

# The effects of continuous vs intermittent oxygen supplementation on repeat sprint cycling performance

MICHAEL STEWART PORTER , KATHERINE REED

*School of Sport, Rehabilitation & Exercise Sciences, University of Essex, Colchester, United Kingdom*

## ABSTRACT

The use of handheld cannisters providing supplementary oxygen to use 'track side' is becoming popular. The aim of this study was to determine the optimal time to administer oxygen supplementation (O<sub>2</sub>Supp) during a repeat sprint protocol on cycling performance. Ten male recreationally active University students participated. Testing comprised four visits to the laboratory in a counterbalanced design. Each session entailed ten x 15s repeated sprints interspersed with 45s passive recovery, during which the air inspired was either 100% oxygen (H) or normal air, (N), thus the oxygen content inspired during the sprints and/or the recovery periods, determined the four conditions; NH, HN, HH, NN respectively. It was hypothesised that the HH condition would evoke the largest performance improvements. Repeated measures ANOVA were used to examine the difference between conditions in the outcome measures of mean power (W), rate of power decline (%) and blood lactate (mmol·L<sup>-1</sup>). There was no significant effect of O<sub>2</sub>Supp on mean power (W), blood lactate or performance decline (%) ( $p > .05$ ), although, the HH condition did result in the lowest levels of lactate accumulation and the shallowest decline in performance. The NH and HN conditions resulted a greater decline in performance than both HH and NN. Continuous O<sub>2</sub>Supp during repeat sprint cycling is more effective on cycling performance, than when it is administered in short repeated bouts. It appears that the rapid changing of oxygen availability may have a detrimental effect on performance. O<sub>2</sub>Supp can be applied to training programmes that have extended (>1min) periods of recovery.

**Keywords:** Oxygen supplementation; Sports medicine; Physiology; Interval training; Sports performance.

### Cite this article as:

Porter, M.S., & Reed, K. (2020). The effects of continuous vs intermittent oxygen supplementation on repeat sprint cycling performance. *Journal of Human Sport and Exercise*, in press. doi:<https://doi.org/10.14198/jhse.2022.172.01>

 **Corresponding author.** School of Sport, Rehabilitation & Exercise Sciences, University of Essex, Colchester, CO4 3SQ, United Kingdom. <https://orcid.org/0000-0002-1720-8698>

E-mail: [mportphd@gmail.com](mailto:mportphd@gmail.com)

Submitted for publication June 05, 2020

Accepted for publication July 27, 2020

Published in press September 28, 2020

JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

© Faculty of Education. University of Alicante

doi:10.14198/jhse.2022.172.01

## INTRODUCTION

Hyperoxia occurs when cells, tissues and organs are exposed to an excess supply of oxygen or higher than normal partial pressure of oxygen (Mach et al., 2011), whilst normoxia is the natural condition that occurs at sea level in absence of disease. To create hyperoxic conditions within the body one must breathe an oxygen enriched gas mixture (oxygen supplementation [O<sub>2</sub>Supp]). Previously, supplementary oxygen was banned by the World Anti-Doping Agency (WADA) due to its potential performance enhancing effect (Karpovich, 1934). Recent evidence (Amann, 2011; Hauser et al., 2014; Hogan et al., 1999; Linossier et al., 2000) has led to the reinstatement of O<sub>2</sub>Supp within training for a competitive sport, resulting in its increasing application (World Anti-Doping Agency, 2009).

O<sub>2</sub>Supp is shown to improve performance via the increased rate of phosphocreatine resynthesis (Linossier et al., 2000; Vanhatalo et al., 2010) and it is increasingly becoming a popular as an ergogenic aid within a range of sporting populations. Research to date has been conducted on; runners, cyclists, swimmers and hockey players (Buchheit et al., 2012; Murray et al., 2015; Nummela et al., 2002; Sperlich et al., 2011), with researchers providing the supplement for a continuous period of 30-240 seconds. These durations may elicit the biggest performance improvements, but they are not easy to administer within real world settings, due to cannister size and health & safety considerations.

