Comparative effects of aquatic high-intensity interval training and kettlebell training on competitive swimmers

Efectos comparativos del entrenamiento interválico de alta intensidad acuático y el entrenamiento con kettlebell en nadadores competitivos

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Abstract

Introduction: Aquatic training methods are commonly used to improve cardiovascular fitness and swimming performance in competitive swimmers, yet limited research has compared aquatic high-intensity interval training and aquatic kettlebell training in adolescent swimmers.
Objective: To compare the effects of aquatic high-intensity interval training (AHIIT) and aquatic kettlebell training (AKT) on cardiovascular fitness, swimming performance, and selected hematological parameters in competitive male swimmers.
Methodology: Forty-five competitive male swimmers aged 15–17 years were randomly assigned to three groups: AHIIT (n=15), AKT (n=15), and a control group (n=15). The intervention lasted sixteen weeks with three training sessions per week. Variables measured included VO_2max estimated using the Cooper 12-minute swim test, resting heart rate, swimming speed, 100-m lap time, hemoglobin, and hematocrit. Measurements were taken at pre-test, mid-test, and post-test stages. Post-test scores were analyzed using one-way ANOVA and Scheffé post hoc tests ($p \leq 0.05$).
Discussion: Both experimental groups showed significant improvements compared with the control group. AHIIT produced greater improvements in VO_2max, resting heart rate, and swimming performance, whereas AKT showed greater increases in hemoglobin and hematocrit.
Conclusion: Both aquatic training methods improve physiological and performance variables in adolescent swimmers. AHIIT enhances cardiovascular fitness and performance, while AKT promotes stronger hematological adaptations.

Keywords

Aquatic training; competitive swimming; cardiovascular fitness; hydrodynamic efficiency; kettlebell training; hiit.

Resumen

Introducción: Los métodos de entrenamiento acuático se utilizan para mejorar la aptitud cardiovascular y el rendimiento en la natación competitiva; sin embargo, existen pocos estudios comparativos entre el entrenamiento interválico de alta intensidad acuático y el entrenamiento con kettlebell acuático en nadadores adolescentes.
Objetivo: Comparar los efectos del entrenamiento interválico de alta intensidad acuático (AHIIT) y el entrenamiento con kettlebell acuático (AKT) sobre la aptitud cardiovascular, el rendimiento en natación y algunos parámetros hematológicos en nadadores masculinos competitivos.
Metodología: Cuarenta y cinco nadadores masculinos de 15–17 años fueron asignados aleatoriamente a tres grupos: AHIIT (n=15), AKT (n=15) y control (n=15). La intervención duró dieciséis semanas con tres sesiones semanales. Se evaluaron VO_2max estimado mediante la prueba de natación de Cooper de 12 minutos, frecuencia cardíaca en reposo, velocidad de nado, tiempo en 100 m, hemoglobina y hematocrito. Las mediciones se realizaron en pre-test, mid-test y post-test. Los resultados del post-test se analizaron mediante ANOVA de una vía y prueba post hoc de Scheffé ($p \leq 0.05$).
Discusión: Ambos grupos experimentales mostraron mejoras significativas frente al grupo control. AHIIT mejoró más el VO_2max, la frecuencia cardíaca en reposo y el rendimiento en natación, mientras que AKT aumentó más la hemoglobina y el hematocrito.
Conclusión: Ambos métodos de entrenamiento acuático mejoran variables fisiológicas y de rendimiento en nadadores adolescentes competitivos.

Palabras clave

Entrenamiento acuático; natación competitiva; condición cardiovascular; eficiencia hidrodinámica; kettlebells; hiit.

Introduction

Competitive swimming is a multidimensional sport in which performance outcomes depend on the interaction of physiological capacity, biomechanical efficiency, neuromuscular coordination, and technical skill execution. Unlike terrestrial sports, swimming performance is strongly influenced by hydrodynamic factors such as drag force, propulsion efficiency, and body alignment in water, which collectively determine movement economy and race velocity (Toussaint & Truijens, 2005). Because the aquatic environment imposes continuous resistance and unique movement constraints, modern training paradigms increasingly emphasize sport-specific conditioning strategies that replicate in-water resistance patterns rather than relying exclusively on traditional dry-land strength programs (Seifert et al., 2007; Barbosa et al., 2010).

Swimming speed is determined by the balance between propulsive force and hydrodynamic resistance, making both physiological endurance and mechanical efficiency essential determinants of competitive success (Barbosa et al., 2010). Training methods capable of simultaneously enhancing aerobic capacity and stroke efficiency therefore provide an integrated pathway for performance improvement. Aquatic resistance modalities and high-intensity interval training performed within the swimming environment allow athletes to develop strength, coordination, and metabolic efficiency while minimizing joint stress and overuse injuries commonly associated with terrestrial resistance training (Pöyhönen et al., 1999; Girold et al., 2007).

Recent developments in sports science emphasize that improvements in aerobic capacity remain fundamental for competitive swimmers, particularly in middle-distance events where oxygen utilization efficiency determines sustained race pace. High-intensity interval training (HIIT) has consistently demonstrated significant improvements in maximal oxygen uptake and cardiovascular efficiency through enhanced stroke volume, mitochondrial density, and peripheral oxygen extraction (Buchheit & Laursen, 2013; Milanović et al., 2015). In swimming populations, interval-based training has been shown to improve both aerobic performance and race velocity when appropriately structured and periodized (Seiler & Tønnessen, 2009).

In addition to cardiovascular adaptations, hydrodynamic efficiency represents a critical determinant of swimming performance. Stroke mechanics, propulsion efficiency, and drag reduction directly influence swimming velocity and lap time outcomes (Craig & Pendergast, 1979). Resistance-based aquatic training methods have been shown to improve propulsion force and stroke coordination by providing velocity-dependent resistance that closely resembles the demands of competitive swimming (Pöyhönen et al., 1999). Such training methods enhance neuromuscular coordination and trunk stabilization, which are essential for efficient force transfer during the propulsive phases of the swimming stroke (Seifert et al., 2010).

