

## Effects of Six-Week Circuit Training on Lactate Kinetics and Recovery In Male Field Hockey Players

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### Abstract

**Background:** Field hockey performance depends heavily on the contribution of anaerobic glycolytic energy during repeated high-intensity efforts. Adaptations in lactate production and clearance are critical indicators of metabolic conditioning and fatigue resistance. **Purpose:** This study examined the effects of Six-Week Circuit Training on Lactate Kinetics and Recovery in Male Field Hockey Players. **Methods:** Fifteen male university-level field hockey players completed a progressive six-week circuit training programme (three sessions per week). Blood lactate concentration was measured at rest, immediately after standardised high-intensity exercise, and after 30 minutes of recovery using a portable lactate analyser. A 2 × 3 repeated-measures ANOVA and paired comparisons were used to assess training effects. **Results:** Repeated-measures ANOVA showed significant reductions in lactate ( $F(1,14)=258.30, p<.001$ ). A significant Training × Condition interaction indicated enhanced metabolic efficiency and faster lactate clearance dynamics. **Conclusion:** Six weeks of structured circuit training effectively modulated lactate production and clearance, suggesting improved anaerobic metabolic regulation and recovery capacity in competitive field hockey players.

**Keywords:** Field hockey, Circuit training, Lactate kinetics, Passive recovery

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**Introduction:** Field hockey is best understood as a sport of oscillating intensities rather than a continuous workload. Phases of controlled movement are repeatedly punctuated by short-lived, high-demand actions accelerations, rapid directional changes, and sprint sequences that cluster into what can be described as maximal intensity intervals. These episodes impose a physiological burden that is not adequately represented by session averages. Empirical profiling suggests that such intervals, typically lasting between one and five minutes, generate demands that exceed those of routine training exposures even when aggregated across sessions (Goods et al., 2025; Torres-Ronda & Ric, 2022). Interpreting adaptation through mean values therefore risks diluting the relevance of the most decisive phases of play. A more precise analytical lens situates these peak demands at the centre of both training prescription and performance evaluation. This reframing has implications for how metabolic responses are

interpreted. Lactate, long treated as an indicator of fatigue or metabolic inefficiency, is more coherently positioned as an intermediary within a distributed energy system. The lactate shuttle paradigm articulates a continuous cycle in which lactate is generated in glycolytically active fibres, transported via monocarboxylate carriers, and oxidised in tissues with higher mitochondrial capacity (Brooks, 2018, 2022). From this standpoint, reductions in lactate accumulation at a fixed external load, alongside a more rapid post-exercise decline, are better interpreted as markers of enhanced transport and oxidative utilisation rather than a suppression of glycolytic flux. The distinction is subtle but consequential: it shifts the focus from limiting production to improving systemic handling. Capturing these dynamics requires attention to temporal specificity. Measurements obtained at rest, immediately following intense effort, and during early recovery provide a phased view of the interplay between lactate

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appearance and removal. Training-induced adaptations are plausibly linked to shifts in transporter expression, particularly the differential roles of MCT1 and MCT4. MCT1, predominantly associated with oxidative fibres, facilitates lactate uptake for mitochondrial oxidation, whereas MCT4 supports efflux from glycolytically active muscle. Evidence that training preferentially upregulates MCT1 lends support to the observation of lower circulating lactate at comparable workloads and a more efficient early recovery profile (Juell, 1999; Bonen, 2000; Halestrap, 2013). Still, attributing these changes solely to transporter dynamics may be overly reductive, as alterations in perfusion, fibre recruitment, and pacing strategies likely contribute in parallel.

Training design offers a practical pathway for targeting these integrated demands. Circuit-based formats that combine repeated sprint efforts, high-intensity interval work, agility tasks, and resistance elements appear well aligned with the mixed metabolic requirements of the sport. Evidence indicates that such approaches can enhance early-phase lactate clearance, extending the window of readiness for subsequent exertion compared with continuous moderate exercise (Xie et al., 2024). Recovery strategies, by contrast, present a more nuanced picture. While both active and passive modalities demonstrate utility, their effectiveness appears contingent on context, timing, and dosage, with recent syntheses pointing to condition-dependent effects on clearance kinetics and subsequent performance (Zouhal et al., 2024). Interpreting post-exercise lactate behaviour can be further refined through modelling approaches. Biexponential or compartmental frameworks allow

separation of appearance and elimination processes, offering a means to determine whether observed changes reflect reduced production, enhanced clearance, or a combination of both (Durand et al., 2021). When these temporal patterns are examined alongside local muscle oxygenation assessed via near-infrared spectroscopy and contextualised with external load metrics from GPS or IMU systems, a more differentiated picture emerges. It becomes possible to distinguish whether lower lactate concentrations arise from diminished local production or from more effective distribution and oxidative use (Perrey, 2024).

