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VPLYV AKÚTNEJ A INTERMITENTNEJ HYPOXIE NA VÝKON PLAVCOV

THE EFFECT OF ACUTE AND INTERMITTENT HYPOXIA ON THE PERFORMANCE OF SWIMMERS

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Abstract

The main objective of the research was to determine the impact of different forms of hypoxia (acute and intermittent) on the performance of performance swimmers. We realised pre and post-tests in 50-meter freestyle swimming speed (T1), counted the number of breaths taken during 50-meter freestyle swimming (T2), and measured the maximum underwater distance covered in one breath (T3). The study was conducted on a sample of n = 12 performance swimmers (4 females and 8 males), with the average age of 15.75 years, average body weight of 56.2 kg, and average body height of 172.5 cm. The testing was preceded by a 10-minute warm-up and a 400-meter swim using any stroke, followed by two repetitions of a 15-meter sprint and a 35-meter easy swim. The experiment involving hypoxic conditions was carried out over a 3-week period / 21 days in February and March 2024. The participants were randomly assigned to three groups: RG1 underwent hypoxic controlled swimming training, RG2 underwent intermittent simulated hypoxic training using the 'AltitudeTechPortable 2020' hypoxic generator, and RG3 served as a control group without any experimental intervention. The results indicate that the most significant average improvement in T1 was achieved by RG2 (+5.3%), in T2 by RG1 (+35.7%), and in T3 by RG1 (+14.3%). Based on the results, we may conclude that for performance swimmers, acute hypoxia in normoxic conditions, incorporated into swimming training in individual periods of 3 weeks and lasting 10-15 minutes per training session after warm-ups, appears to be most effective, especially when combined with intermittent hypoxia as implemented in this study, particularly for improving performance in the shortest 50-meter disciplines.

Keywords: hypoxia; sports training; performance swimming; swimming performance

Souhrn

Hlavným cieľom realizovaného výskumu bolo odhaliť vplyv rôznych foriem hypoxie (akútnej a intermitentnej) na výkon výkonnostných plavcov. Realizovali sme vstupné a výstupné testovanie v rýchlosti preplávania 50 metrov kraulom (T1), zisťovali počet nádychov pri plávaní 50 metrovej vzdialenosti kraulom (T2) a maximálnej preplávanej vzdialenosti pod vodou na jeden nádych T3. Výskum bol realizovaný na n = 12 výkonnostných plavcoch (4 ženy a 8 mužov), ktorých priemerný vek bol 15,75 roka, priemerná telesná hmotnosť bola 56,2 kg a priemerná telesná výška bola 172,5 cm. Testovanie bolo realizované po 10 minútovom spoločnom rozcvičení a rozplávanie 400 metrovej vzdialenosti ľubovoľným spôsobom a 2 x (15 metrov šprint + 35 metrov vyplávanie). Aplikácie a využívanie hypoxických podmienok prebiehalo v mesiacov február – marec 2024, 3 týždne / 21 dní. Sledovaný probandi boli náhodne rozdelený do 3 súborov, kde VS1 absolvoval plavecký hypoxický kontrolovaný tréning, VS2 absolvoval prerušovaný simulovaný hypoxický tréning pomocou hypoxického generátora „AltitudeTechPortable 2020“ a VS3 absolvoval klasický podnet bez aplikácie experimentálneho podnetu. Výsledky poukazujú na zistenia, že v teste T1 dosiahol najvýraznejšie priemerné zlepšenia VS2 (+ 5,3 %), v teste T2 dosiahol najvýraznejšie zlepšenia VS1 (+ 35,7 %) a v teste T3 sa najviac zlepšil VS1 (+ 14,3 %). Na základe výsledkov môžeme konštatovať, že pre plavcov výkonnostnej úrovne sa javí ako najefektívnejšie využívať akútnu hypoxiu v normoxických podmienkach zaraďovaný do plaveckej prípravy v jednotlivých obdobiach v dĺžke 3 týždňov a rozsahu 10-15 minút v tréningovej jednotke po rozcvičení a rozplávaní, ideálne v kombinácii s intermitentnou formou hypoxie podľa realizovanej schémy v tomto výskume najmä pre zlepšenie času v najkratších 50 metrových disciplínach.