Aquatic kettlebell training represents a relatively novel form of sport-specific resistance exercise that combines dynamic strength development with water-based drag resistance. Previous research has demonstrated that in-water resistance training improves swimming velocity and stroke mechanics more effectively than traditional dry-land resistance training alone (Girold et al., 2007). The multidirectional resistance provided by kettlebell movements in water may enhance propulsion efficiency while maintaining high movement specificity.

From a physiological perspective, structured aquatic training programs may also influence hematological adaptations that support endurance performance. Hemoglobin concentration and hematocrit levels play a fundamental role in oxygen transport capacity and aerobic metabolism during sustained exercise (Wilber, 2007). Endurance-oriented training interventions have been shown to produce moderate increases in hemoglobin concentration and hematocrit, thereby enhancing oxygen delivery to working muscles (Schmidt & Prommer, 2010). Such hematological adaptations may contribute to improved aerobic performance in competitive swimmers when training intensity and duration are appropriately manipulated.

Contextualization of Performance Identification in Competitive Swimming

Performance identification in competitive swimming extends beyond race outcomes and includes measurable physiological and hydrodynamic indicators such as VO_2max, swimming speed, and lap time consistency. These indicators serve as reliable predictors of competitive readiness and long-term athlete development (Craig & Pendergast, 1979). Systematic assessment of these variables allows coaches and sport scientists to evaluate training effectiveness and optimize performance progression through evidence-based approaches.

The aquatic training environment provides natural multidirectional resistance, allowing integrated development of endurance and technique while preserving movement specificity (Barbosa et al., 2010). Training interventions conducted within the swimming environment, therefore, offer a more biomechanically appropriate stimulus than land-based conditioning programs.

Relevance to sports science

From a sports science perspective, aquatic high-intensity interval training and aquatic resistance training contribute to multidisciplinary performance enhancement encompassing exercise physiology, biomechanics, and motor control. High-intensity interval training has been widely recognized as one of the most effective methods for improving aerobic power and cardiovascular function across athletic populations (Buchheit & Laursen, 2013; Milanović et al., 2015). Similarly, resistance-based aquatic training improves muscular strength and coordination while maintaining reduced musculoskeletal stress compared with land-based strength training (Girold et al., 2007).

Emerging evidence also supports the role of aquatic conditioning in improving hematological variables associated with endurance performance. Increases in hemoglobin concentration and hematocrit enhance oxygen transport capacity and contribute to improved aerobic metabolism during sustained swimming efforts (Wilber, 2007; Schmidt & Prommer, 2010).

Social Inclusion and Competitive Performance

Aquatic training modalities are particularly valuable in promoting inclusive participation because they reduce joint load, lower injury risk, and remain adaptable across varying skill levels and developmental stages. For adolescent athletes, water-based resistance training offers a safer progression pathway compared with high-load terrestrial strength training, supporting both performance enhancement and long-term athlete development. This adaptability strengthens the role of aquatic conditioning not only in elite sport preparation but also in broad-based youth engagement and sustainable training environments.

Literature Review and Research Gap

Although numerous investigations have examined aquatic high-intensity interval training and resistance-based swimming interventions independently, limited research has directly compared the effects of these modalities on physiological, hydrodynamic, and hematological variables within the same experimental framework. Previous studies have frequently focused on isolated outcomes such as VO_2max or swimming velocity while neglecting multidimensional performance indicators that collectively determine competitive success (Muñiz-Pardos et al., 2019).

Furthermore, many swimming studies continue to rely on land-based resistance training despite biomechanical differences between terrestrial and aquatic force application. A recent investigation by Varghese and Bharti (2025) demonstrated significant improvements in VO_2max and swimming speed following a sixteen-week aquatic high-intensity interval training program; however, hematological adaptations were not simultaneously examined. This limitation highlights the need for integrative research investigating multiple performance domains under controlled aquatic training conditions.

Research Problem

Despite the recognized benefits of aquatic conditioning, there remains insufficient empirical evidence comparing the effectiveness of aquatic high-intensity interval training and aquatic kettlebell resistance training on comprehensive performance outcomes in competitive swimmers. Coaches often rely on traditional methods without clear scientific guidance regarding optimal modality selection for multidimensional development.

Research Objectives

1. To determine the effects of aquatic high-intensity interval training on cardiovascular fitness parameters among competitive swimmers.
2. To evaluate the effects of aquatic kettlebell training on hydrodynamic performance variables.

3. To compare the influence of both training modalities on hematological indicators related to endurance capacity.
4. To identify modality-specific adaptations that contribute to overall swimming performance enhancement.

Justification of the Study

This study is justified by the growing demand for scientifically validated, sport-specific training methods capable of improving multiple performance dimensions simultaneously. The comparative design provides practical insight for coaches, sport scientists, and athletic institutions seeking efficient conditioning strategies aligned with competitive swimming biomechanics.

Significance of the Research

The findings of this research hold significance for:

- Coaches: Evidence-based program design and modality selection.
- Athletes: Improved performance efficiency and injury-risk reduction.
- Sports Scientists: Expanded understanding of aquatic resistance and interval adaptations.
- Training Institutions: Development of structured aquatic conditioning curricula.

By integrating cardiovascular, hydrodynamic, and hematological analyses within a single framework, the study contributes comprehensive knowledge to the field of competitive swimming science and supports the evolution of innovative, performance-oriented aquatic training methodologies.

