

## The effects of high-intensity hypoxic training on 50m freestyle swimming performance

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### Abstract:

This study investigates the effects of a six-week high-intensity hypoxic training intervention on adolescent competitive swimmers. Sixteen participants were divided into two groups: an experimental group (EX), which performed hypoxic training sessions twice per week, and a control group (CG), which followed a standard training program. Performance was assessed through four specific tests: static apnea duration, breath-hold distance, 50-meter freestyle time, and number of breaths taken during exercise. To assess both the statistical and practical significance of the intervention, the effect size coefficient "r" (Effect Size, ES) was calculated for each variable. The EX group demonstrated statistically significant improvements across all measured parameters. Specifically, static apnea duration increased by 9.63% ( $p < 0.05$ ;  $ES = 0.26$ ), breath-hold distance improved by 7.31% ( $p < 0.05$ ;  $ES = 0.38$ ), number of breaths decreased by 47.92% ( $p < 0.05$ ;  $ES = 1.57$ ), and 50-meter freestyle time decreased by 1.97% ( $p < 0.05$ ;  $ES = 0.89$ ). In contrast, the CG showed only marginal improvement, with a statistically significant change observed only in the 50-meter freestyle time (1.06%,  $p < 0.05$ ;  $ES = 0.52$ ). These results are consistent with previous research suggesting that controlled hypoxic training enhances physiological adaptations, including improved oxygen utilization and respiratory efficiency. These findings support prior research suggesting that controlled hypoxic exposure leads to beneficial physiological adaptations, including enhanced oxygen utilization, respiratory control, and improved athletic performance under limited oxygen availability. The study highlights the value of integrating hypoxic training into swim programs for improving both breath control and endurance in young athletes.

**Key Words:** Intermittent hypoxic exposure, respiratory muscle adaptation, oxygen uptake efficiency, swimming sprint capacity, youth athletic performance.

### Introduction

Hypoxic training may elicit various physiological and performance-related effects in youth athletes across multiple sports. In competitive swimming, performance at sprint distances such as 50 meters is highly dependent on efficient oxygen utilization and the ability to tolerate hypoxic conditions. Its primary objective is to enhance athletic performance by increasing aerobic capacity, which is achieved through physiological adaptations such as increased red blood cell count and enhanced blood oxygen capacity due to elevated erythropoietin production (Maciejczyk, M., Palka, T., Wiecek, M, 2024). Additionally, intermittent hypoxic training may improve anaerobic performance by enhancing glycolytic enzyme activity and muscle buffering capacity, which can be beneficial for sports requiring short bursts of high-intensity effort (Maciejczyk, M., Palka, T., Wiecek, M, 2024).

Although increasingly utilized, the long-term and sport-specific effects of hypoxic training in adolescent athletes remain insufficiently investigated. In particular, limited data exist on how hypoxic interventions affect short-distance swimming performance and breath control efficiency in youth populations.

Nevertheless, the specific effects of hypoxic training on youth athletes may vary depending on the sport and individual training responses. While some studies suggest that hypoxic training can be beneficial for endurance and anaerobic performance, the overall evidence is still limited, particularly regarding its long-term effects on youth athletes (Maciejczyk, M., Palka, T., Wiecek, M, 2024).

Studies investigating hypoxic training in swimming have demonstrated notable performance enhancements. High-intensity intermittent hypoxic training (IHT) has been found to improve swimming sprint performance, with studies reporting increases of 2.1% in 100 m and 1.8% in 200 m events among well-trained swimmers (Czuba, M., Wilk, R., Karpiński, J., Chalimoniuk, M., Zajac, A., & Langfort, J., 2017). Additionally, hypoxic training methods that include various training modalities have been effective in improving muscular strength and endurance in moderately trained competitive swimmers (Park, H. Y., & Lim, K. 2017).

Further research indicates that specific hypoxic training protocols, such as repeated-sprint training in hypoxia, can enhance exercise economy and aerobic performance (Camacho-Cardenosa, M., Camacho-Cardenosa, A., González-Custodio, A., Zapata, V., & Olcina, G., 2020). However, while acute hypoxia can negatively impact performance, chronic exposure may lead to acclimatization, potentially improving aerobic capacity over time (Truijens, M., & Rodríguez, F.A., 2013). Common hypoxic training protocols in swimming research encompass various methods designed to enhance performance through reduced oxygen exposure.

