Medicine & Science in Sports & Exercise

The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

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Anna Hauser[1], Christoph Zinner[2], Dennis-Peter Born[3], Jon Peter Wehrlin[1], and Billy Sperlich[3,4]

[1]Swiss Federal Institute of Sport, Section for Elite Sport, Magglingen, Switzerland
[2]The German Research Centre of Elite Sport, Cologne, Germany
[3]University of Wuppertal, Department of Sport Science, Wuppertal, Germany
[4]University of AF Munich, Department of Sport Science, Neubiberg, Germany

Accepted for Publication: 29 August 2013

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000000157

Does Hyperoxic Recovery during Cross-country Skiing Team Sprints Enhance Performance?

Anna Hauser[1], Christoph Zinner[2], Dennis-Peter Born[3], Jon Peter Wehrlin[1], and Billy Sperlich[3,4]

[1] Swiss Federal Institute of Sport, Section for Elite Sport, Magglingen, Switzerland

[2] The German Research Centre of Elite Sport, Cologne, Germany

[3] University of Wuppertal, Department of Sport Science, Wuppertal, Germany

[4] University of AF Munich, Department of Sport Science, Neubiberg, Germany

Corresponding author:
Anna Hauser, MSc
Swiss Federal Institute of Sport, Section for Elite Sport
Alpenstrasse 16, 2532 Magglingen, Switzerland
Phone: +41 32 327 6489
Fax: +41 32 327 6405
E-mail: anna.hauser@baspo.admin.ch

No external funding was received for this work from NIH; Welcome Trust; HHMI; others

The authors declare no conflict of interest

Running title: 3 × 3 min double poling and hyperoxic recovery

ABSTRACT

Purpose: To determine the acute responses of breathing oxygen-enriched air during the recovery periods of a simulated 3 × 3-min cross-country skiing team sprint competition at simulated low altitude. **Methods:** Eight well-trained male endurance athletes performed two 3 × 3-min team sprint simulations on a double-poling ergometer at simulated altitude set at ~1800 m. During the recovery periods between the 3 × 3-min sprints, all the athletes inhaled either hyperoxic (F_iO_2 = 1.00) or hypoxic (F_iO_2 ~0.165) air in randomized and single-blind order. The mean total power output ($P_{mean\ tot}$) and mean power output of each sprint ($P_{mean\ 1,2,3}$) were determined. Perceived exertion, capillary oxygen saturation of hemoglobin, partial pressure of oxygen and blood lactate concentration were measured before and after all the sprints. **Results:** No differences in $P_{mean\ tot}$ were found between hyperoxic (198.4 ± 27.1 W) and hypoxic (200.2 ± 28.0 W) recovery (P = 0.57, effect size (d) = 0.07). $P_{mean\ 1,2,3}$ (P > 0.90, d = 0.04–0.09) and rating of perceived exertion (P > 0.13, d = 0.02–0.63) did not differ between hyperoxic and hypoxic recovery. The partial pressure of oxygen (P < 0.01, d = 0.06-5.45) and oxygen saturation (P < 0.01, d = 0.15-5.40) during hyperoxic recovery were higher than those during hypoxic recovery. The blood lactate concentration was also lower directly after the third sprint (P = 0.03, d = 0.54) with hyperoxic recovery. **Conclusion:** Results indicate that trained endurance athletes who inhale 100% oxygen during recovery periods in a cross-country skiing team sprint at low altitude do not exhibit enhanced performance despite the improvement in the key physiological variables of endurance performance.

Key Words: DOUBLE POLING, HYPEROXIA, HYPOXIA, REPEATED SPRINTS, POWER OUTPUT

INTRODUCTION

The ergogenic effects of breathing oxygen-enriched air (hyperoxia) during endurance exercises at sea level are well documented (16,18,27,28,30). Given that the use of hyperoxic air is no longer prohibited by the World Anti-Doping Agency (32), an issue that arises for elite endurance athletes is whether hyperoxia improves competition performance at sea level or at altitude. Hyperoxic gas inhalation involves technical and heavy assembly (i.e., gas tanks or oxygen generators are used), making its use during the exercise in certain events infeasible. A promising approach is the inhalation of hyperoxic air during recovery periods in competitive events, e.g., cross-country (XC) skiing team sprint competition. In the XC skiing team sprint, an Olympic event, two athletes perform in a relay for a total of six heats (three heats for each athlete). The official distance run on single-sprints varies from 1300 to 1600 m, which corresponds to a mean heat time of approximately 3 min, followed by two 3-min recovery periods when the partner is skiing.

Hyperoxic recovery between bouts of high-intensity exercise has received little scientific attention and the limited studies devoted to this practice provide inconsistent results. Sperlich et al. (25) reported that an elevated fractional content of inspired oxygen (F_iO_2) during 6-min periods of recovery between 5 × 50-s maximal arm strokes increased power output in elite swimmers. By contrast, performance was not enhanced by hyperoxic recovery between 5 × 30-s maximal cycling sessions (24), between two incremental running tests until exhaustion (31), and between 6 × 3-min high-intensity intervals on a kayak ergometer, with the session set at sea level (15). Nevertheless, several studies have indicated that inhaling hyperoxic air during recovery periods from repeated exercise positively affects on different physiological parameters. Nummela et al. (14) and Sperlich et al. (24) demonstrated that exposure to elevated F_iO_2 prevents hemoglobin oxygen saturation from decreasing. Hyperoxic recovery also advances the recovery time of post-exercise hemoglobin saturation levels (15) and enhances the partial pressure of oxygen (24,25). Maeda and Yasukouchi (11) revealed that breathing hyperoxic air after 3 × 5-min submaximal cycling sessions reduced blood lactate concentration.

