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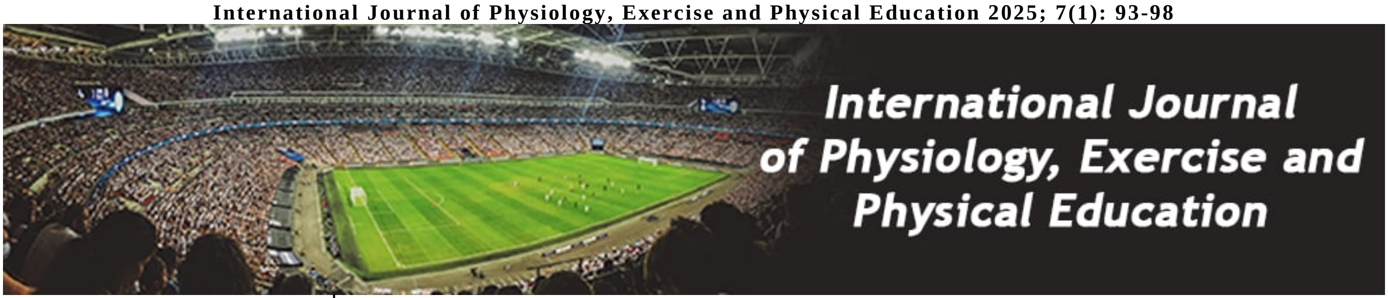


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# Analyzing aerobic endurance via 5×200 m testing in young female competitors

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**Abstract**

This study aimed to assess the aerobic endurance capacity of seven adolescent female athletes (aged 12-14 years; body weight: 45-56.7 kg; height: 155-167.5 cm) through the application of the 5 × 200 m Aerobic Step Test. This protocol provides a structured framework for evaluating physiological responses to submaximal exercise and is particularly relevant for coaches and sports scientists seeking to understand aerobic conditioning parameters in youth athletes. Key performance indicators-namely running speed, heart rate, and blood lactate concentration at the lactate threshold (LT)-were analyzed to evaluate training effectiveness and physiological adaptation to aerobic exercise.

Data collection occurred during and immediately after each 200 m repetition. Heart rate was continuously monitored using a Polar Verify device affixed to the athletes' swim goggles, while blood lactate concentrations were assessed with a portable lactate analyzer. The dataset was processed using the Slope Analysis method, facilitating detailed interpretation of performance dynamics across the five repetitions.

At the lactate threshold, the athletes demonstrated an average completion time of 137.14±1.35 seconds (range: 135-139 s), corresponding to a mean speed of 1.46±0.01 m/s (range: 1.439-1.481 m/s). The average heart rate recorded at LT was 164.86±2.79 bpm (range: 161-169 bpm), with mean blood lactate concentrations of 5.8±0.38 mmol/L (range: 5.2-6.3 mmol/L). These findings suggest that the athletes maintained stable performance throughout the protocol and exhibited a well-developed capacity to sustain aerobic effort at intensities approaching the LT.

The results provide practical implications for developing individualized training programs targeting aerobic endurance in adolescent female athletes. Future investigations may benefit from larger sample sizes, longitudinal study designs, and integration of advanced physiological monitoring tools to enhance the precision of aerobic capacity assessment.

**Keywords:** Aerobic endurance capacity, lactate threshold, slope analysis, adolescent female athletes, 5 × 200 m aerobic step test

## Introduction

In contemporary sports training, particularly in swimming, aerobic endurance is recognized as a fundamental determinant of both performance and long-term athletic development (Bompa & Carrera, 2020) [3]. For adolescent female swimmers, enhancing aerobic capacity is not only critical for sustaining performance during training and competition but also for fostering the development of cardiovascular, respiratory, and related physiological systems (Maglischo, 2003) [5]. Consequently, systematic evaluation of aerobic endurance in this population is essential, serving as a scientific basis for designing safe, individualized, and effective training programs that align with athletes' developmental needs.

Beyond technical and tactical skill acquisition, the integration of physiological monitoring into training has become indispensable in modern coaching practice (Bompa & Carrera, 2020; Anderson & Rhodes, 2018) [3, 1]. Key physiological parameters-such as heart rate (HR), maximal oxygen uptake ($VO_2$max), lactate threshold, and recovery capacity-provide valuable insights into an athlete's fitness profile and adaptive response to training loads (Bishop *et al.*, 2013) [2]. This is particularly relevant for young athletes whose bodies are in dynamic stages of growth and maturation. As physiological systems are still developing, continuous and accurate monitoring is required to assess progress, adjust workloads, and prevent overtraining or injury (Plowman & Smith, 2014) [7].

