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The Impact of Sport on Mental Health: Psychological, Neuroendocrine, and Immune Outcomes

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Abstract

Background. Mental health disorders, notably depression and anxiety, contribute to a rising global burden of disability, further exacerbated by the COVID-19 pandemic and sedentary lifestyles. Physical inactivity is linked to 9% of premature deaths, highlighting the urgency for non-pharmacological interventions.

Aim. This study synthesizes evidence from 26 research datasets to evaluate the impact of varied sports interventions—running, Pilates, aquatic exercise, and team sports—on physiological markers (cortisol, BDNF, immune cells) and psychological well-being across the lifespan.

Materials and methods. A synthesis of primary cohorts was analyzed: 2022 drug-dependent individuals, 23,589 pregnant persons, 1,176 healthy older adults, and university/adolescent samples. Interventions ranged from 5-minute daily home exercises to 32-week multicomponent programs. Analytical methods included salivary cortisol assays, blood biochemistry (WBC, NLR, PLR), and validated psychometric scales (SCL-90, RSES, BDI, EPDS).

Results. Sporting participants consistently exhibited lower baseline salivary cortisol ($p < 0.05$). In drug-addicted cohorts, 24-week Pilates significantly improved White Blood Cell counts and reduced depression ($p < 0.01$). For older adults, meta-analyses showed medium effect sizes for physical health (SMD= 0.42) and social interaction (SMD = 0.78). In adolescents, vigorous physical activity reduced depression risk by 94%(RR = 0.06).

Conclusions

Structured sport and physical activity facilitate neuroendocrine stabilization and psychological resilience, serving as a vital therapeutic resource across clinical and general populations.

Keywords: mental health, sports intervention, neuroplasticity, cortisol, immune recovery

1. Introduction

The connection between physical exertion and psychological stability is encapsulated in the concept of "exercise as medicine". Physical activity (PA) is a fundamental determinant of health, yet sedentary behavior remains a global epidemic. A multisystem response mediates the physiological benefits of exercise. Specifically, aerobic and resistance training increase the expression of Brain-Derived Neurotrophic Factor (BDNF), a neurotrophin critical for neuronal survival, differentiation, and synaptic plasticity. BDNF upregulation promotes neurogenesis in the dentate gyrus of the hippocampus, a region vital for memory and emotional regulation. Furthermore, exercise modulates the availability of neurotransmitters including serotonin, dopamine, and norepinephrine, which underpin mood regulation and the brain's reward system. This "neuroplasticity facilitation" helps offset the 1%- 2% annual hippocampal volume loss observed in normal aging and is severely impaired in depressive disorders.

Psychological theories emphasize the role of sport in developing self-esteem and self-regulatory skills. Rosenberg's Self-Esteem Scale (RSES) is frequently used to assess self-worth in recreational athletes. Regular participation creates a "virtuous circle" in which biological improvements in physical fitness (e.g., increased muscle mass, reduced body fat percentage) enhance physical self-perception, which directly correlates with global self-esteem. Moreover, the organizational structure of team sports offers unique psychosocial benefits compared to individual activities. Team-based interventions foster a sense of belonging and social connectedness, mitigating feelings of loneliness and helplessness. These social outcomes often exceed those achieved through other leisure activities, providing a buffer against the negative psychological impacts of public health emergencies.

Research Objective: Synthesize evidence from 26 specialized sources to assess the multidimensional impact of structured sport on psychological distress, neuroendocrine markers, and functional autonomy.

Research Problems

How do different exercise modalities (aerobic, resistance, mind-body) affect stress biomarkers such as cortisol (COR) and alpha-amylase (α-AMY)?

To what extent does sports participation mediate global self-esteem (RSES) and symptoms of psychiatric distress (SCL-90)?

What role does exercise intensity play in mitigating the long-term risk of depressive and anxiety disorders?

Research Hypotheses

Regular participation in sports significantly reduces clinical symptoms of depression and anxiety across all age groups compared to sedentary behavior.

Mind-body exercises (Pilates, Tai Chi) are highly effective at regulating the HPA axis and immune profiles in clinical populations.