Given that the next Olympic XC skiing team sprint event will be held in Sochi Russia at an altitude of approximately 1500 m, the aim of the present study was to evaluate the acute effects of hyperoxic recovery (F_iO_2 = 1.00) on double-poling (DP) performance, perceived exertion rating, oxygen saturation, partial pressure of oxygen and blood lactate concentration. We conducted the evaluation by simulating a XC skiing team sprint competition (3 × 3-min) at simulated low altitude. Thus far, this study is the first to investigate the effects of hyperoxic recovery between repeated sprints at low altitudes. Because hyperoxic recovery exerts positive effects on physiological parameters at sea level, it can be hypothesized that the ergogenic effects of hyperoxic recovery increase at altitude, where oxygen availability is reduced.

METHODS

Participants

Eight well-trained male endurance athletes (age: 25 ± 3 yrs, height: 181.6 ± 3.9 cm, weight: 74.3 ± 3.5 kg) satisfied the inclusion criteria and completed all the measurements. The experimental group consisted of XC skiers with competition experience and triathletes who engage in XC skiing as part of their routine winter training. The inclusion criteria for participation and data analysis were as follows: 1) male endurance athletes with well-trained upper bodies, 2) a minimum of 5 yrs of endurance training, 3) frequent participation in endurance competitions, 4) completion of four training sessions with all of the experimental set-ups prior to data recording, 5) sufficient power pacing over the three sprints (differences in mean sprint power output between the sprints < 15%), and 6) agreement to participate in the study (with written informed consent). Differences in mean sprint power output up to ~15% between the sprints were associated with sufficient power pacing because the best three teams in the final runs of the 2006 Winter Olympic Games in Turin and the 2009 Nordic World Ski Championships in Liberec demonstrated a mean difference in lap times of up to 15% (8). This study was pre-approved by the ethics committee of the German Sport University in Cologne (Germany), and all the procedures were conducted in accordance with the Declaration of Helsinki.

Study Design

Within a 3-wk period, the athletes completed one familiarization session, a preparatory training period, and two simulated XC team sprint events (Fig. 1) set at sea level (53 m). The two simulated XC team sprint competitions with hyperoxic or hypoxic recovery were separated by at least 3 days and performed in a single-blind random manner at the simulated altitude.

Familiarization Session and Preparatory Training

On the athlete's first visit to the laboratory, age and anthropometric data (body mass and height) were collected. To familiarize the athletes with the DP ergometer and all other diagnostic procedures, they performed a simulation of the test protocol (3 × 3-min DP sprints, separated by 3-min breaks). Each athlete completed four training sessions on the DP ergometer. The training protocol of each session also included 3 × 3-min DP sprints separated by 3-min recovery periods. Training intensity was progressively increased from submaximal to maximal interval workouts, so that all the athletes could sustain performance throughout the three sprints with high power outputs. The familiarization and training sessions were performed in ambient air conditions.

Simulated XC Team Sprint Protocol

The development of the simulated XC team sprint protocol was based on official data from team sprint competitions and in accordance with the regulations of the International Ski Federation (7). In the men's final rounds of the last two Winter Olympic Games in Turin and Vancouver, the mean racing times for one single-sprint run were 174 and 192 s (8), respectively. With these considerations, a single-sprint duration of 3 min was chosen. A SkiErg Concept2 DP ergometer (Hamburg, Germany) was used to simulate XC skiing performance. After a 10-min warm-up that corresponds to a slightly strenuous 12 on Borg's scale, each athlete performed two 3 × 3-min team sprint simulations (Fig. 2). The three sprints were separated by 3-min recovery periods. During these recovery periods, the athletes walked at 1 $m \cdot s^{-1}$ on a treadmill beside the DP ergometer. All the athletes were instructed to perform the 3 × 3-min sprint protocol with maximal effort. During the testing procedure, they received strong verbal encouragement.

Altitude Simulation and Hyperoxic Recovery

The XC skiing events for the upcoming 2014 Winter Olympic Games in Sochi will be held at an elevation of approximately 1500 m. The partial pressure of inspired oxygen at 1500 m can range from 124 to 118 mm Hg because of altitude differences on the race track and changes in air pressure conditions (due to high and low pressure conditions). Thus, we performed the simulation at an altitude of 1800 m. This simulated altitude was achieved by inhaling a hypoxic gas mixture with an inspired oxygen partial pressure (118 mm Hg; barometric pressure 760 ± 8mm Hg) that corresponds to a F_iO_2 of approximately 0.165. Each athlete inhaled hypoxic air by using a face mask connected to an AltiTrainer200® (SMTEC, Nyon, Switzerland), which mixes ambient air with nitrogen to obtain the desired partial pressure of inspired oxygen. To ensure measurement accuracy, the AltiTrainer200® was calibrated before each test day in accordance with actual barometric pressure. During the recovery periods, each athlete inhaled hyperoxic air (F_iO_2 = 1.00) delivered from a 170 L Douglas bag (Hans Rudolph Inc. Kansas, Shawnee, US) attached with plastic tubing to his face mask, or hypoxic air (F_iO_2 ~0.165) delivered from the AltiTrainer200®. The athletes were unaware of which gas mixture they inhaled. In each experimental trial, the athletes wore the same face mask and breathed through the same respiratory tube. They were also prevented from seeing to which device (AltiTrainer or Douglas bag) the valve was connected.

