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Research article

Three sessions of repeated sprint training in normobaric hypoxia improves sprinting performance

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ABSTRACT

The objective of the present study was to evaluate the impacts of three-session repeated sprint training conducted in normobaric hypoxia with 48-h intervals on sprint performance, arterial oxygen saturation (SpO_2), and rating of perceived exertion (RPE) scores. A total of 27 moderately trained male university students voluntarily took part in this study. In this single-blind placebo-controlled study, subjects were assigned into normobaric hypoxia (FiO2: 13.6%; HYP), normobaric normoxia (FiO2: 20.9%; PLA), and control group (CON). The HYP and PLA groups underwent three repeated sprint training sessions (a total of four sets of five times 5-s sprints with a 5-min rest between sets and a 30-s rest between each sprint) on a cycle ergometer in normobaric hypoxia or normoxia conditions. Pre- and post-tests were performed 72 h before and after the training period. Three participants were excluded from the study, and the data from twenty-four participants were analyzed. Contrary to what was observed in the pre and post tests, no time and condition interactions were observed in the relative peak power output (PPO), mean power output (MPO), percentage of sprint decrement score (Sdec%), and RPE parameters. Time effect was found in all observed variables respectively; relative PPO ($F = 5.784$, $p = 0.045$, $\eta^2 = 0.74$), relative MPO ($F = 3.927$, $p = 0.042$, $\eta^2 = 0.66$) and large time effect found for $S_{dec\%}$ ($F = 11.430$, $p = 0.046$, 0.83), and RPE ($F = 14.990$, $p = 0.008$, $\eta^2 = 0.96$). A notable increase in relative peak power output (PPO) and mean power output (MPO) was observed in the post-test in comparison to the pre-test values, indicating statistical significance. The increase in PPO was in HYP 13.44% ($p = 0.006$), in PLA 7.48% ($p = 0.264$) and in CON 2.66% ($p = 0.088$). The decrease in $S_{dec\%}$ was in HYP -13.34%% ($p = 0.048$), PLA -10.54 ($p = 0.577$) and CON -4.83 ($p = 0.644$) at post-test. The results show that although there were no statistical differences between the groups, notable differences in performance-related variables were observed in the HYP group after 3 sessions of repetitive sprint training in hypoxia.

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1. Introduction

Since 1968 Mexico City Olympic Games, the effects of altitude on exercise performance have become a critical topic in sport sciences. In this way, altitude training has been used to improve athletic performance during the season preparation camps or in-season period by the athletes as an important stimulus [1,2]. Due to the fact that it is very difficult to stay for the athletes, especially in-season period, at the natural/terrestrial altitude owing to time-cost and/or different reasons [3], artificial altitude training has attracted attention as time and cost-effective methods amongst athletes and practitioners. Nowadays, repeated sprint training in hypoxia (RSH) is used by athletes with its doubled physiological stress effect which provides exacerbated responses in the aspects of the cardio-pulmonary system, energy metabolism, neuromuscular functions, and perceived fatigability [4,5].

It is well-known that the main goal of altitude training is to enhance cardiorespiratory fitness (i.e. VO_2max) and/or recovery capacity by increasing the red blood cell (RBC) production through endogenous erythropoietin synthesis which could be initiated by hypoxic exposure [3,6–8]. The hemoglobin mass increases in between 7 and 16 days after the first ascent to terrestrial altitude [9,10] or after 10–14 days under 12-h simulated hypoxic exposure [11,12]. In contrast to mentioned goal of training or accommodation under chronic hypoxic exposure, in the present study the main purpose of RSH was to improve the resistance capability to fatigue via stimulating the mechanisms that affect the efficiency of anaerobic energy metabolism during repeated sprint efforts such as greater activation of fast twitch muscle fibers, increase in phosphocreatine resynthesis [13,14] and increase muscle buffering capacity [13]. Thus, it is plausible that there could be increase on sprint/exercise performance or some physiological markers via RSH without a chronic exposure under hypoxia condition [13,15–19]. However, it is important to complete the repeated sprint training sessions with the best muscular efforts to obtain the expected results such as improved power output, neural activation, muscular buffer capacity etc. [20,21]. Therefore, the degree of the hypoxia and training/test protocols must be determined very carefully in accordance with the individual's training levels [4,22,23]. Reduction in arterial O_2 saturation (SpO_2) and physical working capacity has a very strong relation with the hypoxia degree [24–26]. Therefore, determination of the hypoxic dose is a key factor in the sustainability of sprint performance for the selected repeated sprint training or test protocol [24,25]. In the literature, there is not a RSH protocol accepted as a gold standard or a certain hypoxia degree as the most appropriate level to improve repeated sprint performance [18]. However, a meta-analysis provides some protocol recommendations for RSH as follows; 2–3 sessions in a week, 3–4 sets in each session, 4-7 x 4–15 s with <30 s recovery periods and inter-sets rest with 3–5 min [18]. In the present study, the repeated sprint training protocol was determined in compliance with the recommendations made in aforementioned meta-analysis and the RSH protocol was applied similar to a study reported any negative alterations regarding the protocol (4 sets of 5 s x 5 sprints with 25 s recovery and 5 min resting period between the sets) [27]. The hypoxia degree is very important to induce peripheral fatigue in combination with selected RSH protocol. Increasing severity of hypoxia up to FiO_2 13.3% could augment indices related to peripheral fatigue without affect central drive during the maximal sprint efforts [28].

