

Acute Effects of Voluntary Breath-Holding on Cardiovascular and Cognitive Functions in University Athletes

Gopal Chandra Saha^{1*}, Sudarsan Biswas¹, Dibyendu Roy¹

¹Department of Physical Education and Sport Science, Visva-Bharati, Santiniketan, West Bengal India

ARTICLE INFO

Article history:

Received 13 October 2025

Revised 28 August 2026

Accepted 7 September 2026

Online first 15 September 2026

Published 15 September 2026

Keywords:

voluntary breath-holding
cardiovascular function
cognitive function
oxygen saturation
reaction time
university athletes

ABSTRACT

This study examined the acute effects of voluntary breath-holding on cardiovascular and cognitive functions among trained female university football players. Thirty female university football players (age 21.41 ± 1.61 years) participated in a quasi-experimental, within-subject pre-test and post-test study. Cardiovascular variables included heart rate, systolic blood pressure, and oxygen saturation, while cognitive functions were assessed through reaction time, working memory, and decision-making tasks. Baseline measurements were obtained following a 10-minute seated rest, after which participants performed a standardized voluntary breath-holding task for up to 60 seconds under continuous supervision. Post-test measurements were initiated within 10 seconds of cessation of breath-holding. Data were analysed using paired-samples t-tests, with the level of significance set at $p < 0.05$. The findings demonstrated significant acute changes in most measured variables. Heart rate decreased significantly ($t(29) = 3.05$, $p = 0.004$, $d = 1.11$), whereas systolic blood pressure increased ($t(29) = -3.58$, $p = 0.001$, $d = 0.83$). Oxygen saturation showed a substantial decrease ($t(29) = 4.85$, $p < 0.001$, $d = 2.85$). Cognitive performance also changed, with reaction time worsening ($t(29) = -2.92$, $p = 0.007$, $d = 1.08$) and working memory declining ($t(29) = 2.18$, $p = 0.037$, $d = 0.80$). However, decision-making did not change significantly ($t(29) = 1.51$, $p = 0.142$, $d = 0.27$). These findings indicate that brief voluntary breath-holding can produce transient cardiovascular and cognitive responses in trained female university athletes, particularly affecting oxygen saturation, cardiovascular regulation, reaction time, and working memory.

1. INTRODUCTION

The voluntary breath-holding provides unique physiological condition because it disrupts the constant flow of oxygen and causes changes in the body homeostatic response. The use of this method is widely employed in various activities and as a training method for elite athletes; hence, its acute impact on the cardiovascular and cognitive functions of academic-level athletes is well worthy of in-depth research. Breath-holding is a

^{1*}Corresponding author. E-mail address: gopalchandra.saha@visva-bharati.ac.in

voluntary apnea technique that involves a short interruption of breathing and has been investigated in a variety of physiological and sporting circumstances (Vaguine, 2021; Tetzlaff et al., 2021). During breath-holding, oxygen availability progressively declines while carbon dioxide accumulates, leading to changes in autonomic regulation and gas exchange (Costalat et al., 2021). It causes a number of cardiovascular and respiratory reactions, mostly as a result of changes in the body's levels of carbon dioxide and oxygen. Both cardiovascular function and cognitive function may be impacted by these physiological changes. According to previous studies, breath-holding can cause short-term changes in the body's regulatory systems, including changes in blood pressure, heart rate, and oxygen saturation (Paleczny et al., 2021; Woorons et al., 2024). Although breath-holding has been extensively investigated in trained breath-hold divers under extreme situations, these findings are not immediately generalizable to general athletic populations, as the length and context of breath-holding varied significantly (Tetzlaff et al., 2021). Breath-holding is usually done for brief periods of time in non-diver populations, especially athletes, and may result in acute physiological and cognitive reactions rather than long-term adaptations. However, limited research has examined these short-term effects, especially in relation to both cardiovascular and cognitive variables within the same study (Woorons et al., 2024; Liang et al., 2024).

The aim of the study was to examine the acute effects of voluntary breath-holding on cardiovascular variables and cognitive functions among university athletes.