Performance Measurement

During the 3 × 3-min sprints, the power output for each poling cycle was recorded. The mean total power output (i.e., the average power over the three sprints denoted as $P_{mean\ tot}$) was calculated. Mean sprint power output (i.e., the average power of sprint 1, 2, and 3, denoted as $P_{mean\ 1}$, $P_{mean\ 2}$ and $P_{mean\ 3}$, respectively), was also determined. To ensure that all the athletes exerted maximal effort, each of them was asked to estimate their perceived exertion on Borg's 6–20 scale (1) directly prior and after each sprint interval.

Blood Sampling

Blood samples were simultaneously taken from the right and left earlobes to determine the capillary blood levels of oxygen saturation, oxygen partial pressure, and lactate concentration. Next, 120 µL of blood was drawn to measure hemoglobin oxygen saturation and oxygen partial pressure. For blood lactate analysis, 20 µL of blood was also drawn from the right and left earlobes into capillary tubes (Eppendorf AG, Hamburg, Germany). The blood samples were collected before and after warm-up, as well as directly after and 2.5 min after each sprint (Fig. 2). Capillary blood levels of oxygen saturation and oxygen partial pressure were immediately measured using an AVL Omni 3 system (Roche Ltd., Basel, Switzerland). Lactate was enzymatically analyzed with an Ebio Plus automatic analyzer system (Eppendorf AG, Hamburg, Germany). In our laboratory, the coefficient of variation for repeated measurements of lactate concentration is routinely 1.2% at 12 $mmol \cdot L^{-1}$. The corresponding coefficient of variation for oxygen partial pressure is 3.2%, respectively.

Statistical Analyses

The collected data were evaluated for normality and presented as means ± standard deviation (SD). Repeated measures ANOVA was carried out to evaluate the differences in $P_{mean\ 1,2,3}$, perceived exertion rating, hemoglobin oxygen saturation, oxygen partial pressure, and blood lactate concentration between the two test conditions (i.e., hyperoxic and hypoxic recovery). When a significant global effect was detected, Tukey's *post-hoc* test was conducted to identify significant differences between time points. A paired t-test was applied to determine the differences between the pre- and post-values of $P_{mean\ tot}$. An α of $P < 0.05$ was considered significant. All analyses were processed using Statistica software (version 7.1 StatSoft Inc., Tulsa, OK, US). To estimate the practical relevance of the measured values of the hyperoxic and hypoxic treatments, effect size Cohen's d (*d*) was calculated (4). Small, moderate and large effect sizes were classified as 0.20, 0.50 and, 0.80 respectively to Cohen (4).

RESULTS

Performance

Figure 3 shows the individual power data, mean sprint power output for each sprint, and total mean power output under hyperoxic or hypoxic recovery. No differences in $P_{mean\ tot}$ (P = 0.57, d = 0.07) or $P_{mean\ 1,2,3}$ (best P = 0.9, best d = 0.09) between the two conditions were found.

Rating of Perceived Exertion

In both trials, the athletes rated their perceived exertion on Borg's scale as ≥ 17 after each sprint. Perceived exertion did not differ between hyperoxic and hypoxic recovery at any time point (best P = 0.13, best d = 0.63) (Fig. 5B).

Oxygen Saturation and Oxygen Partial Pressure

The oxygen saturation of hemoglobin was higher under hyperoxic recovery than under hypoxic recovery (P < 0.01, best d = 5.40). After the athletes breathed hyperoxic air, oxygen saturation increased from 92.3 ± 6.4% to 99.8 ± 0.2% (P < 0.01), but no such changes followed the breathing of hypoxic air (88.8 ± 3.3% to 93.1 ± 2.4%, P = 0.18) (Fig. 4A). Oxygen partial pressure increased to higher levels with the inhalation of hyperoxic air during recovery than with the inhalation of hypoxic air (P < 0.01, d = 5.45). With hyperoxia, partial oxygen pressure improved 4.1-fold from 87.4 ± 22.3 to 358.6 ± 72.3 mm Hg (P < 0.01), but did not change with hypoxia (66.1 ± 5.8 to 82.2 ± 7.1 mm Hg, P > 0.99) (Fig. 4B).

Lactate Concentration

Directly after the third sprint, the blood lactate levels under hyperoxic recovery were lower than those under hypoxic recovery ($P = 0.03$, $d = 0.54$). At the same time point, blood lactate peaked at 11.9 ± 1.7 $mmol \cdot L^{-1}$ during hyperoxic recovery and at 13.0 ± 2.6 $mmol \cdot L^{-1}$ under hypoxic recovery. No differences were observed between the two trials during the first ($P > 0.92$, best d = 0.32) or second ($P > 0.24$, best $d = 0.49$) recovery period or toward the end of the third recovery period ($P = 0.86$, $d = 0.24$) (Fig. 5A).