In the literature, some studies show improvement on sprint performance which have training periods between 2 and 4 weeks with 6–12 training sessions in normobaric hypoxia condition [15–17,27]. Also, some recent studies have reported that improvements could be observed on repeated sprint performance indices in a shorter period (5–14 days) with 4–5 RSH sessions [19,29,30]. All of the above-mentioned studies applied hypoxic dose in between 13 and 14.8 % fraction of inspired O_2 in the air (FiO_2). Considering the hypoxia dose and applied intervention period in terms of the session numbers, it seems that there is possibility to observe positive changes via shorter intervention period with almost similar number of training sessions by similar hypoxia doses [10,19,29,30].

In conjunction with the above, the present study aimed to investigate the short-term effects of 3-session RSH on repeated sprint performance, SpO_2, and the rating of perceived exertion (RPE) in moderately-trained males. The present study was one of the few studies in the literature which was conducted with 3 RSH sessions performed within 5 days in shock micro-cycle format. The main objective of this paper was to provide a more time-saving training method with the understanding of possible minimum beneficial effects on evaluated variables for the practitioners and athletes which could be used especially during the in-season period. Within the scope of the present study, we hypothesized that 3-session RSH on cycle ergometer could improve repeated sprint performance indices via increase on power output in moderately-trained males.

2. Materials and methods

2.1. Study design

This study, designed with a single-blind placebo-controlled approach, received approval from the Ankara University Human Research Ethics Committee (2020/277). Subjects in the normobaric hypoxia (HYP) and placebo (PLA) groups attended the laboratory six times, while the control (CON) group had three visits. In the first meeting with all subjects, the research objectives and potential results were explained and the familiarization process with the method was conducted. Two weeks before the pretest, they were informed about the study and informed consent forms were duly obtained.

Following anthropometric measurements, the subjects were randomly allocated into three groups using a draw method, and they were pointed on the attendance list as "x" (hypoxia), "y" (placebo), and "z" (control). In their second visit, the baseline tests were conducted. The categorization of groups described as follows: the HYP group (n = 9) experienced normobaric hypoxia with FiO_2 at 13.6%, the PLA group (n = 9) subjected to normobaric normoxia with FiO_2 at 20.9%, facilitated by the utilization of an altitude generator mask for blinding purposes, and the control group (CON; n = 9) underwent solely pre and post-tests. The degree of hypoxia was applied directly without any changes in altitude for the HYP group (900 m, Golbasi, Ankara, Turkey). The apparatus featured a display for tuning the degree of hypoxia within the range of 0.5–12. For the HYP group, a setting of 9 (FiO_2 13.6%) was employed,

while the PLA group utilized a setting of 0.5 (sea level, normoxia condition) during the training sessions. Everest Summit II-Altitude Generator (Hypoxico Hypoxicator, New York, USA) was utilized to accomplish either normobaric hypoxia or placebo condition. The subjects in the HYP and PLA groups executed three repeated sprint training sessions with fourty-eight hours intervals during their 3rd, 4th, and 5th visits in normobaric hypoxia or normoxia conditions, and they finalized research process visiting the laboratory last time for the post-tests. All training and tests performed in the laboratory were performed at the same time of day for each participant. Repeated sprint values, SpO2 levels, and RPE scores obtained within the scope of pre- and post-tests were recorded 72 h before and after the training process under normobaric normoxic condition.