Guided by this integrated framework, the present study investigated the modulation of lactate dynamics following a six-week circuit training intervention. A 2 × 3 repeated-measures design was employed, contrasting Training (pre, post) and Condition (rest, immediate post-exercise, 30-minute recovery). The working expectation was not a uniform reduction in lactate, but a state-dependent shift: attenuated accumulation immediately after high-intensity work at a comparable external load, coupled with an accelerated decline during early recovery. Such a pattern would be consistent with enhanced monocarboxylate transporter activity and improved oxidative utilisation, as predicted by the lactate shuttle model (Brooks, 2018, 2022). By anchoring the protocol around periods that approximate worst-case intensity windows, any detected adaptation is more likely to reflect the physiological adjustments that are most consequential for performance and rapid recovery in elite field hockey (Goods et al., 2025; Torres-Ronda & Ric, 2022).

**2. Materials and Methods:**

Participant Recruitment	Six-Week Circuit Training Intervention	Post-Intervention Assessment (Post-Test)	Statistical Analysis
(N = 15 Male Field Hockey Players) Baseline Assessment (Pre-Test), Resting Blood Lactate, Standardized High-Intensity Exercise Test, 30-min Recovery Lactate	3 Sessions per Week, Progressive Glycolytic Load, Lactate Tolerance Phase, Taper Phase	Rest Lactate, Post-Exercise Lactate, Recovery Lactate	Repeated Measures ANOVA, Pairwise Comparisons, Effect Size Estimation.

**Table 1: Flow diagram illustrating participant progression, intervention protocol, physiological assessment points, and statistical analysis procedures**

**2.1 Study Design**

The investigation was structured around a within-participant repeated-measures framework, configured as a 2 × 3 design, to explore how a six-week circuit-based training regimen alters blood lactate dynamics in competitive male field hockey players. The analytical model distinguished between two temporal phases pre-intervention and post-intervention while simultaneously capturing physiological variation across three functionally distinct states: resting baseline, the immediate post-exercise response, and an early recovery phase extending to 30 minutes.

All assessments were conducted under consistent environmental conditions and at fixed times of day, thereby constraining the influence of circadian rhythms and ambient variability on metabolic responses. While such standardisation cannot fully eliminate biological fluctuation, it provides a stable reference frame for interpreting within-subject adaptations. The training stimulus itself was not static; it was deliberately progressed throughout the intervention. Exercise duration was extended, recovery intervals were incrementally reduced, and sprint-oriented circuit components were integrated to elevate glycolytic stress. This progression was intended to challenge both lactate

production and clearance mechanisms, rather than simply increasing overall workload.

**2.2 Participants :**

The sample size was determined to be sufficient for detecting substantial within-subject effects, with Greenhouse–Geisser adjustments applied in cases where the assumption of sphericity was violated. A total of fifteen male field hockey players, aged between 18 and 25 years, were recruited from an organised training cohort at Indian Institute of Technology (BHU), Varanasi. All participants were actively engaged in regular, structured training and were considered physically and mentally capable of sustaining high-intensity exercise demands.