DISCUSSION

To our knowledge, this study is the first to investigate acute responses to hyperoxic recovery between repeated sprints at a simulated low altitude. The main findings indicate that inhaling 100% oxygen during periods of recovery from 3 × 3-min sprints performed on a DP ergometer at a simulated altitude of 1800 m 1) did not influence performance ($P_{mean\ tot}$ and $P_{mean\ 1,2,3}$), 2) or perceived exertion, despite the 3) enhanced partial pressure of oxygen and hemoglobin saturation; 4) lactate concentration also decreased directly after the third sprint.

Performance

To date, only a few studies have focused on the effects of hyperoxic recovery from exercise on performance at sea level, and such research has produced inconsistent results (5,11,14,15,21,24,25,31). The current findings are in accordance with most studies on hyperoxic recovery; that hyperoxic air conditions resulted in no differences in power output (15,24) or performance time (21,31) after the inhalation of hyperoxic air (F_iO_2 = 1.00) during periods of recovery from intervals of maximal exercise compared to normoxic air scenarios.

Thus far, only one study has demonstrated the beneficial effects of hyperoxic recovery on power output (25). Sperlich and co-workers indicated that among elite swimmers, exposure to 100% oxygen during 5 x 6-min recovery periods from 5 x 50-s intense arm strokes enhanced mean and peak power output to 5% over the levels achieved under normoxic recovery. In contrast to other studies (5, 11, 14, 21, 24, 31), during which athletes performed whole or lower body exercises, Sperlich et al.'s (25) study featured swimmers who executed an all-out arm protocol on a swim bench. Research has shown that oxygen extraction is lower in the arm muscles than in the leg muscles of highly trained XC skiers during submaximal DP under normoxic conditions (2).

Therefore, Sperlich and co-workers suggested that the lower oxygen extraction in the arm muscles, in relation to elevated oxygen partial pressure, enhanced the diffusive transfer of oxygen to mitochondria, resulting in greater arm power output (25). By contrast, the use of hyperoxic recovery during intervals of maximal kayaking (15) and, as in the present study, between 3 × 3-min DP sprints (in both studies primarily upper body exercises were performed) demonstrated no ergogenic effects. This difference may be due to the varied exercise protocols, recovery durations, and body positions (recumbent vs. standing) used in the studies. For instance, Shoemaker and co-workers (23) demonstrated that unlike a supine position, an upright body position, reduces forearm blood flow at the onset of exercise because of diminished venous pressure.

The individual power data (Fig. 3) in the current work demonstrate differences in the effects of hyperoxic recovery on sprint and total power output. Some of the athletes demonstrated the beneficial effects of hyperoxic recovery during the second and/or third sprint, whereas the others showed no enhancement effect after hyperoxic inhalation. Individual variations in power output response to hyperoxic recovery appeared to exist, but further research is warranted to validate this assumption.

Several studies have shown that power output increases when hyperoxic air is applied during high-intensity interval exercise at sea level (17) and at altitude (29). Thus, the ratio of exercise load to recovery duration in the current study may have not been sufficient to evoke a performance-enhancing response. In regard to the present results and those of previous studies lead to assume that the controversial findings regarding the effects of hyperoxic recovery on performance may have arisen from differences in exercise protocols, muscle groups used, and variations in the duration and timing of hyperoxic air inhalation. Nonetheless, inhaling hyperoxic air only during periods of recovery between 3 × 3-min DP sprints seemed to present no beneficial effects on performance.

Rating of Perceived Exertion

In the present study, no changes in perceived exertion rating were observed in the hyperoxic and hypoxic recovery groups. These findings agree with those of Peeling and Andersson (15), who indicated that in contrast to normoxic recovery, hyperoxic recovery ($F_iO_2 = 1.00$) during 6 x 3-min maximal work bouts on a kayak ergometer did not affect athlete's perceived recovery quality. Several studies have reported a reduced perceived exertion rating (24,25) and maintained cerebral oxygenation (12) when hyperoxic air was provided. However, the current findings indicate that hyperoxic recovery between repeated sprints at the simulated low altitude produced no beneficial effect on exercise stress or perceived recovery quality.

Oxygen Saturation and Oxygen Partial Pressure

Hyperoxic recovery enhanced oxygen partial pressure 4.1-fold and increased oxyhemoglobin saturation from 92.3% to 99.8%. These findings are in accordance with several studies on hyperoxia during high- and maximal-intensity exercises at sea level (13,14,19,24,25). The increase in the partial pressure of oxygen under hyperoxic conditions augments the vascular-to-intracellular gradient of oxygen partial pressure (20), thereby increasing oxygen delivery from capillaries to muscle cells (10) and elevating oxygen diffusion into mitochondria (10,16,20). However, evidence shows that exposure to 100% oxygen reduces blood flow because of hyperoxia-induced vasoconstriction (22,28). Rousseau et al. (22) demonstrated an oxygen dose-dependent reduction in lower limb blood flow with increasing oxygen concentration. In addition, exercise under hypoxic conditions results in greater local vasodilatation and blood flow response (3). Accordingly, researchers have suggested that inhaling hyperoxic air does not increase net oxygen delivery to respiring tissues (13,19). Such an observation can explain why hyperoxic recovery did not improve DP performance during the 3 × 3-min sprints under hypoxic conditions in the present study.

