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Brief Report

Exploring the Impact of Training Methods on Repeated Sprints in Hypoxia Training Effects

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Abstract: Background: Emerging evidence suggests that the outcomes of hypoxia training may be influenced by various factors, contingent upon the chosen method, such as chamber, tent, or mask. This study aimed to examine how different training methods influence the effects of Repeated Sprints in Hypoxia (RSH) training. Methods: Sixteen well-trained cyclists were divided into two groups, experimental (tent; n = 8) and control (mask; n = 8), and carried out eight RSH sessions for four weeks. Training sessions consisted of three bouts of high-intensity sprints using a cycle ergometer. The indoor ambient conditions (CO_2, temperature, and humidity), performance variables (power and relative power output), arterial oxygen saturation, local muscle oxygen of vastus lateralis, heart rate, core temperature, and physiological variables (perception of effort) were measured in each training session. Results: The experimental group reported significantly higher CO_2 ($p < 0.001$ ES = 0.784), humidity levels ($p < 0.001$ ES = 0.750), thermal discomfort ($p = 0.003$ ES = 0.266), dehydration (p 0.025 ES = 0.097), heart rate ($p = 0.017$ ES = 0.113), and lower muscle oxygen amplification ($p = 0.002$ ES = 0.181) than the control group. Conclusion: According to the responses observed, interval training performed under hypoxic conditions inside a chamber induces a more severe physiological response.

Keywords: athletic performance; exercise-induced fatigue; hydration; heat stress; thermal regulation; cyclist; muscle oxygenation

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1. Introduction

Repeated sprint ability (RSA) is a key performance factor in a variety of sports, particularly team sports such as mountain and route cycling [1,2]. RSA training consists of repeated bouts of high-intensity sprints followed by brief rest intervals, which can enhance the cyclists' ability to complete multiple sprints with minimum exhaustion [3]. Cycling fatigue resistance has been demonstrated to improve with repeated sprints in hypoxia (RSH) [4]. Hypoxia can raise the physiological demands of exercise and trigger adaptations that improve performance. According to recent findings, RSH has been shown to enhance time to exhaustion and peak power production in cyclists [5].

The training setting and method can have a considerable impact on the success of RSA training [6]. The use of a hypoxic tent may increase humidity, carbon dioxide (CO_2), and temperature during training, affecting the athlete's comfort level and limiting the length of time they may remain in the tent [5]. As a result, while developing a training program, it is critical to carefully examine the possible downsides of various hypoxic approaches.

These environmental variables can influence athletes' physiological response and perceived exertion during training, thus influencing the outcomes of the training regimen [7].

Temperature is a significant environmental component that can have an impact on the metabolic demands of exercise, including RSA and RSH training [8,9]. Heat stress during exercise can raise athletes' core temperatures, thereby prompting an increase in sweating and heart rate as a means of maintaining thermal homeostasis [10]. This rise in physiological stress can have a severe influence on an athlete's performance, particularly if they lack adaptation to heat [11]. Consequently, the appropriate temperature range for RSA and RSH training is determined by the individual's level of acclimatization and the type of sport.

Relative humidity is an additional environmental factor that can potentially affect the metabolic requirements of exercise. Excessive humidity can diminish sweat's evaporative cooling effects, increasing the athlete's heat stress [12]. This can lead to an increase in perceived exertion (RPE), heart rate, dehydration, and core temperature (CoreT°), all of which can contribute to a decrease in aerobic capacity and muscular endurance, consequently compromising the cyclists' performance [13–15]. Maintaining an adequate relative humidity level throughout RSA or RSH training is therefore critical for peak performance.

Finally, the concentration of CO_2 in the atmosphere has been growing, raising concerns about its potential impact on human health and performance [16]. Increased CO_2 levels can trigger physiological response such as an increase in heart rate, breathing rate, hypercapnia, and blood pressure [17]. These reactions can have an impact on athletes' performance by raising perceived effort and lowering aerobic capacity and recovery [18]. Moreover, excessive CO_2 levels can induce headaches, reduce O_2 transportation, and affect peak VO_2max [19]. In addition, these conditions could lead to respiratory alkalosis, increased blood lactate concentrations, and early fatigue [20]. Therefore, it is critical to monitor CO_2 levels throughout RSH training to ensure that the athletes' health and performance are not impaired [21].