Among the validated field tests used to assess aerobic endurance in swimmers, the 5 × 200 m Aerobic Step Test has emerged as a practical and reliable tool (Maglischo, 2003) [5]. This protocol involves five successive 200 m swimming efforts, with progressive monitoring of physiological responses such as heart rate, blood lactate concentration, and recovery metrics (Anderson & Rhodes, 2018) [1]. The structured format allows coaches to determine individual lactate thresholds, evaluate recovery capacity, and refine training intensity zones. Moreover, the stepwise nature of the test reflects the increasing aerobic demand and provides clear indicators of an athlete's endurance capacity and adaptation under controlled overload conditions (Bishop *et al.*, 2013) [2].

The present study aims to analyze and evaluate aerobic endurance and associated physiological responses in adolescent female swimmers using the 5 × 200 m Aerobic Step Test. Specifically, it seeks to explore the relationships among performance metrics, cardiovascular and metabolic responses, and the athletes' ability to sustain and recover from repeated submaximal efforts (Plowman & Smith, 2014) [7]. The results are expected to offer an evidence-based foundation for constructing individualized training programs focused on aerobic development, while also contributing to the assessment and optimization of current coaching practices.

In an increasingly competitive athletic landscape, the use of objective assessment tools such as the Aerobic Step Test is no longer optional, but a strategic imperative for performance optimization. The integration of sports science methodologies with applied coaching not only enhances the effectiveness of training but also supports the holistic development of youth athletes. By contributing to the refinement of evaluation protocols and offering practical insights into endurance training, this study aspires to support the advancement of competitive youth swimming at both national and international levels (Bompa & Carrera, 2020) [3].

## Method

This study involved 7 female swimmers aged 12-14 years, with body weights ranging from 45 to 56.7 kg and heights between 155 and 167.5 cm. All participants had a minimum of 2 years of formal swimming training and no history of severe cardiovascular or respiratory conditions. Data collection was conducted in early 2023, at the beginning of a new training cycle. Participants, along with their parents or guardians (for those under 14), and coaches, were fully informed of the study's objectives, procedures, and potential risks, and all consented voluntarily to participate.

Participants perform five consecutive 200 m swims at incrementally increasing intensities, ranging from easy to near-maximal effort. Each swim starts with a push-off from the pool wall rather than a dive start and is separated by a 5-minute recovery interval. Prior to the test, swimmers complete a pre-step test questionnaire to confirm readiness and receive briefing on testing procedures, environmental conditions, and pacing targets. The target time for each stage is determined in consultation with the swimmer, coach, and support staff, typically calculated from the estimated final split, plus a 5-second margin for the push start (e.g., 1:50 → 1:55 for stage 5). Working backward, an additional 5 seconds is added at each preceding step to outline the entire testing protocol.

Manual timing is used to record both the 100 m split and the total 200 m time; stroke rate is measured on the third lap and stroke count on the fourth. Immediately upon completing each 200 m, the swimmer measures HR via a waterproof heart rate monitor, rates their perceived exertion using the Borg scale (6-20 or 1-10), and exits the pool for a quick capillary blood sample (earlobe) to determine [La-]. This procedure is done promptly to adhere to the 5-minute cycle, allowing swimmers enough time to re-enter the water (at least 15 seconds prior to the start of the next swim). For the final (fifth) swim, the blood sample is drawn at 3 minutes post-exercise; coaches may optionally take additional samples for up to 10 minutes to capture peak post-exercise lactate.

Data analysis included Slope Analysis to assess relationships between swim speed and physiological responses, with slope (b) and correlation coefficient (r) calculations identifying the rate of change in variables such as lactate. The Slope Analysis method is used to evaluate the relationship between velocity and blood lactate concentration ([La]) during progressively increasing exercise intensities. At each step of the test, velocity (viv_ivi) is calculated by dividing the distance (200 m) by the time taken (in seconds). Simultaneously, lactate concentration (LiL_iLi) is measured using a lactate analyzer.

