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Effects of a Four-Week Heart Rate Coherence Breathing Program on Exercise Heart Rate, Post-Exercise Cardiac Down-Regulation, and Perceived Fatigue in Amateur Female Handball Players: A Randomized Controlled Study

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Abstract

Background: Heart rate coherence (HRC) breathing is a simple paced-breathing technique intended to support autonomic regulation and recovery.

Objective: To evaluate the effects of a four-week HRC program on (i) heart rate during an ergometer test, (ii) heart rate measured after a standardized 3-minute recovery period (paced breathing in HRC vs quiet sitting in controls), and (iii) perceived tiredness in amateur female handball players.

Methods: Thirty amateur female handball players (22.80 ± 2.75 years) were randomized to an HRC group (n = 15) or a control group (n = 15). Pre- and post-testing included an ergometer test with ECG monitoring and a tiredness rating (Borg scale). Immediately after the test, the HRC group performed 3 minutes of paced breathing (6 breaths/min), whereas the control group sat quietly for the same duration before the post-recovery heart rate measurement.

Results: From pre- to post-test, the HRC group showed substantial reductions in heart rate during the test (161.33 → 136.00 bpm), post-recovery heart rate (72.93 → 50.73 bpm), and perceived tiredness (4.73 → 2.27). The control group showed minimal changes. ANCOVA indicated significant between-group effects for all outcomes ($p < .005$).

Conclusion: A four-week HRC breathing routine added to usual training was associated with lower exercise heart rate, faster post-exercise cardiac down-regulation, and reduced perceived fatigue in amateur female handball players.

Keywords: Heart rate coherence, physical recovery, ergometric test, handball.

1. Introduction

Recovery plays a critical role in athletic performance, especially in sports such as handball where repeated high-intensity efforts are required. While professionals may have strict protocols for recovery, amateur athletes generally have underdeveloped strategies due to limited access to professional therapy and advanced resources. This balance creates a favorable Heart Rate Coherence (HRC), so monitoring training status plays an important role in ensuring recovery by tracking HRC. Handball is a contact sport with accelerations that result in short periods of high intensity effort; however, this places significant metabolic an performance. Recovery techniques tend to focus on active recovery, supplemented by HRC focused exercises. Although the research is mixed, the incorporation of HRC techniques into practice has shown benefits in restoring players' muscle sensation and improving performance.

Vigorous exercise affects motor function through several mechanisms. Research highlights two main scenarios: firstly, local muscle fatigue caused by metabolic processes following strenuous exercise [1]; and secondly, muscle soreness resulting from atypical training involving variations in duration, intensity or movement type, particularly those that emphasize eccentric contractions [2]. Although muscle fatigue and soreness differ in their clinical presentation and cellular mechanisms, recovery methods such as massage, stretching, ultrasound, and active recovery are often applied to both [3]. However, few studies have investigated whether HRC techniques can reduce soreness caused by ergometric exercise [4]. Recently, *Afonso et al* [5] highlighted the need for targeted research to validate the therapeutic efficacy of interventions aimed at reducing post-exercise soreness and improving muscle recovery. The aim of this research was to study the effect of HRC on the physical recovery of amateur handball players, focusing on its effect on metabolic fatigue following intense physical exertion.

In addition, the study investigated the potential benefits of incorporating weekly HRC-focused training over four weeks to optimize recovery and performance. This paper adds to the growing body of evidence supporting HRC as a valuable tool in sports science, particularly for athletes without access to advanced recovery techniques.

Heart coherence involves the regulation of heart rate to achieve a state of coherence between heart rate, breathing and other biological rhythms [6]. This can lead to an increase in heart rate variability, which is often considered an indicator of cardiovascular health [13]. Increased variability is generally associated with an improved ability of the body to adapt to different physiological demands. Therefore, cardiac coherence training may contribute to improved baroreflex function (a feedback mechanism that regulates blood pressure), which could have beneficial effects on blood pressure and cardiovascular regulation [7]. Heart rate variability (HRV) reflects the ability of the heart to adapt to changes in physiological demand. For example, a healthy heart has higher variability, indicating its ability to flexibly adjust its heart rate according to the body's needs.

The autonomic nervous system (ANS), which regulates HRV, is influenced by various factors such as stress, physical activity, posture, breathing and even emotions. The ANS comprises an intricate network that spans different brain regions, such as cortical and limbic areas, which together govern its regulation [8].