Klíčová slova: hypoxia; športový tréning; výkonnostné plávanie; plavecký výkon

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Introduction

There are currently numerous options for improving swimming performance, allowing coaches to select the most optimal ones for each individual athlete. Hypoxic training in its various forms is an under-utilised method of training in performance swimming. While acute hypoxia, characterized by controlled breathing in normoxic conditions, is a common practice among swimmers, other forms of hypoxic training remain less frequently employed. Reasons may include higher financial costs involved, the need for long-term application, or the more demanding organizational requirements associated with high-altitude training, the relative complexity of using hypoxic tents, masks, and chambers, as well as the relatively lower number of studies on the effects of these forms of hypoxia on specific swimming performance. When comparing hypoxia and swimming performance, it is essential to consider the specific form of hypoxia, as recent research has shown that different forms of hypoxia and the extent to which they affect swimming performance vary (Hamlin & Hellemans, 2003; Rodriguez et al., 2004; Bonetti & Hopkins, 2009; Hamlin et al., 2010; Suchý, 2011; Woorons, et al., 2014).

The primary reason is the potential to delay the onset of oxygen debt and lactate accumulation in the muscles, as well as to optimize the ability to prolong underwater time on one breath, reduce the number of breaths and the time required to complete swimming disciplines. Cardelli et al. (2000) who reported a time loss of 1.46% when taking a breath every four strokes at 25 meters and 3.14% when taking a breath every second stroke, representing a significant time loss considering the distance covered, support these findings.

Hypoxic training equipment can be incorporated into the training process essentially anytime and anywhere. The idea behind the use of simulated intermittent hypoxic preparation is to replace breathing normal air with oxygen-reduced air. According to Pupiš and Korčok (2007), equal intervals of normoxia and hypoxia are used in a 5:5 ratio. To enhance athletic performance, a model of 6 - 10 x 5 minutes of hypoxia and 5 minutes of normoxia, 1 - 2 times a day, ideally for 21 days, is also used. However, the simulated altitude is variable and is determined based on oxygen saturation values, ideally between 75-80%. For a positive effect, it is recommended to undergo the process for at least 90-180 minutes a day or every other day (Hellemans, 1999). However, the body's response to hypoxic conditions is individual and can vary significantly across a range of parameters (Ferritty, 2010). Suchý a Dovalil (2011) and Czuba et al. (2018) warn that this can lead to a faster onset of fatigue, overtraining and even burnout, which are considered very negative phenomena in sports training. The authors also emphasise the need to monitor physiological and biochemical parameters, most commonly by tracking heart rate and metabolic response. Dívald (2009) stresses the importance of pre-hypoxia medical evaluations. The most common methods include heart rate monitoring and performance testing in the specific sport.

Czuba et al. (2011) and Roels et al. (2007) specifically direct the use of intermittent hypoxic training towards improving anaerobic capacity and sprint performance. It is necessary to mention that training hypoxia is nowadays abandoned for several reasons. The most important reason is the increased likelihood of overloading the body, often leading to overtraining. In addition, it is necessary to realize that the load itself decreases the oxygen saturation of the blood, while using hypoxic simulation we can reduce the saturation, but the accompanying phenomenon is a significant reduction in the intensity of the load or even even the interruption of activity due to lack of oxygen. Thus, training efficiency may be reduced, while other physiological benefits have not been clearly described (Rodriguez et al., 1999; Garcia et al., 2000; Pupiš, 2014). We will aim to confirm these studies and expand our understanding of its applications and effects on selected swimming parameters.

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Aim

The aim of the research was to uncover the impact of various forms of hypoxia on the performance of performance swimmers.

Method

We opted for three tests. In test T1, the swimmers performed a 50-meter freestyle swim at maximum speed. Test T2 focused on breath count during a 50-meter swim. In the third test, T3, swimmers completed a maximum underwater distance in one breath. Prior to testing, all participants completed a warm-up consisting of a 400-meter swim using any stroke and 2 x (of a 15-meter sprint + a 35-meter easy swim). The participants were given a 10-minute overview of the tests and their objectives.