This research is essential because repeated sprint ability training is a popular form of exercise for athletes, but environmental conditions can significantly affect its efficacy and safety. The aim of this study is to examine how different training methods influence the effects of RSH training. We have hypothesized that RSH training using a tent could lead to greater environmental exposure (e.g., higher CO_2, air temperature, and relative humidity) than when using a mask to simulate hypoxia. This exposure could result in a decrease in performance associated with physiological parameters such as peak power, muscle saturation (SmO_2), and peak heart rate, and an increase in perceived parameters of fatigue.

2. Materials and Methods

2.1. Study Design

The study design followed a randomized parallel protocol. A total of sixteen well-trained cyclists participated (age = 25 ± 5.8 years, maximal oxygen consumption (VO_2max) = 69 ± 5.9 and W/kg = 7.2 ± 1.6) [22]. An intervention of eight RSH sessions was carried out for four weeks. Each RSH session began with a 10 min warm-up of continuous cycling (100 watts/80–90 rpm). The rest of the session consisted in performing three sets of five repetitions of 10 s (maximum sprints), with an active recovery of 20 s between repetitions and 180 s between sets [23].

The experimental condition group (n = 8) carried out sessions in a normobaric environment using a tent (CAT-12, Louisville, Colorado) whereas the control group (n = 8) used a facial mask (Im Sachsenhausen, Bickenbach, Germany) to avoid high temperatures, relative humidity, and elevated CO_2 in the environment [5]. Normobaric hypoxia was calibrated at a fraction of inspired oxygen (FIO_2) of 14.3% corresponding to 3700 m.s.n.m. as well as a moderate to high altitude [18], and was simulated via a generator using a semi-permeable filtration membrane (nitrogen filter technique) attached to a face mask or waterproof tent.

2.2. Materials and Procedures

Indoor ambient conditions were recorded with an internal stable non-dispersive infrared sensor for digital detection of CO_2, temperature, and humidity (Green Eye, TechGrow, The Hague, The Netherlands).

Power output (W) and relative power output (W/kg) were measured by coupling the cassette of each participant's bicycle to a cycle ergometer with electronic resistance (CycleOps®Hammer, Madison, WI, USA).

The arterial oxygen saturation (SpO_2%) was recorded using a finger oximeter (Checkme O_2, Viatom Technology Co., Shenzhen, China).

The local muscle oxygen saturation (SmO_2) was assessed with a near-infrared spectroscopy (NIRS) device (MOXY, Fortiori Design LLC, Minneapolis, MN, USA) in the vastus lateralis muscle. NIRS technology allows SmO_2 evaluation taking into consideration the relative change in total haemoglobin (tHb) and the interaction between O_2Hb and HHb with the following equation: $SmO_2 = O_2 O_2hB / O_2 O_2HB + H\,Hb \times 100$. NIRS data analysis included SmO_2 decrease (during sprint; 10 s) and SmO_2 recovery (during recovery; 20 s).

Heart rate (HR) was recorded for each sprint bout using a heart rate monitor chest strap (HRM-Tri, GarminTM, Olathe, KS, USA).

Core temperature (CoreT°) was measured with a specific non-invasive sensor 306 used to assess core body temperature (CORE®, Green TEG, Rümlang, Switzerland).

Perception variables: The rate of perceived exertion (RPE) was registered as a perceptual effort–fatigue marker. The Borg Scale 0–10 was used, where 0 was defined as "very, very light" effort and 10 as "maximum, strenuous" effort [24]. Perceived respiratory discomfort was assessed using a visual analogue scale of 0–10 where 0 was defined as "minimal discomfort or difficulty" and 10 as "maximal discomfort or difficulty" [25].