2.2. Participants

Twenty-seven males moderately-trained university students (n = 27; 16 football players, 4 basketball players, 4 volleyball players and 3 handball players) participated in this study voluntarily. The participants' characteristics were expressed as mean ± standard deviation (SD): age 21.41 ± 1.9 years, stature 180.33 ± 7.43 cm, body mass 78.88 ± 5.9 kg, body mass index (BMI) 18.87 ± 3.66 kg m^2, and weekly training duration 4.7 ± 0.82 h. Male participants who exercised regularly at least three days a week, did not have a chronic disease, did not have a musculoskeletal injury in the last six months, did not use medication, did not smoke, did not reside and train at an altitude of 1500 m or more in the last three months were included in the study.

Subjects were included to the research based on predetermined criteria; non-smokers, male gender, absence of chronic diseases, no use of medication, no engagement in training or residence at altitudes exceeding 1500 m in the last 3 months, absence of musculoskeletal injuries in the past 6 months, and regular training at least 3 days in a week.

The participants were asked to keep on their regular diet program and replicate the same diet before the tests and trainings, avoid to intake any ergogenic aids/dietary supplements throughout the study period and caffeinated or alcoholic beverages/foods for 24 h before the testing and training days. Also, they were asked not to do any vigorous physical activity/exercise until the end of the study period.

At the beginning, twenty-seven participants were included in the study on voluntary basis. Three of them left the study (2 from placebo and 1 from control group) after the first training session on their own accord with different individual reasons. Therefore, the study was completed with twenty-four participants.

2.3. Procedures

2.3.1. Repeated sprint test and training intervention

All of the participants were subjected to repeated sprint test and trainings on cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands). The protocol was comprised of 4 sets, 5 s x 5 sprints with 25 s active recovery (low cadence ~50 W) between the sprints and 5 min resting (~50 W) periods between the sets. Before starting the test or training, 5 min warm-up at low cadence with 5 s sprints at the end of each 1 min was applied [27]. During the repeated sprint testing and training sessions all the participants were asked to maintain pedaling on low cadence in recovery periods similar to warm-up period and encouraged verbally to perform their best efforts during the sprinting phases to eliminate the pacing effect.

The pedal resistance was fixed as 0.075 $Nm.kg^{-1}$ for each participant. The RSA test protocol also was used as training protocol on

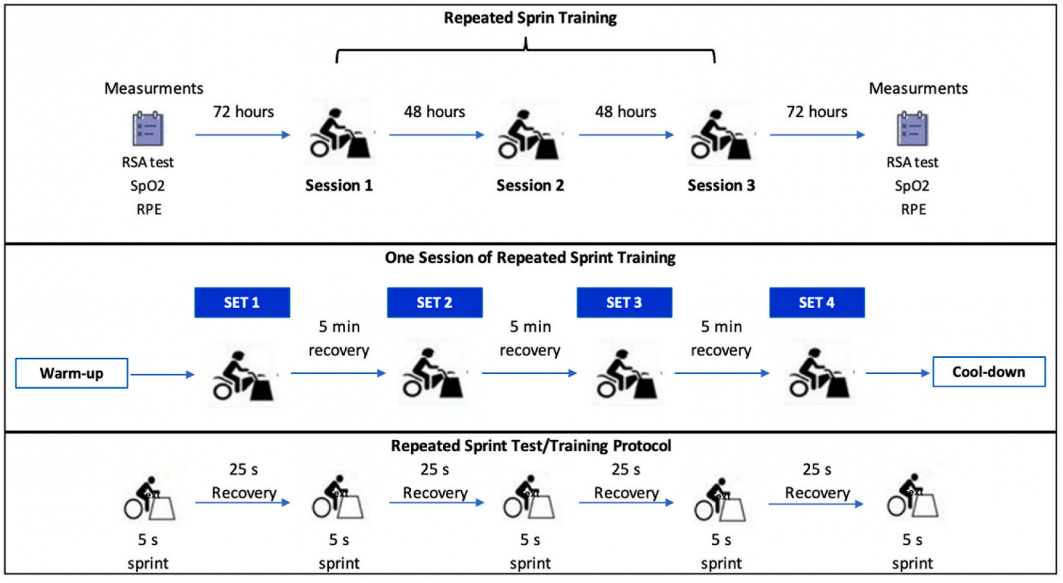

Fig. 1. Training intervention and repeated sprint protocol used also as test protocol.