The drop in hemoglobin oxygen saturation after the sprints was about 4% less in the hyperoxic trial than in the hypoxic trial. At the end of the recovery periods, the degree of oxygen saturation increased to about 100% under hyperoxia, but increased to about 93% under hypoxia. Oxygen partial pressure remained above the post-warm up level during all the recovery periods after the sprints and increased to about 360 mm Hg under hyperoxic recovery. Athlete 2 demonstrated hypoxemia (S_aO_2 < 85%) after the sprints and greater power output for the succeeding sprint under hyperoxic recovery than under hypoxic recovery. Therefore, exercise-induced hypoxemia may be prevented by adopting hyperoxic recovery at low altitudes. Given the small number of subjects, however, further research is needed to verify this assumption. Conversely, the high amount of dissolved oxygen in the blood and the augmented degree of oxygen saturation after hyperoxic inhalation were immediately released upon exposure to hypoxic air and therefore could not improve the performance of the other athletes during the 3 × 3-min sprints.

Although the mean of hyperoxic recovery between the 3 × 3-min sprints at the simulated altitude demonstrated no performance enhancement, hyperoxic recovery may be beneficial to performance at high altitudes, at which reduced oxygen availability and more pronounced exercise-induced hypoxemia occur. In this regard, hyperoxic recovery between bouts of exercise may be useful for other sports professionals who exercise or compete at high altitudes (e.g., alpine skiers). Again, this issue requires validation through further investigation.

Lactate Concentration

Blood lactate levels significantly decreased directly after the third sprint and were attenuated at various time points under hyperoxic recovery. A low concentration of blood lactate in connection with hyperoxia has been reported in many studies (6,9,11,26,29). In this context, it is hypothesized that hyperoxia decreases pyruvate production and glycogen breakdown, resulting in a low lactate efflux and lactate production (26). Stellingwerff and co-workers (26) also reported that the reduced glycogenolysis in hyperoxia is related to attenuated phosphocreatine utilization and the accumulation of inorganic phosphate and phosphorylase effectors, suggesting that hyperoxia alters substrate utilization with increased oxidative metabolism. Maeda and Yasukouchi (11) demonstrated enhanced blood lactate disappearance with hyperoxic recovery after sessions of submaximal cycling. The authors reported that the effects of hyperoxia depend on physical fitness. They also assumed that athletes with greater endurance training more considerably profit from the effects of hyperoxia on lactate clearance than do athletes with less endurance training because of the greater oxidative capacity in the working muscles and superior circulatory function of the former. In the present study, all the participants were well-trained endurance athletes who demonstrated low lactate concentration under hyperoxic recovery. However, this outcome posed no beneficial effects on performance, suggesting that the present results reflect a physiological effect rather than practical relevance.

Study Limitations

This study primarily aimed to determine whether hyperoxic recovery during a simulated 3 × 3-min XC team sprint competition poses beneficial effects on performance. Important notes for consideration in evaluating the findings are that the test scenarios are simulations and that the athlete selection does not fully represent all highly trained XC skiers. Nevertheless, the study participants were well-trained endurance athletes with a minimum of five years of training, and their perceived ratings indicated that all of them exercised at maximal intensity. Another key consideration is that the study protocol involved only the DP technique, which mainly involves upper body muscles. Official team sprint competitions are performed in either classical or freestyle technique, involving both upper and lower bodies. Thus, the results of this research are not generalisable to all the skiing techniques executed during XC skiing team sprint competitions.

We cannot exclude that the high oxygen saturation during hyperoxic recovery directly after the sprints was possibly a result of a small time delay in blood sampling and not an effect of hyperoxic breathing. Blood sampling for two of the athletes (athletes 1 and 8) was approximately 10 s longer than the normal duration (10 s). These athletes demonstrated higher oxygen saturation (+5%) after the first sprint than did the other athletes under hyperoxic recovery at the same time point. Additionally, ventilation could not be measured during the exercise protocol because of the combined mask-valve construction. Perhaps the athletes who benefit from hyperoxic recovery at low altitudes (i.e., do reduce exercise-induced hypoxemia), may also respond positively to reduced ventilation. In addition, oxygen saturation and oxygen partial pressure were not measured during the sprints. These values would have been interesting for the analysis of hyperoxic recovery effects on the magnitude of hypoxemia at the beginning, during, and end of each sprint. Future research is needed to better understand the effects of hyperoxic recovery on performance at low altitudes.

CONCLUSION

The present results indicate that inhaling hyperoxic air (F_iO_2 = 1.00) during recovery periods following 3 × 3-min DP sprints at the simulated low altitude (~1800 m) did not improve the mean power output of each sprint or all the sprints compared to hypoxic recovery, despite the enhanced pressure of oxygen and oxygen saturation of hemoglobin, as well as the reduced lactate concentration after the third sprint. Furthermore, hyperoxic recovery had no beneficial effects on perceived exertion.