Thermal sensation was measured with a sensation rating scale [26] that includes 17 categories of thermal comfort, ranging from 0.0 (unbearably cold) to 8.0 (unbearably hot), in 0.5 unit increments.

The calculation of the hydration level was based on the percentage of weight lost and was carried out using the following formula [27]: Percentage (%) Weight Loss or Dehydration = [(Weight before − Weight after)/Weight before] × 100 Express weight in kg.

2.3. Statistical Analysis

Results were reported using the mean and standard deviation of each variable during one session per week. A mixed analysis of variance (MANOVA) was performed for each variable to explore the mean differences between groups. The hypotheses were tested, setting alpha at $p < 0.05$. Omega-squared ($\omega p2$) was used to qualify and quantify the magnitude of the differences (effect size: ES) as follows: <0.01, trivial; >0.01, small; >0.06, moderate; and >0.14, large. For the non-metric rating variables (RPE, thermal sensation, and perceived respiratory discomfort), the Kruskal–Wallis non-parametric test was used, and the range average and p value < 0.05 were reported.

All data were analyzed and systematized using the Statistical Package for the Social Sciences (SPSS, IBM, SPSS Statistics, v.22.0, Chicago, IL, USA). The power of each variable was calculated a posteriori with the G * Power statistical software (v3.1.3, 3 Düsseldorf, Germany) using the effect size, group mean, SD, and sample size. The assessment of power was calculated as between 0.8 and 1, indicating sufficient statistical power.

3. Results

Table 1 shows high values of CO_2 and humidity in the experimental condition (RHS tent). Likewise, higher values of dehydration were observed during RSH tent compared to RSH mask (control group).

Table 2 shows a higher HR during RSH training in the tent compared to the mask. Likewise, a significant decrease in SmO_2 and a lower SmO_2 recovery are shown in RSH tent; this indicates a lower amplification of muscle oxygenation when using a tent compared to a mask system.

Table 1. Comparison of environmental conditions, hydration, and perceptual variables during repeated sprint training over 4 weeks.

Variables	Experimental Condition				Control Condition				Fixed Models	G Power
	1st Week	2nd Week	3rd Week	4th Week	1st Week	2nd Week	3rd Week	4th Week	*p* Value/Effect Size	
CO_2 (ppm)	4469 ± 1660	5077 ± 1601	5064 ± 1688	4631 ± 1611	1060 ± 708	710 ± 226	966 ± 271	802 ± 236	Group effects: <**0.001** */0.783 ‡ Time effects: 0.899/0.012 Interactions effects: <**0.001** */0.784 ‡	0.96
Relative Humidity %	78.4 ± 11.2	79.3 ± 14.1	82.0 ± 14.4	79.0 ± 18.6	40.5 ± 8.3	43.4 ± 5.5	44.6 ± 11.4	40.9 ± 8.9	Group effects: <**0.001** */0.748 ‡ Time effects: 0.791/0.020 Interactions effects: <**0.001** */0.750 ‡	0.98
Environmental Temperature (°C)	21.3 ± 3.1	21.5 ± 2.9	20.2 ± 2.4	19.5 ± 1.8	21.3 ± 3.7	20.1 ± 2.4	19.7 ± 3.3	18.9 ± 3.7	Group effects: 0.457/0.011 Time effects: 0.226/0.075 † Interactions effects: 0.329/0.087 †	0.95
Hydration level (%)	2.06 ± 1.23	1.40 ± 0.75	1.95 ± 1.26	1.62 ± 0.61	1.45 ± 0.87	0.89 ± 0.45	1.34 ± 0.96	1.15 ± 0.79	Group effects: **0.025** */0.097 † Time effects: 0.275/0.074 † Interactions effects: 0.066/0.159 ‡	0.83

p-value < 0.05 (*) statistically significant is highlighted in bold. ES = Effect Size. Qualitative interpretation as follows: <0.01, trivial; >0.01, small; >0.06, moderate (†); and >0.14, large (‡).