Companies such as Boost Oxygen© and Oxygen Plus© offer handheld oxygen canisters that contains between 25 to 220 breaths of pure 100% oxygen. These offer enough oxygen to use continually in short duration exercise, or sporadically during recovery periods between exercise bouts. Oxygen has been administered at many different performance time points; before exercise, during training and between exercise bouts (Sperlich et al., 2017), yet the exact timing of supplementary oxygen in relation to the greatest acute performance enhancement is not yet clear.

Thus, the primary aim of this research was to evaluate the effects altering the timing of O<sub>2</sub>Supp (during recovery periods and/or exercise) on repeat sprint cycling performance.

It was hypothesised that the greatest increase in mean sprint cycling power output (W) would occur during the continuous O<sub>2</sub>Supp condition compared with partial O<sub>2</sub>Supp or control conditions. Additionally, it was hypothesised that the continuous O<sub>2</sub>Supp condition would elicit reductions in blood lactate concentration during each sprint for the same workload, compared to the other conditions.

## MATERIALS AND METHODS

### *Participants*

Ten healthy university students were recruited to take part in the study. Participants ( $1.79 \pm 0.05$  m,  $74.7 \pm 10.5$  kg,  $22.8 \pm 4.5$  years) were recreational cyclists who all had previous experience using a cycle ergometer and repeated sprint protocols.

Participants were informed of the procedure and provided written informed consent prior to study commencement. Ethical approval for the study was granted by the University ethics committee in accordance with the Helsinki declaration.

### **Measures**

This study was a single-blind, within-participant design comprising four counterbalanced assessments of repeat sprint performance under; O<sub>2</sub>Supp (FiO<sub>2</sub> 1.00) or normal air (FiO<sub>2</sub> ~ 0.21). Laboratory tests were completed at the same time of the day ( $\pm 2$  h). Participants undertook the same procedure on all 4 visits; 5 min warm up at a workload of ~200 W, 5 min passive recovery, and ten x 15 s cycle sprints with 45 s recovery.

Participants were asked to maintain normal activity and sleep pattern between testing sessions. Participants were asked to refrain from strenuous physical activity 24 h prior to participating. All participants had previous experience with repeat sprint lab testing protocols. Performance measures such as: mean and peak power output were taken, performance decline was assessed, along with blood lactate concentrations.

### **Procedures**

O<sub>2</sub>Supp and normoxic gas mixtures were administered via a rig of 4 x 200 L Hans Rudolph Douglas bags connected to a Hans Rudolph mask and head net (Hans Rudolph, Shawnee, KS, USA). The O<sub>2</sub>Supp (FiO<sub>2</sub> 1.00) condition used medical grade oxygen cylinder (BOC, Surrey, UK). In each condition, participants wore the mask and breathed from the Douglas bag during the repeated sprints and the recovery periods. Gas was administered to the participants through the Douglas bags after allowing it to warm to the environmental conditions. Gas administration was manipulated during the sprint and recovery to make up four conditions; O<sub>2</sub>Supp in sprint and normoxia in recovery (HN), normoxia in sprint and O<sub>2</sub>Supp in recovery (NH), O<sub>2</sub>Supp in both sprint and recovery (HH), and finally normoxia in both sprint and recovery (NN).

A pre-exercise 20  $\mu$ l capillary sample was taken from the right ear lobe as a baseline measure. Each sample was mixed with haemolysing solution within a 0.5 ml haemolysing solution cup. Subsequent samples were taken during the recovery period of each sprint repetition to look at accumulation of lactate over the 10 sprints. All samples were analysed for blood lactate within ~1 h of withdrawal using a Biosen (EKF diagnostics, Cardiff, UK).

Following the warmup each participant undertook ten repetitions of 15 s cycling sprint followed by 45s static recovery. Participants were instructed to stay seated to isolate leg power. During the sprints the Wattbike (Watt Bike Ltd, Nottingham, UK) with the magnetic setting set to zero and air brake set to ten. This protocol was set in accordance with pilot testing conducted prior to this study as it was determined this resistance allowed participants to generate their peak power whilst not exceeding their peak cadence. Performance data used for analysis were peak sprinting power (the highest W achieved in each cycle) and mean sprint power (the average W produced during each 15 s cycle). Mean power was used to calculate performance decline (%) ((Best sprint – worst sprint)/best sprint) \*100.

