Effectiveness of Structured Hypoventilation Training on Cardiovascular Endurance in Swimmers.

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ABSTRACT
Background: Cardiovascular endurance is an essential component of swimming performance, as it influences aerobic capacity, fatigue resistance, and recovery. Hypoventilation training, which involves controlled reduction of breathing frequency during exercise, has emerged as a practical method to improve respiratory efficiency and endurance. However, evidence regarding its effectiveness among recreational swimmers remains limited.
Materials and Methods: An interventional experimental study was conducted among 55 male and female swimmers aged 16–25 years in Karad. Participants were selected using a simple random sampling method and underwent a structured hypoventilation training programme for three weeks. Cardiovascular endurance was assessed before and after the intervention using 400 m freestyle swim time, Time to Exhaustion (TTE), Heart Rate, Oxygen Saturation (SpO_2), Rate of Perceived Exertion (RPE), and Maximum Breath-Hold Time. Data were analysed using descriptive statistics along with paired and independent *t*-tests, with statistical significance set at $p < 0.05$.
Results: Significant improvements were observed following the intervention. The mean 400 m freestyle swim time improved from 294.20 ± 15.03 to 275.15 ± 11.29 seconds ($p < 0.001$). Time to Exhaustion, one-minute recovery heart rate, Rate of Perceived Exertion, and Maximum Breath-Hold Time also showed statistically significant improvements. Resting heart rate, peak heart rate, and oxygen saturation did not demonstrate significant changes after the training programme.
Conclusion: Structured hypoventilation training significantly improved cardiovascular endurance, swimming performance, recovery, and breath-hold capacity in swimmers. The findings suggest that this training method can be incorporated into regular swimming programmes as a safe and effective strategy to enhance endurance performance and respiratory efficiency.
Keywords: Hypoventilation training, cardiovascular endurance, swimmers, breath-hold training, swimming performance, physiotherapy
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INTRODUCTION

Swimming is a highly demanding endurance sport that requires the coordinated functioning of the cardiovascular, respiratory, and musculoskeletal systems to sustain prolonged activity and achieve optimal performance. Cardiovascular endurance is considered a key determinant of swimming success, as it influences oxygen delivery, energy production, fatigue resistance, and recovery capacity. Swimmers with higher cardiovascular endurance can maintain speed over longer distances and demonstrate better physiological efficiency during training and competition.

Conventional swimming training programs generally emphasize stroke technique, muscular strengthening, aerobic conditioning, and training volume. These programs include continuous swimming, interval training, and dry-land exercises to improve physical fitness and swimming performance. However, such training approaches often focus on general aerobic conditioning and may not specifically target respiratory control and tolerance to hypoxic conditions that occur during swimming. During swimming, breathing is restricted by stroke mechanics, which can result in temporary reductions in oxygen availability and increased carbon dioxide accumulation, highlighting the importance of respiratory training interventions.

Hypoventilation training (HVT) has recently gained attention as a novel method to enhance endurance performance in athletes. Hypoventilation training involves deliberate reduction in breathing frequency or controlled breath-holding during exercise, leading to mild hypoxic and hypercapnic conditions. This training method is believed to stimulate physiological adaptations similar to altitude or hypoxic training, including improved oxygen utilization, enhanced buffering capacity, and increased tolerance to carbon dioxide. Previous studies have reported that hypoventilation training performed during swimming can improve performance by increasing anaerobic and aerobic metabolic stress and inducing cardiovascular and respiratory adaptations.[1]

Research has demonstrated that swimmers can simulate hypoxic training at sea level through voluntary hypoventilation, making it a practical and cost-effective alternative to altitude training.[2] This approach allows swimmers to experience hypoxic stress without the logistical challenges associated with high-altitude environments. Additionally, swimming-specific repeated sprint training in hypoxia has been shown to induce greater physiological stress compared to normoxic training, indicating its potential application in aquatic sports training programs.[3]

Hypoxic and hypoventilation training have also been associated with improvements in cardiovascular and autonomic nervous system responses, including heart rate variability, oxygen uptake, and hemodynamic function.[4] Such adaptations contribute to enhanced endurance performance, improved recovery, and increased efficiency of the cardiovascular system. Training with reduced breathing frequency has been shown to improve adaptation to hypercapnia and respiratory acidosis, leading to improved breath control and swimming performance.[5]

Despite the growing interest in hypoventilation training, evidence regarding its structured application and its direct impact on cardiovascular endurance in swimmers remains limited. Many previous studies have focused on sprint performance, acute physiological responses, or laboratory-based experiments, while fewer studies have evaluated endurance performance outcomes such as 400-meter swim time, time to exhaustion, heart rate recovery, oxygen saturation, and perceived exertion. Furthermore, most studies have been conducted on elite athletes, and limited data are available for recreational or regularly training swimmers, indicating a research gap.