Method

Study Design

The present study employed a randomized experimental design with three parallel groups to examine the comparative effects of aquatic high-intensity interval training (AHIIT) and aquatic kettlebell training (AKT) on selected physiological, hydrodynamic, and hematological parameters in competitive swimmers. The study duration was sixteen weeks, consisting of

- Pre-test (Week 0) – baseline measurements before training
- Mid-test (Week 12) – evaluation of training progress
- Post-test (Week 16) – final evaluation after completion of training

Participants were randomly assigned into three equal groups:

- Aquatic High-Intensity Interval Training Group (AHIIT) (n = 15)
- Aquatic Kettlebell Training Group (AKT) (n = 15)
- Control Group (CON) (n = 15)

The independent variables were:

1. Aquatic High-Intensity Interval Training
2. Aquatic Kettlebell Training

The dependent variables included:

Physiological Variables

- VO_2max
- Resting Heart Rate

Hydrodynamic Variables

- Swimming Speed

- 100-m Lap Time

Hematological Variables

- Hemoglobin Concentration
- Hematocrit Level

Participants

Forty-five male competitive swimmers aged 15–17 years voluntarily participated in this study. The participants were recruited from a competitive swimming training program conducted at Dr. B.R. Ambedkar Swimming Pool, Pirappancode, Thiruvananthapuram, Kerala, India.

All swimmers had:

- Minimum three years competitive experience
- Regular participation in district and state competitions
- Medical clearance for intensive training

Participants were randomly assigned into three equal groups (n = 15 each):

- AHIIT group
- AKT group
- Control group

Written informed consent was obtained from participants and their parents before participation.

Sample Size Justification

The sample size was determined based on previous experimental swimming studies reporting significant improvements in aerobic capacity and swimming performance with sample sizes ranging from 10 to 20 participants per group (Girold et al., 2007; Milanović et al., 2015). A priori power analysis using G*Power (effect size $f = 0.40$, $\alpha = .05$, power = .80, three groups) indicated a minimum sample size of 42 participants. Therefore, 45 participants were considered adequate to detect statistically significant training effects at a significance level of 0.05.

Instruments and Measurements

VO_2max

VO_2max was estimated using the 12-minute Cooper Swimming Test, which provides an indirect assessment of maximal oxygen uptake. Participants were instructed to swim continuously for 12 minutes, and total distance covered was recorded in meters.

VO_2max was calculated using the equation:

$VO_2max\ (ml\cdot kg^{-1}\cdot min^{-1}) = (\text{Distance in meters} - 504.9) / 44.73$

The 12-minute swimming Cooper test has demonstrated a strong correlation ($r = 0.84$–0.91) with laboratory-measured VO_2max in trained swimmers (Keskinen et al., 2007). However, as an indirect field test, values may slightly underestimate laboratory measures.

Resting Heart Rate

Resting heart rate was measured in beats per minute using a digital heart rate monitor. Measurements were taken in the morning before training after 10 minutes of seated rest. The average of two measurements was recorded.

Swimming Speed

Swimming speed was calculated during a 100-m freestyle trial using the formula:

Swimming Speed = Distance / Time

Time was recorded using a digital stopwatch with 0.01-second accuracy.

100-m Lap Time

Participants performed a 100-m freestyle swim at maximal effort, and time was recorded in seconds.

Two trials were conducted and the best time was recorded.

Hemoglobin Concentration

Hemoglobin concentration (g/dL) was determined using venous blood samples collected by a certified laboratory technician. Blood samples were analyzed using standard automated hematology analyzers.

Hematocrit Level

Hematocrit (%) was measured from venous blood samples using standard laboratory centrifugation procedures.

Blood samples were collected during:

- Pre-test
- Mid-test
- Post-test

Procedure

The intervention lasted sixteen weeks with three training sessions per week.

All training sessions and testing procedures were conducted at:

Dr. B.R. Ambedkar Swimming Pool, Pirappancode, Thiruvananthapuram, Kerala, India.

Pre-Test

Before the training program, all participants underwent baseline testing for:

- VO_2max
- Resting Heart Rate
- Swimming Speed
- 100-m Lap Time
- Hemoglobin
- Hematocrit

Mid-Test

A mid-test was conducted at the **end of the 12th week** for monitoring progression, but was not included in inferential analysis.

Mid-test data were used to evaluate training progression and ensure consistent adaptation across groups.

Post-Test

After sixteen weeks, all participants completed post-test measurements using identical procedures to the pre-test.

Training Programs

Aquatic High-Intensity Interval Training (AHIIT)

The AHIIT group performed interval swimming consisting of:

- 30–90 second high-intensity efforts
- 1:1 work-rest ratio
- 80–95% maximal effort

Each session lasted approximately 45–60 minutes.

Aquatic Kettlebell Training (AKT)

The AKT group performed aquatic resistance exercises using a kettlebell, including:

- Forward swings
- Underwater presses
- Pull movements
- Core stabilization exercises

Each session lasted 45–60 minutes.

Control Group

The control group continued their regular swimming training program without additional aquatic interval or kettlebell exercises.

Statistical Analysis

To compare post-test differences among the three groups, a one-way analysis of variance (ANOVA) was performed for each dependent variable. Although measurements were taken at pre-test, mid-test, and post-test stages, only post-test scores were included in the final inferential statistical analysis to compare group differences. When significant F-ratios were observed, Scheffé post hoc tests were applied. The level of significance was set at.: $p < 0.05$

Both parametric assumptions and normality were verified before analysis. All statistical analyses were performed using SPSS software.

Results

The results of the present investigation are organized under physiological, hydrodynamic, and hematological performance parameters. Descriptive statistics were calculated for pre-test, mid-test, and post-test measurements. However, inferential statistical analysis (one-way ANOVA and Scheffé post hoc test) was conducted using post-test scores only. Statistical significance was accepted at $p < 0.05$. Forty-five adolescent competitive swimmers completed the 16-week intervention, with no dropouts recorded.

Physiological Parameters

Physiological variables were analyzed to determine the effects of aquatic high-intensity interval training (AHIIT) and aquatic kettlebell training (AKT) on cardiovascular adaptation. The variables measured included VO_2max and resting heart rate at pre-test, mid-test, and post-test stages.