T1: 50-meter freestyle swim at maximum speed – dive start at the signal. Participants completed the test twice and the results show the best time achieved. The goal was to complete the distance as quickly as possible while minimizing the number of breaths taken. The participants had a 10-minute rest period between attempts.

T2: Stroke count during a 50-meter freestyle swim - three examiners counted the number of strokes during the previous trial. The number of strokes from both attempts was counted and the data from the faster attempt was recorded.

T3: Maximum underwater distance covered in one breath - the objective was to swim the longest possible distance underwater, with a grab start from the edge (turning board), in a single breath. The participants were instructed to complete the test underwater without surfacing and were allowed two attempts. The participants rested for 10 minutes between attempts. We recorded the longer distance achieved.

Tabuľka 1./ Table 1.
Hypoxický tréningový plán – normoxia realizovaný na VS1./ Hypoxic training plan – normoxia, group RG1.

Week	Monday	Wednesday	Friday
1.	2x25m H (breaststroke) with 25m easy swim 2x50 m BC 3-5-7 2x50 m BC 5-7-9 2x25m F (with breathing restriction)/without breathing 2x25m sprint without breathing F	2x25m H (dolphin kick + fins) 2x50 m BC 3-5-7 2x50 m BC 5-7-9 2x25m F (with breathing, first breath after 15m sprint) 2x25m sprint without breathing F	4x25 m H (Breaststroke) 4x50 m BC 3-5-7 4x50 m BC 5-7-9 2x25m sprint without breathing F (fins)
2.	4x25 m H (dolphin kick + fins) 4x25 m BC 5-7-9 4x25m F (with breathing restriction) breathing after 12,5m 2x25m + turn - sprint without breathing F (fins)	4x25 m H (Breaststroke) 6x25m FK (with breathing restriction, 1 breath after 12,5m) 3x50m F (breathing every 5 strokes) 2x50m sprint without breathing F (fins)	6x25 m H (dolphin kick + fins) 6x50 m BC 5-7-9 4x25m FK (with breathing restriction, 1 breath after 15m) 2x50m sprint without breathing F (fins)
3.	4x25 m. H (dolphin kick + fins) 4x50 m. BC 7-9 4x25m FK (with breathing restriction, 1 breath after 15m) 2x50m sprint without breathing F (fins)	6x25 m H (Breaststroke) with start 2x100 m BC 3-5-7 4x50m sprint without breathing F (fins)	4x25 m H (Breaststroke) 2x100 m BC 7-9 4x25m FK (with breathing restriction, 1 breath after 15m) 4x50m sprint without breathing F (fins)

⋆*Legend.* FK – Freestyle kick, BC – Breath control, H – Hypoxia (Single-breath underwater swim), F – Freestyle, B – Breaststroke

The study was conducted on a sample of n = 12 performance swimmers (4 females and 8 males), with the average age of 15.75 years, average body weight of 56.2 kg, and average body height of 172.5 cm. The tests took place during the months of February - March 2024, 4 weeks / 28 days. The post-tests were carried out 7 days after the end of the application of the experimental stimuli. The participants were randomly divided into 3 groups. Research group 1 (RG1) completed swimming-based hypoxic controlled training, research group 2 (RG2) underwent intermittent simulated hypoxic training using the 'AltitudeTechPortable 2020' hypoxic generator, and research group 3 (RG3) received a classic stimulus without the application of any experimental stimulus.

RG1: experienced a classical training stimulus combined with acute hypoxic training. Table 1 shows the training programme that the participants followed for 21 days, 3 times a week for 10-15 minutes after a warm-up swim at the beginning of the training session. In this set there were 3 men and 1 woman included in the group of performance swimmers.