Table 2. Comparison of performance and physiological parameters during repeated sprint training over 4 weeks.

Variables	Experimental Condition				Control Condition				Fixed Models	G Power
	1st Week	2nd Week	3rd Week	4th Week	1st Week	2nd Week	3rd Week	4th Week	*p* Value/Effect Size	
Relative power (W/kg)	11.18 ± 2.15	12.01 ± 1.87	12.08 ± 1.70	12.34 ± 1.55	9.69 ± 2.21	11.44 ± 2.40	12.10 ± 1.91	11.17 ± 2.82	Group effects: 0.187/0.087 † Time effects: 0.108/0.121 † Interactions effects: 0.144/0.137 †	0.86
Peak power (W)	718 ± 182	757 ± 172	754 ± 154	788 ± 186	677 ± 229	785 ± 231	837 ± 208	759 ± 243	Group effects: 0.818/0.001 Time effects: 0.582/0.039 Interactions effects: 0.727/0.039	0.85
Heart rate (bmp)	168 ± 9	174 ± 9	166 ± 13	170 ± 7	177 ± 6	175 ± 7	178 ± 6	173 ± 6	Group effects: **0.017** */0.113 † Time effects: 0.709/0.028 Interactions effects: 0.137/0.117 †	0.92
Arterial oxygen saturation (%)	84.5 ± 3.9	83.2 ± 3.8	81.7 ± 5.6	81.5 ± 3.1	82.9 ± 3.6	85.9 ± 3.1	84.4 ± 4.1	84.7 ± 3.2	Group effects: 0.101/0.060 Time effects: 0.746/0.025 Interactions effects: 0.709/0.028	0.96
SmO_2 decrease (%)	6.9 ± 4.7	7.0 ± 5.3	4.6 ± 2.1	4.8 ± 3.7	13.4 ± 9.1	16.5 ± 15.7	12.3 ± 8.1	13.2 ± 11.2	Group effects: **0.002** */0.181 ‡ Time effects: 0.755/0.020 Interactions effects: **0.023** */0.196 ‡	0.81
SmO_2 recovery (%)	60 ± 16	34 ± 13	31 ± 10	54 ± 18	53 ± 23	51 ± 25	54 ± 27	76 ± 16	Group effects: **0.020** */0.108 † Time effects: 0.084/0.080 † Interactions effects: 0.357/0.086 †	0.79
Core temperature (°C)	37.57 ± 0.29	38.01 ± 0.40	37.73 ± 0.25	37.65 ± 0.36	37.97 ± 0.52	37.84 ± 0.58	38.22 ± 0.85	38.20 ± 0.89	Group effects: 0.060/0.086 † Time effects: 0.084/0.080 † Interactions effects: 0.357/0.086 †	0.83

p-value < 0.05 (*) statistically significant is highlighted in bold. ES = Effect Size. Qualitative interpretation as follows: <0.01, trivial; >0.01, small; >0.06, moderate (†); and >0.14, large (‡).

Table 3 shows high values of perceived respiratory discomfort in RSH with the use of tent. However, both the RPE and thermal sensation increased in both groups. But it should be considered that there is a major range of responses in the experimental condition (RSH tent) compared to the control group (RSH mask).

Table 3. Comparison of perceptual variables during repeated sprint training over 4 weeks.

Variables	Experimental Condition					Control Condition					
	1st Week	2nd Week	3rd Week	4th Week	Average Range	1st Week	2nd Week	3rd Week	4th Week	Average Range	*p* Value/H Value
Thermal sensation (Scale: 0–8)	8.36	8.67	10.25	6.57	30.4	5.42	6.63	5.44	6.40	24.3	0.134/2.24
RPE (Scale: 0–10)	7.33	6.44	6.13	6.57	30.8	6.71	8.92	9.93	6.40	24.0	0.107/2.59
Perceived respiratory discomfort (Scale: 0–10)	7.42	9.08	8.25	8.50	32.3	6.64	6.31	6.94	5.07	22.9	**0.027** */4.89

p-value < 0.05 (*) statistically significant is highlighted in bold. H value of Kruskal–Wallis indicates the variable power for confirming the null hypothesis.