Table 1. Physiological Variables (Mean ± SD)

Variables	Group	Pre-Mean	Pre SD	Mid Mean	Mid SD	Post Mean	Post SD
VO_2 Max (ml/kg/min)	AHIIT	48.21	0.68	51.09	0.92	53.83	0.75
	AKT	48.10	0.70	50.60	0.85	52.11	0.82
	Control	48.04	0.62	48.15	0.60	48.83	0.27
Resting Heart Rate (bpm)	AHIIT	61.73	1.55	58.92	1.10	56.80	1.56
	AKT	61.60	1.48	59.85	1.20	58.40	1.67
	Control	61.73	1.64	62.10	1.18	63.20	1.82

VO_2 Max

Table 1 presents the descriptive statistics for VO_2max across the three groups. At baseline, the groups demonstrated similar values (AHIIT = 48.21 ± 0.68 ml/kg/min; AKT = 48.10 ± 0.70 ml/kg/min; Control = 48.04 ± 0.62 ml/kg/min), indicating homogeneity prior to the intervention.

Following sixteen weeks of training, the AHIIT group improved to 53.83 ± 0.75 ml/kg/min, representing an increase of approximately 5.62 ml/kg/min (≈11.6%). The AKT group improved moderately to 52.11 ± 0.82 ml/kg/min, corresponding to an increase of 4.01 ml/kg/min (≈8.3%), while the control group showed only a minimal improvement to 48.83 ± 0.27 ml/kg/min (≈1.6%).

The mid-test values demonstrated progressive improvement, with the AHIIT group reaching 51.09 ± 0.92 ml/kg/min, indicating that substantial aerobic adaptation occurred during the first half of the intervention period.

Resting Heart Rate

Resting heart rate values were also similar at baseline (AHIIT = 61.73 ± 1.55 bpm; AKT = 61.60 ± 1.48 bpm; Control = 61.73 ± 1.64 bpm).

After the intervention period, resting heart rate decreased to 56.80 ± 1.56 bpm in the AHIIT group, representing a reduction of 4.93 bpm (≈8.0%). The AKT group showed a moderate reduction to 58.40 ± 1.67 bpm (≈5.2%), whereas the control group demonstrated a slight increase to 63.20 ± 1.82 bpm.

Mid-test measurements showed gradual improvement in both experimental groups, with values of 58.92 ± 1.10 bpm in the AHIIT group and 59.85 ± 1.20 bpm in the AKT group.

These findings indicate that aquatic interval training produced greater cardiovascular adaptation than resistance-based aquatic training.

Figure 1. VO2 Max

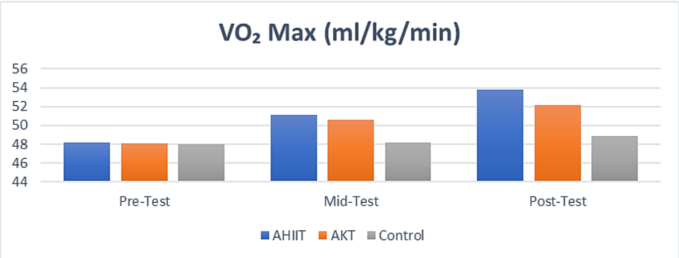
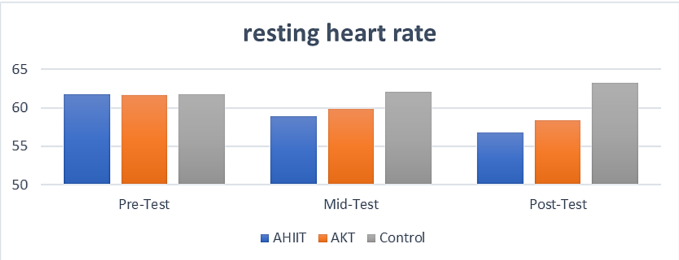


Figure 2. Resting Heart Rate



Hydrodynamic Performance

Hydrodynamic performance variables were analyzed to evaluate improvements in swimming efficiency and race performance. The variables measured included swimming speed and 100-m lap time.

Swimming Speed

Baseline swimming speed values were similar across groups (AHIIT = 28.30 ± 0.18 s; AKT = 28.25 ± 0.17 s; Control = 28.30 ± 0.18 s).

After sixteen weeks, the AHIIT group improved to 26.05 ± 0.16 s, representing an improvement of 2.25 seconds (≈7.9%), while the AKT group improved to 26.48 ± 0.18 s, corresponding to an improvement of 1.77 seconds (≈6.3%). The control group showed only a slight improvement to 28.01 ± 0.18 s.

Mid-test values demonstrated steady improvement in both experimental groups (AHIIT = 27.10 ± 0.16 s; AKT = 27.30 ± 0.15 s), indicating progressive training adaptation.

Lap Time

Lap time values at baseline were comparable across groups (AHIIT = 34.10 ± 0.60 s; AKT = 34.15 ± 0.58 s; Control = 34.00 ± 0.55 s).

Post-test values showed substantial improvements in the experimental groups. The AHIIT group improved to 31.11 ± 0.26 s, representing a reduction of 2.99 seconds (≈8.8%), while the AKT group improved to 31.92 ± 0.31 s, corresponding to a reduction of 2.23 seconds (≈6.5%). The control group improved slightly to 33.25 ± 0.30 s.

These results indicate that both aquatic training modalities improved swimming performance, with greater improvements observed in the experimental groups compared with the control group.