Measurement of HRV is used in various fields, including medicine, psychology, and stress research. It can provide valuable insights into heart health, stress levels, post-exercise recovery, and other aspects of autonomic regulation [9].

Psychological research suggests that depression, panic disorder and anxiety may adversely affect autonomic function. Heart rate variability (HRV) is affected by several factors: 1) the daily (circadian) rhythm, which varies heart rate over cycles of 5 hours or more; 2) temperature regulation, with cycles lasting about 25 seconds; 3) cardiac sympathetic (fight-or flight) nerve activity, which fluctuates about every 6 seconds; and 4) synchronization with respiratory rhythm, which changes beat-to-beat intervals with each breath [10]. This natural rhythmic variation, influenced by the interplay of sympathetic and vagal nerve impulses at the sinoatrial node, is known as respiratory sinus arrhythmia (RSA).

Respiratory sinus arrhythmia (RSA) is a normal variation in heart rate associated with breathing [11]. During inspiration, there is a natural increase in sympathetic activity that accelerates the heart rate. Conversely, during exhalation, parasympathetic activity predominates, leading to a decrease in heart rate [12]. This creates a rhythmic modulation of the heart associated with breathing, known as respiratory sinus arrhythmia. Respiratory sinus arrhythmia (RSA) is generally considered to be a normal and healthy phenomenon. It demonstrates heart rate variability, which is a desirable characteristic of the cardiovascular system. In fact, increased heart rate variability is often associated with better cardiovascular health [14].

Heart coherence, on the other hand, refers to consciously synchronizing breathing with the heart rate to promote a state of coherence between sympathetic and parasympathetic nervous systems. This can be achieved through specific breathing techniques and is sometimes recommended as a method of stress management. Heart rate variability (HRV) can be influenced by several factors, and these factors, such as age, gender, body position, time of day, physical activity and stress, can vary from person to person [15].

Technological advances in heart rate recording and measurement devices have indeed streamlined the process and improved the reliability of heart rate variability (HRV) measurements (Kim et al., 2024). Wearable devices, such as heart rate monitors and smartwatches, now allow continuous and non-intrusive monitoring of HRV, providing a more accurate insight into variability and its changes under different conditions. Indeed, physical exercise leads to a decrease in parasympathetic activity and an increase in sympathetic activity, causing the heart rate to increase. The rate at which the heart rate slows down after exercise is as a measure of cardiac vagal reactivation. The study of heart rate variability (HRV) and its complexity can provide valuable insights into the autonomic regulation of the cardiovascular system [16].

During intense physical activity, the body undergoes several stress-related physiological responses, including increased heart rate, increased secretion of cortisol (a stress hormone), and increased muscle tension. These responses are critical for short-term adaptation but can hinder the recovery process if prolonged. Cardiac coherence, a technique involving controlled, rhythmic breathing, has been identified as an effective approach to improving recovery by mitigating the negative effects of these stress mechanisms [17]. One of the main benefits of Cardiac Coherence is its ability to reduce cortisol levels. Controlled breathing techniques have been shown to reduce the secretion of this hormone, allowing the body to return to a relaxed and regenerative state more quickly [18]. In addition, cardiac coherence significantly improves heart rate variability (HRV), a physiological marker of the autonomic nervous system flexibility. Higher HRV is associated with better stress resilience and more efficient recovery processes [19]. In addition, practicing cardiac coherence increases oxygenation by improving the efficiency of gas exchange during respiration. This ensures an increased supply of oxygen to the muscles while facilitating the removal of carbon dioxide, optimizing the physiological mechanisms essential for recovery. The relaxation effect of cardiac coherence also helps to reduce muscle tension, reducing the likelihood of cramping and minimizing post-exercise muscle soreness [20].

For athletes, these physiological benefits translate into practical benefits. Cardiac coherence exercises performed after training or competition can help the body transition more quickly to an optimal resting state, speeding recovery. Over time, consistent practice helps to reduce cumulative fatigue, enabling athletes to maintain peak performance over extended periods of training.