**Living High-Training Low (LHTL):** A strategy where athletes reside at high altitudes while training at lower elevations, LHTL is favored for its minimal interference with standard training regimens (Camacho-Cardenosa, M., Camacho-Cardenosa, A., González-Custodio, A., Zapata, V., & Olcina, G., 2020).

**Intermittent Hypoxic Training (IHT):** This approach typically involves shorter hypoxic exposure times, lasting less than three hours, and is conducted two to five times per week. It is considered effective in improving performance with relatively low time demands (Park, H. Y., & Lim, K. 2017).

**Repeated Sprint Training in Hypoxia (RSH):** RSH emphasizes swimming-specific repeated sprints under hypoxic conditions, inducing considerable physiological stress, though its effectiveness varies across events such as the 100 and 400 m freestyle (Camacho-Cardenosa, M., Camacho-Cardenosa, A., González-Custodio, A., Zapata, V., & Olcina, G., 2020).

**Resistance Training in Hypoxia (RTH):** This involves incorporating resistance training while in hypoxic conditions, which can also contribute to improvements in muscular strength and endurance (Park, H. Y., & Lim, K. 2017).

To address the gap in understanding the effectiveness of hypoxic training in adolescent swimmers, this study employed an experimental design focusing on performance metrics in the 50-meter freestyle. Sixteen youth swimmers were divided into two groups: an experimental group that participated in hypoxic training sessions twice per week and a control group that followed a standard training plan. Over six weeks, the study evaluated four key variables: static apnea duration, breath-hold distance, 50-meter freestyle time, and the number of breaths taken during exercise. Statistical analyses were applied to determine significance and effect sizes, allowing for comparison between groups and pre/post intervention outcomes.

Repeated Sprint Training in Hypoxia (RSH) is most often used in swimming. RSH has been the subject of various scientific studies that explore its methodology, physiological adaptations, and effects on athletic performance. Research indicates that RSH can lead to significant improvements in repeated-sprint performance compared to training in normoxia (RSN). (Brocherie, F., Girard, O., Faiss, R., & Millet, G. P. 2017). A meta-analysis of multiple studies suggests that RSH enhances mean repeated-sprint performance during sea-level activities, indicating its effectiveness as a training strategy. (Brocherie, F., Girard, O., Faiss, R., & Millet, G. P. 2017). Additionally, a case study highlighted the benefits of RSH in professional cyclists, demonstrating performance gains and muscular adaptations after a regimen of repeated sprints in hypoxia (Faiss, R., & Rapillard, A. 2020). The methodology typically involves training under controlled hypoxic conditions, which can induce greater physiological adaptations than normoxic training (Piperi, A., Warnier, G., VAN Doorslaer DE Ten Rye, et al 2024). However, the specific protocols and outcomes can vary across studies, with some reporting additional performance improvements when hypoxia is incorporated into sprint training (Faiss, R., Raberin, A., Brocherie, F., & Millet, G. P. 2024). Limited information is available on specific RSH protocols and their long-term effects across diverse athletic populations (Julius AI. 2024).

## Material & methods

### Participants

Sixteen performance-level swimmers participated in the experiment. The average age was  $14.6 \pm 0.4$  years, with an average height of 169.6 cm ( $\pm 6.9$  cm) and an average weight of 55.75 kg ( $\pm 8.3$  kg). Each participant had been engaged in competitive swimming for more than five years, and all had achieved at least a 5th-place finish in Slovak national competitions.

### Procedure

In the study, we used a quasi-experimental parallel-group design. Participants were assigned to two groups using a purposive-random sampling method. The experimental group underwent hypoxic training, while the control group did not receive this intervention. Both the experimental and control groups consisted of eight participants and followed the same training load, except for the hypoxic sessions. The participants completed a six-week training program, during which hypoxic training was implemented twice per week, specifically during Monday and Thursday training sessions. Final testing was conducted at the end of the training program.