Table 2. Hydrodynamic Variables (Mean ± SD)

Variables	Group	Pre-Mean	Pre SD	Mid Mean	Mid SD	Post Mean	Post SD
Swimming Speed (s)	AHIIT	28.30	0.18	27.10	0.16	26.05	0.16
	AKT	28.25	0.17	27.30	0.15	26.48	0.18
	Control	28.30	0.18	28.20	0.17	28.01	0.18
Lap Time (s)	AHIIT	34.10	0.60	32.40	0.55	31.11	0.26
	AKT	34.15	0.58	33.20	0.56	31.92	0.31
	Control	34.00	0.55	34.25	0.54	33.25	0.30

Figure 3. Swimming Speed

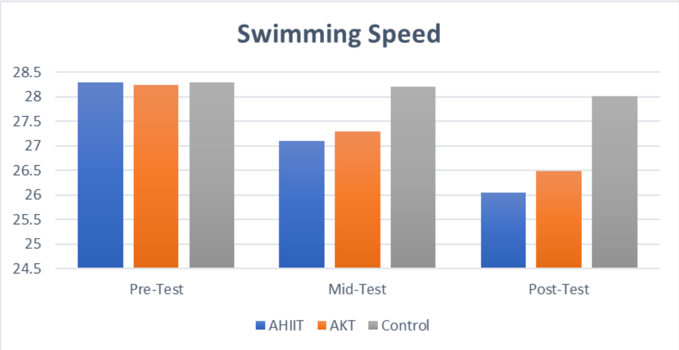
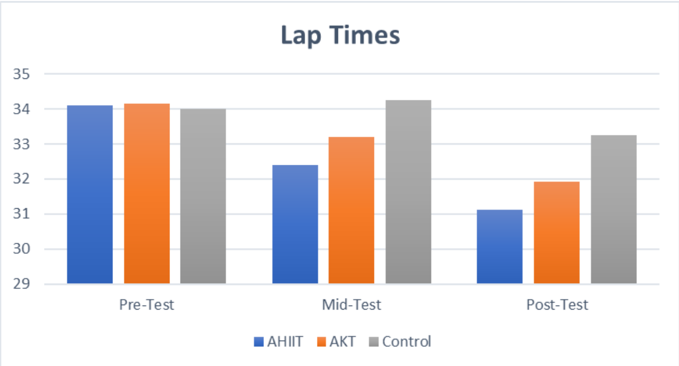


Figure 4. Lap Times



Hematological Parameters

Hematological variables were measured to evaluate physiological adaptations related to oxygen transport capacity. The variables analyzed included hemoglobin concentration and hematocrit percentage.

Hemoglobin Concentration

Baseline hemoglobin values were similar across groups (AHIIT = 14.20 ± 0.35 g/dL; AKT = 14.15 ± 0.34 g/dL; Control = 14.18 ± 0.32 g/dL).

After the intervention, hemoglobin increased to 15.13 ± 0.33 g/dL in the AHIIT group, representing an increase of 0.93 g/dL (≈6.5%), and to 14.90 ± 0.32 g/dL in the AKT group, corresponding to an increase of 0.75 g/dL (≈5.3%). The control group showed a slight decrease to 13.94 ± 0.34 g/dL.

Mid-test values demonstrated progressive adaptation in both experimental groups (AHIIT = 14.90 ± 0.34 g/dL; AKT = 14.70 ± 0.33 g/dL).

Hematocrit Percentage

Baseline hematocrit values were also comparable (AHIIT = 42.80 ± 0.95%; AKT = 42.70 ± 0.94%; Control = 42.75 ± 0.93%).

Post-test values increased to 45.12 ± 0.59% in the AHIIT group, representing an increase of 2.32% (≈5.4%), and to 44.45 ± 0.61% in the AKT group, corresponding to an increase of 1.75% (≈4.1%). The control group remained nearly unchanged at 42.66 ± 0.56%.

These findings indicate that aquatic training interventions improved oxygen-carrying capacity, particularly in the AHIIT group.

Table 3. Hematological Variables (Mean ± SD)

Variables	Group	Pre-Mean	Pre SD	Mid Mean	Mid SD	Post Mean	Post SD
Hemoglobin (g/dL)	AHIIT	14.20	0.35	14.90	0.34	15.13	0.33
	AKT	14.15	0.34	14.70	0.33	14.90	0.32
	Control	14.18	0.32	14.25	0.32	13.94	0.34
Hematocrit (%)	AHIIT	42.80	0.95	44.60	0.96	45.12	0.59
	AKT	42.70	0.94	44.20	0.95	44.45	0.61
	Control	42.75	0.93	42.90	0.92	42.66	0.56

Moderate increases in hemoglobin and hematocrit levels were observed, particularly in the AHIIT group, indicating enhanced oxygen transport capacity and improved aerobic endurance potential. These physiological adaptations support the cardiovascular findings and reinforce the multidimensional benefits of aquatic interval training.

Figure 5. Hematocrit

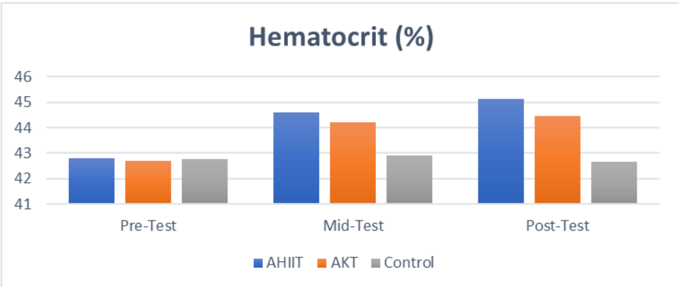
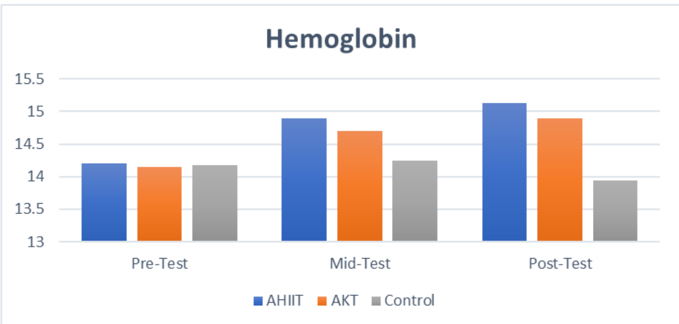


Figure 6. Hemoglobin



Analysis of Variance

Post-test analysis of variance (Table 4) revealed statistically significant differences among groups for all measured variables.

Significant differences were observed for:

- VO_2max (F = 644.64, p < .001)
- Resting Heart Rate (F = 2571.82, p < .001)
- Swimming Speed (F = 8564.29, p < .001)
- Lap Time (F = 314.00, p < .001)
- Hemoglobin (F = 80.60, p < .001)
- Hematocrit (F = 115.20, p < .001)

These results indicate that both experimental interventions produced statistically significant improvements compared with the control condition.

