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Effects on performance of active and passive hypoxia as a re-warm-up routine before a 100-metre swimming time trial: a randomized crossover study

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ABSTRACT: Passive and active hypoxia could be used as a tool during a transitional phase to maintain the effects of warm-up and optimize athletic performance. Our purpose was to evaluate and compare the effects of four different re-warm-up strategies, i.e. rest in normoxia (RN) at FiO_2 = 20.9%, rest in hypoxia (RH) at FiO_2 = 15%, active (5 minutes dryland-based exercise circuit) in normoxia (AN) and active in hypoxia (AH), during the transitional phase, on subsequent 100 m maximal swimming performance. Thirteen competitive swimmers (n = 7 males; n = 6 females; age: 15.1±2.1 years; height: 164.7±8.8 cm; weight: 58.1±9.7 kg; 100 m season's best time 72.0±11.8 s) completed a 20-minute standardized in-water warm-up followed by a 30-minute randomized transitional phase and 100 m freestyle time trial. Compared to AH (73.4±6.2 s), 100 m swim time trials were significantly ($p = 0.002$; $\eta^2 = 0.766$) slower in RN (75.7±6.7 s; $p = 0.01$), AN (75.2±6.7 s; $p = 0.038$) and RH (75.0±6.4 s; $p = 0.009$). Moreover, compared to AH (36.3±0.4ºC), tympanic temperature was significantly lower ($p<0.001$; $\eta^2 = 0.828$) at the end of the transitional phase in passive conditions (RN: 35.9±0.6; $p = 0.032$; RH: 36.0±0.4; $p = 0.05$). In addition, countermovement jump height at the end of the transitional phase was significantly higher in active than in passive conditions ($p = 0.001$; $\eta^2 = 0.728$). A dryland-based circuit under hypoxia could be useful to swimmers, once it has attenuated the decline in tympanic temperature during a 30-minute transitional phase after warm-up, improving 100 m swimming performance in young amateur swimmers.

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INTRODUCTION

Before training or competitive events, athletes complete different warm-up routines in order to maximize their performance in subsequent efforts [1,2]. These routines are known to promote an increase in blood flow through vasodilatation [3] to optimize metabolic reactions, thus improving the efficiency of muscle glycolysis and phosphate degradation during exercise [4], and to cause faster oxygen dissociation from haemoglobin [5]. In addition, warm-up routines provide an elevation of baseline oxygen uptake (VO_2) and increase the amplitude of the primary VO_2 response in subsequent exercise (6). Warm-up routines are also known to enable an increase in nerve conduction rate [7] and reduce joint and muscle resistance [5]. All of these described effects are mostly attributed to an increase in body and muscle temperature [5].

However, after 15 to 20 minutes of passive rest [8] the muscle temperature can rapidly decrease and impair performance [7]. Previous research in swimming found that longer rest periods can effectively impair performance in subsequent efforts [9,10]. For example, a longer passive rest in comparison to a shorter interval (45 vs. 10−20 min [10,11]) produces a greater decrease in performance (1.5 and 1.4%, respectively) in a 200 m freestyle time trial. Furthermore, swimmers with a passive rest of only 10 minutes demonstrated a better performance during a 100 m freestyle, when compared to those with a 20-minute rest period [9]. Thus, the beneficial effects of in-water warm-up decrease over time and may influence the subsequent swimming performance.

Research suggests that warm-up routines should be conducted as close as possible to a competitive event in order to have positive effects on performance [1]. However, official requirements during a swimming competition increase the transitional rest period (transitional phase) between the in-water warm-up and the competitive event, promoting a decrease in muscle temperature with noticeable effects on performance [12]. This transitional phase can also increase in lower-level competitions (local and national championships, in some cases) whenever swimmers are only able to compete several hours after performing the in-water warm-up. Consequently, athletes and coaches tend to apply some re-warm-up routines closer to competitive events, during the last minutes of the transitional phase, to minimize the decremental effects on performance.