### Test Protocol

The Static Apnea (STA) test measures an individual's ability to hold their breath underwater for as long as possible without movement. The participant remains stationary, lying face-down in the water, focusing on relaxation and mental control to maximize breath-hold duration. The test is conducted under the supervision of an external examiner who ensures safety and adherence to standard protocols. To successfully complete the test, the participant must perform a proper surface protocol upon resurfacing, demonstrating full awareness and control. The time was recorded. The STA test was performed first.

Following the STA test, participants swam between 800 and 1000 meters as a warm-up at an intensity corresponding to 120–140 heartbeats per minute, monitored using Garmin HRM-Swim™ chest straps. The second test measured the distance swum in one breath using the front crawl technique (breath-hold distance). In this test, the participant stood by the pool wall, took a deep breath, and pushed off. The subject then swam a slow front crawl to the maximum distance possible. During the test, the swimmer executed a pendulum turn. The entire effort was closely monitored by an examiner walking alongside the participant at the pool's edge. The test ended at the moment the swimmer stopped.

The third test involved measuring the time and the number of breaths taken during a 50-meter front crawl. The participant started from the swimming platform. At the signal, the swimmer began and performed the 50-meter front crawl at maximum intensity in accordance with FINA rules. Both the time and the number of breaths were recorded during the swim.

#### Data Collection

Time was recorded to the hundredth of a second using an OMEGA touchpad, and distance was measured in centimeters using BinarySports software in conjunction with a GoPro HERO 12 camera. For the STA test, a handheld stopwatch was used, and time was recorded with accuracy to the nearest second.

#### Statistical Analysis

We used IBM SPSS 27 (IBM, Armonk, NY, USA) to process and evaluate the data obtained. To determine the statistical significance of pre- and post-training diagnostics within each group, we applied the non-parametric Wilcoxon signed-rank test for paired samples. A non-parametric Mann-Whitney U-test was used to evaluate statistical significance between the post-training values of the two groups.

To assess practical significance and the magnitude of the methods' effects, we calculated the effect size coefficient "r" (Effect Size; ES), in accordance with the guidelines of Cohen (1994) and Maher et al. (2013). Differences were considered statistically significant at a p-value of less than 0.05.

The research was granted ethical approval by the FPES CU Committee of Ethics in Bratislava (ref. 9/2023) and complied with the World Medical Association's Code of Ethics (Declaration of Helsinki).

## Results

### Static Apnea

We recorded the following changes: The CG group improved from  $191.625 \pm 60$  [s] to  $191.5 \pm 57$  [s]; 2.69%; n.s.; ES = 0.15. The EX group improved from  $192 \pm 54$  [s] to  $206.375 \pm 52$  [s]; 9.63%;  $p < 0.05$ ; ES = 0.26. Post-training values between CG and EX were significant ( $p < 0.05$ ).