2. MATERIALS AND METHODS

2.1 Participants

Out of fifty, thirty trained female university football players (age 21.41 ± 1.61), participated in the study. A priori power analysis was conducted using G*Power 3.1.9.7 to determine the required sample size for a paired-samples t-test. Assuming a moderate effect size ($d = 0.5$), $\alpha = 0.05$, and power = 0.80, the analysis indicated a minimum required sample size of 27 participants. To ensure adequate power and account for potential dropouts, 30 university-trained female football players were recruited. The subjects under the study were selected from the Visva-Bharati University team, a Central University of National importance, Visva-Bharati, Santiniketan, West Bengal, India.

2.2 Design of the Study

This study follows a quasi-experimental, within-subject design with pre-test and post-test measures to assess the acute effects of voluntary breath-holding on cardiovascular and cognitive functions. A total of 30 university athletes was recruited through purposive sampling. Each participant underwent two testing conditions: baseline measurements of dependent variables and post-breath-holding.

3. PROCEDURE

An orientation programme for the athletes was organized in collaboration with the University Sports Board to orient and explain the need for the study. Participants trained year-round, averaging 3.4 ± 0.8 years of experience. Their routine included five weekly 150-minute sessions, practice matches every two weeks, and a competition every three months. Willful students who fulfilled the study's objective were invited to join the research study. All subjects filled out a questionnaire in which they reported their injury

history that needed medical treatment. Moreover, the questionnaire also asked for medication use, known disease, and daily diet patterns. The participants were informed of any risks and discomforts associated with the study. Written informed consent was obtained from the participants and, if necessary, from their parents/legal guardians prior to study participation.

3.1 INCLUSION AND EXCLUSION CRITERIA

As inclusion criteria, female athletes with university sports achievements in their respective sports specialization and at least three years of regular active participation in inter-university level sports competitions were considered subjects in this study. All the subjects stayed in the hostel, and the regular students at the university followed a similar lifestyle regarding the biological clock and diet pattern. As exclusion criteria, we defined the presence of chronic diseases (e.g., diabetes, obesity, metabolic syndrome) and medication usage that affects the female's fitness attributes.

3.2 COLLECTION OF DATA

3.2.1 Cardiovascular variables measurement

Cardiovascular data were collected in a temperature-controlled environment ($24 \pm 1^\circ \text{C}$ with participants in a standardized seated position.

(i) Instrumentation: Heart rate (HR) and Oxygen Saturation (SpO_2) were monitored using a Finger Pulse Oximeter (Dr. Trust Professional Series; accuracy $\pm 2\%$) Blood Pressure (BP) was measured using a calibrated digital sphygmomanometer (Omron HEM-7120; accuracy $\pm 3 \text{ mmHg}$).

(ii) Protocol: Participants rested in a quiet room for 10 minutes before baseline measurements. BP was measured on the left arm at heart level. Post-test measurements were initiated within 10 seconds of the cessation of the breath-holding task to capture acute physiological shifts.

3.2.2 Cognitive Performance Assessment

Cognitive functions were assessed via a computerized Tests. To minimize learning effects, participants completed three familiarization trials 24 hours before the actual study.

- **Reaction Time (RT):** A computer-based visual stimulus test. Participants responded to a colour change on the screen. **Scoring:** Mean response time of 10 trials (measured in milliseconds).
- **Digit Span Test (Working Memory):** Participants recalled sequences of numbers in forward and backward order. **Scoring:** Total number of correctly recalled sequences (Span Length).
- **Stroop Colour-Word Test (Executive Function):** Participants identified the ink colour of words where the text and colour were incongruent. **Scoring:** Interference score calculated as the time difference (seconds) between congruent and incongruent tasks