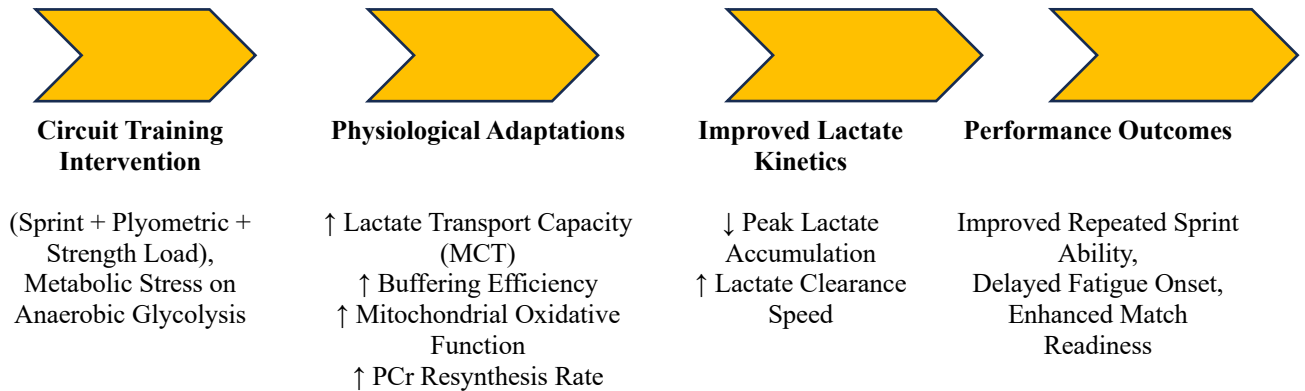
**2.3 Training Intervention:**

The intervention consisted of a six-week traditional circuit training programme, delivered across three sessions per week, with each session lasting

approximately 45 to 60 minutes. The structure of the programme reflected a staged progression rather than a uniform training load. Initial weeks prioritised movement quality and aerobic conditioning, establishing a base from which more demanding stimuli could be introduced. The subsequent phase shifted emphasis toward glycolytic and anaerobic stress, characterised by higher-intensity efforts and reduced recovery durations. This was followed by a brief overload period designed to maximise physiological strain, before concluding with a taper phase aimed at facilitating recovery and consolidation of adaptation.

Each training session was composed of three integrated components: a dynamic warm-up, a multi-station circuit, and a structured cool-down. The circuit itself incorporated a combination of sprint drills, plyometric exercises, agility tasks, and resistance-based movements, reflecting the multidimensional demands of field hockey performance. .

**Figure 01: Interpretation of Training-Induced Metabolic Adaptations**



**Table: 02 Weekly Training Plan**

WEEKS	AIM	ROUNDS × STATIONS	SEQUENCE	WORK: REST	BETWEEN ROUNDS	RPE
1	Neuromuscular Adaptation + Aerobic Base	2 × 6	Bodyweight squats, Push-ups, 20 m shuttle, skipping, Plank, Light agility ladder	30 second: 30 second	90 seconds	5-6
2	Initial Lactate Production	3 × 7	30 m sprint, Jump squats, Burpees, Fast feet drill, Mountain climbers, Lunges, Core twist	30 seconds: 15 seconds	90 seconds	6-7
3	High Glycolytic Stress	4 × 8	40 m shuttle sprint, Box jumps, Dumbbell thrusters, Skater jumps, Clap push-ups, Weighted lunges, Jump rope, Plank walk	30 seconds: 15 seconds	2 minutes	7-8
4	Peak Lactate Load + Repeated Sprint Ability	4 × 8	Tabata sprint station (20:10 × 4), Kettlebell swings, Tuck jumps, Wall balls, Farmer carry, Lateral cone	40 seconds: 20 seconds	3 minutes	8-9

			jumps, Plank-to-push-up, Battle rope			
5	Lactate Tolerance & Buffering Capacity	5 × 8	40 m shuttle sprint, Weighted jump squats, Sled push, Burpee tuck jumps, Jump lunges, High-knee sprint; Core circuit	45 seconds: 15 seconds	3 minutes	9
6	Lactate Clearance Optimization (Active Recovery Focus)	3 × 6	Tempo push-ups, Med-ball throw, Low-intensity agility run, Cycling / jog flush, Mini-hurdles, Dynamic mobility	20 seconds: 40 seconds	2 minutes	6

\* Bompa, T. O., & Buzzichelli, C. (2019)

**2.4 Blood Lactate Assessment:**

Capillary blood lactate concentration (mmol·L<sup>-1</sup>) was assessed using a portable lactate analyser following standardised procedures. Participants rested in a seated position for at least 10 minutes before baseline sampling, and finger sites were cleaned before collection to ensure accuracy. Lactate values were recorded at rest, immediately after a standardised high-intensity shuttle sprint test, and after 30 minutes of passive recovery. The same testing protocol was applied during both pre- and post-intervention assessments.