RG2: In this set there were 3 men and 1 woman included in the group of performance swimmers.. Experienced a classical training stimulus combined with simulated intermittent hypoxic training using the 'AltitudeTechPortable 2020' hypoxic generator. The application period was 21 days. For the first 7 days, the simulated altitude was 3500-4000 meters above sea level, with oxygen saturation maintained between 88-90%.

Hypoxia was applied in cycles of 5 min with mask and 5 min without mask, as follows:

- 1. day 6 cycles,
- 2. day 7 cycles,
- 3. day 8 cycles,
- 4.-6. day 9 cycles,
- 7. day off

On days 8-14, the altitude was adjusted according to saturation, aiming to keep it between 85 - 88%. Hypoxia was applied in cycles of 6 min with mask and 4 min without mask, as follows:

- 1.-6. day 9 cycles,
- 7. day off

For the last 7 days (days 15-21), saturation was maintained below 85% but not below 80%. Simulated altitude was adjusted accordingly. The participants were breathing for 6 min with mask and 3 min without mask as follows:

- 1.-6. day 10 cycles,
- 7. day off

RG3: experienced classical training stimulus without any experimental stimulus, meaning that their 'classical' swimming training did not include swimming exercises with controlled breathing or underwater swimming with breath holding. In this set there were 2 men and 2 women included in the group of performance swimmers.

The research groups (RG1, RG2, and RG3) completed the following during the observation period:

- Morning swimming training – 1.5 hours 5 x Per Week
- Afternoon swimming training – 1 hour 3 x Per Week
- Gym - 1 hour 3 x Per Week

Diagnostic We selected three specific swimming performance tests for our study.

T1: Swimming 50 meters freestyle at maximum speed
- The goal was to complete the specified distance as quickly as possible while minimizing the number of breaths. The participants had two attempts. Between attempts, the participants had a 10-minute rest period. The results show the better performance.

T2: Breath count during a 50-meter freestyle swim

- We measured the stroke count for each attempt and selected the data from the faster one. Between attempts, the participants had a 10-minute rest period.

T3: Maximum distance swam underwater on one breath

- The goal was to swim (Breaststroke, dolphin kick) the longest distance underwater on one breath, with a grab start from the edge (turning board). A 10-minute rest was given between attempts. The results show the longer distance achieved.

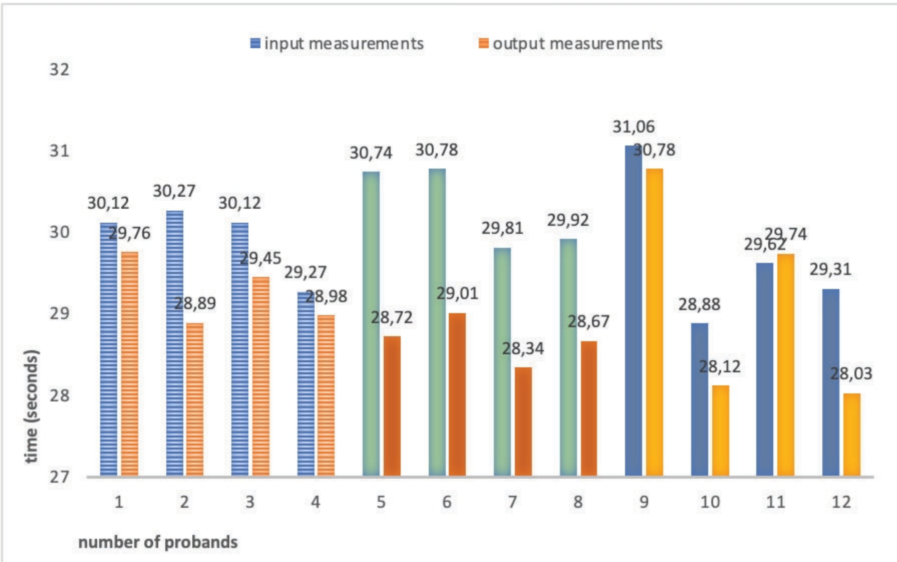
Given the number of participants in each research group, the results were analysed and evaluated using basic qualitative methods (analysis, synthesis, induction, deduction, comparison, case study) and basic quantitative methods (mean, variation range, percentage).