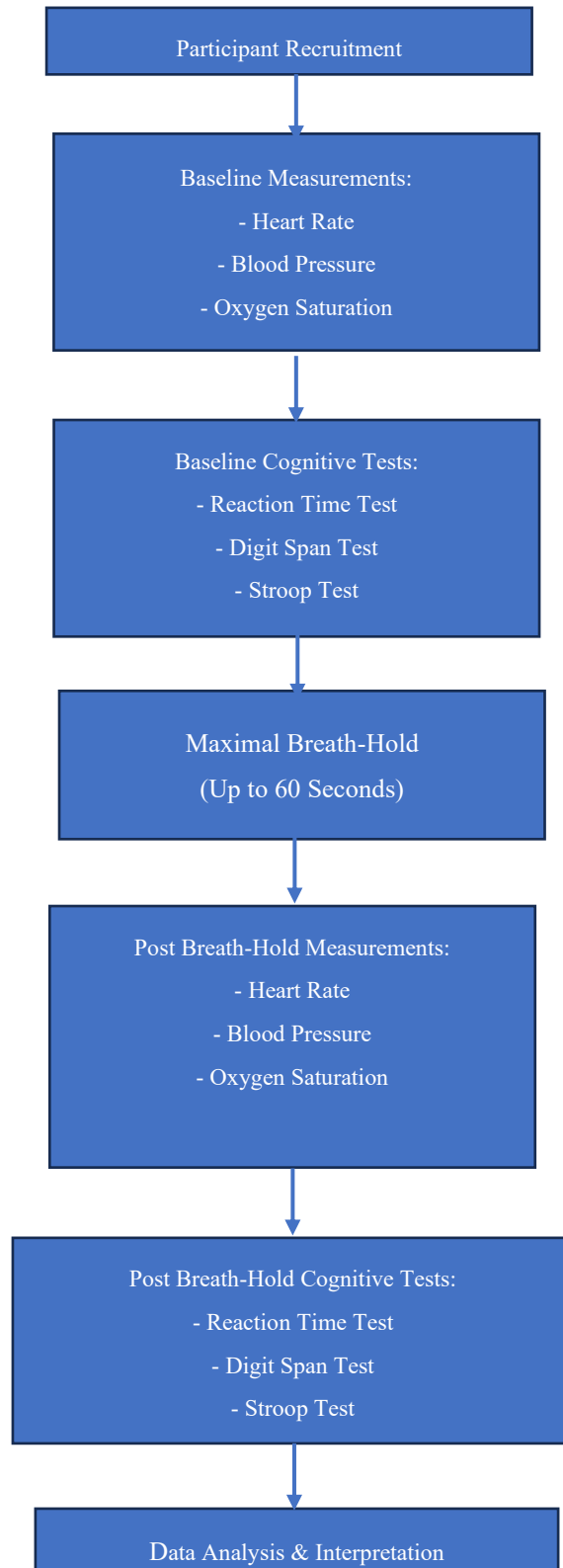
3.2.3 Voluntary Breath-Holding (VBH) Protocol

The VBH task was standardized to ensure lung volume consistency and participant safety.

- (i) Procedure:** Following a "normal inhalation" (approximately 70–80% of Vital Capacity), participants performed a maximal breath-hold using a nose clip to prevent nasal leakage.

- (ii) Safety and Supervision:** The task was limited to a maximum of 60 seconds for safety. A trained sports physiologist supervised all sessions. Participants were monitored via continuous pulse oximetry; the protocol was terminated immediately if SpO₂ dropped below 80% or if the participant showed signs of light-headedness or distress.
- (iii) Criteria:** Success was defined as the ability to maintain the hold until the "breaking point" or the 60-second safety limit.

FIGURE 1. FLOW DIAGRAM: COLLECTION OF DATA



3.3 STATISTICAL ANALYSIS

Means and Standard Deviations (SD) were used to describe all variables and baseline characteristics of the athletes. To ensure the validity of our statistical analyses, the researchers assessed the assumptions of normality and homogeneity of variances. The Shapiro-Wilk test was performed to evaluate the normality of data distribution. Data were analyzed using paired t-tests to compare pre- and post-breath-holding values of trained female university football players. It was hypothesized that female university athletes participating in Football would exhibit significant effects of Voluntary Breath-Holding on Cardiovascular and Cognitive Functions. The level of significance was set at $p < 0.05$. All analyses were carried out using JAMOWI Version 2.4 software.

4. RESULTS

Prior to conducting inferential analyses, the assumptions for parametric testing were examined. The Shapiro–Wilk test indicated that all variables were normally distributed ($p > 0.05$), supporting the use of paired-samples t-tests. No missing data were observed, as all participants completed both pre- and post-test assessments.