With respect to swimming, re-warm-up routines have focused on maintenance of muscle temperature after warming up. Previous research has shown that, in comparison to limited clothing (only the swimsuit and t-shirt), wearing warm clothing (t-shirt, hooded top, trousers, gloves, socks and trainers) [13] during a 30 min transitional phase improved swimmers' performance by 0.6%. In addition, active re-warm-up activities during a transitional phase, such as dryland-based exercise circuits, completed alone or in combination with heated tracksuit jackets [12], significantly improved the 100 m freestyle swimming performance by 0.7 and 1.1%, respectively. Therefore, active re-warm-up routines, isolated or in combination with passive strategies, seem to be more effective in maintaining an elevation of muscle temperature and maximization of swimming performance [14].

Further research has focused on the effects of passive exposure or exercise training in O_2- deprived environments. Active and passive hypoxia seem to improve glucose intake and transport, glycolysis, lactate production to provide ATP [15], and oxygen transport [16].

Furthermore, exercise in hypoxia is intended to produce compensatory vasodilatation with an induced nitric oxide-dependent increase in muscle blood flow [17]. Specific molecular adaptations arising from the oxygen-sensing pathways [18] and greater reliance on the anaerobic metabolism [19] have been reported after hypoxic exercise. When compared to normoxia, hypoxic exercise induces greater microvascular oxygen delivery to fast-twitch fibres [20] and higher motor unit recruitment [21]. A higher elevation of baseline VO_2 has also been found after a hypoxic exercise in comparison to normoxia [22]. Thus, these positive effects produced by passive and active hypoxia could be used as a tool during a transitional phase to maintain the effects of warm-up and optimize athletic performance. In addition, a recent study evaluated the effects of active preconditioning techniques using systemic hypoxic exposure, showing that this preconditioning method did not have an ergogenic effect on repeated sprint cycling performance, despite some specific haemodynamic responses (e.g. greater oxygen extraction and changes in blood volume), which were emphasized in the trained cyclists [23]. However, to our knowledge, no studies have analysed the effects of performing a re-warm-up routine under hypoxia.

Therefore, the purpose of our study was to analyse the effect of four types of re-warm-up routines: i) rest in normoxia (RN); ii) rest in hypoxia (RH); iii) dryland-based circuit in normoxia (AN); and iv) dryland-based circuit in hypoxia (AH) on the 100 m freestyle time trial performance and on the countermovement jump (CMJ) height in young swimmers. It was hypothesized that an active re-warm-up under hypoxic conditions could help improve the swimming performance in a 100 m time trial.

MATERIALS AND METHODS

Design

A counterbalanced, repeated-measures cross-over design was used to determine whether different types of transitional phase re-warm-ups affected the 100 m time trial swimming performance. The swimmers completed the following four testing sessions with different re-warm-up routines: i) RN with the fraction of inspired oxygen (FiO_2) equal to 20.9%; ii) RH with FiO_2 equal to 15%; iii) AN with the fraction of inspired oxygen (FiO_2) equal to 20.9%; and iv) AH with FiO_2 equal to 15%. Testing sessions under hypoxic conditions were performed in a normobaric chamber (CAT 430, Colorado Altitude training, USA) using two generators (CAT-12, Colorado Altitude Training, USA). Transitional phases under normoxia were also completed inside the normobaric chamber but the generators were turned off. The normobaric chamber was placed close to the swimming pool, in a specific room, with a temperature of 22.0±0.5ºC. All in-water warm-ups and 100 m time trials were carried out in a 25-metre indoor pool (water temperature 27.0±0.3ºC, air temperature 25.6±0.4ºC, relative humidity 51.6±1.2%).