Cardiovascular endurance is influenced by multiple physiological factors, including cardiac output, pulmonary ventilation, oxygen transport, and muscular oxidative capacity. Training interventions that improve these factors are essential for endurance sports such as swimming. Hypoxic and hypoventilation training methods have been reported to enhance endurance performance through improvements in aerobic capacity and metabolic adaptations.[6–8] General exercise physiology literature also highlights the role of aerobic training, interval training, and endurance conditioning in improving cardiovascular fitness.[9–12]

Swimming performance is influenced by training intensity, duration, tapering strategies, and training specificity.[13–15] Physiological adaptations such as improved stroke volume, mitochondrial density, and capillary perfusion are critical for endurance performance.[16] Research has also shown that subjective measures such as the Borg rating of perceived exertion scale are reliable indicators of exercise intensity and physiological stress.[17] Endurance performance is strongly associated with cardiovascular and metabolic efficiency, which are key determinants of athletic success.[18–19] Hypoxic training has also been explored in team sports and endurance sports, emphasizing its potential to enhance performance through physiological stress adaptation.[20]

In physiotherapy and sports rehabilitation, improving cardiovascular and respiratory efficiency is an important objective. Physiotherapists play a key role in designing training and rehabilitation programs for athletes to optimize performance and prevent injuries. Understanding the effects of hypoventilation training on cardiovascular endurance may help physiotherapists and coaches develop evidence-based training protocols and integrate respiratory training strategies into swimming programs.

Therefore, the present study aims to evaluate the effectiveness of structured hypoventilation training on cardiovascular endurance in swimmers. The study will assess outcomes such as 400-meter freestyle performance, time to exhaustion, heart rate responses, oxygen saturation, rate of perceived exertion, and breath-hold capacity. The findings of this study are expected to contribute to the scientific literature and provide practical recommendations for incorporating hypoventilation training into swimming conditioning programs.

MATERIALS AND METHODS

Prior to the commencement of the study, ethical approval was obtained from the Institutional Ethics and Protocol Review Committee. An interventional experimental study employing a Randomized Controlled Trial (RCT) design was conducted to evaluate the effect of hypoventilation training on cardiovascular endurance among swimmers in Karad.

A total of 55 participants were recruited for the study. The calculated sample size was 55 participants. Male and female swimmers aged 16–25 years were selected using the simple random sampling method. Eligible participants were recreational or regularly training swimmers who had been actively participating in structured swimming programs at swimming academies, sports clubs, or university teams. Participants with cardiovascular, respiratory, musculoskeletal, or neurological disorders, recent injuries affecting swimming performance, or any medical condition contraindicating exercise or breath-control training were excluded from the study.

Participants were randomly allocated into two groups:

an experimental group and a control group. The experimental group underwent a 3-week hypoventilation training program in addition to their regular swimming practice, whereas the control group continued with their routine swimming training without hypoventilation exercises. Before initiating the study, the objectives and procedures were clearly explained to all participants, and written informed consent was obtained.

Cardiovascular endurance and physiological parameters were assessed before and after the intervention using standardized assessment procedures. Performance measures included 400 m freestyle swim time, Time to Exhaustion (TTE), Maximum Breath-Hold Time, Heart Rate, Oxygen Saturation (SpO_2), and Rate of Perceived Exertion (RPE). The 400 m freestyle swim time and breath-hold duration were measured using a calibrated digital stopwatch. Heart rate was monitored using a heart rate monitor or wrist-based sensor, while oxygen saturation was measured using a calibrated digital pulse oximeter. Perceived exertion during exercise was assessed using Borg's Rating of Perceived Exertion (RPE) Scale. All measurements were performed following standardized testing protocols to ensure consistency, reliability, and accuracy.

The hypoventilation training protocol consisted of supervised swimming sessions in which participants intentionally reduced their breathing frequency during selected swimming sets to simulate mild hypoxic conditions. The intervention was conducted over a period of three weeks under the supervision of trained personnel to ensure participant safety and adherence to the prescribed protocol.

The collected data were systematically organized and analysed using appropriate statistical methods. Descriptive statistics, including mean and standard deviation, were calculated for all outcome variables. The effectiveness of the intervention was evaluated by comparing pre- and post-intervention values within and between groups using appropriate statistical tests, such as paired and independent t-tests.