**2.5 Statistical Analysis**

Statistical analyses were performed using IBM SPSS Statistics with significance set at  $\alpha = .05$ . A two-way repeated-measures ANOVA evaluated the effects of training phase, physiological condition, and their interaction. Where the sphericity assumption was violated, Greenhouse–Geisser corrections were applied to ensure robust F-statistic estimation.

**3. Results:**

**Table 3.1. Assumption diagnostics and post hoc power analysis for repeated-measures lactate data**

TEST DOMAIN	VARIABLE / EFFECT	STATISTICAL TEST	STATISTIC VALUE	P-VALUE	INTERPRETATION
	Post-Exercise (Pre–Post)	Shapiro–Wilk	W = 0.974	.915	Normal distribution assumed
	Recovery (Pre–Post)	Shapiro–Wilk	W = 0.968	.821	Normal distribution assumed
Multivariate Outliers	Six lactate variables	Mahalanobis Distance	D <sup>2</sup> max = 9.44	> .05	No problematic multivariate outliers
Sphericity (Condition Factor)	Pre-phase	Approx. Mauchly’s W	0.795	.224	Sphericity assumption acceptable
	Post-phase	Approx. Mauchly’s W	0.924	.597	Sphericity assumption acceptable
Sample Adequacy (Power Analysis)	Rest condition	Cohen’s dz	1.05		Achieved power = 0.97 (adequate)
	Post-exercise condition	Cohen’s dz	3.06		Achieved power = 1.00 (very high)
	Recovery condition	Cohen’s dz	3.04		Achieved power =1.00 (very high)

The assumption testing results indicate that the dataset satisfies the statistical requirements for repeated-measures analysis. The Shapiro–Wilk test values for post-exercise (W = 0.974, p = .915) and recovery (W = 0.968, p = .821) show that the distribution of paired difference scores does not significantly deviate from normality, confirming that the assumption of normal distribution is met. Screening for univariate and multivariate outliers revealed no extreme cases, as the

maximum standardized z-score remained within acceptable limits ( $\leq \pm 2.11$ ), and distance statistics were non-significant (p > .05). Furthermore, Mauchly’s test of sphericity indicated that the sphericity assumption was acceptable across training phases. The post-hoc power analysis demonstrated very high statistical power ( $\geq 0.97$ ), suggesting that the sample size was sufficient to detect meaningful training-related changes in blood lactate concentration.

**Table 3.2. Descriptive Statistics by Training × Condition**

Condition	Phase	Mean (mmol·L <sup>-1</sup> )	S.D
Rest	Pre	2.13	0.31
	Post	1.91	0.21
Post-Exercise	Pre	9.38	1.32
	Post	7.31	0.92
Recovery	Pre	5.95	0.83
	Post	3.99	0.68

The descriptive statistics reveal a consistent reduction in blood lactate levels following the six-week circuit training programme across all physiological conditions. At rest, mean lactate concentration decreased from 2.13 mmol·L<sup>-1</sup> (pre) to 1.91 mmol·L<sup>-1</sup> (post), indicating a statistically significant reduction in mean lactate concentration. During post-exercise, lactate levels showed a substantial decline from 9.38 to 7.31 mmol·L<sup>-1</sup>, suggesting reduced lactate accumulation under high-intensity stress. Similarly, during recovery, lactate concentration decreased from 5.95 to 3.99 mmol·L<sup>-1</sup>, reflecting enhanced lactate clearance capacity.

**Table 3.3. Repeated-Measures ANOVA (2 × 3)**

Effect	F	df	p	Partial η <sup>2</sup>
Training Phase	258.30	1,14	<.001	.949
Condition	311.08	2,28	<.001	.957
Training × Condition	57.52	2,28	<.001	.804

The repeated-measures ANOVA results demonstrate statistically significant main and interaction effects. A strong main effect of training phase was observed ( $F = 258.30$ ,  $p < .001$ ,  $\eta^2 = .949$ ), indicating that circuit training significantly influenced lactate responses. The condition effect was also highly significant ( $F = 311.08$ ,  $p < .001$ ,  $\eta^2 = .957$ ), confirming that lactate levels varied substantially across rest, post-exercise, and

recovery states. Importantly, the training × condition interaction effect ( $F = 57.52$ ,  $p < .001$ ,  $\eta^2 = .804$ ) indicates that the magnitude of training adaptation differed across physiological conditions. This finding suggests that the training intervention produced state-specific metabolic improvements, particularly in exercise and recovery phases.