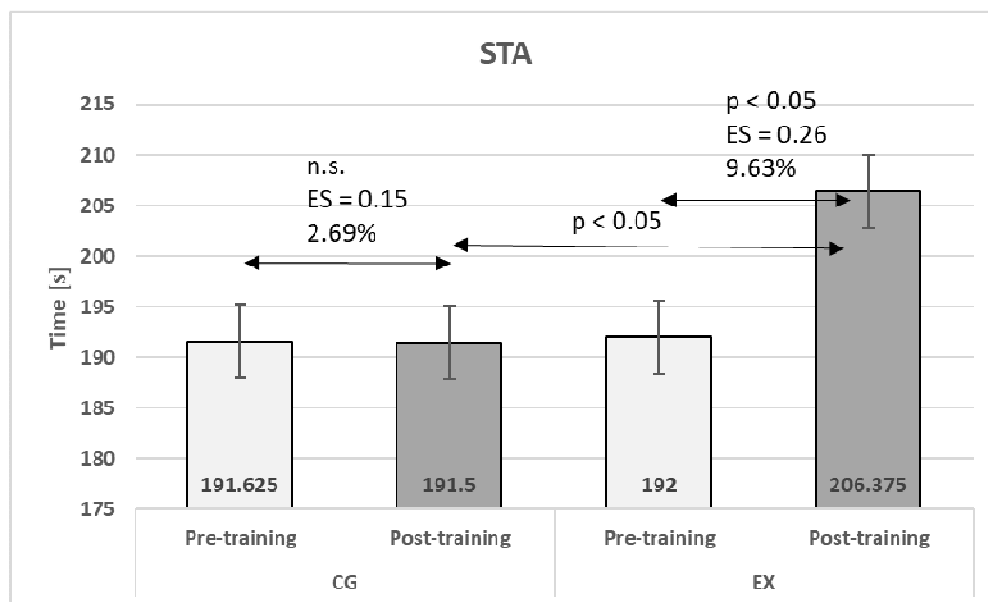


Figure 1. Static Apnea

### Breath-hold distance

We recorded the following changes: The CG group improved from  $49.75 \pm 8$  [m] to  $51 \pm 8$  [m]; 2.69%;  $p > 0.05$ ; ES = 0.15. The EX group improved from  $51.875 \pm 9$  [m] to  $55.375 \pm 9$  [m]; 7.31%;  $p < 0.05$ ; ES = 0.38. Post-training values between CG and EX were significant ( $p < 0.05$ ).

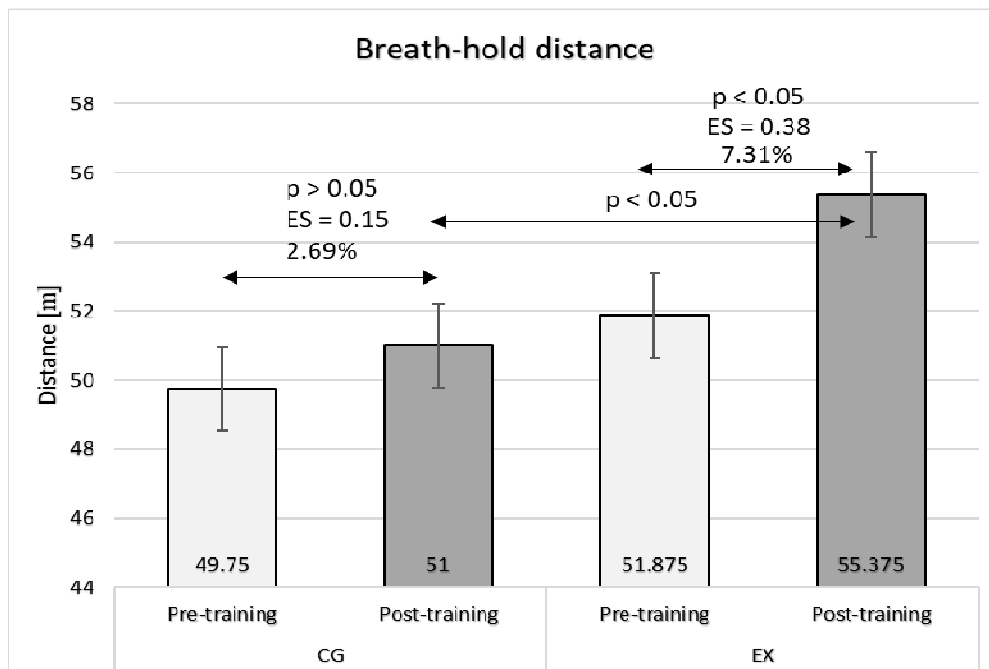


Figure 2. Breath-hold distance

#### Number of breaths

We recorded the following changes: The CG group improved from  $2.25 \pm 0.8$  [rep] to  $2.21 \pm 0.6$  [rep]; 1.78%;  $p > 0.05$ ; ES = 0.16. The EX group improved from  $2.25 \pm 0.6$  [rep] to  $1 \pm 0.7$  [rep]; 47.92%;  $p < 0.05$ ; ES = 1.57. Post-training values between CG and EX were significant ( $p < 0.05$ ).