2. Method

2.1 Participants

Thirty amateur female handball players (mean age = 22.80 ± 2.75 years; mean height = 176.0 ± 4.2 cm; mean body mass = 68.2 ± 5.3 kg) volunteered to participate. All participants were healthy and regularly involved in amateur handball training. They were randomly allocated to either an experimental Heart Rate Coherence group (HRC; n = 15) or a control group (CTR; n = 15). The study was conducted in accordance with the Declaration of Helsinki (1964), and the protocol was approved by the University Ethics Committee.

2.2 Design and Procedure

A randomized controlled pre–post design was implemented over four weeks. At baseline (Week 0), all participants completed the same cycle-ergometer exercise test while heart activity was continuously monitored using ECG. Immediately after the ergometer test, participants entered a standardized 3-minute seated recovery period. During this period, the HRC group performed paced breathing (6 breaths/min; 5 s inhalation, 5 s exhalation) to induce heart rate coherence, whereas the control group remained seated quietly for the same duration. All baseline measures were repeated after four weeks (Week 4).

During the four-week intervention, the HRC group integrated heart rate coherence practice into their usual training routine through daily 15-minute sessions based on controlled breathing. The control group continued their usual training without any added breathing practice.

2.2.1 Study Overview (Protocol Summary)

Table 1 summarizes the experimental protocol used to compare physiological recovery responses between the Heart Rate Coherence (HRC) group and the control group over a four-week period. Importantly, both groups followed identical testing conditions at pre-test (Week 0) and post-test (Week 4), differing only in the standardized 3-minute recovery strategy performed immediately after the ergometer test. Specifically, the HRC group completed a 3-minute paced-breathing task intended to promote cardiac coherence, whereas the control group sat quietly for an equivalent duration. This design allowed the assessment of the distinct effects of paced breathing on post-exercise cardiac down-regulation (HR_recovery3min) and perceived fatigue (Borg score). Between the two testing sessions, only the HRC group added approximately 15 minutes of daily coherence practice, while the control group maintained usual training only—thereby isolating the breathing-based intervention as the primary experimental factor.

Table 1. Study protocol across four weeks

Phase	HRC Group (n=15)	Control Group (n=15)
Pre-test (Week 0)	1. Ergometer test (HR_test) 2. 3-min paced breathing 3. HR_recovery3min measurement	1. Ergometer test (HR_test) 2. 3-min quiet sitting 3. HR_recovery3min measurement

	4. Borg Rating of Perceived Exertion	4. Borg Rating of Perceived Exertion
Intervention (Weeks 1-4)	Usual training + HRC (15 min/day)	Usual training only
Post-test (Week 4)	Same as pre-test	Same as pre-test

2.3 Measures and Instruments

2.3.1 Perceived Fatigue (Borg Scale)

General fatigue/perceived tiredness was assessed using the Borg scale, as described in the study protocol. The scale was administered in connection with the testing sessions (pre- and post-intervention) to capture subjective fatigue responses. Higher scores reflect greater perceived tiredness.

2.3.2 Sleep Quality (Pittsburgh Sleep Quality Index; PSQI)

Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), a 19-item self-report questionnaire covering the previous month and yielding a total score from 0 to 21 (higher scores indicate poorer sleep; scores > 5 are typically considered clinically meaningful [21]. In the present report, PSQI data are presented descriptively because the available PSQI dataset in the manuscript is not organized in a clearly paired pre–post format by group, which prevents valid inferential comparisons.

2.4 Ergometer Exercise Test

Participants performed a cycle-ergometer test with continuous ECG recording via chest electrodes. A blood pressure cuff was placed on the right arm to allow monitoring during the test. Workload was adjusted in 2-minute stages by changing the resistance while participants maintained a constant pedaling cadence (RPM). The test duration was approximately 30 minutes on average.

2.5 Heart Rate Coherence (HRC) Breathing Task

Immediately after the ergometer test, participants in the HRC group sat upright and performed deliberate paced breathing at 6 breaths per minute. They inhaled for 5 seconds and exhaled for 5 seconds continuously, without breath-holding, for a total of 3 minutes

2.6 Outcomes

Based on the variables reported in Table 2, the main outcomes were:

1. Heart rate during the ergometer test (HR_test): heart rate recorded during the ergometer protocol.
2. Heart rate at the end of the 3-minute post-test period (HR_after): heart rate measured immediately after the 3-minute paced-breathing task in the HRC group and at the equivalent time point (after 3 minutes of quiet sitting) in the control group. This corresponds to the “Heart Rate aft CC” variable reported for both groups in Table 2.
3. Perceived tiredness: subjective tiredness rating (Borg scale), reported as “Tiredness” in Table 2.