### **Statistical analysis**

All statistical analysis was performed using the statistical package, SPSS statistics version 25 for windows (SPSS Inc, Chicago, IL, USA). An a priori power analysis revealed that ten participants would provide significant power to detect differences in mean power by 3-4% at an  $\alpha$ -level of .05 (Porter et al., 2019).

Repeated measures analysis of variance (ANOVA) were conducted to look for differences according to the four conditions for; mean power (W), peak power (W), performance decline (%) and blood lactate (mmol·L<sup>-1</sup>) for each sprint. Alpha level set  $p = .05$  for all data analysis. Effect size for individual measures were calculated and reported as Cohen's d and interpreted using bounds as 0.2, 0.5, > 0.8, which are small, medium and large respectively (Cohen, 1988).

## RESULTS

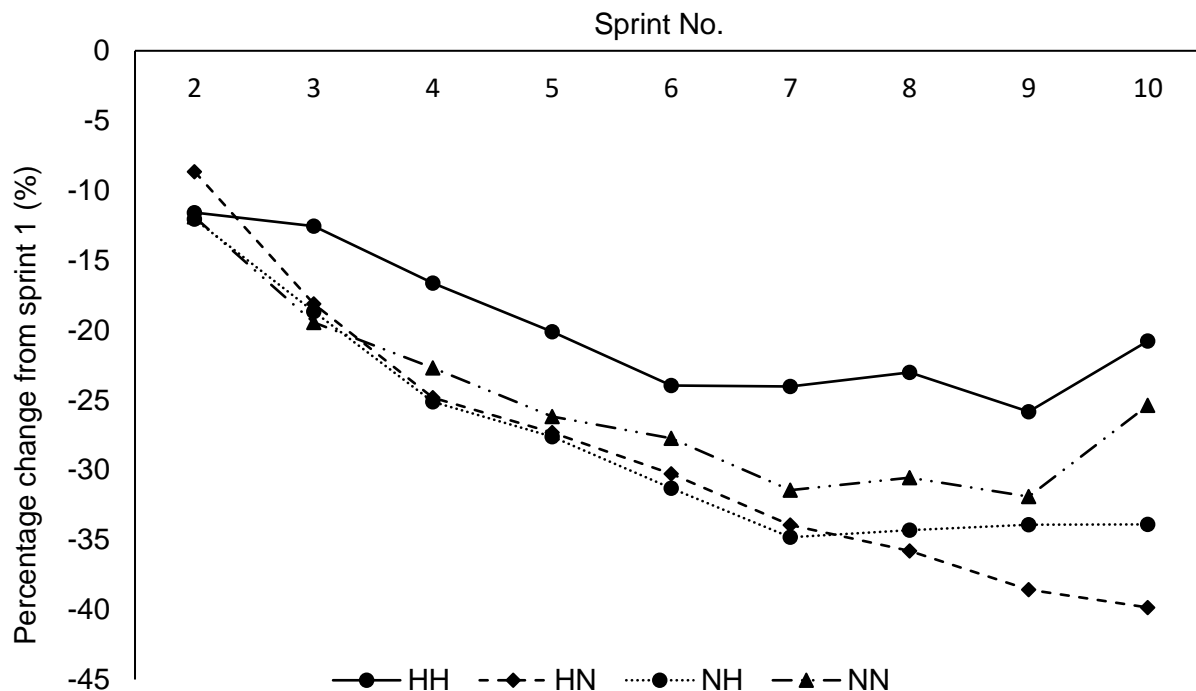
Mean Power (Table 1). There was a significant main effect of time across the 10 Sprints  $F(9,27) = 35.73$ ,  $p < .01$ ,  $d = 2.61$ . There was no significant main effect for sprint performance according to condition  $F(3,12) = 0.21$ ,  $p = .99$ ,  $d = 0.35$ . No interaction effect was evident.

Table 1. Mean cycling power over ten sprints in four conditions ( $M \pm SD$ ) ( $n = 10$ ).