The slope between two consecutive steps ($slope_{i \to i+1}$) is determined using the formula $(L_{i+1} - L_i)/(v_{i+1} - v_i)$, representing the rate of lactate increase relative to the change in velocity. A steeper slope indicates a rapid rise in lactate, suggesting a transition from aerobic to anaerobic metabolism. The Lactate Threshold (LT) is typically identified at the "breakpoint," where the slope (slopeslopeslope) increases sharply compared to previous steps. This breakpoint is often the step with the steepest slope or the step immediately preceding the abrupt rise in slope, marking a critical metabolic transition point for the athlete. Descriptive statistics (mean, standard deviation, and range) were computed for swim times, heart rate, and lactate.

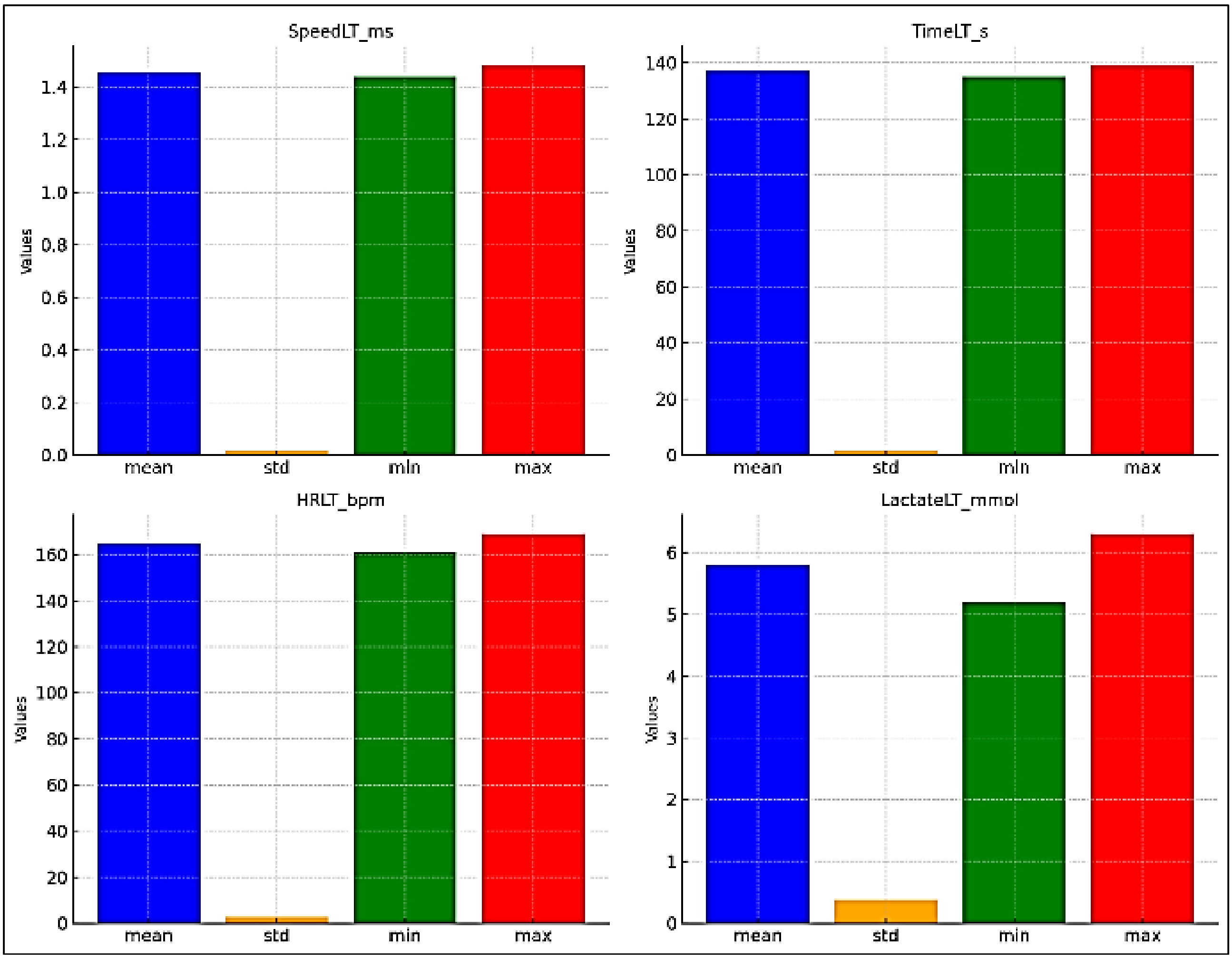
Ethical considerations ensured voluntary participation with full disclosure, guaranteed data confidentiality, and the presence of medical staff or certified coaches to handle any adverse events during the testing process.