High-intensity vigorous physical activity (VPA) correlates with the greatest reduction in psychological ill-being among adolescents and young adults.

2. Research materials and methods

2.1. Categories of Included Studies

The source database comprising the 26 investigated documents was structured into four analytical sub-categories based on clinical status, baseline age, and functional vulnerability.

Cohort Category	Target Population Characteristics	Sample Size (N)	Primary Authors / Dataset Sources
Clinical / Rehabilitation	Drug-dependent individuals, substance addiction recovery, inpatient psychiatric adolescent care units.	n ≈2082	Ye & Liu; Ji et al.; Bretler Zager et al.
Age-Specific Cohorts	Pregnant and postpartum persons, healthy community-dwelling older adults, rural school students.	n≈ 26205	Hicks et al.; Tao et al.; Yang et al.
General Student & Adult	University students under academic stress, recreational	n≈304	Szmodis et al.; Markotić et al.; von Haaren et al.

	marathon runners, sedentary healthy controls.		
Frail / Institutionalized	Institutionalized pre-frail older women with advanced functional limitations.	n = 84	Furtado et al.

2.2. Intervention Protocols

The analyzed 26 datasets utilized a broad range of protocols:

- Long-Term Multicomponent/Strength Training: Furtado et al. implemented a 28-week program for frail women (2 sessions/week), including multicomponent chair-based exercise (MCE: aerobic + strength) and elastic band resistance exercise (ESE) executed at 12–15 repetitions.
- Mind-Body Interventions: Ji et al. used a 24-week Pilates program (2 sessions/week, 60 min per session). Other synthesized studies employed 12-week aquatic aerobic training or 12-week Tai Chi regimens.
- Aerobic and Running: Protocols ranged from 20-week aerobic training during exam periods to 9-week group-based running in psychiatric care.
- Minimal Dose Protocols: Kirk et al. evaluated a daily, home-based 5-minute eccentric exercise program (10 repetitions/day) for 2 weeks.

2.3. Measurement Tools and Selection Rationale

Tools were selected based on high psychometric validity for their respective domains:

- Psychological Distress (SCL-90 / SCL-90-R): Selected for its comprehensive evaluation of nine categories (somatization, depression, anxiety, etc.) in psychiatric and general populations.
- Self-Esteem (RSES): The 10-item Rosenberg scale is the gold standard for measuring global self-worth and self-acceptance.
- Biological Stress (COR / α-AMY): Salivary cortisol was chosen to track HPA axis activation, while α-AMY served as a biomarker for autonomic nervous system (ANS) activity.

- Immune/Oxidative Markers: Selected to track systemic recovery, including White Blood Cell counts, Neutrophils, and oxidative markers like Glutathione (GSH) and Nitric Oxide (NO).

2.4. Data Collection and Statistical Analysis

2.4.1. Statistical Software

Statistical processing across the 26 datasets utilized IBM SPSS (versions 24.0–29.0), Statistica 12, Stata (16.0, 18.0), Jamovi (2.3.21), and Review Manager 5.4.

2.4.2. AI Declarations

Claude 3.7 Sonnet/NotebookLM assisted in refining the manuscript's academic English under strict human supervision. The final interpretation of results, error checking, and text verification were performed entirely by human experts.

2.4.3. Statistical Methods

Analyses included repeated measures ANOVA for group $\times$ time interactions, independent-samples t-tests, and random-effects meta-analyses using Weighted Mean Differences (WMDs) and Standardized Mean Differences (SMDs).

3. Research results

3.1. Clinical Rehabilitation and Immune Recovery

In the 24-week Pilates intervention by Ji et al. (2025) involving male drug addicts, significant group × time interactions were found for immune biomarkers. White Blood Cell (WBC) count increased significantly [$F(2,40) = 29.79$, $p < 0.01$,
$\eta 2 = 0.598$] and Neutrophil count rose from weeks 0 to 12 [$F(2,40) = 10.12$, $p < 0.01$, $\eta 2 = 0.336$]. These physiological gains were accompanied by a marked decline in Self-Rating Depression Scale (SDS) scores [$F(2,40) = 283.1$, $p < 0.01$, $\eta 2 = 0.934$] and SAS anxiety scores [$F(2,40) = 111.9$, $p < 0.01$, $\eta 2 = 0.848$].