Results

The results of the three tests are presented in the following section. Figure 1 shows the individual results of the participants in test T1: swimming 50 meters freestyle at maximum speed. Table 2 summarizes the results using fundamental statistical and mathematical analysis. Figure 2 shows the individual results of the participants in test T2: the number of breaths during the 50 m freestyle swim. Table 3 presents the results of this test using basic mathematical and statistical methods. Figure 3 and Table 4 present the results of test T3: Maximum distance swam underwater on one breath.

Obrázok 1./ Figure 1.

Výsledky testu T1 (plávanie 50 metrov kraulom max.rýchlosťou)./ Results of test T1 (Swimming 50 meters freestyle at maximum speed).



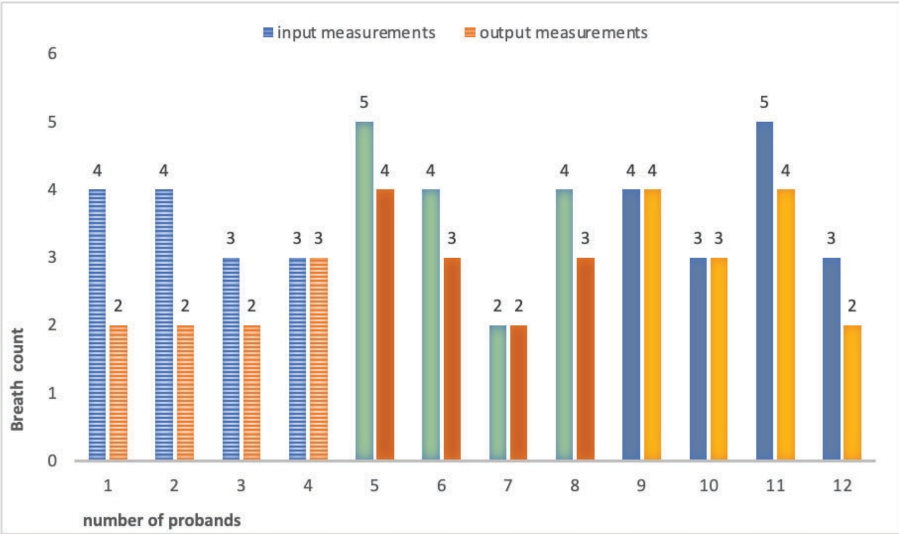
In Figure 1 we can see that in research group 1, 11 participants showed improvement. The most significant improvement was observed in participant 5, who improved by 2.02 seconds. This participant exhibited the most notable improvement, likely due to feeling positive effects under the experimental stimulus of intermittent hypoxia, which he described as a light yet powerful stroke when swimming. The only decrease in performance was observed in a participant from RG3 (participant 11), who reported feeling cold, weak, and with reduced energy during the training process for the last 3 days before the test.

In Table 2, we present the qualitative results of test T1 using basic mathematical and statistical data. It is clear that the best percentage improvement was recorded in RG2, where the average improvement due to hypoxic training was 5.30% (the average improvement due to intermittent hypoxia and classical swimming training stimulus was 1.62 seconds). In research group 1 (RG1), we recorded an average improvement of 2.27% (the impact of acute hypoxia and swimming training was 0.68 seconds), and in RG3, an improvement of 1.85% (improvement of 0.55 seconds). The improvement resulting from the 'classical swimming training', which all participants underwent, indicates the direct impact on the mean values of 0.42% in RG1 and 3.45% in RG2.

Tabuľka 2./ Table 2.
Kvantitatívne ukazovatele výsledkov testu T1./ Quantitative indicators of T1 test results.

TEST 1 50 RG (seconds)	**RG 1**		**RG 2**		**RG 3**	
Min	29,27	28,89	29,81	28,34	28,88	28,12
Max	30,27	29,76	30,78	29,01	31,06	30,78
mean	29,95	29,27	30,31	28,69	29,72	29,17
SD	0,39	0,35	0,45	0,24	0,82	1,15
median	30,12	29,21	30,33	28,7	29,46	28,93
average improvement		0,68		1,62		0,55
average % improvement		2.27%		**5.30%**		1.85%

Obrázok 2./ Figure 2.
Výsledky testu T2 (Počet nádychov na 50 metrov voľným spôsobom)./ Results of test T2 (Count of breaths during a 50-meter freestyle swim).