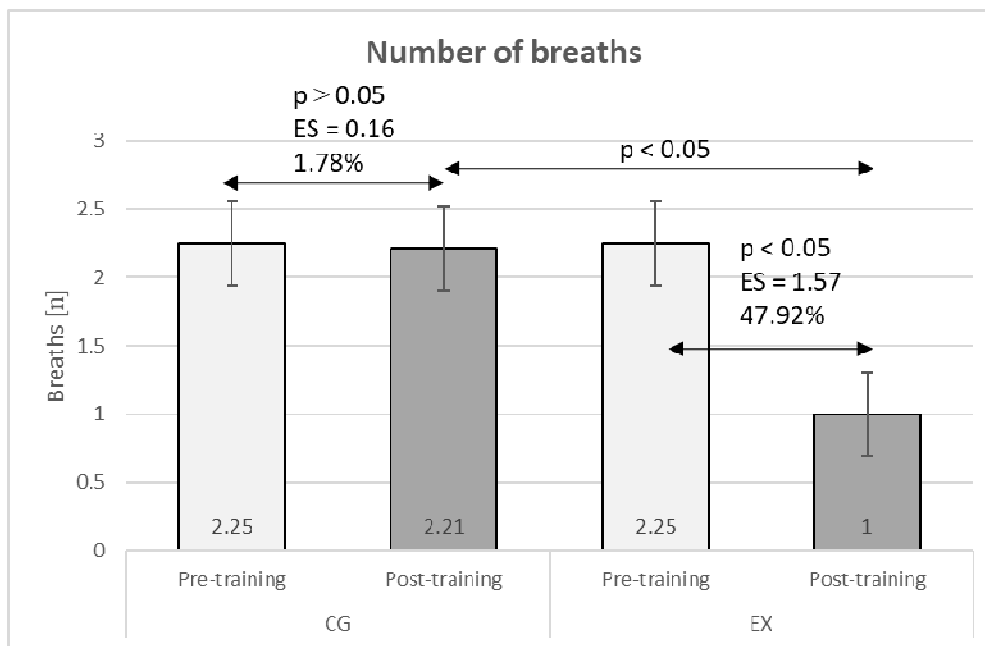


Figure 3. Number of breaths

#### 50 m freestyle time

We recorded the following changes: The CG group improved from  $25.12 \pm 0.49$  [s] to  $24.85 \pm 0.51$  [s]; 1.06%;  $p < 0.05$ ; ES = 0.52. The EX group improved from  $24.8 \pm 0.54$  [s] to  $24.31 \pm 0.54$  [s]; 1.97%;  $p < 0.05$ ; ES = 0.89. Post-training values between CG and EX were significant ( $p < 0.05$ ).