2.7 Statistical Analysis

Data were summarized as means (M) and standard deviations (SD). The normality of distributions was examined using Shapiro–Wilk tests. Within-group pre–post changes were assessed using paired-samples t-tests. Between-group post-intervention differences were examined using ANCOVA with baseline values entered as covariates. Statistical significance was set at $p < .005$, consistent with the manuscript’s reporting.

3 Results

3.1 Descriptive Statistics

Table 2. Pre- and post-test values (Mean ± SD)

Variable	HRC Pre (M ± SD)	HRC Post (M ± SD)	Control Pre (M ± SD)	Control Post (M ± SD)
Heart rate during ergometer test (HR_test, bpm)	161.33 ± 12.17	136.00 ± 8.06	156.21 ± 9.81	155.13 ± 8.32
Heart rate after 3-min recovery (HR_recovery3min, bpm)	72.93 ± 2.19	50.73 ± 2.84	96.33 ± 2.01	90.31 ± 2.01
Perceived tiredness (Borg score)	4.73 ± 1.39	2.27 ± 0.96	4.62 ± 1.20	4.02 ± 1.02

Table 2 displays the descriptive statistics for physiological and perceptual measures, highlighting a clear divergence between the two groups following the intervention. The data reveals that the HRC group experienced substantial improvements across all three variables, suggesting a robust adaptation to the paced breathing training. Most notably, the HRC group's cardiovascular efficiency improved significantly, shown by a drop in exercise heart rate (161.33 to 136.00 bpm) and a remarkable decrease in recovery heart rate, which fell to just 50.73 bpm in the post-test. This physiological recovery was mirrored by their subjective experience; the HRC participants reported feeling significantly less fatigued, with their Borg scores dropping by more than half. In stark contrast, the Control group remained relatively stagnant, showing only negligible variances in heart rate and perceived tiredness compared to their baseline values.

Figure 1 illustrates the comparative changes in cardiovascular and subjective metrics between the HRC group and the Control group from baseline to the four-week follow-up. The heatmap color density visually represents the magnitude of the values, where darker shades indicate higher heart rates or fatigue levels. Regarding the Heart Rate During Ergometer Test, the HRC group demonstrated a notable reduction, decreasing from a baseline mean of 161.33 \pm 12.17 bpm to 136.00 \pm 8.06 bpm at Week 4. In contrast, the Control group remained stable, with a negligible change (156.21 to 155.13 bpm). A similar trend was observed for the Heart Rate After 3-min Recovery. The HRC group showed a sharp decline in post-exercise heart rate, falling from 72.93 \pm 2.19 bpm to 50.73 \pm 2.84 bpm. The Control group showed a much smaller reduction, maintaining significantly higher recovery values (90.31 \pm 2.01 bpm) compared to the HRC group at the end of the study. Finally, the Perceived Tiredness (Borg Score) followed this downward trajectory for the HRC group, dropping from 4.73 \pm 1.39 to 2.27 \pm 0.96. The Control group reported only a minor decrease in perceived fatigue (4.62 to 4.02), as evidenced by the sustained color intensity in the heatmap row for this group.

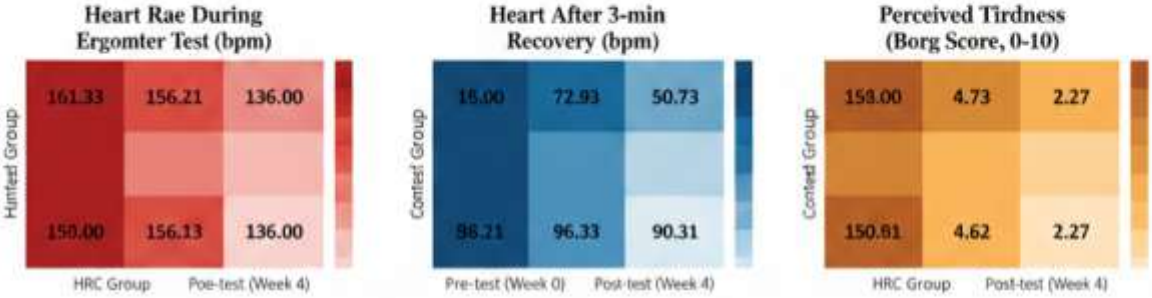

Figure 1. Comparative heatmap analysis of physiological and perceptual markers between the HRC and Control groups from baseline (Week 0) to post-intervention (Week 4).