## Results

The present study sought to detail the physiological and biomechanical profiles of seven young female swimmers (ages 12-14) under progressively increasing workloads. The findings presented below are divided into three main sections to clarify key aspects of their performance.

**Table 1:** Time and physiological variables at lactate threshold

| | mean | std | min | 25% | 50% | 75% | max |
|---|---|---|---|---|---|---|---|
| Time_at_LT (s) | 137.14 | 1.35 | 135 | 136.5 | 137 | 138 | 139 |
| Speed_at_LT (m/s) | 1.46 | 0.01 | 1.439 | 1.449 | 1.46 | 1.4655 | 1.481 |
| Heart_Rate_at_LT (bpm) | 164.86 | 2.79 | 161 | 163 | 165 | 166.5 | 169 |
| Lactate_at_LT (mmol/L) | 5.8 | 0.38 | 5.2 | 5.55 | 5.9 | 6.05 | 6.3 |




**Graph 1:** Descriptive Statistics: Group 1 Metrics

The lactate threshold (Time_at_LT) typically emerged during the third or fourth Step (B3-B4), indicating variability in individual swimmers' total time to threshold. On average, swimmers reached this point at around 137 seconds (SD = 1.35), suggesting most approached threshold intensity near two minutes and 17 seconds. The mean speed at threshold (Speed_at_LT) was 1.46 m/s (SD = 0.01), indicating a relatively narrow range of swimming velocities among participants. Heart_Rate_at_LT averaged approximately 165 bpm, suggesting a moderate-to-high cardiovascular effort at LT. Meanwhile, lactate_at_LT had a mean of 5.80 mmol/L (SD = 0.38), with values ranging from 5.2 to 6.3 mmol/L, aligning with typical lactate threshold profiles observed in adolescent swimmers.