Subjects

Thirteen competitive swimmers with at least eight years of training experience and who exercised for at least six times per week volunteered to participate (n = 7 males; n = 6 females; age: 15.1±2.1 years; height: 164.7±8.8 cm; weight: 58.1±9.7 kg). All swimmers had previous experience in competing at a national level. The average personal best time in the 100 m freestyle time trial was 72.0±11.8 s. None of the swimmers reported any musculoskeletal disorder or exposure to high altitude during the three months prior to the study. All participants were instructed to maintain their regular dietary consumption during the study and to avoid ingesting caffeine or alcohol at least 24 hours before each visit. Also, they agreed not to consume ergogenic aids, supplements or medications that might influence performance. All experimental procedures were explained, and written consent was obtained from each volunteer or parent (participants under 18 years of age) in accordance with the Declaration of Helsinki. Our study was approved by the University of Évora Ethics Committee (Ref: 19007).

Testing procedure

Testing was carried out twice a week, on consecutive Mondays and Thursdays, during usual training hours between 4 and 6 p.m. Swimmers performed a low-intensity and low-volume workout the day before each testing session. During each session, swimmers completed a 20-minute in-water warm-up, similar to those performed prior to a competitive event, which included the following components: 300 m freestyle (easy pace); 4×50 m with 15 seconds of rest between sets technical drills; 4x50 m freestyle (15 m race pace, 35 m easy) with 30 seconds rest between sets; 4×25-m freestyle (dive start, race pace) with 1 minute of rest between sets; 200 m freestyle (ease pace). During the 7 minutes after the in-water warm-up, participants changed into their racing suits (around 23 to 30 minutes prior to the 100 m time trial). The re-warm-up routines (RN, RH, AN, AH) were then distributed randomly between participants. In all conditions, swimmers wore a t-shirt and tracksuit. Seven of the swimmers remained seated in the normobaric chamber (RN or RH) for 20 minutes (23 to 30 minutes before the 100 m time trial) with minimal activity. The other six swimmers were required to complete 5 minutes of the dryland-based exercise circuit (AN or AH), from 8 to 13 minutes before the 100 m time trial. This circuit was based on previous studies [12], and simulated swimming movements. Exercises included were: 3 × medicine ball (2 kg) throw-downs, 3 × 10 simulated underwater butterfly kick whilst in a streamline position holding a BodyBlade (Mad Dogg Athletics Inc., California, USA) oscillation device above the head, and 3 × horizontal jump. All exercises were completed twice at maximum effort, with a 10-second rest taken between each exercise. When the circuit was finished, swimmers remained seated for 5 minutes in normoxia or hypoxia. The last 3 minutes of the transitional phase, prior to the 100 m time trial, were used to walk from the normobaric chamber to the pool, take off the t-shirt and the tracksuit, and put on the swimming cap and goggles. The last task was to perform a 100 m time trial (Figure 1).

The tympanic temperature (Ttymp) was used as a proxy measure of deep body temperature. It was measured and recorded prior to the baseline warm-up and immediately before the 100 m time trial using Braun ThermoScan (IRT 4520, Braun GmbH, Kronberg, Germany). The technical error of measurements was 0.2° for temperatures in the range 35.5–42.0°C, and 0.3°C outside this range. The 100 m times were recorded using a Geonaute chronometer Onstart 710 (Decathlon, Villeneuve-d'Ascq, France) by two of the researchers, and the mean of these values was used for analysis. The heart rate (HR) data were recorded by a Polar RS800 (Polar, Polar Electro OY, Kempele, Finland) monitor at the end of the warm-up, throughout the transitional phase and at the end of the 100 m freestyle time trial. Additionally, after the end of the re-warm-up, the SaO_2 levels were measured using a pulse oximeter (Onyx, Nonin, USA). Ratings of perceived exertion (RPE) were determined using the 10-point Borg scale [24] following the in-water warm-up and the 100 m time trial.