RESULT: -

Table 1: Demographic Characteristics of Participants: -

Variable	**Frequency (n)**	**Percentage (%)**
Sex		
Male	30	54.5%
Female	25	45.5%
Total	55	100%

Age Distribution: -

Age Group (years)	**Frequency (n)**	**Percentage (%)**
16 – 18	12	21.8%
19 – 21	23	41.8%
22 – 25	20	36.4%
Total	55	100%

A total of 55 swimmers participated in the study. Among them, 30 (54.5%) were males and 25 (45.5%) were females. The mean age of the participants was 20.3 ± 2.26 years. The majority of participants belonged to the 19–21 years age group (41.8%), followed by 22–25 years (36.4%) and 16–18 years (21.8%).

Table 2

Effect of Hypoventilation Training on Swimming Performance

Outcome Measure	**Pre-test Mean ± SD**	**Post-test Mean ± SD**	**p-value**
400 m Freestyle Time (sec)	294.20 ± 15.03	275.15 ± 11.29	**<0.001**
Time to Exhaustion (sec)	238.58 ± 36.39	211.16 ± 28.32	**<0.001**

The comparison of pre- and post-intervention swimming performance is presented in Table 2. The mean 400 m freestyle swim time significantly improved from 294.20 ± 15.03 seconds at baseline to 275.15 ± 11.29 seconds after the intervention ($p < 0.001$).

Similarly, time to exhaustion showed a significant improvement, decreasing from 238.58 ± 36.39 seconds to 211.16 ± 28.32 seconds following the training program ($p < 0.001$).

Table 3

Effect of Hypoventilation Training on Heart Rate Parameters

Outcome Measure	Pre-test Mean ± SD	Post-test Mean ± SD	p-value
Resting Heart Rate (bpm)	63.85 ± 5.07	64.89 ± 4.25	0.210
Peak Heart Rate (bpm)	182.21 ± 6.99	183.56 ± 6.46	0.118
1-min Recovery Heart Rate (bpm)	105.98 ± 9.31	103.30 ± 8.85	**0.032**

Changes in heart rate parameters are shown in Table 3. Resting heart rate increased slightly from 63.85 ± 5.07 bpm to 64.89 ± 4.25 bpm, but the difference was not statistically significant ($p = 0.210$).

Peak heart rate also showed no significant difference between pre- and post-intervention values ($p = 0.118$).

However, 1-minute recovery heart rate demonstrated a statistically significant improvement, decreasing from 105.98 ± 9.31 bpm to 103.30 ± 8.85 bpm ($p = 0.032$).

Table 4

Effect on Rate of Perceived Exertion and Oxygen Saturation

Outcome Measure	Pre-test Mean ± SD	Post-test Mean ± SD	p-value
Rate of Perceived Exertion (RPE)	15.10 ± 1.55	12.05 ± 2.95	**<0.001**
Oxygen Saturation SpO_2 (%)	95.30 ± 2.09	95.92 ± 2.14	0.084

As shown in Table 4, the rate of perceived exertion (RPE) significantly decreased from 15.10 ± 1.55 to 12.05 ± 2.95 following hypoventilation training ($p < 0.001$), indicating reduced perceived fatigue during swimming.

Oxygen saturation (SpO_2) showed a slight increase from 95.30 ± 2.09% to 95.92 ± 2.14%, but the difference was not statistically significant ($p = 0.084$).

Table 5

Effect of Hypoventilation Training on Breath-Hold Capacity

Outcome Measure	Pre-test Mean ± SD	Post-test Mean ± SD	p-value
Maximum Breath-Hold Time (sec)	51.60 ± 9.18	74.80 ± 12.33	**<0.001**

The effect of hypoventilation training on breath-hold capacity is presented in Table 5. A significant improvement was observed in maximum breath-hold time, increasing from 51.60 ± 9.18 seconds at baseline to 74.80 ± 12.33 seconds after the intervention ($p < 0.001$).

DISCUSSION

The present study was conducted to evaluate the effectiveness of structured hypoventilation training on cardiovascular endurance among swimmers aged 16–25 years. A total of 55 swimmers participated in the study, and the findings demonstrated that a three-week hypoventilation training programme significantly improved several physiological and performance-related parameters. These findings indicate that controlled breathing techniques can positively influence cardiovascular endurance and swimming performance when incorporated into regular training programmes.