ACKNOWLEDGEMENTS

No external funding was received for the preparation of this article, but the study was financed through the resources of all the involved institutions. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The authors declare no conflicts of interest.

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FIGURE CAPTIONS

FIGURE 1. Study design.

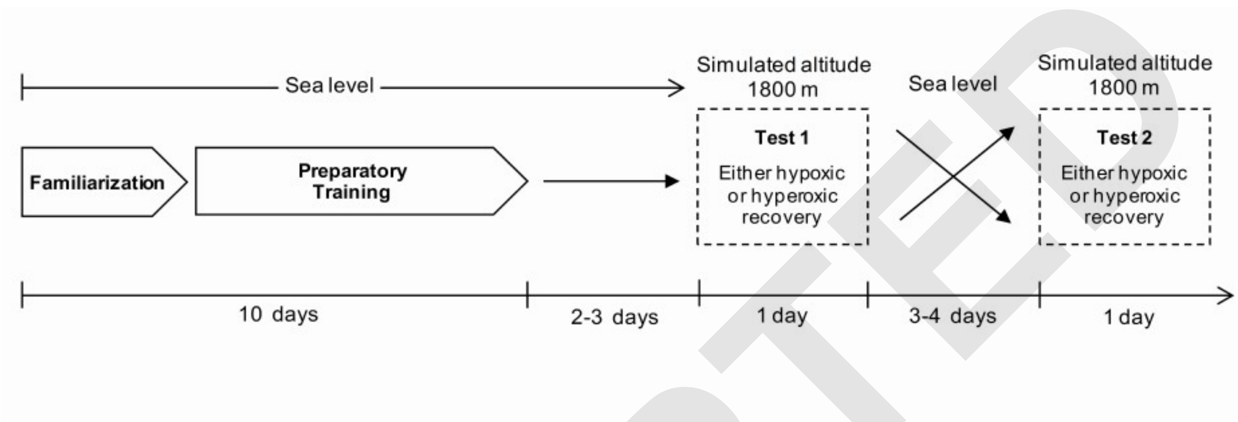
FIGURE 2. Simulated cross-country skiing team sprint competition.

FIGURE 3. Mean sprint power output and mean total power output of each athlete (1 – 8) and the mean ± SD of the three sprints as the athletes inhaled hyperoxic or hypoxic air during the recovery periods.

FIGURE 4. Individual and mean data for oxygen saturation (A) and oxygen partial pressure (B) before and at various time points during periods of recovery from 3 × 3-min sprints, with athletes breathing hyperoxic or hypoxic air. * $P < 0.05$ vs. hypoxia.

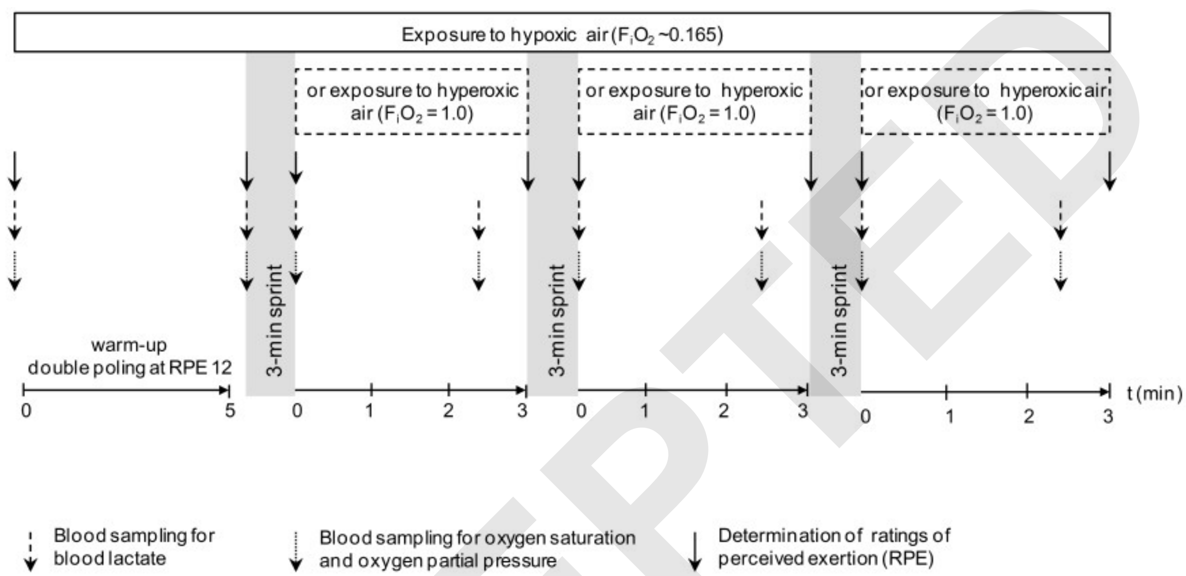
FIGURE 5. Individual and mean data on blood lactate concentration (A) and rating of perceived exertion (B) before and at various time points during periods of recovery from 3 × 3–min sprints, with athletes breathing hyperoxic or hypoxic air. * $P < 0.05$ vs. hypoxia.