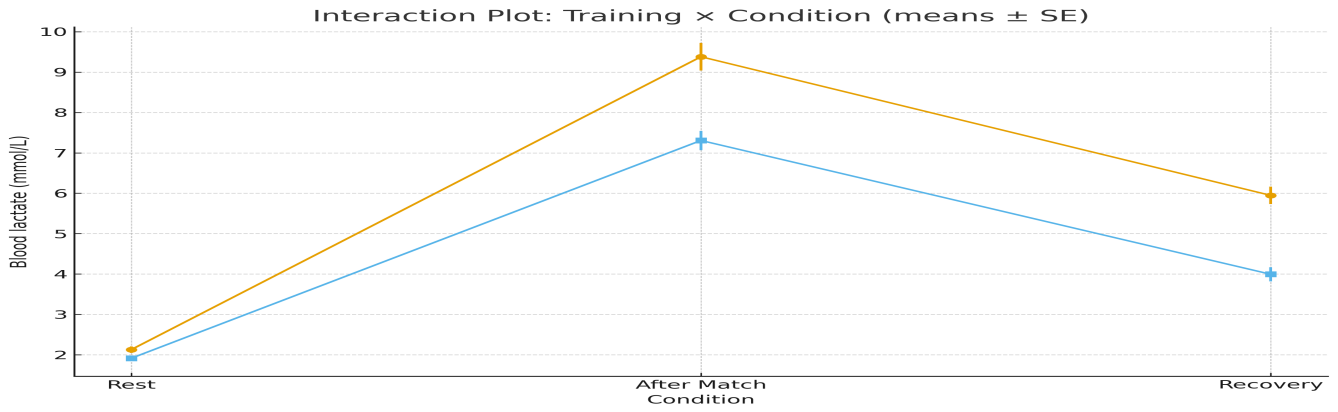
**Table 3.4. Paired Sample t-Test (Pre vs Post)**

Condition	Mean Difference	t	p	Effect Size (dz)
Rest	-0.21	-4.07	.001	1.05
Post-Exercise	-2.07	-11.87	<.001	3.06
Recovery	-1.95	-11.76	<.001	3.04

The paired sample t-test results confirm significant reductions in lactate concentration after training in all conditions. At rest, a modest but statistically meaningful decrease was observed ( $t = -4.07$ ,  $p = .001$ ,  $dz = 1.05$ ), indicating improved baseline metabolic efficiency. The largest reduction occurred in the post-exercise condition ( $t = -11.87$ ,  $p < .001$ ,  $dz = 3.06$ ), demonstrating a very

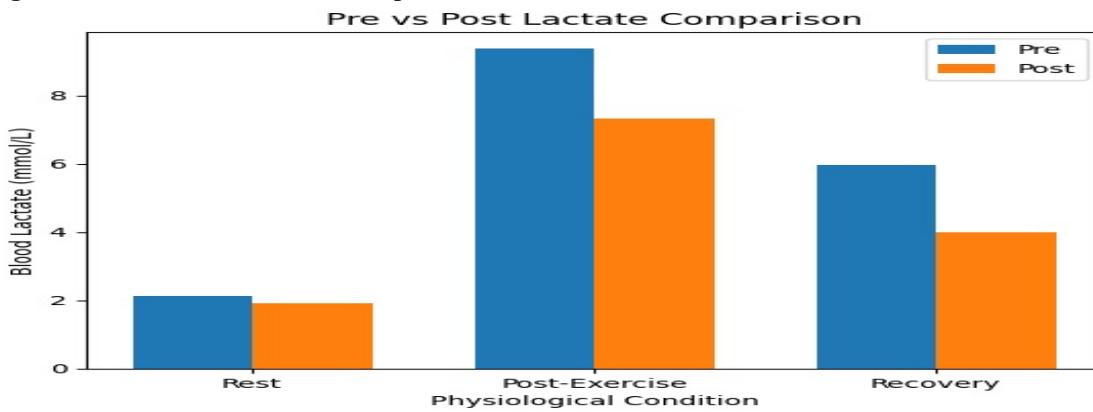
large training effect in limiting lactate accumulation during intense activity. Similarly, in the recovery phase, lactate levels declined significantly ( $t = -11.76$ ,  $p < .001$ ,  $dz = 3.04$ ), reflecting markedly improved lactate clearance mechanisms. Overall, the large effect sizes across conditions highlight the strong physiological impact of the circuit training programme.