The analysis revealed significant acute effects of breath-holding on most cardiovascular and cognitive variables among university athletes. Heart rate significantly decreased ($t(29) = 3.05$, $p = 0.004$, Cohen's $d = 1.11$), while systolic blood pressure increased significantly ($t(29) = -3.58$, $p = 0.001$, $d = 0.83$). A marked reduction in oxygen saturation was also observed ($t(29) = 4.85$, $p < 0.001$, $d = 2.85$), indicating substantial physiological stress. On the cognitive front, reaction time significantly worsened ($t(29) = -2.92$, $p = 0.007$, $d = 1.08$), and working memory performance declined ($t(29) = 2.18$, $p = 0.037$, $d = 0.80$). However, changes in decision-making scores were not statistically significant ($t(29) = 1.51$, $p = 0.142$, $d = 0.27$). The 95% confidence intervals for the mean differences further supported the statistical findings, indicating consistent reductions in heart rate and oxygen saturation and increases in systolic blood pressure and reaction time following voluntary breath-holding.

Table-1: Descriptive statistics of Cardiovascular and Cognitive Functions in University Athletes

Variable	Mean (Pre)	SD (Pre)	Mean (Post)	SD (Post)	Cohen's d	Interpretation
Heart Rate (bpm)	78.50	6.10	71.20	6.85	1.11	Large reduction
Systolic BP (mmHg)	112.30	7.45	118.70	8.20	0.83	Moderate increase
Oxygen Saturation (%)	98.10	0.90	95.20	1.10	2.85	Very large decrease
Reaction Time (ms)	320.60	24.50	348.80	28.30	1.08	Large increase (slower)
Working Memory (score)	7.80	1.10	6.90	1.15	0.80	Moderate decline
Decision-Making (ms)	850.50	58.00	870.90	62.00	0.27	Small increase

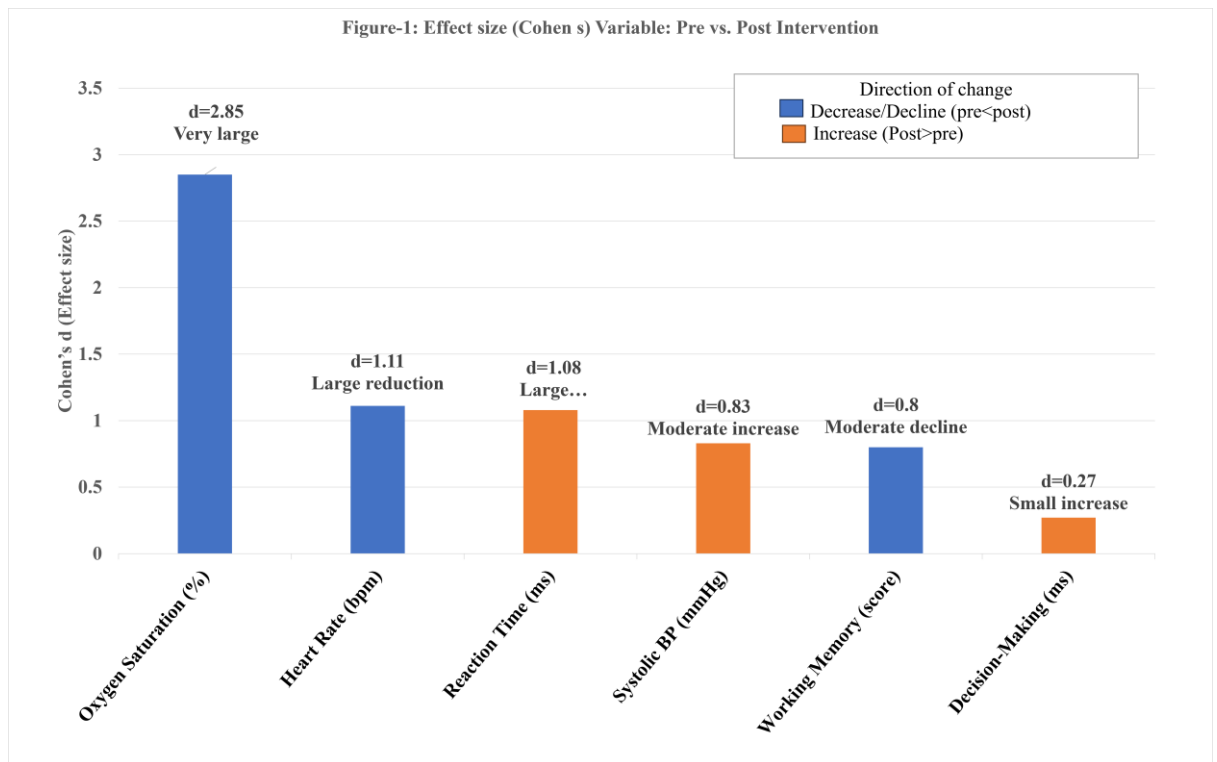


Table-2: Paired t-test of Cardiovascular and Cognitive Functions in University Athletes