4. Discussion

This study found that the RSH tent led to higher levels of CO_2 and humidity, as well as increased thermal sensation, respiratory discomfort, and dehydration compared to the mask. However, it was noted that thermal sensation decreased over time in both conditions. Our results show that indoor CO_2 levels increase during exercise due to human exhalation and perspiration, and are exacerbated under hypoxic conditions [28]. As such, it is important for athletes, coaches, medical staff, and other stakeholders to consider the differences between using a tent and a mask when simulating hypoxia during RSH.

The study also underscores the importance of monitoring the environmental conditions when applying hypoxia in the field to avoid health issues [29,30]. While the isolated and controlled conditions of this study did not allow the environmental temperature to rise to hazardous levels, studies have identified that exercising in normobaric hypoxia tents increases temperature and humidity, which can prevent thermoregulation at the neural level and influence the thermal comfort zone [31].

Furthermore, our findings suggest that the use of an RSH tent may lead to reduced performance and increased risk of heat-related illness due to the higher heart rate during training and the lower amplification of muscle oxygenation compared to when using a mask. We recommend that future research explores the combined hypoxic and heat stress and considers the intensity, volume, and type of workout to fully understand the impact of CO_2 levels and environmental factors on physiological responses during heat stress training.

The finding that the RSH tent resulted in a higher heart rate during training and a lower amplification of muscle oxygenation compared to the mask is of particular interest. This could be attributed to the higher levels of CO_2 and humidity in the tent, which may have increased physiological strain and contributed to the reduced oxygen uptake observed.

The increase in heart rate observed during RSH training in the tent compared to the mask is consistent with previous studies that have shown a similar effect of heat stress on heart rate [32]. Additionally, a previous study found that higher levels of CO_2 can lead to an increase in heart rate and a decrease in stroke volume, which could contribute to the lower amplification of muscle oxygenation observed in the present study [33–35].

The lower SmO_2 recovery observed in the RSH tent compared to the mask further supports the idea that the use of an RSH tent for heat stress training may pose physiological challenges and could lead to reduced performance. A previous study found that heat stress can impair the recovery of muscle oxygenation following exercise, which could be due to the increased demand for oxygen to support heat dissipation mechanisms and maintain homeostasis [36,37].

The absence of significant changes in relative power, peak power, and heart rate in the context of the study's investigation into the effects of different training methods on RSH training could stem from a combination of factors such as training protocol design, individual variability, acclimatization, and measurement limitations [25,38,39]. Further research with refined methodologies and extended training duration might shed more light on the potential impact of different training methods on these variables.

In conclusion, the higher heart rate and lower amplification of muscle oxygenation observed during RSH training in the tent compared to the mask could be attributed to the higher levels of CO_2 and humidity in the tent, which may have increased physiological strain and impaired oxygen uptake.

Limitations

The main limitation of this study is the small sample size; however, the study results are promising for future investigations of hypoxic training under different conditions. Likewise, another limitation is the lack of biochemical measures that would give us information on the physiological response at the cellular level. Future research should assess the health risk of athletes by conducting studies with pulmonary ventilation measurements when using a tent to train in hypoxia. Finally, in the future, researchers need to be more rigorous in the study design; for example, a calculation of the test–retest reliability and of the confidence intervals would improve the results.

5. Conclusions

In summary, our study suggests that the use of a tent in RSH training results in several physiological challenges, including increased levels of CO_2 and humidity, as well as thermal discomfort and dehydration. Furthermore, the tent appears to lead to a higher heart rate during training and a lower amplification of muscle oxygenation compared to the mask. These findings highlight the importance of carefully considering the choice of equipment when conducting RSH training and the potential impact it may have on physiological responses. Further research is needed to fully understand the implications of these findings and to identify strategies for mitigating the negative effects of RSH training in different settings.

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