**Table 2:** Arm frequency and stride length across five steps

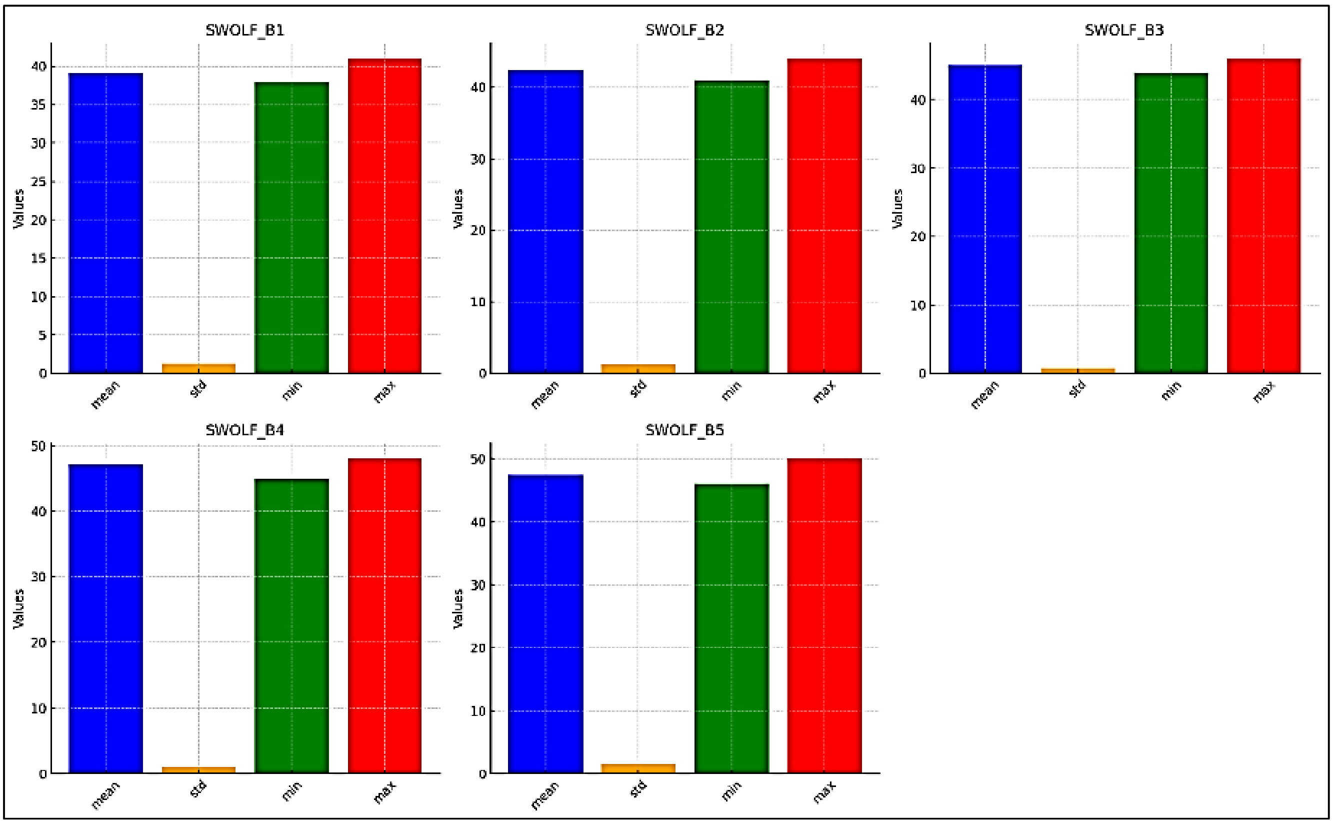
| | mean | std | min | 25% | 50% | 75% | max |
|---|---|---|---|---|---|---|---|
| Arm_Frequency_B1 | 32 | 1.73 | 30 | 30.5 | 32 | 33.5 | 34 |
| Arm_Frequency_B2 | 35.86 | 1.35 | 34 | 35 | 36 | 36.5 | 38 |
| Arm_Frequency_B3 | 39.86 | 1.35 | 38 | 39 | 40 | 40.5 | 42 |
| Arm_Frequency_B4 | 44 | 1.53 | 42 | 43 | 44 | 45 | 46 |
| Arm_Frequency_B5 | 48.14 | 1.35 | 46 | 47.5 | 48 | 49 | 50 |
| Stride_Length_B1 (m) | 1.9 | 0.08 | 1.8 | 1.85 | 1.9 | 1.95 | 2 |
| Stride_Length_B2 (m) | 1.8 | 0.06 | 1.7 | 1.8 | 1.8 | 1.8 | 1.9 |
| Stride_Length_B3 (m) | 1.69 | 0.07 | 1.6 | 1.65 | 1.7 | 1.7 | 1.8 |
| Stride_Length_B4 (m) | 1.56 | 0.05 | 1.5 | 1.5 | 1.6 | 1.6 | 1.6 |
| Stride_Length_B5 (m) | 1.43 | 0.05 | 1.4 | 1.4 | 1.4 | 1.45 | 1.5 |


**Graph 2: a)** Arm Frequency Metrics **b)** Stride Length Metrics

Arm frequency (strokes per minute measured or cycle count per unit time) increased steadily from B1 (mean = 32) to B5 (mean = 48.14), reflecting intensified exertion and the need to maintain higher swimming velocity across successive bouts. Conversely, stride length (or effective distance per stroke cycle) showed a decreasing trend (from a mean of 1.90 m in B1 to 1.43 m in B5), indicating that as stroke rate increases, individual stroke distance tends to shorten-likely a result of fatigue or the biomechanical constraints of faster arm turnover.

**Table 3:** SWOLF Index over five steps

| | mean | std | min | 25% | 50% | 75% | max |
|---|---|---|---|---|---|---|---|
| SWOLF_B1 | 39.14 | 1.21 | 38 | 38 | 39 | 40 | 41 |
| SWOLF_B2 | 42.43 | 1.27 | 41 | 41.5 | 42 | 43.5 | 44 |
| SWOLF_B3 | 45 | 0.82 | 44 | 44.5 | 45 | 45.5 | 46 |
| SWOLF_B4 | 47.14 | 1.07 | 45 | 47 | 47 | 48 | 48 |
| SWOLF_B5 | 47.43 | 1.62 | 46 | 46 | 47 | 48.5 | 50 |




**Graph 3:** SWOLG Scores Metrics

Focusing solely on arm frequency across the five bouts highlights a clear progression in stroke rate as intensity rises. Swimmers began with a moderate stroke rate (mean = 32 at B1) and escalated to nearly 48 strokes per minute by B5, reinforcing the finding that higher stroke frequencies are employed to sustain increased speeds. The standard deviations remain modest, suggesting relatively consistent technique adjustments among the swimmers as they move from lower to higher intensities.