Variable	t-Value	df	p-Value	Significance ($\alpha = 0.05$)
Heart Rate	3.05	29	0.004	Significant
Systolic BP	-3.58	29	0.001	Significant
Oxygen Saturation	4.85	29	<0.001	Significant
Reaction Time	-2.92	29	0.007	Significant
Working Memory	2.18	29	0.037	Significant
Decision-Making (Stroop)	1.51	29	0.142	Not Significant

5. DISCUSSION

These results suggest that voluntary breath-holding exerts notable short-term impacts on both physiological and selected cognitive functions in athletes.

4.1 Heart Rate:

The present study demonstrated a significant reduction in heart rate following voluntary breath-holding, indicating an acute cardiovascular response in university athletes. Transient parasympathetic (vagal) activation, which frequently happens during short-duration apnea and represents quick autonomic responses to the disruption of regular respiration, may be the cause of this drop in heart rate (Costalat et al., 2021; Tetzlaff et al., 2021). During purposeful breath-holding, the gradual accumulation of carbon dioxide and decrease in oxygen availability stimulate peripheral chemoreceptors, influencing autonomic regulation of heart activity. This causes a quick but brief drop-in heart rate, indicating a systemic oxygen-conserving response (Paleczny et al., 2021). Unlike long-term adaptations described in skilled breath-hold divers, the current findings are better explained by acute autonomic modulation that occurs over a short period of time (Tetzlaff et al., 2021). Previous studies in athletic and non-diver populations have found similar reductions in heart rate during brief breath-holding or hypoventilation settings, confirming the involvement of short-term autonomic regulation in mediating these responses (Woorons et al., 2024; Costalat et al., 2021). The extent of the reduction found in the current study, as indicated by significant effect size, shows that trained university athletes may experience a significant but brief cardiovascular adjustment in response to breath-holding. Overall, the findings suggest that purposeful breath-holding causes a quick, temporary bradycardia, which is most likely mediated by short-term autonomic regulation rather than long-term physiological adaptation. These findings emphasize the potential of cardiovascular function to transient respiratory changes in athletic populations.

4.2 Systolic BP:

Voluntary breath-holding resulted in a significant rise in systolic blood pressure, indicating an immediate cardiovascular reaction among university athletes. This elevation is most likely due to short-term sympathetic nervous system activation, which occurs when regular respiration is briefly interrupted and carbon dioxide levels begin to rise (Costalat et al., 2021; Woorons et al., 2024). Carbon dioxide accumulation, combined with a decrease in oxygen availability, stimulates peripheral chemoreceptors, resulting in vasoconstriction and increased peripheral resistance, associated with the observed rise in systolic blood pressure (Paleczny et al., 2021). These alterations are a rapid physiological response designed to maintain adequate blood flow during brief durations of breathing stoppage. Similar results have been reported in studies investigating breath-holding and hypoventilation during physical activity, where short-term blood pressure increases were linked to quick autonomic and vascular responses (Woorons et al., 2024). In the current study, the moderate effect size shows that, while the rise is statistically significant, it is due to a temporary and regulated physiological reaction rather than a long-term change in cardiovascular function. The findings indicate that voluntary breath-holding causes a brief increase in systolic blood pressure, which is predominantly caused by short-term autonomic and vascular adaptations. This demonstrates the sensitivity of blood pressure regulating mechanisms to transient disturbances in typical breathing patterns in athletic populations.