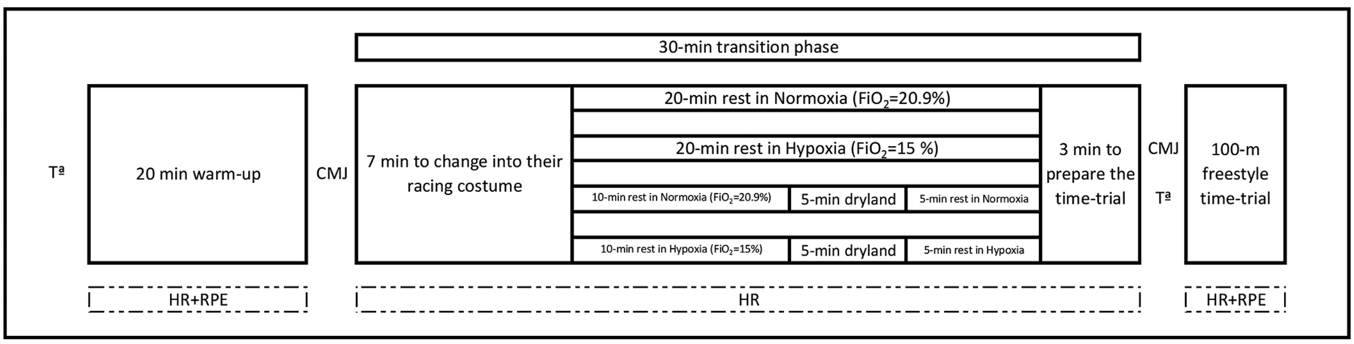
Countermovement jump heights were calculated using the contact platform (Ergotester, Globus, Codogne, Italy). CMJ height was measured before the warm-up and prior to the 100 m time trial. The CMJ was performed at the centre of the platform with the feet placed shoulder-width apart in the standing position. Participants were asked to jump as high as possible with a rapid self-selected countermovement. Participants were asked to try and land close to the take-off point. Each participant performed two attempts, with 90 seconds of rest in between attempts. The best trial from each participant was used for data analysis.

Statistical analysis

Data analysis was performed using the statistical package SPSS v.24 (IBM, New York, USA). Descriptive statistics with measures of central tendency and dispersion were used. The assumption of normality and homoscedasticity was verified with the Shapiro–Wilk and Levene test, respectively. A one-way analysis of variance with repeated measures and Bonferroni post hoc test was used to investigate differences between study variables. The effect size was calculated using eta squared. For all procedures, a level of significance of $p \leq 0.05$ was chosen.

RESULTS

With respect to the warm-up variables, no main effect of the transitional phase was observed for the basal temperature, RPE, HR at the end of the warm-up or CMJ height after warm-up (Table 1). Among the physiological variables, analysed during the four different transitional phases, there was a significant effect on SaO_2 ($F = 57.922$; $p<0.001$; $\eta^2 = 0.946$), with lower values for the RH and AH compared to the normoxia strategies (RN and AN).



HR: Heart Rate; RPE: rating of perceived exertion; FiO_2: fractional inspired oxygen concentration; CMJ: countermovement jump; Tª: tympanic temperature.

FIG. 1. Research design and testing protocol.

TABLE 1. Warm-up, transition and 100-m time-trial results in the four strategies applied.