**Figure 3.1. Interaction Plot: Training × Condition.**



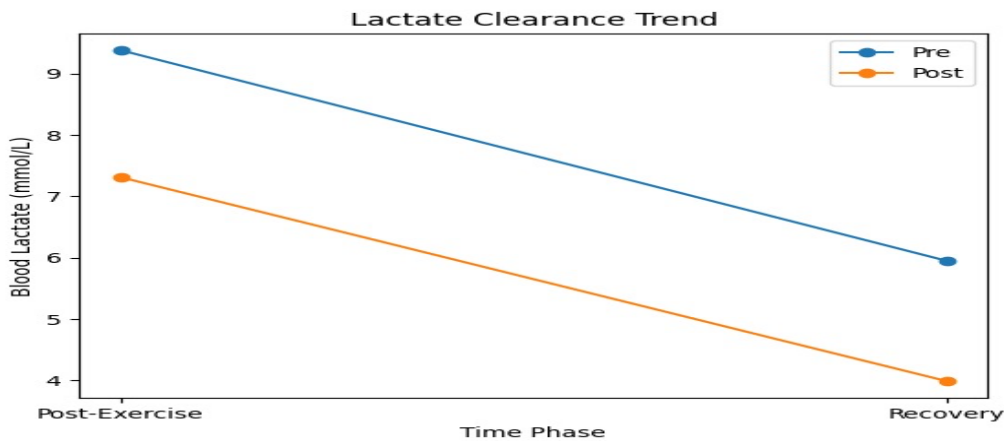
Post-training, mean lactate values were lower in every condition while the expected order was retained (Immediately After > 30-min Recovery > Rest). Reductions were greatest immediately after exercise, moderate at 30-min recovery, and modest at rest. The non-parallel pre–post profiles indicate a Training × Condition interaction, and the smaller post-training standard errors suggest reduced between-trial variability

Figure 3.1. Pre vs Post Lactate Comparison



The bar graph compares blood lactate levels before and after a six-week circuit training programme under rest, post-exercise, and recovery conditions. Lactate values decreased in the post-training phase across all conditions, indicating improved metabolic efficiency. The greatest reduction is seen after exercise, suggesting better tolerance to high-intensity activity and reduced fatigue. A notable decline during recovery also reflects faster lactate clearance and improved physiological recovery

Figure 3.1. lactate clearance trend



The line graph shows that blood lactate levels decrease from post-exercise to recovery in both phases, indicating the natural recovery process. However, post-training lactate values are lower and decline more sharply, suggesting improved lactate clearance and faster

physiological recovery. This reflects better tolerance to high-intensity effort, which supports sustained performance during the repeated sprint demands of field hockey.

#### 4. Discussion and conclusion:

The present findings align with a growing body of evidence indicating that circuit-based and high-intensity interval conditioning can meaningfully alter lactate dynamics in athletes engaged in intermittent team sports. Rather than simply reducing accumulation, these training approaches appear to recalibrate the balance between production, transport, and utilisation. Prior work has shown that repeated-sprint and progressive circuit formats can attenuate post-exercise blood lactate while improving buffering capacity and overall metabolic efficiency, thereby facilitating faster recovery between high-intensity efforts. In this context, the observed changes are consistent with adaptations in mitochondrial oxidative function and enhanced lactate transport, processes that have been linked to more rapid clearance during the early recovery phase (Brooks, 2018; Xie et al., 2024).

At the same time, the relevance of these adaptations becomes clearer when considered against the intensity profile of team-sport competition. Conditioning models that specifically target short-duration, maximal-intensity phases have been shown to reduce peak metabolic strain and improve the capacity to sustain repeated sprint activity under match conditions (Torres-Ronda & Ric, 2022; Goods et al., 2025). The magnitude and direction of lactate modulation observed here fall within the range reported in such studies, suggesting that the intervention did not merely produce isolated physiological shifts but engaged mechanisms directly relevant to performance demands. Even so, the extent to which these changes translate into competitive advantage may depend on contextual factors such as pacing strategy and match tempo.

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