4.3 Oxygen Saturation (%):

Following voluntary breath-holding, a significant decrease in oxygen saturation was seen, indicating an acute hypoxic reaction in university athletes. The main cause of this reduction is the brief

stoppage of breathing, which limits oxygen intake while metabolic processes continue to use up available oxygen, causing arterial oxygen levels to gradually drop (Vaguine, 2021; Woorons et al., 2024). Breath-holding causes a reduction in SpO₂ due to continuing oxygen use by body tissues and lack of external oxygen supply. Meanwhile, carbon dioxide accumulation affects the blood gas balance, altering oxygen transport and availability. These reactions are short-term physiological modifications caused by acute breathing restriction, rather than long-term adaptations. Similar results have been shown in research on hypoventilation and breath-holding, where decreases in oxygen saturation were noticeable even for short periods of time (Woorons et al., 2024). The highly significant effect size in this study indicates that a short period of deliberate breath-holding is enough to cause a significant but temporary physiological strain on the oxygen transport system. These findings suggest that voluntary breath-holding results in a temporary decrease in oxygen saturation, which is an acute hypoxic challenge that is swiftly induced and likely reversible upon the restoration of normal breathing.

4.4 Reaction time:

The current study found that voluntary breath-holding significantly increased reaction time, suggesting a decrease in university athletes' cognitive processing speed. During brief hypoxic exposure, this slowdown of reaction may be linked to brief decreases in brain oxygen availability, which can reduce neuronal efficiency (Costalat et al., 2021; Liang et al., 2024). Changes in attention, alertness, and information processing speed might result from the combined effects of decreased oxygen availability and elevated carbon dioxide levels on central nervous system function. Reaction times may be slowed as a result of these alterations, which are likely to impact the quick integration of motor output and sensory input. These outcomes support the idea that even brief disturbances in oxygen homeostasis can have an impact on cognitive function. Similar results were seen in other studies, where breath-holding or hypoventilation had a negative impact on reaction time, especially during short periods of exposure (Woorons et al., 2024; Allinger et al., 2024). The significant effect size in this study further suggests that the observed change is not only statistically significant but also meaningful in terms of functional cognitive performance. Overall, the findings suggest that voluntary breath-holding leads to a **temporary impairment in reaction time**, likely, this is due to acute physiological changes that alter brain processing.

4.5 Working Memory:

Voluntary breath-holding resulted in a considerable reduction in working memory function. This decline could be linked to short-term hypoxic and hypercapnic circumstances, which can impair higher-order cognitive processes that require sustained attention and information processing (Liang et al., 2024; Allinger et al., 2024). Working memory is particularly sensitive to changes in cerebral oxygen availability, and even brief interruptions in oxygen flow can impair the ability to store and handle information. Previous research has also found that breath-holding or hypoventilation circumstances reduce working memory performance, which supports the current findings (Allinger et al., 2024). The moderate effect size observed in this study shows that the reduction is significant, although likely short-term and reversible upon return to normal breathing. These findings suggest that short-duration breath-holding can have an impact on cognitive skills necessary for decision-making and task execution in sports settings.

4.6 Decision-Making (Stroop):

In contrast to other cognitive variables, there was no statistically significant change in decision-making ability after voluntary breath-holding. This finding shows that executive processes like inhibitory control and cognitive flexibility may be relatively resilient in response to short-term hypoxia exposure, at least within the parameters of the current experiment (Park et al., 2020; Williamson et al., 2019).

The duration of breath-holding in this study was not sufficient to produce substantial impairment in more complex cognitive processes. While simpler functions such as reaction time and working memory appear to be affected more readily, higher-level executive functions may require more prolonged or severe physiological stress to show measurable changes. Additionally, task characteristics may have influenced the outcome. The Stroop-based decision-making task used in the present study may not have been sensitive enough to detect subtle, short-term cognitive fluctuations. Similar findings have been reported in studies where mild or transient hypoxia did not significantly impair executive functioning (Park et al., 2020). Therefore, the absence of a significant effect should not be interpreted as a lack of influence, but rather as an indication that decision-making processes may be comparatively more stable under brief respiratory stress, or that the experimental conditions were insufficient to elicit detectable changes.

6. CONCLUSION

The present study investigated the acute effects of voluntary breath-holding on cardiovascular and cognitive functions in university athletes. Findings revealed significant alterations in heart rate, systolic blood pressure, oxygen saturation, reaction time, and working memory following breath-holding, while decision-making ability showed a slight, non-significant decline. These results suggest that voluntary breath-holding can transiently impact both physiological and cognitive parameters and may induce temporary physiological and cognitive responses in trained athletes.