the same cycle ergometer. During the training sessions, HYP and PLA participants were informed that they would be exposed to normobaric hypoxia at the level of $FiO_2 = 13.6\%$. In this study, blinding was provided in practice by using the simulation device for the normoxia condition. SpO_2 values and RPE were recorded immediately after the end of each set. The RPE was evaluated by using the 6–20 scale [31]. SpO_2 (arterial oxygen saturation percentage) was measured via fingertip pulse oximeter and monitored throughout the training and testing sessions (Hypoxico, New York, USA). The relative peak power output (PPO, watt) and relative mean power output (MPO, watt) values were recorded for each performed sprints via the Lode cycle ergometer software. The sprint decrement score formula (Sdec%) was used to evaluate repeated sprint performance. The Sdec% calculated as follows: "Sdec% = [1 - (total power/ideal power)] × 100." While the PPO calculated based on the number of sprints defines the total power, the highest PPO obtained during the repetitions corresponds to the ideal power [32]. At the end of the 3rd training session, the total normobaric hypoxia exposure duration was approximately ~90 min (each training session lasted ~30 min) for each participant in HYP group. The training and testing protocol are demonstrated in Fig. 1.

2.4. Statistical analysis

IBM SPSS V. 22 (SPSS Inc., Chicago, IL, USA) was used for all statistical data analysis. First, the distribution of the data was analyzed with the Shapiro-Wilk Test. According to the distribution, the Paired Sample T-test or the Wilcoxon Test was utilized for comparison of the pre- and post-test values. Two-way repeated-measures ANOVA [(Time (Pre and Post-test) × Group (RSH, PLA vs. CON)] was used for pre- and post-test comparisons. The effect size calculated via partial eta-squared (η2) and evaluated by Cohen's d (d) and classified as follows; $d < 0.2$ as trivial, 0.2–0.4 as small, 0.5–0.7 as moderate and >0.8 as large effect [33]. The study was completed with twenty-four participants, and the post-hoc power score (1-β err prob) was detected as 0.91 when the effect size was 0.4, for three groups and two measurements. All the data were provided with mean and standard deviation values, and the alpha value was accepted as 0.05.

3. Results

Independent sample *t*-test analysis was applied for SpO_2 and RPE measurements obtained during the training sessions. The results in regard of SpO_2 showed that values were statistically lower for all the sets of training sessions in HYP group. SpO_2 were significantly lower than PLA across all sets in HYP group ($p < 0.05$). This showed that the hypoxic exposure was provided successfully. SpO_2 values were 72–83.22 for HYP group and 90.57–94 for PLA group. It was observed that RPE values decreased after first training session in HYP group, but the difference was not statistically significant in between HYP and PLA groups ($p > 0.05$). The values related to SpO_2 and RPE presented as mean ± SD in Table 1.

There was no detected significant interaction for time and condition regarding pre- and post-test SpO_2. A significant large time effect was observed ($p = 0.007$, $\eta^2 = 0.98$) and there were decrease in SpO_2 at post-test relatively to pre-test in HYP (97.66 ± 1.73 vs. 95.55 ± 1.74; $p < 0.05$) and PLA (98.14 ± 0.37 vs. 95.42 ± 2.37; $p < 0.05$), but not in CON (97 ± 1.41 vs. 95 ± 2.32; $p > 0.05$).

All the performance related variables obtained in the scope of pre- and post-test were analyzed via two-way repeated-measures ANOVA. The outcomes were presented in Table 2. There were not any significant interactions (time x condition) or group effect for all the variables. However, significant moderate time effect was found for the variables respectively; relative PPO ($F = 5.784$, $p = 0.045$), relative MPO ($F = 3.927$, $p = 0.042$) and large time effect found for $S_{dec\%}$ ($F = 11.430$, $p = 0.046$), and RPE ($F = 14.990$, $p = 0.008$).

No statistically significant differences were observed between the groups with respect to relative PPO, relative MPO, $S_{dec\%}$, and RPE. Although no statistically significant changes were found in the interaction between group and time x condition, statistically significant differences emerged in relative PPO, relative MPO, $S_{dec\%}$, and RPE for HYP group pre-to post-test. The increase in relative PPO in HYP group (13.44%, $p = 0.006$) was almost 2 times higher than PLA (7.48%, $p = 0.264$) and 4 times higher than CON group (2.66%, $p = 0.088$) pre-to post-test. MPO was not changed pre-to post-test in the PLA (4.3%, $p = 0.617$) and CON (6.44%, $p = 0.288$)

Table 1
SpO_2 values for the groups during repeated sprint training sessions by sets.