In Figure 2, we present the results of test T2 monitoring changes in the number of breath count during a 50-meter freestyle swim compared to the previous test. The most significant reduction in breath count was observed in two participants from RG1 and one participant from RG2, decreasing their breath count by two. The other participants showed a decrease of one breath, contributing to a faster 50-meter swim time.

Tabuľka 3./ Table 3.
Kvantitatívne ukazovatele výsledkov testu T2./ Quantitative indicators of T2 test results.

TEST 2: Breath Count	**RG 1**		**RG 2**		**RG 3**	
Min	3	2	4	2	3	2
Max	4	3	5	4	5	4
mean	3,5	2,25	3,75	3	3,75	3,25
SD	0,5	0,43	1,09	0,71	0,83	0,83
median	3,5	2	4	3	3,5	3,5
average improvement		1,25		0,75		0,5
average % improvement		**35.70%**		20.00%		13.30%

In Table 3, we present the results in the form of basic quantitative mathematical and statistical data. The most significant mean improvement achieved RG1, with a 35.7% increase (an average of 1.25 breaths). Research group RG2 exhibited a mean improvement of 20% (0.75 breaths), while RG3 demonstrated a mean improvement of 13.3% (0.5 breaths).

In Table 3, we present the results in the form of basic quantitative mathematical and statistical data. The most significant mean improvement achieved RG1, with a 35.7% increase (an average of 1.25 breaths). Research group RG2 exhibited a mean improvement of 20% (0.75 breaths), while RG3 demonstrated a mean improvement of 13.3% (0.5 breaths).

Obrázok 3./ Figure 3.

Výsledky testu T3 (max. vzdialenosť plávaná pod vodou na jeden nádych)./ Results of test T3 (Maximum distance swam underwater on one breath).

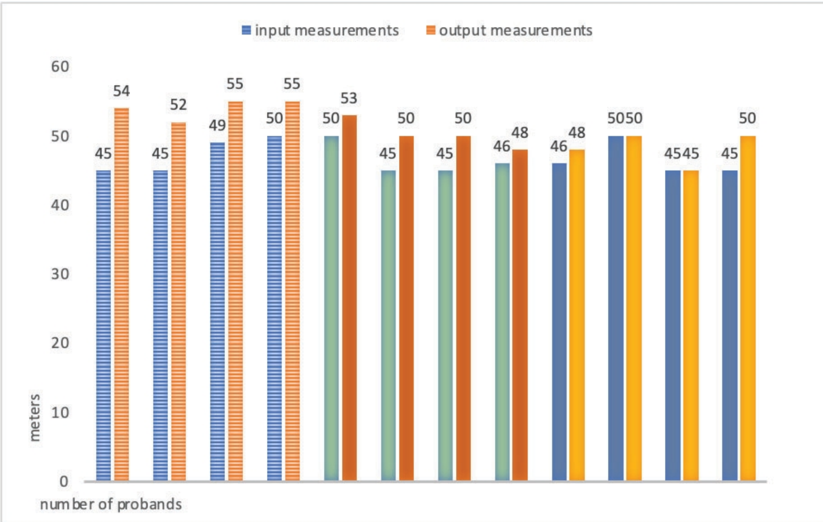


Figure 3 shows the results recorded in test T3, where the participants were instructed to cover maximum distance underwater in one breath using breaststroke. The longest swimming distance was recorded in the post-test measurements for participants 3 and 4 in RG1 (55 meters). The shortest distance was recorded in the pre-tests for participants 1 and 2 in RG1, participants 6 and 7 in RG2, and participants 9 and 12 in RG3 (all of them covering a distance of 45 meters). In the post-test measurements, the shortest swimming distance was achieved by participant 11 from RG3, who was the only participant to show no improvement. However, this is the only participant who did not show any improvement in test T1 either.