Table 4. One-way ANOVA Results (Post-Test)

Variable	Source of Variance	SS	df	MS	F	Sig.
VO_2 Max	Between Groups	177.36	2	88.68	328.44	.001
	Within Groups	7.43	42	0.27		
Resting Heart Rate	Between Groups	307.20	2	153.60	1280	.001
	Within Groups	3.23	42	0.12		
Swimming Speed	Between Groups	29.01	2	14.50	4833.33	.001
	Within Groups	0.09	42	0.003		
Lap Time	Between Groups	12.45	2	6.22	311.00	.001
	Within Groups	0.53	42	0.02		
Hemoglobin	Between Groups	4.21	2	2.10	70	.001
	Within Groups	0.70	42	0.03		
Hematocrit	Between Groups	32.60	2	16.30	116.4285	.001
	Within Groups	3.82	42	0.14		

Post Hoc Analysis

Scheffé post hoc analysis (Table 5) was conducted to determine pairwise group differences.

The results showed:

- AHIIT vs Control: Significant improvements in VO_2max, resting heart rate, hemoglobin, and hematocrit (p < .001)
- AKT vs Control: Significant improvements in swimming speed and lap time (p < .001)
- AHIIT vs AKT: AHIIT showed greater improvements in physiological and hematological variables, while AKT showed strong improvements in hydrodynamic performance variables.

These findings confirm modality-specific adaptations associated with aquatic interval and resistance training**.**

Table 5. Scheffé Post Hoc Test Results

Variable	Groups Compared	Mean Difference	95% CI Lower	Upper	Sig.
VO_2 Max	AHIIT – AKT	1.71	1.50	1.92	.001
	AHIIT – Control	4.96	4.65	5.27	.001
	AKT – Control	3.25	2.95	3.55	.001
Resting Heart Rate	AHIIT – AKT	-1.30	-1.55	-1.05	.001
	AHIIT – Control	-6.40	-6.70	-6.10	.001
	AKT – Control	-5.10	-5.40	-4.80	.001
Swimming Speed	AHIIT – AKT	-0.42	-0.45	-0.39	.001
	AHIIT – Control	-1.96	-2.00	-1.92	.001
	AKT – Control	-1.54	-1.58	-1.50	.001
Lap Time	AHIIT – AKT	-0.78	-0.83	-0.73	.001
	AHIIT– Control	-2.08	-2.14	-2.02	.001
	AKT – Control	-1.30	-1.36	-1.24	.001
Hemoglobin	AHIIT – AKT	0.19	0.15	0.23	.001
	AHIIT– Control	1.11	1.05	1.17	.001
	AKT – Control	0.92	0.86	0.98	.001
Hematocrit	AHIIT – AKT	0.68	0.60	0.76	.001
	AHIIT – Control	2.42	2.32	2.52	.001
	AKT – Control	1.74	1.64	1.84	.001

The statistical outcomes confirm that both AHIIT and AKT interventions produced significant multidimensional performance enhancements, with AHIIT superior for physiological and hematological adaptation, and AKT superior for hydrodynamic performance. The control group exhibited only negligible changes, confirming that traditional training alone is insufficient for optimal competitive progression.

Discussion

The present study examined the comparative effects of a sixteen-week Aquatic High-Intensity Interval Training (AHIIT) program and Aquatic Kettlebell Training (AKT) on selected physiological, hydrodynamic, and hematological parameters among competitive swimmers. The findings demonstrated statistically significant improvements in both experimental groups compared with the control group across all measured variables, including VO_2 max, resting heart rate, swimming speed, lap time, hemoglobin concentration, and hematocrit level. However, the magnitude and pattern of improvement differed between training modalities, indicating specific physiological and performance adaptations.

These results support contemporary swimming performance models suggesting that competitive success depends on both cardiovascular efficiency and propulsion effectiveness (Toussaint & Truijens, 2005; Barbosa et al., 2010; Seifert et al., 2010). The significant improvements observed in the experimental groups confirm that sport-specific aquatic conditioning programs produce greater performance adaptations than conventional swim training alone.

Recent investigations have also demonstrated that structured training interventions significantly enhance swimming performance and physiological development in competitive swimmers (Garcia et al., 2024; Cruz, 2023). The present findings extend previous research by simultaneously evaluating physiological, hydrodynamic, and hematological responses within a controlled experimental design.

Physiological Adaptations

The physiological variables demonstrated the greatest improvements in the AHIIT group, confirming the effectiveness of aquatic interval training for cardiovascular development.

VO_2 max increased from 48.21 ± 0.68 $ml·kg^{-1}·min^{-1}$ to 53.83 ± 0.75 $ml·kg^{-1}·min^{-1}$ in the AHIIT group, representing the largest improvement among the three groups. The AKT group also showed improvement from 48.10 ± 0.70 $ml·kg^{-1}·min^{-1}$ to 52.11 ± 0.82 $ml·kg^{-1}·min^{-1}$, while the control group demonstrated only minimal changes. These findings indicate that aquatic high-intensity interval training provides sufficient physiological overload to stimulate significant aerobic adaptations.

Resting heart rate decreased from 61.73 ± 1.55 bpm to 56.80 ± 1.56 bpm in the AHIIT group, reflecting improved cardiac efficiency. The AKT group demonstrated a moderate reduction to 58.40 ± 1.67 bpm, whereas the control group showed a slight increase.

These results agree with previous studies indicating that high-intensity interval training significantly improves aerobic capacity and cardiovascular efficiency through enhanced oxygen utilization and stroke volume adaptation (Buchheit & Laursen, 2013; Milanović et al., 2015). The reduction in resting heart rate observed in the experimental groups represents a typical adaptation to endurance training and improved autonomic regulation (Wilber, 2007).

The greater physiological improvement observed in the AHIIT group confirms that interval-based aquatic conditioning is particularly effective for enhancing cardiovascular fitness in swimmers.