SpO_2						RPE			
		HYP	PLA	t	p	HYP	PLA	t	p
Session 1	Set 1	82 ± 5.52	91.85 ± 3.93	−3.988	0.001	13.55 ± 2.06	13.14 ± 1.34	0.456	0.655
	Set 2	79.11 ± 3.85	92.14 ± 3.76	−6.778	0.000	15.33 ± 1.73	15.14 ± 0.89	0.263	0.796
	Set 3	77.22 ± 3.63	93.28 ± 3.09	−9.342	0.000	16.33 ± 1.5	16.71 ± 0.95	−0.584	0.568
	Set 4	76.44 ± 4.21	90.57 ± 4.72	−6.314	0.000	17.44 ± 1.94	17.14 ± 1.67	0.326	0.749
Session 2	Set 1	79.77 ± 4.96	92.71 ± 3.94	−5.631	0.000	12.77 ± 1.78	13.71 ± 1.6	−1.086	0.296
	Set 2	74.44 ± 3.04	91.57 ± 4.99	−8.498	0.000	14.77 ± 1.56	15.57 ± 0.97	−1.172	0.261
	Set 3	72.77 ± 3.63	93.28 ± 4.11	−10.583	0.000	15.66 ± 1.73	16.57 ± 1.13	−1.193	0.253
	Set 4	72 ± 2.59	94 ± 3.10	−15.434	0.000	16.55 ± 2	17.85 ± 1.34	−1.472	0.163
Session 3	Set 1	83.22 ± 4.23	92.85 ± 3.97	−4.633	0.000	12.22 ± 2.68	13 ± 1.63	−0.673	0.512
	Set 2	77.66 ± 6.06	91.14 ± 5.52	−4.582	0.000	13.77 ± 2.04	14.71 ± 1.38	−1.037	0.317
	Set 3	75.44 ± 6.3	93.57 ± 2.76	−7.055	0.000	15 ± 1.65	15.85 ± 1.46	−1.078	0.299
	Set 4	72 ± 7.81	91.85 ± 5.45	−5.709	0.000	16 ± 1.58	17 ± 2.08	−1.095	0.292

Values are presented as mean ± SD. SpO_2, arterial oxygen saturation; RPE, rating of perceived exertion; HYP, hypoxia group; PLA, placebo group.

Table 2
Variables related to repeated sprint performance, RPE and SpO_2 for pre- and post-test.

		GROUP				ANOVA p-values (η^2)	
		HYP	PLA	CON	Time	Condition	Interaction
Peak Power ($W.kg^{-1}$)	Pre-test	15.99 ± 1.32	16.29 ± 2.35	14.99 ± 1.97	**0.045 (0.74)**	0.157 (0.84)	0.484 (0.03)
	Post-test	18.14 ± 1.42	17.51 ± 3.62	15.39 ± 1.5			
	p-value	**0.006**	0.264	0.088			
Mean Power ($W.kg^{-1}$)	Pre-test	11.26 ± 1.54	12.08 ± 2.13	11.64 ± 2.80	**0.042 (0.66)**	0.826 (0.17)	0.390 (0.04)
	Post-test	13.71 ± 1.41	12.60 ± 3.47	12.39 ± 1.39			
	p-value	**0.001**	0.617	0.288			
Sdec%	Pre-test	9.22 ± 4.85	10.53 ± 5.21	8.29 ± 3.02	**0.046 (0.83)**	0.054 (0.94)	0.938 (0.003)
	Post-test	7.99 ± 2.11	9.42 ± 2.12	7.89 ± 2.70			
	P-value	**0.048**	0.577	0.644			
RPE	Pre-test	12.56 ± 1.94	13.43 ± 2.82	12.88 ± 1.25	**0.008 (0.96)**	0.063 (0.93)	0.940 (0.003)
	Post-test	11.33 ± 1.73	12.14 ± 1.46	12.00 ± 0.76			
	p-value	**0,011**	0.253	0.155			

Values are presented as mean ± SD. Sdec%, percentage of sprint decrement score; SpO_2, arterial oxygen saturation; RPE, rating of perceived exertion; HYP, hypoxia group; PLA, placebo group; CON, control group. Significant differences from pre-to post-test indicated as bold. Cohen's d (d) was calculated to measure the effect size for two-way repeated measures ANOVA and indicated in parenthesis.

groups; however, a significant increase was detected for the HYP group after the training intervention period at post-test (21.76%, $p = 0.001$). Regarding the Sdec% measurements, no statistically significant differences were observed between the groups. Nevertheless, a significant decrease in Sdec% was exclusively observed in the HYP group (−13.34%, $p = 0.048$) after the training intervention period but not in PLA (−10.54%, $p = 0.577$) and CON (−4.83%, $p = 0.644$) groups. There were no observed significant differences regarding the RPE values between the three groups at pre- and post-test. In comparison of pre- and post-test, a significant decrease for RPE was observed in only HYP group ($p = 0.011$).