However, the findings should be interpreted with caution because the study only included a small and homogeneous sample of female university athletes and lacked a control condition. Furthermore, the study's acute nature limits the ability to draw conclusions about long-term adaptations or performance results.

Future research should examine the effects of different breath-holding durations, include more diverse populations, and use controlled experimental conditions to better understand the effects of breath-holding in sports and exercise settings.

This study contributes to understanding how breath control techniques may have potential applications in training or recovery contexts, with careful consideration of their cognitive implications.

7. ACKNOWLEDGEMENTS/FUNDING

The author expresses sincere gratitude to the Department of Physical Education and Sport Science, Visva-Bharati University, for providing institutional support and access to the necessary facilities for conducting this research. The cooperation of the participating university athletes is also deeply acknowledged. Appreciation is extended to colleagues and mentors who provided valuable insights and assistance throughout the study process.

8. CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest related to the publication of this manuscript

9. AUTHORS' CONTRIBUTIONS

Gopal Chandra Saha contributed the study design, data collection, analysis, and manuscript preparation. Sudarsan Biswas contributed to statistical analysis and interpretation of results. Dibyendu Roy assisted with data collection and literature review. All authors reviewed and approved the final manuscript.

10. DECLARATION OF GENERATIVE AI IN THE WRITING PROCESS: DATA AVAILABILITY/SUPPLEMENTARY MATERIALS

During the preparation of this work, the author(s) used claude (anthropic) in order to improve the readability and language quality of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

(i) Available upon request:

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

11. ETHICS STATEMENT

This study was reviewed and approved by the institutional ethics committee of visva-bharati university (**APPROVAL NO: 25RS/163**). All procedures involving human participants were in fulfilment of the ethical standards of the 1964 helsinki declaration. Informed consent was obtained from all participants, and data anonymity was strictly maintained throughout the study.

12. REFERENCES

- Allinger, J., Gueit, P., Faure, S., & Costalat, G. (2024). Cognitive impairments after maximal repeated breath-holding in elite breath-hold divers. *The Journal of Sports Medicine and Physical Fitness*, 65(3). <https://doi.org/10.23736/S0022-4707.24.16564-4>
- Bosco, G., Ionadi, A., Data, P. G., & Mortola, J. P. (2004). Voluntary breath-holding in the morning and in the evening. *Clinical Science*, 106(4). <https://doi.org/10.1042/CS20030260>
- Brignole, M., Alboni, P., Benditt, D. G., Bergfeldt, L., Blanc, J.-J., Bloch Thomsen, P. E., van Dijk, J. G., Fitzpatrick, A., Hohnloser, S., Janousek, J., Kapoor, W., Kenny, R. A., Kulakowski, P., Masotti, G., Moya, A., Raviele, A., Sutton, R., Theodorakis, G., Ungar, A., & Wieling, W. (2004). Guidelines on management (diagnosis and treatment) of syncope—update 2004. *Europace*, 6(6), 467–537. <https://doi.org/10.1016/j.eupc.2004.08.008>