One of the most important findings of the study was the significant improvement in 400 m freestyle swimming performance. The mean swimming time decreased significantly after the intervention, indicating enhanced endurance and improved exercise efficiency. This improvement may be attributed to physiological adaptations induced by hypoventilation training, including improved oxygen utilization, increased tolerance to carbon dioxide accumulation, and enhanced respiratory muscle efficiency. These adaptations enable swimmers to sustain higher exercise intensity while delaying the onset of fatigue.

The study also demonstrated a significant improvement in time to exhaustion following the training programme. This finding suggests that participants developed greater endurance capacity and were able to tolerate prolonged swimming efforts more efficiently. Repeated exposure to controlled hypoxic conditions during hypoventilation training is known to stimulate cardiovascular and respiratory adaptations, which contribute to improved aerobic performance and reduced fatigue during endurance exercise.

Heart rate analysis revealed that resting heart rate and peak heart rate did not change significantly after the intervention. The absence of significant changes may be explained by the relatively short duration of the training programme and the fact that participants were already physically trained swimmers with good baseline cardiovascular fitness. However, one-minute recovery heart rate showed a significant reduction after training, indicating improved cardiovascular recovery and autonomic regulation. Faster heart rate recovery is widely recognized as an indicator of enhanced cardiovascular fitness and exercise adaptation.

Another important finding was the significant reduction in the Rate of Perceived Exertion (RPE). Participants reported lower levels of perceived effort following the intervention, suggesting that swimming became physiologically less demanding after completing the hypoventilation training programme. Improved breathing control and greater tolerance to respiratory discomfort may have contributed to this reduction in perceived fatigue.

Oxygen saturation showed only a slight, non-significant increase after the intervention. Since all participants were healthy young swimmers with normal baseline oxygen saturation, substantial changes were not expected. The maintenance of normal oxygen saturation despite breath-control training indicates that hypoventilation training is relatively safe when performed under appropriate supervision.

Maximum breath-hold capacity demonstrated a marked improvement after the intervention. This finding reflects enhanced respiratory control, improved tolerance to elevated carbon dioxide levels, and increased respiratory muscle efficiency, all of which are expected physiological adaptations to hypoventilation training.

Overall, the findings of the present study suggest that structured hypoventilation training is an effective supplementary training strategy for improving cardiovascular endurance, swimming performance, recovery, and respiratory efficiency. These results support the inclusion of controlled breathing exercises in swimming conditioning programmes and may assist physiotherapists and swimming coaches in developing evidence-based training protocols for enhancing athletic performance.

STRENGTH OF THE STUDY:

- The study used an experimental design, allowing evaluation of the effects of hypoventilation training.
- Standardized and validated outcome measures improved the reliability of the findings.
- Inclusion of both male and female swimmers increased the applicability of the results.
- The intervention was safe, supervised, and easy to implement in routine swimming training.
- The study provides valuable evidence on hypoventilation training in swimmers, where limited research is available.

FUTURE RECOMMENDATIONS: -

- Future studies should include a larger sample size to improve the generalizability of the findings.
- A longer duration of hypoventilation training should be investigated to evaluate long-term physiological adaptations.
- Similar studies should be conducted among competitive, elite, and different age groups of swimmers.
- Future research should include additional outcome measures such as VO_2 max, blood lactate levels, and pulmonary function tests.
- Comparative studies between hypoventilation training and other endurance training methods are recommended to determine the most effective training approach.

LIMITATIONS OF THE STUDY:

- The study included a small sample size (55 participants), which may limit the generalizability of the findings.
- The intervention duration was limited to three weeks, which may not reflect long-term training effects.
- Participants were recruited from a single geographical location (Karad), limiting the wider applicability of the results.
- Only selected cardiovascular and performance parameters were assessed; variables such as VO_2 max, blood lactate levels, and pulmonary function were not evaluated.
- Participants dietary habits, sleep patterns, and daily physical activity were not controlled, which may have influenced the outcomes.

CONCLUSION:

The present study concluded that structured hypoventilation training is an effective supplementary training method for improving cardiovascular endurance in swimmers. The intervention resulted in significant improvements in 400 m freestyle performance, time to exhaustion, one-minute recovery heart rate, rate of perceived exertion (RPE), and maximum breath-hold capacity**.** However, resting heart rate, peak heart rate, and oxygen saturation (SpO_2) did not show statistically significant changes after the three-week training programme. Overall, the findings suggest that incorporating structured hypoventilation training into regular swimming practice may enhance endurance performance, respiratory efficiency, and recovery, making it a valuable strategy for swimmers, physiotherapists, and coaches.

ETHICS STATEMENT

The study received approval from the Institutional Ethical Committee of XXX, Karad (Protocol Number 414/2025-2026).

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest related to this article.

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