No time and condition effects were found for any of the relative PPO values produced during each 5-sprint performed at pre- and post-test. There were not any significant changes in between the groups for each sprint but statistically significant increase from pre-to post-test was observed only in HYP group for all repetitions. For PLA and CON groups no significant changes were observed in PPO values from pre-to post-test ($p > 0.05$).

4. Discussion

In this study, participants were applied a 5-day shock-micro cycling program that included 3 sessions of repeated sprint training with 48-h rest intervals in normobaric hypoxia or normoxia. In the present study hypoxic degree determined as FiO_2 13.6% and each RSH session lasted ~30 min. The total duration was ~90 min for 3-RSH session. The hypoxia dose in the current research and the studies discussed was calculated via a simple formula (determined by multiplying hypoxia duration by hypoxia level) [34]. The hypoxic dose was 4.08 for per session and 12.24 for 3 RSH sessions. The applied protocol consisted of 4 sets of 5 s x 5 sprints with 25 s recovery and 5 min resting period between the sets. According to studies which implemented the same training protocol, there were not reported any negative alterations during repeated sprint exercise in comparison with normoxia condition [27,35]. All the participants completed each training and testing sessions without any physical or respiratory discomfort which could interrupt the training sessions. The training protocol implemented with lesser number of RSH sessions in the present study (3 sessions within 5 days at FiO_2 13.6%) compared to mentioned studies (6 sessions in 2–3 weeks at FiO_2 14.5%). Therefore, the hypoxia degree increased to provide more exaggerated physiological stress in a short period to enhance fast twitch muscle fibers activation and neural activation under hypoxic condition such a short period. According to outcomes of two-way repeated-measures ANOVA, there was no significant time and condition interaction for the observed performance-related variables between the three groups. However, statistically significant positive changes were observed in the performance-related parameters only in the group subjected to hypoxic training intervention, as indicated by intra-group comparisons between pre- and post-test. Based on this observed change, it can be suggested that 3 sessions of RSH in shock microcycle format may be a more effective training to improve performance-related parameters (Table 2) compared to the same training protocol implemented in normoxia condition.

The results obtained in the present study indicated that relative PPO was increased 13.44% and MPO 21.76% in HYP group after intervention period compared to pre-test values. The increase in relative PPO for HYP group were higher approximately 2 times than PLA (7.48%) and 4 times than CON group (2.66%). When the sprints are evaluated separately in terms of relative PPO for pre- and post-test, it was observed that the post-test relative PPO values for each sprint significantly increased compared to the pre-test values. Beard et al. [29] reported 6% increase in relative PPO (W/KG = 12.84 ± 0.83 vs. post-test W/KG = 13.63 ± 1.03; 6%) in RSH group in their study conducted with national-level rugby players (each session 24 min and total exposure duration 96 min for 4 sessions; total hypoxia dose: 13.24). The training sessions, consisting of 3 sets x eight 10 s sprints with 20 s passive recovery, were performed over 2 weeks at a simulated altitude of FiO_2 13.8% [29]. Also, they reported significant changes in 5 of 6 sprints in their study which is parallel with the results of the present study [29]. Considering this result, it can be understood that the synergistic application of repeated sprint training and normobaric hypoxia exposure can provide a greater increase in relative PPO and relative MPO even in a short-time period compared to the same training performed in normobaric normoxic condition. Evaluating the loading of the same

intensity, when compared in both normoxic and hypoxic conditions, it is obvious that hypoxic condition could provide more physiological stress. Thus, it is possible to provide faster physiological adaptations at the same physical load intensity compared to the normoxic condition [36]. In a study which 19 male participants with sprint training background were exposed to hypoxia at the level of $FiO_2 = 14.5\%$ and subjected to a sprint training program in 5 consecutive days (850 min for 9 sessions; total hypoxia dose: 123.25), it was reported that there was significant improvement in PPO (pre-test: 13.34 ± 0.20 W/kg; post-test 13.70 ± 0.17 W/kg) in hypoxic training group [19]. Kasai et al. [14] reported improvement on some sprint performance indices in another study which have similar design and hypoxia level with their another study. In this study 18 male sprinters performed sprint training sessions consisted of 3 sets with variable time and repeats on 6 consecutive days (each session 90 min and total exposure duration 540 min for 6 sessions; total hypoxia dose: 78.3). According to results submitted by Kasai et al. [14] there was not significant change in regard of repeated sprint performance indices except increase in mean power (3.2% in hypoxia group and 8.7% in normoxia group). However, intramuscular phosphocreatine contents were increased in only hypoxia group. The studies published by Kasai et al. [14,19] are very similar in terms of the intervention period with the present study. However, the training regimen is more intensive than the present study. Also, the participants of their study were individuals with sprint training background, and it reported that the participants continued their training routines during the intervention period. In the present study, all the participants were asked to avoid any high-intensity exercises during the intervention period which could cause a possible overstrain that may hinder performing their best efforts during the training and testing days. Therefore, in the absence of appropriate adjustments to the overall training load may swiftly lead to overreaching or overtraining [22].

