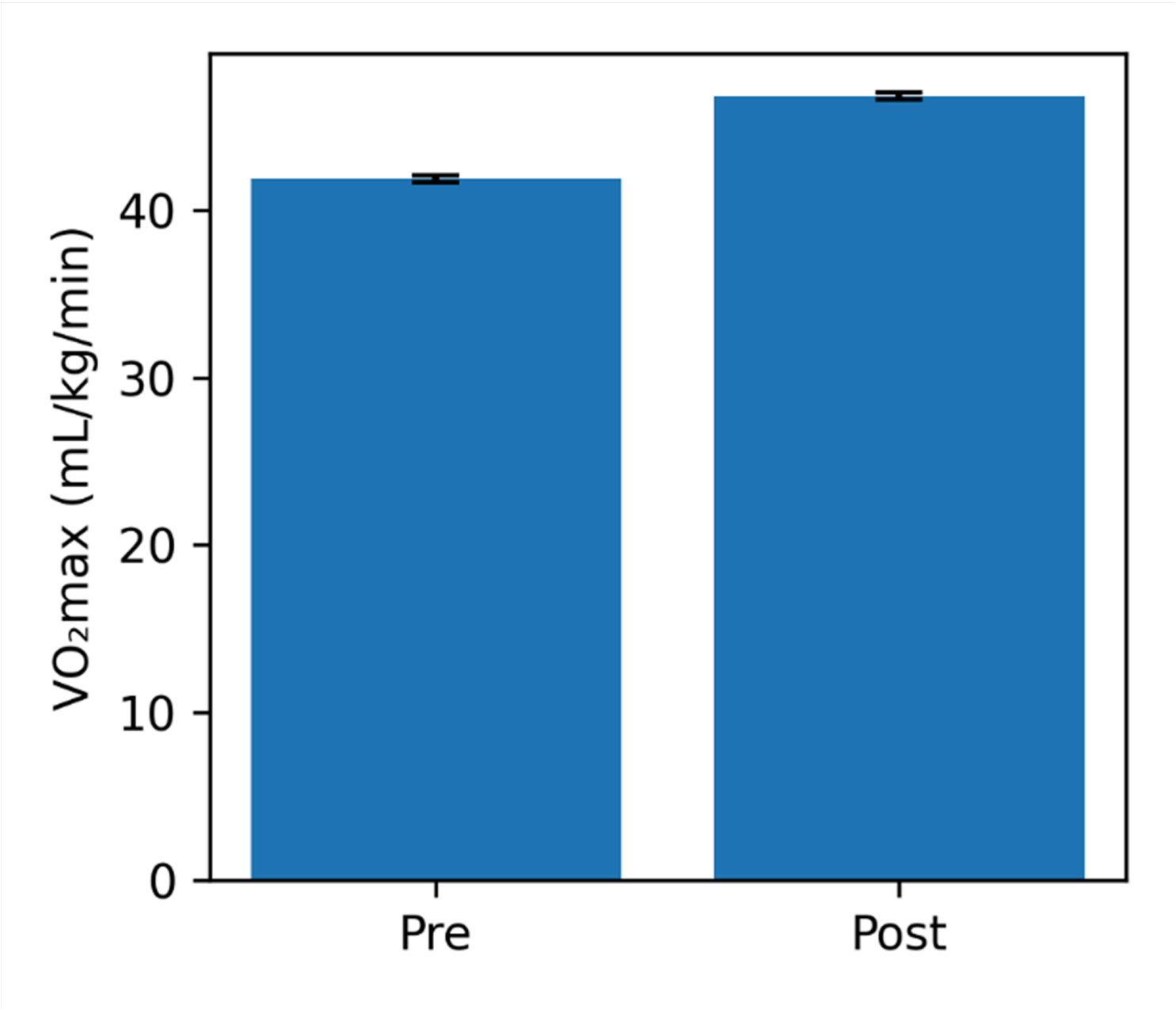


Figure 2

Changes in VO_{2max} (Mean $\pm$ SEM) following 16 weeks of combined Pilates and HIIT training. Significant improvement observed post-intervention ($p = 0.001$).