FIGURE 1



Sea level
Simulated altitude 1800 m
Sea level
Simulated altitude 1800 m
Familiarization
Preparatory Training
Test 1
Either hypoxic or hyperoxic recovery
Test 2
Either hypoxic or hyperoxic recovery
10 days
2-3 days
1 day
3-4 days
1 day

FIGURE 2



Exposure to hypoxic air (F$_i$O$_2$ ~0.165)
or exposure to hyperoxic air (F$_i$O$_2$ = 1.0)
or exposure to hyperoxic air (F$_i$O$_2$ = 1.0)
or exposure to hyperoxic air (F$_i$O$_2$ = 1.0)
3-min sprint
3-min sprint
3-min sprint
warm-up double poling at RPE 12
0
5
0
1
2
3
0
1
2
3
0
1
2
3
t (min)
Blood sampling for blood lactate
Blood sampling for oxygen saturation and oxygen partial pressure
Determination of ratings of perceived exertion (RPE)

FIGURE 3

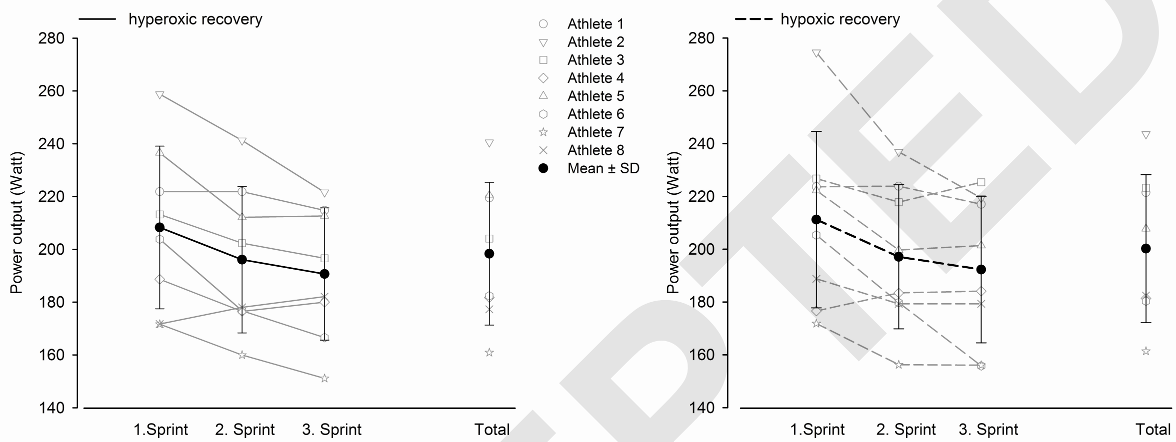

hyperoxic recovery
Power output (Watt)
280
260
240
220
200
180
160
140
1.Sprint
2. Sprint
3. Sprint
Total
Athlete 1
Athlete 2
Athlete 3
Athlete 4
Athlete 5
Athlete 6
Athlete 7
Athlete 8
Mean ± SD
hypoxic recovery