Another study conducted with 8 trained cyclists on 6 consecutive days with 6 training sessions ($FiO_2 = 14.5\%$; 3 × 30 s, all-out sprints with 5 min recovery periods; total duration of hypoxic exposure 159 min; total hypoxia dose: 23.05) showed that repeated sprint training in hypoxia delayed fatigue time in normobaric normoxia condition. The study also stated that RSH training decreases the lactate level, increases the lactate oxidation capacity, and provides effective glucose breakdown [37]. Additionally, a case study conducted by Faiss and Rapillard [38] with a professional cyclist showed that 5 RSH sessions (total 150 sprints, each session 50 min and total duration of exposure 250 min; total hypoxia dose: 35) performed in ten days in normobaric hypoxia at FiO_2 14% had positive effects on peak power (best sprint power increase 11%) and total work capacity (increased 6%) for the similar physiological strain. So, through the RSH interventions, the increase on repeated sprint performance indices could be occurred by the short-term adaptations of anaerobic energy metabolism (increased phosphocreatine contents, muscle buffering capacity, and activation of fast twitch muscle fibers) as reported by some studies [13,14,19].

Brechbuhl et al. [30] stated that in a study conducted on tennis players, there was decrease −1.9% at post-1 and -2.5% after 3 weeks at post-2 in terms of total sprint time after top-up training intervention period with 5 RSH sessions at FiO_2 14.5% in 12 days (each session 60 min and total duration of exposure 300 min; total hypoxia dose: 43.5); consisted of 4 sets, five ~8 s maximal sprints with ~22 s passive recovery and ~5 min rest between sets. The observed improvement on sprint performance after three weeks at post-2 is indicating that the additional post tests are very important to evaluate any possible beneficial effect of a training intervention. This mentioned study also reported that there was an increase in muscle blood perfusion (82.5% for post-1 and 137% for post-2).

The change in $S_{dec\%}$ score was lower in favor of HYP group (−13,34%) than the other two groups (−10,54% in PLA and −4,83% in CON) and the changes were in parallel with increase on relative PPO values. By the increase in relative PPO and relative MPO in HYP group during the repeated sprint test in normoxia condition, it can be said that the HYP group could create more resilience to fatigue and perform the sprints with more power production and less power loss compared to the other groups. Also, the present study's findings regarding $S_{dec\%}$ score complies with the results of some other studies even if the intervention period was shorter in the present study than these studies [27,37]. In contrast to present study, some studies which have almost similar intervention period and number of training sessions reported no change in terms of $S_{dec\%}$ [29,30] or fatigue index [10] for pre-to post-test.

The SpO_2 was lower in HYP group set by set in all the training sessions, especially in second training session. The SpO_2 was slightly increased at the third training session. This situation may be interpreted that the participants in the HYP group adapted to hypoxic stimulus as respiratory by the third session. Although the blinding procedure was provided through the hypoxicator, no important decrease was observed for SpO_2 during the training sessions in PLA group. According to the results provided by Hamlin et al. [27], the SpO_2 level could increase at the second training day of hypoxic exposure relative to the first training day under hypoxic exposure. It is well known that as hypoxia degree increases, SpO_2 level and physical working capacity decrease inversely [24,25,39]. Furthermore, the exposed hypoxia level may cause different responses according to individual variability [23,40]. Therefore, SpO_2 values must be observed carefully during the training intervention period to reach optimal hypoxic degree regarding practical applications in the scope of a training program. The SpO_2 was decreased in HYP and PLA groups at post-test which performed in normoxia condition. The decrease in SpO_2 may be interpreted as decrease in O_2 contents as a result of increased power production in the active muscles [13,15] which may be related with improvement in relative PPO and MPO in the present study. A remarkable difference between the groups in regards of RPE values was not observed. Notwithstanding, RPE was decreased only in the HYP group at significant level but not in PLA and CON groups in regard of pre- and post-test. Townsend et al. [28], reported that peripheral fatigue could be increased by the hypoxic stress at FiO_2 13.3% during all-out effort repeated sprint running without affecting the central fatigue. In the present study, peripheral fatigue was not measured but when the changes in SpO_2 and RPE evaluated together with the increase in PPO and MPO in HYP group pre-to post test, this can be considered as an improvement in the capacity to resist physical fatigue and perception of the sensation of fatigue. These suggest that the preferred HYP degree (FiO_2: 13.6 %) was an appropriate hypoxia level for moderately-trained male participants to improve tolerance against perception of fatigue during maximal repeated sprint efforts.