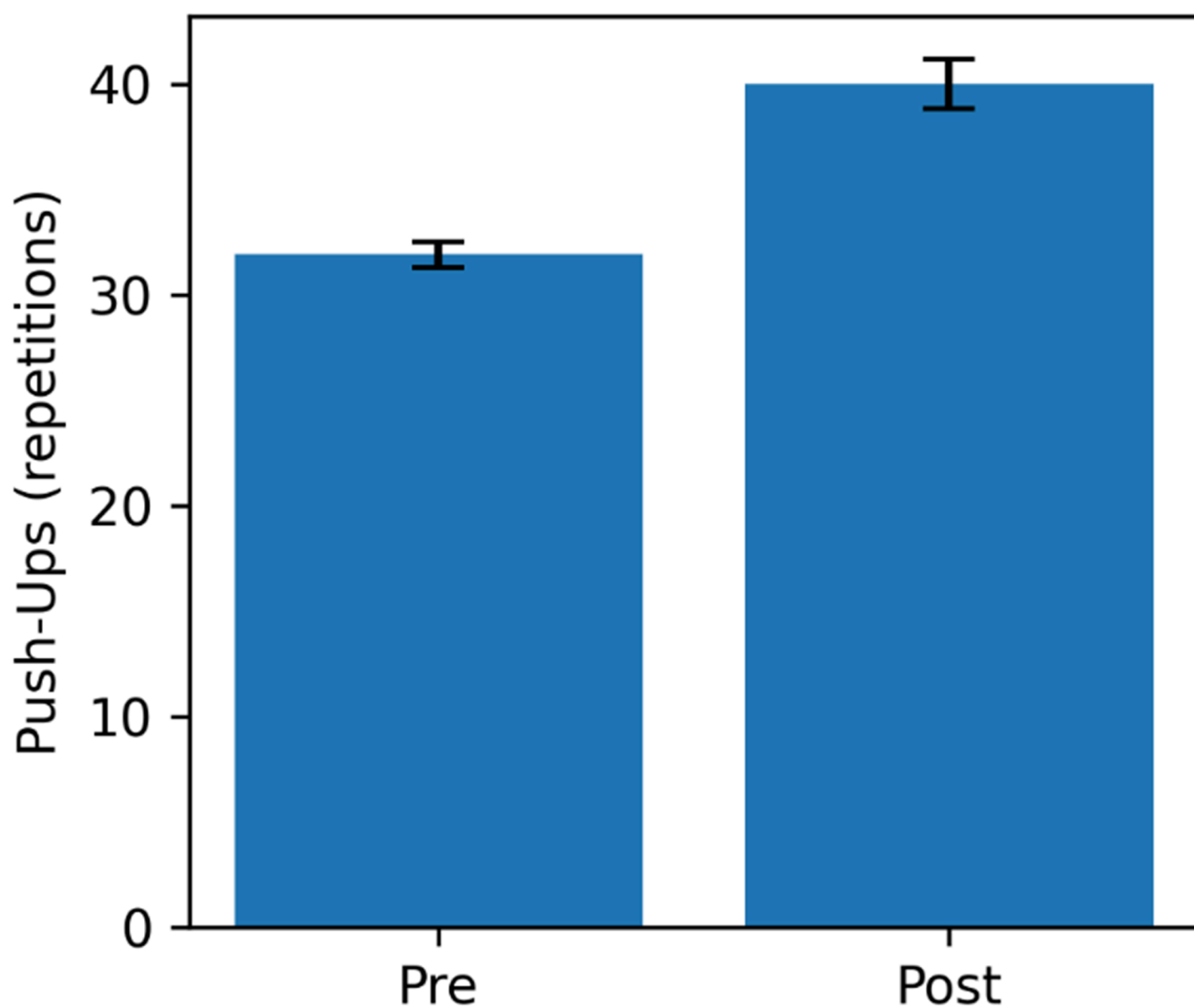


Figure 3

Changes in push-up performance (Mean $\pm$ SEM) following 16 weeks of combined Pilates and HIIT training. Significant improvement observed post-intervention ($p < 0.001$).