				95 % confidence interval		ANOVA			Post-hoc	
		Mean	**SD**	**lower**	**upper**	***F***	***p***	η^2	***Comparison***	***p***
Baseline Tª (ºC)	RN	36.3	0.3	36.1	36.5	0.923	0.465	0.217		
	AN	36.2	0.4	35.9	36.4					
	RH	36.1	0.4	35.8	36.4					
	AH	36.1	0.2	36.0	36.3					
HR post WU (bpm)	RN	144.2	14.5	135.5	153.0	0.943	0.456	0.221		
	AN	145.2	12.4	137.8	152.7					
	RH	149.8	15.9	140.2	159.4					
	AH	147.9	13.6	139.6	156.1					
RPE WU	RN	4.5	1.3	3.7	5.3	1.564	0.259	0.319		
	AN	4.2	0.7	3.8	4.7					
	RH	4.7	0.9	4.1	5.2					
	AH	4.4	1.4	3.6	5.2					
CMJ height post WU (cm)	RN	27.0	5.0	24.0	30.0	0.795	0.524	0.193		
	AN	27.1	6.3	23.3	30.9					
	RH	28.2	5.7	24.8	31.7					
	AH	27.9	5.0	24.9	30.9					
SaO_2 (%)	RN	97.5	1.0	96.9	98.0	57.922	**<0.001**	0.946	RN *vs* RH	0.001
	AN	97.8	0.7	97.3	98.2				RN *vs* AH	<0.001
	RH	90.8	4.6	88.0	93.6				AN *vs* RH	<0.001
	AH	87.5	3.0	85.7	89.4				AN *vs* AH	<0.001
Mean HR Rwup (bmp)	RN	91.9	13.9	83.5	100.3	22.157	**<0.001**	0.869	RN *vs* AN	0.005
	AN	103.0	12.1	95.7	110.3				RN *vs* AH	0.002
	RH	94.9	7.7	90.2	99.5				AN *vs* AH	0.002
	AH	104.9	9.8	99.0	110.8					
Peak HR Rwup (bmp)	RN	126.9	13.9	118.6	135.3	107.662	**<0.001**	0.970	RN *vs* AN	0.024
	AN	147.5	9.8	141.6	153.5				RN *vs* AH	0.001
	RH	114.3	7.4	109.8	118.7				AN *vs* RH	<0.001
	AH	153.5	7.9	148.7	158.2				AN *vs* AH	<0.001
Tª pre time-trial (ºC)	RN	35.9	0.6	35.6	36.3	16.023	**<0.001**	0.828	RN *vs* AH	0.032
	AN	36.3	0.4	36.0	36.5				RH *vs* AH	0.05
	RH	36.0	0.4	35.7	36.2					
	AH	36.3	0.4	39.0	36.5					
CMJ height pre time-trial (cm)	RN	25.9	5.3	22.7	29.1	11.933	**0.001**	0.782	AN *vs* RH	0.008
	AN	28.9	5.6	25.5	32.2				RH *vs* AH	0.002
	RH	25.6	4.9	22.7	28.5				RN *vs* AH	0.04
	AH	28.7	5.3	25.6	31.9				RN *vs* AN	0.01
Time 100 m (s)	RN	75.7	6.7	71.7	79.8	10.925	**0.002**	0.766	RN *vs* AH	0.01
	AN	75.2	6.7	71.1	79.2				AN *vs* AH	0.038
	RH	75.0	6.4	71.1	78.9				RH *vs* AH	0.009
	AH	73.4	6.2	69.7	77.1					
HR after 100 m (bmp)	RN	175.0	7.5	170.5	179.5	0.412	0.748	0.110		
	AN	179.1	12.8	171.3	186.8					
	RH	181.3	15.9	171.7	190.9					
	AH	177.1	7.5	172.6	181.6					
RPE 100 m	RN	7.7	1.3	6.9	8.4	0.756	0.544	0.185		
	AN	7.5	1.2	6.8	8.3					
	RH	7.8	1.3	7.0	8.6					
	AH	7.9	1.0	7.3	8.5					

RN: rest in normoxia, AH: active in normoxia; RH: rest in hypoxia; AH: active in hypoxia; HR: Heart rate; RPE: Rating of perceived exertion; SaO_2: arterial oxygen saturation; WU: Warm-up; CMJ: countermovement jump Tª:temperature.

In addition, a significant effect was observed on the mean (F = 22.157; p<0.001; η^2 = 0.869) and peak (F = 107.662; p<0.001; η^2 = 0.970) HR data during the transitional phase, showing significantly higher values in the active (AN and AH) compared to the passives strategies (RN and RH) (Table 1). Likewise, when compared to AN (148 ± 10 bpm), peak HR was significantly higher in AH (154 ± 8 bpm). Furthermore, compared to AH (36.3±0.4ºC), the Ttymp was significantly lower (F = 16.023; p<0.001; η^2 = 0.828) at the end of the transitional phase in passive conditions (RN: 35.9 ± 0.6; p = 0.032; RH: 36.0±0.4; p = 0.05).