Meta-analytical data by Ye & Liu (2023) for 2022 drug addicts confirmed aerobic exercise reduced SCL-90 scores for anxiety [MD = -0.22, $p < 0.0001$] and depression [MD = -0.21, $p < 0.00001$]. Furthermore, da Silva et al. (2019) reported that 12 weeks of aquatic exercise in elderly individuals with depression reduced protein carbonylation by 46% and nitric oxide by 60% ($p < 0.001$), while Glutathione (GSH) increased by 170%.

3.2. Older Adults, Frailty, and Social Interaction

Tao et al. (2025) conducted a meta-analysis of 1,176 healthy older adults, finding that physical exercise significantly improved social interaction with a large effect size [SMD = 0.78, 95% CI (0.37, 1.19), $p = 0.0002$]. Mental health improvements were significant but smaller (SMD = 0.34, $p < 0.001$).

Furtado et al. (2025) investigated pre-frail women and reported a significant time × group interaction for the α-AMY/COR ratio. While the sedentary control group showed a substantial increase in baseline cortisol (ES = 1.13, $p < 0.05$), the exercise groups maintained neuroendocrine stability. Multicomponent exercise (MCE) induced large improvements in the Physical Frailty (PF) compound score (ES= 1.65, $p < 0.001$) and General Self-Efficacy (ES = 0.86, $p < 0.001$).

3.3. Students, Adolescents, and Academic Stress

In the university cohort studied by Szmodis et al. (2022), sports 0.254 ± students (> 7 h/week) had significantly lower baseline salivary cortisol than sedentary peers (0.212 ± 0.188 vs. 0.254± 0.203 mg/dL, $p < 0.05$). Perceived stress scores were also lower in the sporting group (21.0 ± 5.7 vs. 23.3± 7.2). von Haaren et al. (2015) demonstrated that a 20-week training program reduced emotional stress reactivity during exams, with perceived stress remaining stable (2.27 to 2.24) while increasing in the control group (2.43 to 2.51).

For adolescents, Hrafnkelsdottir et al. (2018) found that the group with less screen time and more vigorous PA had a significantly lower risk of depressive symptoms [Relative Risk RR = 0.06, 95% CI (0.01 - 0.41)]. In psychiatric care, Bretler Zager et al. (2026) confirmed that 9 weeks of group running improved emotional regulation and heart rate recovery compared to controls.

3.4. Statistical Hypothesis Testing (Specialized Immune Recovery)

Based on integrated neuro-immune data derived from the baseline verification protocols [Popovych et al.; Zukow et al.]:

- Hypothesis 1 (NK Cells):H1 (intervention significantly increases NK cell levels) was accepted ($t=4.60$,$p<0.001$)
- Hypothesis 2 (T-killers):H1 (intervention increases T-killer levels) was accepted ($t=2.57$, $p=0.013$).
- Hypothesis 3 (IgM): H1 (intervention decreases pathologically elevated IgM) was accepted ($t=3.11$, $p=0.003$).

- Discriminant Analysis**:** Highly significant model (Wilks' $\Lambda=0.547$; $\chi2=60$; $p<10-6$), identifying NK cells and T-killers as the primary recovery predictors.

4. Discussion

The synthesis of 26 sources establishes a robust argument linking mechanical physical fitness and psychological homeostasis. A primary debate emerges regarding the intensity-dose response. While Hrafnkelsdottir (2018) suggests high-intensity VPA is most protective for adolescents (RR = 0.06), family-based models [Yang et al., 2025] indicate that for younger and older populations alike, moderate-intensity group exercises provide superior compliance by meeting social needs and avoiding excessive physiological fatigue [Zukow & Qin, 2025].

The neuroendocrine pathway serves as a highly consistent explanatory theme across the entire lifespan. The stabilization of the HPA axis—reflected directly in the maintenance of lower baseline salivary COR—in sporting students [Szmodis, 2022] and institutionalized frail women [Furtado, 2025] provides a clear biological substrate for the classic "stress-buffering" hypothesis. This is complemented by the direct immune system activation observed by Ji et al. (2025), in which improvements in WBC and neutrophil counts were uniquely linked to the systematic, controlled movements of mind-body interventions.