Tabuľka 4./ Table 4.

Kvantitatívne ukazovatele výsledkov testu T3./ Quantitative indicators of T3 test results.

TEXT 3 Max distance covered underwater (meters)	**RG 1**		**RG 2**		**RG 3**	
Min	45	52	45	48	45	45
Max	50	55	50	53	50	50
mean	47,25	54	46,5	50,25	46,5	48,25
SD	2,27	1,22	2,06	1,79	2,06	2,04
median	47	54,5	45,5	50	45,5	49
average improvement - difference		6,75		3,75		1,75
average % improvement		**14.29%**		8.06%		3.76%

Table 4 summarizes the qualitative findings, revealing that RG1 achieved the greatest mean improvement of 14.29% (6.75 meters). Improvement was also observed in the research group RG2 by 8.06% (3.75 meters) and in RG3 by 3.76% (1.75 meters). When comparing the data and excluding the influence of classical swimming training, we assume that the effect of acute hypoxia led to an improvement of 5 meters and the effect of intermittent hypoxia led to an improvement of 3 meters in the average results of the participants.

Discussion

The impact of different forms of hypoxia on performance swimming appears to be positive, as our observations have revealed improvements in the monitored parameters. Upon analyzing the individual participant data, excluding participant 13 from group 3 (the only one who did not improve or showed minimal improvement due to illness during the study), the results consistently demonstrate a positive impact on all measured parameters, including 50-meter freestyle performance, breath count in the T1 test, and maximum underwater swimming distance.

In our research, we implemented the use of IHT over an application period of 21 days, where for the first 7 days the altitude was simulated at 3500-4000 m a.s.l. and saturation was maintained at between 88-90%. Hypoxia was implemented in cycles of 5 min with mask and 5 min without mask. The authors Garcia et al. (2000) performed IHT for 120 min/day for 5 days of IHT/at a simulated altitude of 3800 m.a.s.l. and Piel-Aulin et al. (1998) for 12 h for 10 days of IHT/at a simulated altitude of 2000-2700 m.a.s.l. They observed a significant increase in the proportion of reticulocytes, which should be a clear evidence of erythropoiesis. Similar results were found by Rodriguez et al. (1999), where a nine-day exposure to IHT/at a simulated altitude of 5000 m.a.s.l. induced a significant increase in red blood cell count, reticulocyte proportion and haemoglobin concentration, again indicating increased erythropoiesis. All the above studies confirm our results and Lianshi (2004), which confirm the positive effect of IHT.

Contradictory to our findings are studies that, on the contrary, have found no significant changes in sports performance (Martino, Myers, & Bishop, 1995; Vallier et al., 1996; Frey et al., 2000, Levine, 2002).

With this in mind, it is important to note the limitations of the research, the largest of which was the relatively small number of swimmers, where it was difficult to recruit a group of swimmers with similar performance. Ideally, the research would be carried out on a larger sample and, if possible, the effects of a combination of several of the stimuli studied, acute hypoxia together with classical swimming training and simulated intermittent hypoxia would be identified and analysed. Future research could compare our results with studies using hypoxia at higher altitudes, such as living at a lower altitude and training at a higher altitude, or vice versa.

Conclusion

Based on our results, we can conclude that both forms of hypoxia, acute and simulated intermittent hypoxia, have a beneficial effect on the measured parameters. Simulated intermittent hypoxia appears to be more beneficial for improving performance in short 50-meter freestyle disciplines. Conversely, acute hypoxia, which can be applied into swimming training, demonstrates greater effectiveness in reducing breathing rate and increasing underwater distance covered in a single breath.

Any expectations in terms of the positive impact of hypoxic training, especially for increasing erythropoiesis, improving endurance training and increasing VO2max depend significantly on the choice of the type and form of hypoxia as well as the duration of exposure of the body in a hypoxic environment (number of days or weeks as well as the number of hours per day. Based on the results, we evaluate our research as positive and useful for swimming training practice.

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