Regarding performance, CMJ height (cm) at the end of the transitional phase was significantly higher in active (AN: 36.3±0.4; AH: 36.3±0.4) compared to passive conditions (RN: 35.9±0.6; RH: 36.0±0.4; F = 11.933; p = 0.001; η^2 = 0.728). Compared to AH (73.4±6.2 s), 100 m swim time trials were significantly (F = 10.925; p = 0.002; η^2 = 0.766) slower in RN (75.7±6.7 s; p = 0.01), AN (75.2±6.7 s; p = 0.038) and RH (75.0±6.4 s; p = 0.009) (Figure 2). However, no main effect was observed on RPE or HR at the end of the time trial.

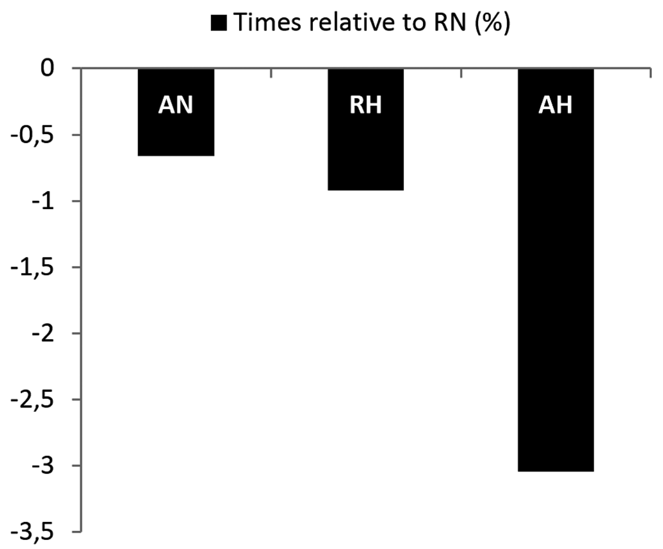


FIG. 2. One-hundred-meter freestyle time-trial times for the three additional transition intervention conditions (active in normoxia – AN; rest in hypoxia – RH; active in hypoxia – AH). Times were normalized against the control condition (rest in normoxia – RN).

DISCUSSION

To the best of our knowledge, this is the first study to investigate the effects of including active or passive hypoxia in the 30-minute transitional phase, after a traditional warm-up on the 100 m freestyle swimming time trial performance. We found that Ttymp was significantly higher prior to the 100 m time trial in the AH transitional phase condition, when compared with AN, RH and RN. Accordingly, swimmers registered significantly faster 100 m freestyle time trials (3%) in the AH condition when compared to the RN condition. Also, swimmers performed significantly faster time trials in comparison to RH and AN. Moreover, compared to passive strategies (RH and RN), the CMJ height was higher when during the transitional phase a dryland-based circuit was included in both environment conditions (AH and AN).

During a 100 m swimming race the anaerobic metabolism is a substantial source of energy [25], leading to a blood lactate concentration higher than 10 mMol/L [26]. Similarly, it has been demonstrated that an increase in muscle temperature augments the muscle glycogenolysis, glycolysis and high-energy phosphate degradation during exercise [27]. In addition, a warm-up has been proposed to maintain the acid-base level by stimulating the buffering capacity [28]. Moreover, exercise in hypoxia produces a greater reliance on the anaerobic metabolism, improving the glucose metabolism [19] and lactate production to provide ATP synthesis [15]. Therefore, one possible explanation of the results obtained in the present study could be related to higher stimulation of the anaerobic metabolism pathway during the AH transition, which could improve the subsequent swimming performance. In addition, the limited oxygen availability produced under hypoxia induces vasodilatation to increase the blood flow and oxygen delivery [29], and previous research found a relationship between the rise of body temperature and the increases in muscle blood flow [30]. These physiological effects could explain the data obtained in the present study, where in comparison with AN, RH and RN, a significantly higher Ttymp prior to the 100 m freestyle time trial and a concomitant increase in performance were reported after AH. Although this was the first study using a hypoxic environment during the transitional phase after the warm-up, some of the physiological variables that can explain the response to this novel strategy have not been analysed. Therefore, more research on the physiological effects of hypoxic exercise during the transitional phase are necessary.