Furthermore, a critical connection exists between mechanical fitness markers and perceived self-efficacy. In the frail cohort, structural reductions in physical frailty compound scores were significantly correlated with objective handgrip strength and general self-efficacy scales. Similarly, Ji et al. (2025) found that gains in vital capacity and mechanical flexibility (measured via the sit-and-reach test) were negatively correlated with clinical depression scores ($r = -0.490$ and $r = -0.657$, respectively). This suggests that "feeling fitter"—through tangible improvements in objective somatic markers—is a primary driver of psychological self-worth, supporting the "virtuous circle" framework proposed by Smith & Merwin (2021).

From a mechanistic perspective, the psychological resilience observed across the cohorts can be further explained by the cross-stressor adaptation (CSA) hypothesis. The CSA hypothesis posits that regular exposure to the acute physiological stress of physical exercise—characterized by temporary spikes in heart rate, metabolic demands, and sympathetic nervous system activation—induces structural and functional adaptations that blunt the body's reactivity to psychological stressors. In our synthesis, this is vividly illustrated by the stability of perceived stress during highly vulnerable periods, such as academic examinations [von Haaren et al., 2015] or severe external crises, such as public health lockdowns. When an individual engages in regular structured sporting disciplines, the constant modulation of the autonomic nervous system creates a higher threshold for emotional dysregulation. Consequently, the neurobiological shield provided by up-regulated neurotransmitters and stabilized cortisol levels directly translates into subjective mental fortitude, validating the use of physical training as a core prophylactic intervention against clinical psychological deterioration.

Finally, the social context of participation acts as a critical moderator. Eather et al. (2023) and Yang et al. (2025) highlight that social connectedness and parental co-participation significantly moderate the global mental health benefits of PA, providing systemic psychological protective factors that individual, isolated physical tasks cannot replicate.

4.1. Limitations of the Study and Future Research Directions

While the synthesized findings strongly confirm the therapeutic utility of sports interventions, several programmatic limitations must be addressed. First, the heterogeneous nature of the 26 included datasets—spanning clinical substance-dependence cohorts, frail elderly populations, and healthy university students—poses inherent challenges to universal generalization. The precise "minimum effective dose" of physical exertion remains complex to establish, as individual physical thresholds vary dramatically across demographic strata. Second, the vast majority of the synthesized studies relied on short- to medium-term tracking (ranging from 2 to 32 weeks), leaving the long-term sustainability of neuroendocrine and psychological adaptations relatively unmapped. Future empirical research should prioritize longitudinal randomized controlled trials that utilize standardized digital tracking metrics alongside advanced biomolecular assessments (e.g., direct tracking of epigenetic modifications and long-term BDNF serum expression). Additionally, exploring the precise interactions between group-based sport dynamics and individual mind-body adherence will provide deeper clinical insights into tailored psychiatric prescriptions.

5. Conclusions

1. Regular sport significantly reduces clinical symptoms of depression and anxiety across all populations, with a standardized effect size of SMD = 0.34 in older adults and a 94% risk reduction (RR = 0.06) in highly active adolescents.
2. Neuroendocrine and immune stabilization are verified through the regulation of baseline salivary cortisol and the marked, statistically significant increase in Natural Killer cells, WBC counts, and Neutrophils ($p < 0.01$).

3. Mind-body interventions such as Pilates are highly effective in clinical drug rehabilitation, while group-based aerobic sports maximize social interaction and life satisfaction among older populations.
4. Strong, direct correlations exist between mechanical markers (vital capacity, grip strength) and psychological self-efficacy, confirming that physical gains translate directly to mental resilience.
5. In conclusion, structured sporting programs are a primary, non-pharmacological tool for the prevention and treatment of mental health disorders across the lifespan.

6. Disclosure

Supplementary Materials

Not applicable

Conflicts of Interest

The authors declare that there are no financial or personal relationships with other people or organizations that could inappropriately influence or bias this work.

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