3.2 Exact Change Scores Derived from Means

These values are precisely calculated based on the data presented in **Table 2**. HR during the ergometer test (HR_test) HRC group: 136.00 − 161.33 = −25.33 bpm (−15.70%) Control group: 155.13 − 156.21 = −1.08 bpm (−0.69%) Difference in change: −24.25 bpm (indicating a greater reduction in the HRC group) Interpretation: The HRC group exhibited a substantial reduction in exercise heart rate post-intervention, suggesting improved cardiovascular efficiency during physical exertion. In contrast, the control group showed minimal change, highlighting the specific effect of heart coherence training on modulating cardiac response to exercise.

3.3 HR after the 3-minute recovery period (HR_recovery3min)

- HRC group: 50.73 − 72.93 = −22.20 bpm (−30.43%) Control group: 90.31 − 96.33 = −6.02 bpm (−6.25%) Difference in change: −16.18 bpm

The pronounced decrease in post-exercise heart rate among HRC participants reflects accelerated autonomic recovery, likely due to enhanced parasympathetic reactivation. This aligns with the principle that heart coherence facilitates a quicker return to physiological baseline, a key marker of recovery readiness.

3.4 Perceived tiredness (Borg Scale)

- HRC group: 2.27 − 4.73 = −2.46 (−52.01%) Control group: 4.02 − 4.62 = −0.60 (−12.99%) Difference in change: −1.86.

The marked reduction in perceived fatigue in the HRC group underscores the psychophysiological benefits of coherence training. By promoting relaxation and reducing neuromuscular tension, the intervention appears to alleviate subjective exhaustion, which may support continued athletic performance and motivation.

3.5 Within-Group Changes in the HRC Group

Normality was confirmed using the Shapiro–Wilk test, indicating acceptable distribution of the data. Paired t-tests revealed significant pre-post changes in the HRC group across all measured variables:

- HR_test: Significant decrease (t = 25.091 , $p < 0.005$; t=25.091,$p<0.005$)
- HR_recovery3min: Significant decrease (t = − 13.650 , $p < 0.005$; t=−13.650, $p<0.005$).
- Tiredness: Significant decrease (t = 6.555 , $p < 0.005$; t=6.555, $p<0.005$).

The consistent and statistically significant reductions within the HRC group across all variables confirm the internal efficacy of the intervention. The correction regarding heart rate after coherence is important—it reflects a genuine recovery response, not an increase. These results suggest that regular heart coherence practice systematically enhances both objective and subjective recovery parameters.

3.4 **Between-Group Differences**

Analyzed via ANCOVA An ANCOVA was conducted with baseline scores as a covariate to compare post-intervention outcomes between the HRC and control groups. The results demonstrated significant group effects:

- HR_recovery3min: F = 17.21 ; $p < 0.005$; partial $\eta^2 = 0.96$
- HR_test: F = 13.033 ; $p < 0.005$; partial $\eta^2 = 0.87$
- Tiredness: F = 12.13 ; $p < 0.005$; partial $\eta^2 = 0.75$

The large effect sizes (partial $\eta^2 > 0.75$) indicate that heart coherence training accounted for the majority of variance in recovery outcomes, strongly supporting its superiority over standard training alone. These differences between the two groups reinforce that the improvements are attributable to the intervention and not to external or coincidental factors. The findings validate heart coherence as a potent, non-invasive tool for enhancing physiological and perceptual recovery in athletes.

4 Discussion

This study aimed to examine the impact of a Heart Rate Coherence (HRC) breathing method on recovery from exercise-induced fatigue following four weeks of ergometer-based training in amateur female handball players. Conceptually, heart rate coherence reflects the capacity of the autonomic nervous system (ANS) to regulate internal states efficiently when the body is exposed to stressors—whether physical (exercise, fatigue) or psychological (pressure, anxiety). The ANS operates through two complementary branches: the sympathetic system, which mobilizes energy and supports action, and the parasympathetic system, which promotes restoration and recovery [23]. Because heart rate variability (HRV) is widely considered an index of autonomic flexibility and self-regulatory capacity, paced breathing interventions that target ANS balance have been proposed as practical tools to enhance recovery processes [18, 24, 19].