The results of the present study are consistent with the results of the above-mentioned studies. According to these results, it could also be said that there is a strong possibility to improve the repeated sprint performance in a short period without an accommodation period under hypoxia condition. Despite the short hypoxia exposure time, it is very surprising to see an increase on observed RSA

performance related indices within such a short period with RSH implementations. The total sprint time was 300 s (sprinting time was 100 s for each session) and the total duration of hypoxia exposure was 90 min (hypoxic exposure time was 30 min for each session) in the present study.

According to two studies that reported positive changes as the present study with similar number of training sessions, the total sprinting time and total hypoxic exposure duration were respectively: 800 s total sprint time and 6 h hypoxic exposure [30], and 960 s total sprint time and 96 min hypoxic exposure duration [29]. This study was one of the papers that reported improvement on relative PPO and MPO with 3 RSH sessions within such a short period. However, it should be kept in mind that the participants in the present study were moderately-trained males. Therefore, it could be beneficial to test this design with individuals who have different training levels and modalities, especially in elite level athletes. Last but not the least, the RSH still seems like an important issue to be investigated for providing more data regarding its short-term effects on physical performance, physiological and biochemical variables, which may lead to improvement on physical performance and recovery period.

The results of studies mentioned above are consistent with the present study's results. The studies shown that it is possible to improve sprint related indices within a short training intervention period conducted within 5–14 days with 3–9 RSH sessions between 13.05 and 123.25 calculated hypoxia dose [14,19,29,30,37,38]. The calculated hypoxia dose was 4.08 for per session and 12.24 for 3 RSH sessions in the present study.

Besides, Jung et al. (2020) emphasized that in a meta-analysis, exercise under hypoxic exposure can improve cognitive functions [34]. The cognitive functions can highly affect especially the team sports performance and success of team sports athletes. Therefore, it could be considered in conjunction with exercise under hypoxic exposure with different exposure durations and exercise intensities for the future studies. According to another meta-analysis, there are various hypoxic training paradigms which considered effective training methods to enhance VO_2max with varying levels of hypoxia exposure. Additionally, it is suggested that there could be supplemental effect to implement different hypoxic training methods in mixed format [41].

5. Conclusions

In the present study, the results suggest that, despite the absence of a statistical differences between the training groups, notable changes were observed in the hypoxia group between the pre-test and post-test of performance-related variables following 3-session RSH with FiO_2 set at 13.6%. However, it is obvious that there is a need to test the effects of the short-term intervention design that was used in the present study with future studies which will be conducted on elite athletes with different hypoxia degrees. Moreover, to see any possible improvements as post-effects of the training intervention, there is a need to perform additional post-tests at different time points after the intervention period. On the other hand, in the present study all training and testing sessions were performed at 900 m terrestrial altitude in Ankara, Türkiye. The simulated hypoxic exposure was provided as respiratory, and no correction was made according to terrestrial altitude.

Limitations

The most important limitation of this study was the number of subjects. At the beginning of the study, twenty-seven moderately-trained participants who met the inclusion criteria volunteered to participate in the research, and only twenty-four of them were able to complete the study. Besides, this research was performed with moderately-trained male athletes. Since, the research data would be collected during the in-season period and the athletes would be exposed to hypoxia during physical loading, elite athletes could not be included in the study. Finally, having only one hypoxia degree (FiO_2 13.6%) in the present research could be considered as the last limitation.

Informed consent statement

Informed consent was obtained from all participants involved in the study.

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Data availability statement

All the data obtained and produced in the scope of this study has been not deposited into a publicly available repository and the data will be made available on request.

CRediT authorship contribution statement

Abdulkadir Birol: Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Dicle Aras:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision,

Software, Project administration, Methodology, Formal analysis, Conceptualization. **Cengiz Akalan:** Writing – review & editing, Supervision. **Monira I. Aldhahi:** Writing – review & editing, Funding acquisition. **Mehmet Gülü:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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