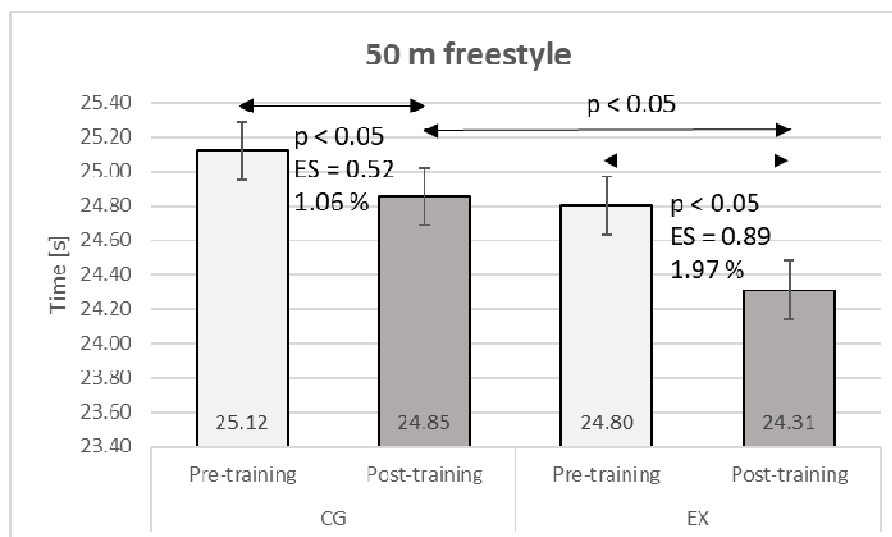


Figure 4. 50 m freestyle time

### Discussion

The results of this study demonstrate that hypoxic training can significantly improve breath-hold distance, static apnea duration, and the number of breaths in adolescent competitive swimmers. The experimental group (EX) showed a statistically significant improvement in breath-hold distance (+7.31%,  $p < 0.05$ ; ES = 0.38), static apnea duration (+9.63%;  $p < 0.05$ ; ES = 0.26), and the number of breaths (−47.92%;  $p < 0.05$ ; ES = 1.57), whereas the control group (CG) did not exhibit significant changes. These findings align with previous research on the benefits of hypoxic training for enhancing aerobic and anaerobic performance in swimming athletes. A study (Faiss, R., Léger, B., Vesin, J. M., Fournier, P. E., Eggel, Y., Dériaz, O., & Millet, G. P. 2013). found that repeated sprint training in hypoxia (RSH) led to improved sprint performance and aerobic capacity. The improvements observed in our study in 50 m freestyle time confirm that hypoxic training may positively influence sprint speed, potentially due to enhanced buffering capacity and increased oxygen utilization efficiency. Similarly, research (M., Waskiewicz, Z., Zajac, A., Poprzecki, S., Cholewa, J., & Rocznio, R. 2011) reported significant gains in endurance performance among swimmers undergoing intermittent hypoxic training (IHT). Their findings showed that hypoxia-induced physiological adaptations, including increased hemoglobin mass and improved ventilatory efficiency, contributed to better swimming performance. Our study supports these conclusions by demonstrating improved breath-hold capacity, a reduced number of breaths, and a decrease in 50 m freestyle time, which may be indicative of enhanced respiratory control and tolerance to hypoxic conditions. Additionally, a study (Galvin, H. M., Cooke, K., Sumners, D. P., Mileva, K. N., & Bowtell, J. L. 2013). investigating hypoxic resistance training (RTH) in swimmers found significant improvements in muscular endurance and anaerobic capacity. Our results align with this research, as the EX group demonstrated meaningful gains in hypoxia-related performance metrics, reinforcing the notion that controlled hypoxia exposure can be beneficial for swimmers.

However, a study (Girard, O., Amann, M., et al 2013).indicated that while hypoxic training can be advantageous for some athletes, individual responses may vary, and prolonged exposure could lead to negative effects, such as increased fatigue or decreased training efficiency. In our study, no adverse effects were observed, but future research should examine the long-term consequences and inter-individual variability in adaptation to hypoxic training.

### Limitations and Future Research

One limitation of this study is the relatively small sample size ( $n = 16$ ), which may restrict the generalizability of the findings. Additionally, the six-week intervention period, while sufficient to observe significant changes, may not capture long-term adaptations or potential drawbacks of hypoxic training. Future studies should consider larger cohorts and extended training durations to further validate these findings.

Moreover, while this study focused on breath-hold distance, static apnea, and the number of breaths as performance metrics, additional physiological markers such as hemoglobin concentration,  $\text{VO}_2$  max, and lactate threshold could provide deeper insights into the mechanisms underlying hypoxic adaptations.

Overall, the present study contributes to the growing body of evidence supporting the effectiveness of hypoxic training in enhancing key physiological and performance-related parameters in competitive swimmers.

### Conclusion

The findings of this study highlight the potential benefits of hypoxic training for improving key performance metrics in adolescent competitive swimmers. The significant improvements observed in static apnea duration, breath-hold distance, number of breaths, and 50 m freestyle time in the experimental group

suggest that controlled exposure to hypoxia can enhance an athlete's ability to tolerate low-oxygen conditions and improve sprint performance, which is critical for competitive swimming.

These results are consistent with previous research demonstrating the efficacy of hypoxic training in enhancing both aerobic and anaerobic capacity. However, individual responses to hypoxic training may vary, and further research is needed to determine the long-term effects and to identify optimal training protocols for different athlete populations. In conclusion, hypoxic training represents a promising method for improving physiological adaptations and sprint performance in swimmers. Coaches and sports scientists should consider incorporating structured hypoxic training sessions into their programs to maximize performance benefits while ensuring athlete safety and well-being.

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**Conflicts of interest** - The authors declare no conflict of interest.

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