Across the intervention period, the HRC group demonstrated clear improvements compared with the control group on three outcomes: heart rate during the ergometer test (HR_test), heart rate measured after a standardized 3-minute recovery period (HR_recovery3min), and perceived tiredness (Borg score). The magnitude of change was substantial. Heart rate during the ergometer test decreased in the HRC group by −25.33 bpm (−15.70%), whereas the control group showed near-stability (−1.08 bpm; −0.69%). Under comparable testing conditions, a lower exercise heart rate is often interpreted as reduced cardiovascular strain and/or improved efficiency for a given external workload. While exercise heart rate is influenced by several factors (e.g., fitness adaptations, pacing strategies, and workload), the pattern observed here is consistent with a shift toward a more adaptive internal response to exertion, potentially reflecting improved autonomic regulation.

The most striking finding concerned post-exercise down-regulation. Heart rate at the end of the standardized 3-minute post-test period declined by −30.43% in the HRC group compared with −6.25% in controls. This supports the idea that paced breathing around six breaths per minute may accelerate recovery of cardiac control after exertion. Slow-paced breathing has been consistently associated with increased parasympathetic engagement and baroreflex-related mechanisms that stabilize cardiovascular function and promote a quicker transition toward a calmer physiological state [12, 4]. In intermittent, high-intensity sports such as handball—where athletes must repeatedly switch between intense actions and brief recovery windows—faster down-regulation may be especially valuable for readiness and sustained performance between bouts [25].

In parallel with the heart-rate changes, perceived tiredness decreased markedly in the HRC group (−52.01%) but only modestly in controls (−12.99%). This is meaningful because fatigue is not purely a peripheral physiological phenomenon; it is also shaped by attentional, emotional, and cognitive regulation. A structured breathing routine may therefore influence recovery through both physiological pathways (autonomic rebalancing) and perceptual pathways (improved self-regulation and a reduced sense of strain). This interpretation aligns with broader work describing cardiac coherence practices as strategies that can enhance autonomic stability and self-regulation in stress-related contexts [17].

From a mechanistic standpoint, when the body experiences intense effort, rapid ANS-mediated regulation is essential to restore homeostasis. The literature suggests that paced breathing and coherence-focused techniques may contribute to recovery by supporting autonomic balance and reducing prolonged stress activation [8, 12]. Some authors have also linked recovery optimization to downstream processes such as reduced stress-hormone activity and improved oxygenation dynamics [26]. However, it is important to interpret these mechanisms cautiously in the present study: cortisol, lactate, and direct HRV indices were not reported as quantified outcomes in the results table. Consequently, these mechanisms should be understood as plausible explanations grounded in literature, rather than effects directly demonstrated by the current dataset.

Finally, although two questionnaires were included in the protocol (Borg and PSQI), only Borg-based tiredness was suitable for inferential analyses here because the PSQI information available in the manuscript was not structured in a clearly paired pre–post format by group. Future studies should ensure complete PSQI pre/post collection—or complement self-reports with objective sleep monitoring—to clarify whether improvements in autonomic regulation translate into measurable changes in sleep quality [21, 22]. Likewise, if muscle soreness/pain (e.g., VAS) is a target outcome, it should be reported with clear pre/post values and group comparisons. Changes in pain perception can occur in multiple contexts [27], but robust conclusions require pain-specific measures within the same intervention.

5 Conclusion

A four-week heart rate coherence breathing program integrated into usual training was associated with (i) lower heart rate during an ergometer exercise test, (ii) a substantially lower heart rate after a standardized 3-minute recovery period, and (iii) reduced perceived tiredness in amateur female handball players. These findings support the feasibility of paced breathing as a low-cost strategy to promote autonomic down-regulation and perceived recovery in amateur sports settings.

6 Limitations and Practical Implications

- **Limitations:** Heart rate outcomes are sensitive to workload standardization, hydration, stress, and sleep. Additionally, PSQI could not be analyzed due to incomplete and unstructured data, limiting conclusions regarding sleep. The sample size was modest.
- **Practical implication:** A brief daily breathing routine (15 minutes) may represent an accessible recovery tool for amateur athletes, especially when medical and recovery resources are limited.

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