- Costalat, G., Godin, B., Balmain, B. N., Moreau, C., Brotherton, E., Billaut, F., & Lemaitre, F. (2021). Autonomic regulation of the heart and arrhythmogenesis in trained breath-hold divers. *European Journal of Sport Science*, 21(3). <https://doi.org/10.1080/17461391.2020.1749313>
- Drigas, A., & Mitsea, E. (2022). Breathing: A powerful tool for physical and neuropsychological regulation: The role of mobile apps. *Technium Social Sciences Journal*, 28(1). <https://doi.org/10.47577/tssj.v28i1.5922>
- Ferretti, G., Fagoni, N., Taboni, A., Vinetti, G., & di Prampero, P. E. (2022). A century of exercise physiology: Key concepts on coupling respiratory oxygen flow to muscle energy demand during exercise. *European Journal of Applied Physiology*. <https://doi.org/10.1007/s00421-022-04901-x>
- Khodaei, M., Edelman, G. T., Spittler, J., Wilber, R., Krabak, B. J., Solomon, D., Riewald, S., Kendig, A., Borgelt, L. M., Riederer, M., Puzovic, V., & Rodeo, S. (2016). Medical care for swimmers. *Sports Medicine - Open*, 2, 27. <https://doi.org/10.1186/s40798-016-0051-2>
- Liang, W.-M., Ji, Y., Xiao, J., Truskauskaitė-Kunevičienė, I., Hendrixson, A., Bai, Z., & Ruknas, O. (2024). Respiratory patterns and physical fitness in healthy adults: A cross-sectional study. *BMC Public Health*. <https://doi.org/10.1186/s12889-024-17687-8>
- Malinowski, K. S., Wszędybył-Winklewska, M., & Winklewski, P. J. (2025). Sex influence on trigeminal nerve stimulation and breath-hold diving performance. *NeuroSci*, 6(1), 3. <https://doi.org/10.3390/neurosci6010003>
- Meyer, J. S., Gotoh, F., Takagi, Y., & Kakimi, R. (1966). Cerebral hemodynamics, blood gases, and electrolytes during breath-holding and the Valsalva maneuver. *Circulation*, 33(5 Suppl). <https://doi.org/10.1161/01.cir.33.5s2.ii-35>
- Nakamura, N., Heng, P., & Naoyuki, H. (2024). The interaction of breath holding and muscle mechanoreflex on cardiovascular responses. *European Journal of Applied Physiology*, 124(7), 2183–2192. <https://doi.org/10.1007/s00421-024-05431-4>
- Pernett, F., Schagatay, E., & Holmström, P. (2024). Sex-based variations in breath-holding: Oxygen storage and diving response among non-divers. *Frontiers in Physiology*, 15. <https://doi.org/10.3389/fphys.2024.1515232>
- Palczyński, B., Seredyński, R., Wyciszkiewicz, M., Bujak, R., & Zając, A. (2021). Low ventilatory responsiveness to transient hypoxia or breath-holding predicts fast marathon performance in healthy middle-aged and older men. *Scientific Reports*, 11, 10255. <https://doi.org/10.1038/s41598-021-89766-4>
- Park, S. Y., Ahn, J., Kim, J., & Park, H. K. (2020). Cognitive performance following voluntary breath-hold-induced hypoxia. *Frontiers in Human Neuroscience*, 14, 298. <https://doi.org/10.3389/fnhum.2020.00298>
- Sizonenko, S. V., Babiloni, C., de Bruin, E. A., Isaacs, E. B., & Lucas, A. (2013). Brain imaging and human nutrition: Which measures to use in intervention studies? *British Journal of Nutrition*, 110(S1), S1–S30. <https://doi.org/10.1017/S0007114513001384>

- Tancredi, F. B., & Hoge, R. D. (2013). Comparison of cerebral vascular reactivity measures using breath-holding and CO₂ inhalation. *Journal of Cerebral Blood Flow & Metabolism*, 33(7), 1066–1074. <https://doi.org/10.1038/jcbfm.2013.48>
- Tetzlaff, K., Lemaitre, F., Burgstahler, C., Luetkens, J. A., & Eichhorn, L. (2021). Going to extremes of lung physiology: Deep breath-hold diving. *Frontiers in Physiology*. <https://doi.org/10.3389/fphys.2021.710429>
- Vaguine, Y. E. (2021). Causes of bradycardia with static respiratory hypoxia in athletes. *Sports Medicine: Research and Practice*, 11(1), 30–36. <https://doi.org/10.47529/2223-2524.2021.1.3>
- Walsh, J., Ramsey, J. L., Guluzade, N. A., Faricier, R., Keir, D. A., & Belfry, G. R. (2025). The physiological effects of breath-holding during high-intensity exercise. *Physiological Reports*, 13(12). <https://doi.org/10.14814/phy2.70437>
- Williamson, J. W., Mulvane, S. L., & Nguyen, M. D. (2019). Short-term hypoxia and its effects on executive functions and decision-making in athletes. *Physiology & Behavior*, 206, 239–245. <https://doi.org/10.1016/j.physbeh.2019.04.015>
- Woorons, X., Daussin, F., Combes, A., & Mucci, P. (2024). Physiological responses to supramaximal running exercise with breath holding. *Journal of Human Kinetics*, 90. <https://doi.org/10.5114/jhk/174465>



© 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY-NC-ND) license (<http://creativecommons.org/licenses/by/4.0/>).