## Discussion

The findings of this study offer critical insights into the physiological and biomechanical profiles of adolescent female swimmers (aged 12-14 years) when subjected to progressively increasing training loads. Notably, the analysis of lactate threshold (LT) parameters revealed that, on average, participants reached LT at approximately 137 seconds (Time_at_LT), corresponding to a mean swimming velocity of 1.46 m/s. Blood lactate concentration at this threshold averaged 5.80 mmol/L, accompanied by a mean heart rate of approximately 165 bpm. These values are consistent with previous literature, which suggests that adolescent swimmers typically exhibit LT values in the range of 4-6 mmol/L (Maglischo, 2003; Toupalik & Struhar, 2011) [5], and submaximal heart rates between 160-170 bpm in well-trained youth athletes (Toubekis & Tokmakidis, 2013) [9].

From a biomechanical perspective, results presented in Parts 2 and 3 illustrate a clear inverse relationship between stroke rate (arm frequency) and stroke length as intensity increases. Arm frequency rose from approximately 32 cycles (B1) to 48 cycles (B5), while stroke length declined from 1.90 m to 1.43 m over the same intervals. This trade-off, where swimmers increase stroke rate at the expense of stroke length to maintain or enhance velocity, is well documented in competitive swimming (Pyne & Sharp, 2014) [8]. While this adaptation may be effective in high-intensity sprint efforts, it may compromise efficiency and energy economy during middle- and long-distance performance (Toubekis & Tokmakidis, 2013) [9].

The average lactate threshold value of 5.80 mmol/L further suggests a favorable metabolic profile among these young athletes, indicative of structured and consistent training designed to improve both aerobic and anaerobic capacities. Previous work by Foster *et al.* (1993) [4] highlighted that lactate responses at submaximal levels serve as proxies for skeletal muscle adaptation. Accordingly, the data imply that these athletes have already developed a moderate-to-high tolerance to lactate accumulation-an adaptation that can be enhanced with targeted endurance conditioning.

In parallel, the observed mean heart rate of ~165 bpm at LT points to robust cardiovascular conditioning. This capacity to sustain high workloads without approaching maximal effort underscores the importance of integrating periodized training models. Combining high-volume aerobic work to build an endurance base with strategically placed high-intensity intervals to elevate LT is a well-supported strategy for enhancing performance in developing athletes (Bompa & Carrera, 2020; Maglischo, 2003) [3, 5].

Regarding stroke mechanics, the study reinforces the need for coaches and sports scientists to balance stroke rate and stroke length across training phases. While increased stroke rate may yield short-term velocity gains, preserving stroke length is essential for propulsion efficiency and injury prevention, particularly in longer-distance events (Olbrecht, 2000) [6]. Training interventions should therefore aim to optimize this balance, promoting stroke efficiency alongside enhanced lactate management.

In conclusion, this study highlights the interplay between physiological responses (e.g., lactate threshold, heart rate) and biomechanical adaptations (e.g., stroke frequency and length) in adolescent female swimmers. The findings establish baseline performance parameters that can inform individualized training prescription. Future research should consider longitudinal monitoring across competitive seasons, incorporate oxygen uptake ($VO_2$) and recovery metrics, and explore sex- and age-specific adaptations to refine developmental training frameworks further. Collectively, these results contribute to a growing body of evidence supporting science-driven approaches to youth athletic development.

## Conclusion

The present findings indicate that female swimmers aged 12-14 possess a relatively solid foundation in both physical conditioning and technical proficiency, as demonstrated by their mean lactate threshold time (~137 seconds) around step 3 and 4 and subthreshold velocity (1.46 m/s). An average lactate concentration of around 5.80 mmol/L at threshold, coupled with a heart rate of approximately 165 bpm, highlights these swimmers' capacity to tolerate and adapt to moderately high workloads. Meanwhile, the observed increase in stroke frequency (arm frequency) was accompanied by a decrease in stride length and swimming efficiency (SWOLF) under higher intensities, underscoring the trade-off between stroke rate and overall performance. These results underscore the importance of designing training programs that balance aerobic-anaerobic development with the preservation of efficient stroke mechanics to ensure sustainable, long-term improvements in young swimmers' performance.

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