Moreover, it has been shown that an increase in muscle temperature improves the muscle oxygen uptake kinetics of subsequent exercise. This physiological response is higher after exercise in hypoxia, producing higher basal VO_2 levels after exercise in hypoxia compared to the same exercise in normoxia [22]. Thus, swimmers may have greater oxygen uptake during the 100 m swimming time trial when performing AH re-warm-up. Furthermore, the elevation of the muscle temperature increases the speed of the muscle contraction, and it has been previously reported that exercise in hypoxia produces higher motor unit recruitment [21] compared to the same exercise in normoxia. Therefore, AN could increase the neuromuscular performance in a subsequent 100 m swimming time trial.

The elevation of the core and muscle temperature prior to a competition is a key factor in optimizing the sprint and power performance [27]. Thus, a higher core temperature reflects improved maintenance of muscle temperature. For this reason, some active exercise and heated clothing have been included during the transitional phase between the warm-up and the start of the competitive event [12,13] in order to minimize the decrease in body temperature.

Our results showed that the inclusion of active exercises (normoxia and hypoxia) during the transitional phase improved CMJ height in comparison with passive strategies (normoxia and hypoxia). These results are in agreement with a previous study using a similar dryland-based exercise circuit, where the inclusion of this type of exercise (alone or in combination with a heated jacket) minimized the decrease in Ttymp and improved swimming performance.

Previous research in swimmers [12,13] has revealed a relationship between the core temperature and the swimming performance, showing that a faster time trial performance is strongly associated with a smaller decline in temperature. These studies [12,13] used active and passive (e.g. heated jackets) strategies to attenuate the decline in muscle temperature, as we reported above. However, although the tympanic temperature was found to be higher with active strategies, our results are not in accordance with these two previous studies, because AN did not improve the 100 m freestyle time trial performance. According to previous studies [31] in swimmers, which produced similar results to those obtained in the present study, one reason for these controversial findings could be the low load of our chosen task, where swimmers only performed exercises with their body weight. However, AH could increase the stress of this exercise, obtaining positive effects on the subsequent exercise. Interestingly, passive rest in hypoxia did not improve the 100 m freestyle time trial in comparison to normoxia (passive and active). One possible explanation for this finding is related to Ttymp. As we reported previously, RN produced lower Ttymp when compared with AH, which may explain the swimming performance obtained after this condition. Therefore, passive hypoxic exposure alone during the transitional phase was not able to improve the subsequent swimming performance.

This research unveils a new line of re-warm-up protocols under hypoxic conditions, in an effort to develop the most effective and efficient method to maximize performance. From an applied perspective, swimming coaches and sport scientists should keep in mind that, if the transitional phase between warm-up and competition is too long, a 5-minute dryland-based circuit exercise under hypoxia performed from 8 to 13 minutes before the time trial is a suitable method, given its positive effect on a 100 m freestyle time trial. In line with previous research [12], the circuit programme should consist of 3 sets of three exercises designed to simulate swimming movements. In order to induce the hypoxic effects, each exercise should be performed at maximum effort and in an environment of a FiO_2 of 15%. Rest periods between consecutive exercises should last around 10 seconds.

The main limitation of the present study was the small sample size of each group. In addition, the performance level of the swimmers is another limitation in the present research, and coaches must take this aspect into consideration. Another limitation is the lack of an easily portable technology that would allow us to apply the active hypoxic strategies at poolside during a competition. Currently, the applicability of the present study is limited due to the unavailability of a hypoxic chamber near to the swimming pool. Concerning the methodological procedures employed herein, the fact that some physiological and metabolic variables were not assessed (i.e. core temperature, blood lactate concentration, VO_2, electromyography, etc.) may also be considered as a potential limitation. In this regard, practitioners are advised to take into consideration the above-mentioned aspects and limitations when interpreting the provided data.

CONCLUSIONS

A dryland-based exercise re-warm-up routine, under hypoxic conditions, attenuated the decline of tympanic temperature during a 30 min transitional phase, thus improving 100 m time trial performance in young amateur swimmers.

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Conflict of interest

None declared

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