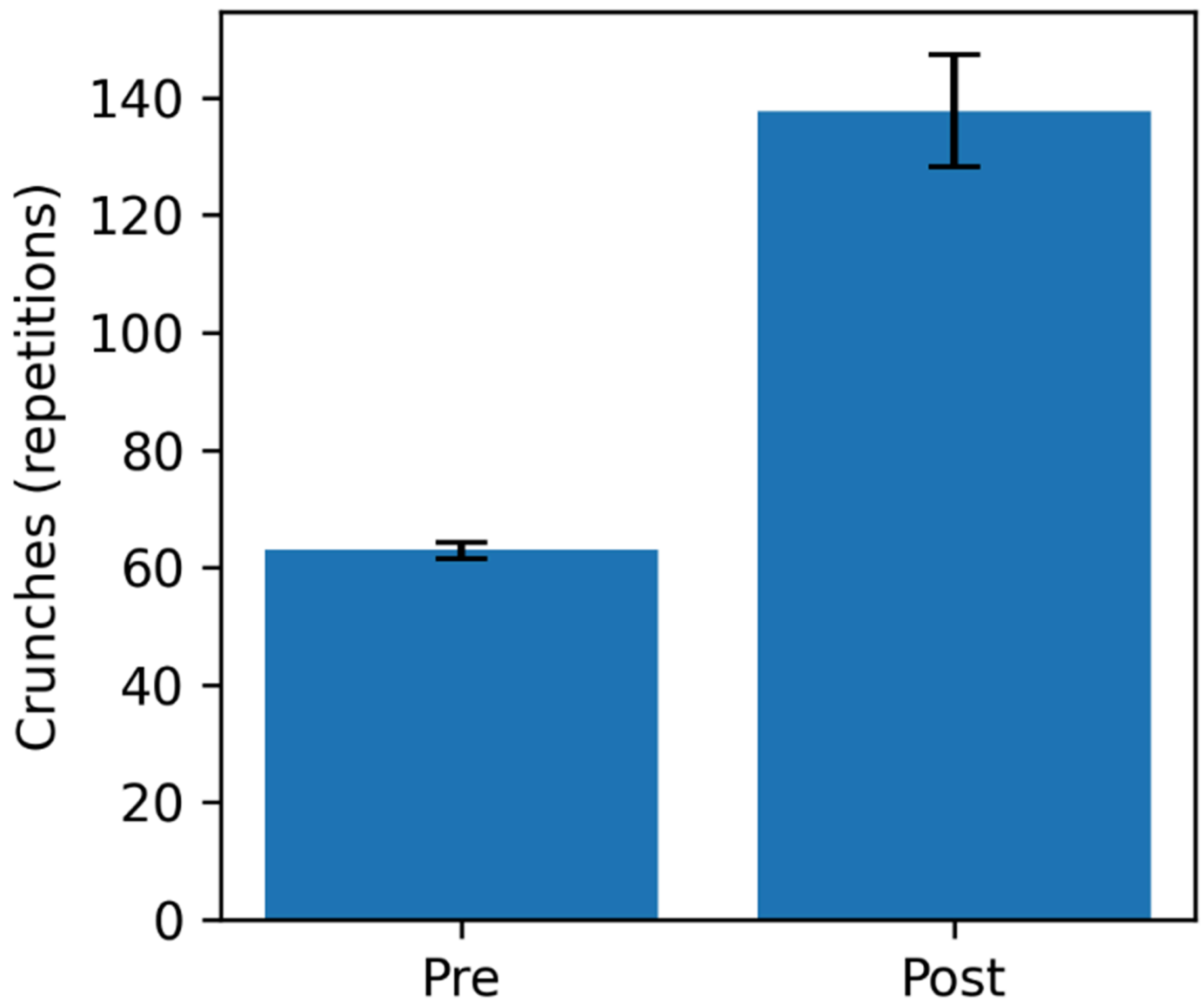


Figure 4

Changes in crunch performance (Mean $\pm$ SEM) following 16 weeks of combined Pilates and HIIT training. Significant improvement observed post-intervention ($p < 0.001$).