Hydrodynamic Performance

Hydrodynamic performance variables, represented by swimming speed and lap time, improved significantly in both experimental groups, with greater improvements observed in the AKT group.

Swimming speed time decreased from 28.25 ± 0.17 s to 26.48 ± 0.18 s in the AKT group, indicating improved propulsion efficiency. The AHIIT group also improved from 28.30 ± 0.18 s to 26.05 ± 0.16 s, while only minimal changes were observed in the control group.

Similarly, lap time improved from 34.15 ± 0.58 s to 31.92 ± 0.31 s in the AKT group, compared with 34.10 ± 0.60 s to 31.11 ± 0.26 s in the AHIIT group. The control group showed only minor improvement.

These improvements indicate enhanced propulsion efficiency and stroke force application following aquatic resistance training. Resistance exercises performed in water provide multidirectional drag forces that closely replicate swimming propulsion patterns and improve neuromuscular coordination.

These findings are consistent with biomechanical research demonstrating that propulsion efficiency and force production are critical determinants of swimming performance (Barbosa et al., 2010; Seifert et al., 2010). Aquatic resistance training has previously been shown to improve swimming velocity and stroke mechanics through increased muscular coordination and propulsion effectiveness (Girold et al., 2007; Muñiz-Pardos et al., 2019).

The results suggest that aquatic kettlebell training represents an effective sport-specific resistance training method for improving hydrodynamic performance.

Hematological Adaptations

Moderate but significant improvements were observed in hematological parameters following both training interventions.

Hemoglobin concentration increased from 14.20 ± 0.35 g/dL to 15.13 ± 0.33 g/dL in the AHIIT group and from 14.15 ± 0.34 g/dL to 14.90 ± 0.32 g/dL in the AKT group, while the control group showed minimal change.

Similarly, hematocrit levels increased from 42.80 ± 0.95% to 45.12 ± 0.59% in the AHIIT group and from 42.70 ± 0.94% to 44.45 ± 0.61% in the AKT group.

These improvements indicate enhanced oxygen transport capacity and aerobic endurance potential following structured aquatic training.

These findings agree with previous studies indicating that endurance training stimulates hematological adaptation through increased red blood cell production and improved oxygen-carrying capacity (Sawka et al., 2000; Schmidt & Prommer, 2010; Wilber, 2007).

The larger hematological improvements observed in the AHIIT group correspond with the greater cardiovascular demand imposed by high-intensity interval training.

Integrated Interpretation

The results of the present investigation demonstrate that aquatic high-intensity interval training and aquatic kettlebell training produce complementary performance adaptations in competitive swimmers.

AHIIT produced superior improvements in:

- VO_2 max
- Resting heart rate
- Hemoglobin
- Hematocrit

AKT produced strong improvements in:

- Swimming speed
- Lap time

These findings support modern sport science approaches recommending the integration of interval training and resistance training within sport-specific environments to maximize performance adaptation (Buchheit & Laursen, 2013; Muñiz-Pardos et al., 2019).

Practical Implications

The findings of this study provide several practical implications for swimming coaches and sport scientists.

1. Coaching Application

Coaches may incorporate aquatic high-intensity interval training during aerobic conditioning phases to improve cardiovascular fitness and endurance capacity.

2. Sport-Specific Resistance Training

Aquatic kettlebell training provides water-based resistance while maintaining stroke-specific movement patterns, making it suitable for swimming performance enhancement.

3. Training Periodization

Integrating both aquatic interval training and aquatic resistance training within seasonal training plans may produce complementary performance adaptations.

4. Youth Athlete Development

Both training programs were well tolerated by adolescent swimmers, suggesting that supervised aquatic interval and resistance training can be safely implemented in youth swimming programs.

Limitations of the study

Despite the meaningful findings observed in the present investigation, several limitations should be acknowledged.

First, the sample size was relatively small and limited to forty-five adolescent male competitive swimmers from a single training center, which may restrict the generalizability of the results to other populations or elite-level swimmers.

Second, the intervention period was limited to sixteen weeks, which may not have been sufficient to observe long-term physiological and hematological adaptations.

Third, only six variables were selected, including VO_2max, resting heart rate, swimming speed, lap time, hemoglobin concentration, and hematocrit level. Although these variables represent key indicators of swimming performance, inclusion of additional biomechanical and metabolic variables such as stroke length or blood lactate concentration could have provided a more comprehensive performance analysis.

Fourth, dietary intake and lifestyle factors such as sleep and physical activity outside training were not strictly controlled, which may have influenced physiological responses.

Finally, hydrodynamic performance was assessed using swimming speed and lap time without advanced biomechanical analysis. Future studies are recommended to include underwater motion analysis and larger sample sizes to improve external validity.

Conclusions

The present investigation was undertaken to examine the comparative effects of Aquatic High-Intensity Interval Training (AHIIT) and Aquatic Kettlebell Training (AKT) on selected physiological, hydrodynamic, and hematological variables among adolescent competitive swimmers over a sixteen-week intervention period. The findings of the study clearly demonstrate that both training modalities produced statistically significant improvements when compared with the control group; however, the magnitude and nature of adaptations varied according to the training stimulus applied.

AHIIT proved to be more effective in enhancing cardiovascular and aerobic efficiency, as reflected by improvements in VO_2 Max and reductions in resting heart rate. These changes indicate improved cardiac output efficiency, oxygen utilization capacity, and overall endurance potential. On the other hand, AKT showed comparatively greater improvements in hydrodynamic performance, particularly swimming speed and lap time, suggesting that resistance-based aquatic training contributes substantially to propulsion mechanics, stroke force, and water-based muscular coordination.

Both experimental groups also demonstrated moderate yet meaningful improvements in selected hematological parameters, specifically hemoglobin concentration and hematocrit levels. These adaptations signify improved oxygen-carrying capacity and physiological readiness for sustained performance. The control group, which continued routine training without structured intervention, exhibited only marginal or negligible changes across all variables, emphasizing the necessity of systematic, scientifically designed aquatic training protocols.