FIGURE 4

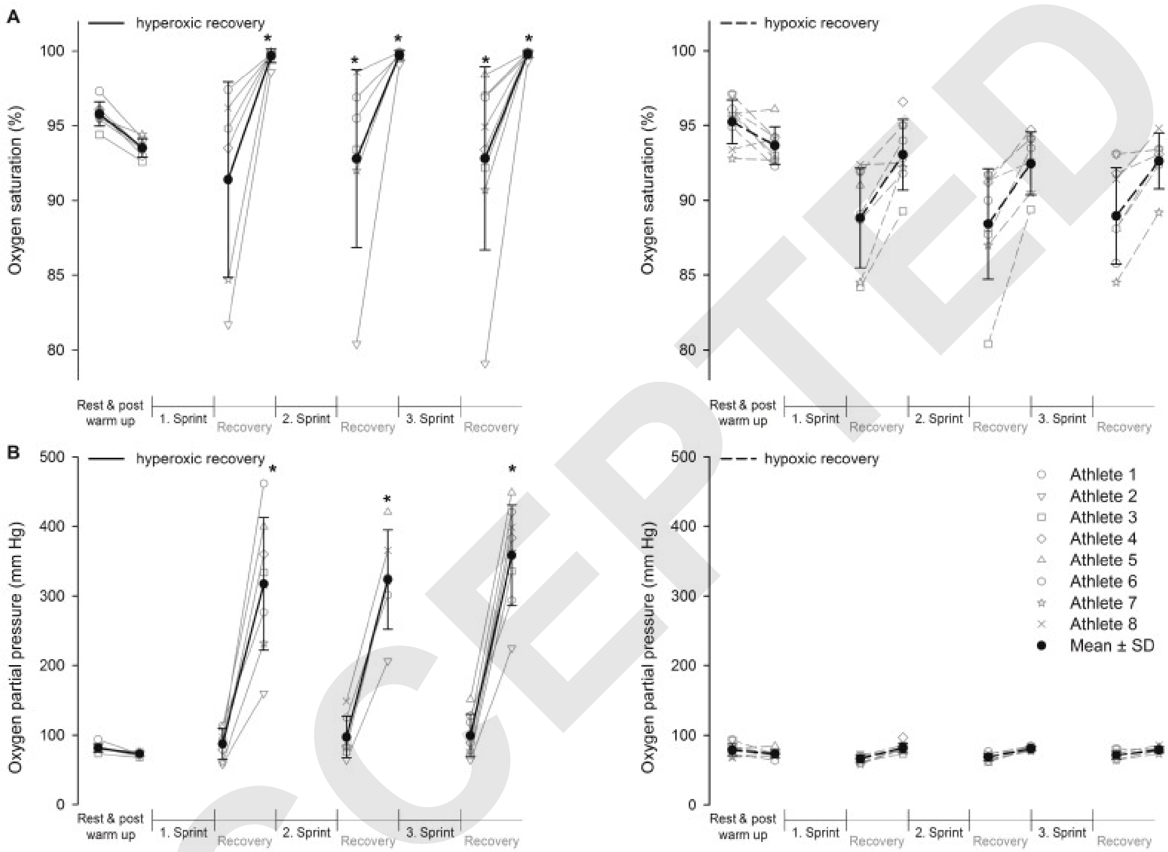
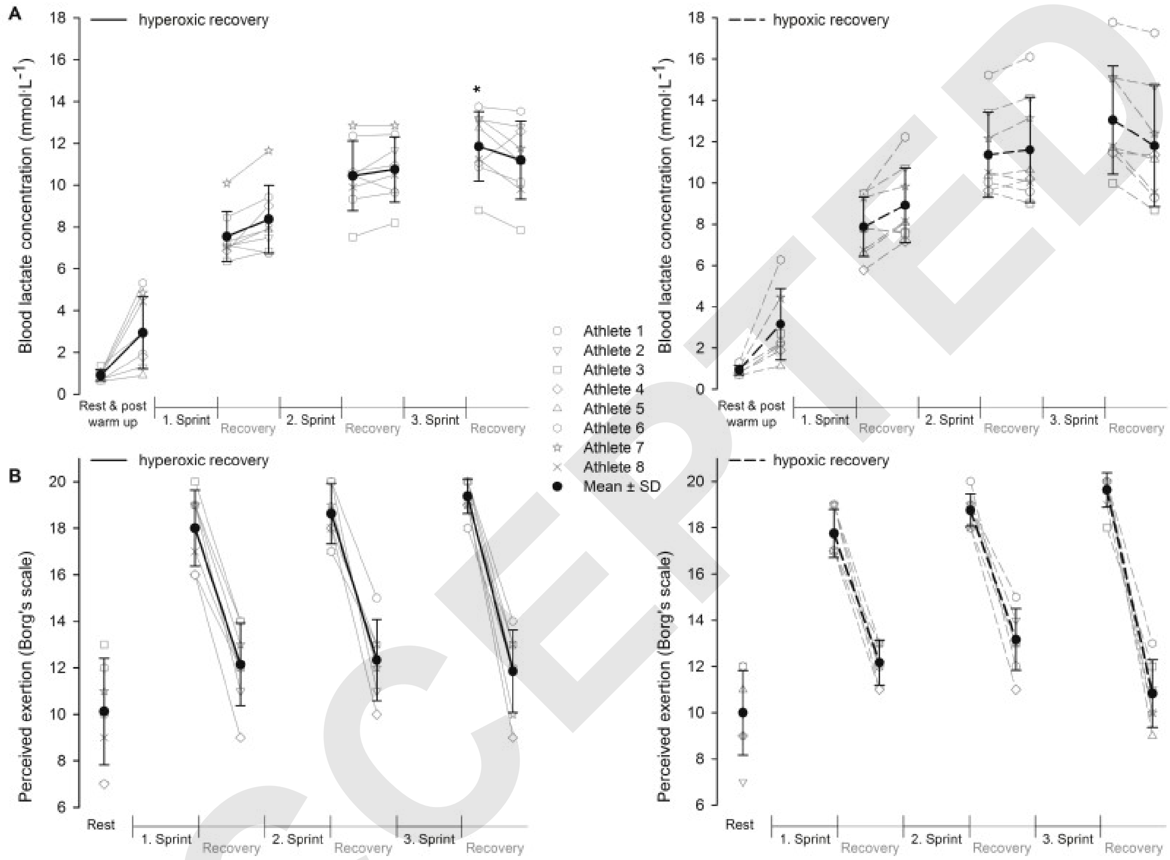

A
hyperoxic recovery
hypoxic recovery
Oxygen saturation (%)
Rest & post warm up
1. Sprint
Recovery
2. Sprint
Recovery
3. Sprint
Recovery
B
Oxygen partial pressure (mm Hg)
Athlete 1
Athlete 2
Athlete 3
Athlete 4
Athlete 5
Athlete 6
Athlete 7
Athlete 8
Mean ± SD

FIGURE 5


A
hyperoxic recovery
Blood lactate concentration (mmol·L-1)
hypoxic recovery
Rest & post warm up
1. Sprint
Recovery
2. Sprint
Recovery
3. Sprint
Recovery
Athlete 1
Athlete 2
Athlete 3
Athlete 4
Athlete 5
Athlete 6
Athlete 7
Athlete 8
Mean ± SD
B
Perceived exertion (Borg's scale)
Rest