Overall, the study confirms that sport-specific aquatic interval and resistance training methods are effective, safe, and complementary approaches for improving multidimensional swimming performance in adolescent athletes. The results strongly support the inclusion of structured AHIIT and AKT programs within competitive swim training schedules. A combined or periodized application of both modalities may yield optimal performance benefits by simultaneously addressing endurance, strength, efficiency, and physiological adaptation.

Thus, the study contributes meaningful empirical evidence to sports training literature and provides practical direction for coaches, trainers, and sports scientists seeking evidence-based aquatic conditioning strategies.

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References

Barbosa, T. M., Fernandes, R. J., Keskinen, K. L., & Vilas-Boas, J. P. (2008). The influence of stroke mechanics on energy cost of elite swimmers. *European Journal of Applied Physiology, 103*(2), 139–149. https://doi.org/10.1007/s00421-008-0676-z

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle. *Sports Medicine, 43*(5), 313–338. https://doi.org/10.1007/s40279-013-0029-x

Costa, M. J., Bragada, J. A., Mejias, J. E., Louro, H., Marinho, D. A., Silva, A. J., & Barbosa, T. M. (2013). Effects of swim training on energetics and performance. *International Journal of Sports Medicine, 34*(6), 507–513. https://doi.org/10.1055/s-0032-1327573

Craig, A. B., & Pendergast, D. R. (1979). Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. *Medicine & Science in Sports & Exercise, 11*(3), 278–283. https://doi.org/10.1249/00005768-197901130-00011

Crowley, E., Harrison, A. J., & Lyons, M. (2017). The impact of resistance training on swimming performance: A systematic review. *Sports Medicine, 47*(11), 2285–2307. https://doi.org/10.1007/s40279-017-0730-2

Garcia, WF., Soares Mendes Nunes, R., Nunes Carreira, C., & Vitor Suto Aizava, P. (2024). Distribution of training loads and periodization in open water swimming: A systematic review. *Retos* , *56* , 1-8. https://doi.org/10.47197/retos.v56.102741

Girold, S., Maurin, D., Dugué, B., Chatard, J., & Millet, G. (2007). EFFECTS OF DRY-LAND VS.RESISTED- AND ASSISTED-SPRINT EXERCISES ON SWIMMING SPRINT PERFORMANCES. *The Journal of Strength and Conditioning Research*, *21*(2), 599–605. https://doi.org/10.1519/00124278-200705000-00054

Laursen, P. B., & Jenkins, D. G. (2002). The scientific basis for high-intensity interval training. *Sports Medicine,* *32*(1), 53–73. https://doi.org/10.2165/00007256-200232010-00003

Milanović, Z., Sporiš, G., & Weston, M. (2015). Effectiveness of high-intensity interval training vs moderate continuous training. *Sports Medicine,* *45*(10), 1469–1481. https://doi.org/10.1007/s40279-015-0365-0

Muniz-Pardos, B., Gomez-Bruton, A., Matute-Llorente, A., Gonzalez-Aguero, A., Gomez-Cabello, A., Gonzalo-Skok, O., Casajus, J. A., & Vicente-Rodriguez, G. (2019). Swim-Specific Resistance Training: A Systematic review. *The Journal of Strength and Conditioning Research*, *33*(10), 2875–2881. https://doi.org/10.1519/jsc.0000000000003256

Orejuela Aristizabal, DF., Cardona Orejuela, JS, & Rengifo Cruz, R. (2023). Bibliometric analysis of scientific production in the field of swimming. *Retos* , *47* , 215-220. https://doi.org/10.47197/retos.v47.94160

Pöyhönen, T., Keskinen, K. L., Hautala, A., Savolainen, J., & Mälkiä, E. (1999). Human isometric force production and electromyogram activity of knee extensor muscles in water and on dry land. *European Journal of Applied Physiology,* *80*(1), 52–56. https://doi.org/10.1007/s004210050557

Sawka, M. N., Convertino, V. A., Eichner, E. R., Schnieder, S. M., & Young, A. J. (2000). Blood volume: importance and adaptations to exercise training. *Medicine & Science in Sports & Exercise, 32*(2), 332–348. https://doi.org/10.1097/00005768-200002000-00012

Schmidt, W., & Prommer, N. (2010). Impact of alterations in total hemoglobin mass on VO_2max. *Exercise and Sport Sciences Reviews,* *38*(2), 68–75. https://doi.org/10.1097/JES.0b013e3181d4957a

Seifert, L., Komar, J., Lepretre, P. M., Lemaitre, F., Chavallard, F., Alberty, M., Hausswirth, C., Chollet, D., & Hellard, P. (2010). Swim specialty affects energy cost and motor organization. *International Journal of Sports Medicine,* *31*(9), 624–630. https://doi.org/10.1055/s-0030-1255066

Seiler, S., & Tønnessen, E. (2009). Intervals, thresholds, and long slow distance. *Sportscience, 13*, 32–53.

Toussaint, H. M., & Truijens, M. J. (2005). Biomechanical aspects of peak performance in human swimming. *Animal Biology,* *55*(1), 17–40. https://doi.org/10.1163/1570756053276907

Wilber, R. L. (2007). Application of Altitude/Hypoxic training by elite athletes. *Medicine & Science in Sports & Exercise*, *39*(9), 1610–1624. https://doi.org/10.1249/mss.0b013e3180de49e6

Barbosa, T. M., Costa, M., Marinho, D., Coelho, J., Moreira, M., & Silva, A. (2010). Modeling the links between young swimmers' performance: energetic and biomechanical profiles. *Pediatric Exercise Science,* *22*(3), 379–391. https://doi.org/10.1123/pes.22.3.379

Varghese, A., & Bharti, R. S. (2025). Effects of aquatic high-intensity interval training on VO_2max and swimming speed in competitive swimmers: A 16-week intervention study. Fizjoterapia Polska, 25(4). https://doi.org/10.56984/8ZGA431B2H9

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