	Sprint 1 (W)	Sprint 2 (W)	Sprint 3 (W)	Sprint 4 (W)	Sprint 5 (W)	Sprint 6 (W)	Sprint 7 (W)	Sprint 8 (W)	Sprint 9 (W)	Sprint 10 (W)
HH	677.8 ± 128.0	615.4 ± 105.0	581.0 ± 111.6	550.3 ± 121.9	526.5 ± 122.9	500.3 ± 120.7	498.9 ± 117.0	504.2 ± 121.2	489.3 ± 93.5	510.7 ± 108.1
HN	735.8 ± 138.6	657.5 ± 118.1	584.8 ± 103.7	535.2 ± 94.4	514.5 ± 95.4	492.1 ± 102.5	462.9 ± 116.4	467.9 ± 129.7	463.5 ± 109.7	470.6 ± 122.4
NH	709.6 ± 125.0	616.4 ± 68.3	578.1 ± 96.5	540.0 ± 93.2	529.1 ± 100.9	502.5 ± 97.9	478.5 ± 106.8	475.1 ± 116.2	444.5 ± 98.4	456.8 ± 121.7
NN	709.9 ± 138.3	620.5 ± 106.8	567.6 ± 111.9	541.2 ± 91.4	517.2 ± 89.8	504.8 ± 82.2	474.1 ± 83.8	471.3 ± 95.6	490.9 ± 91.5	502.6 ± 99.8

Legend:  $O_2Supp - O_2Supp$ ; HH,  $O_2Supp - Normoxia$ ; HN, Normoxia -  $O_2Supp$ ; NH, Normoxia - Normoxia; NN, Watts; W.

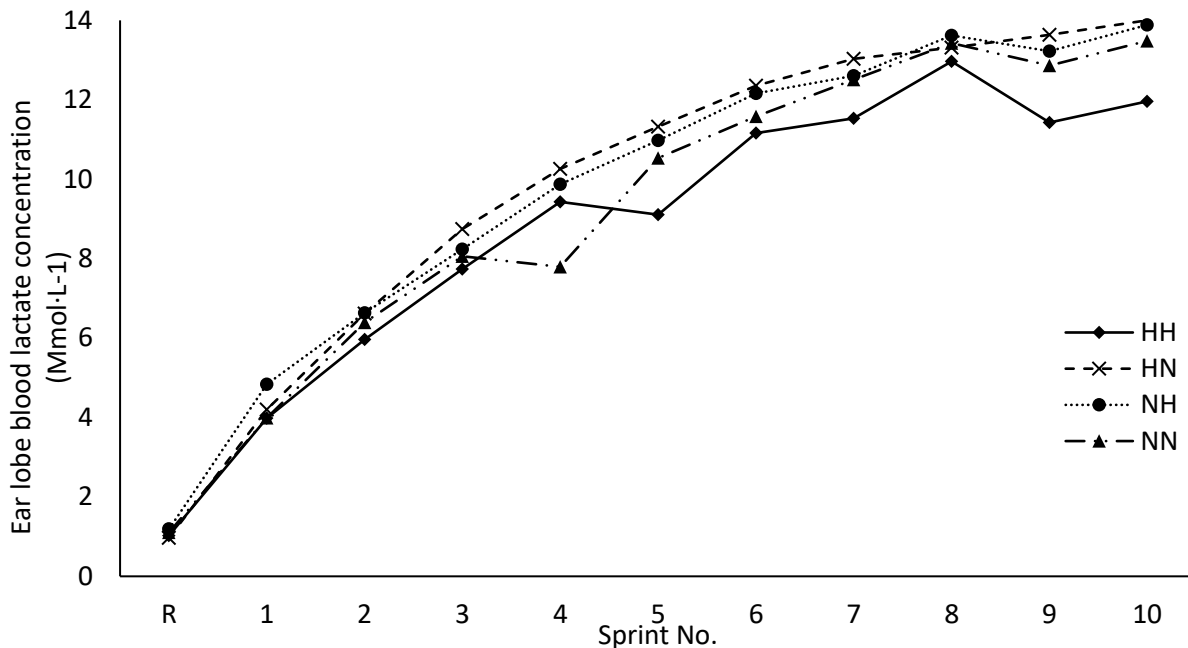
Peak Power. There was a significant main effect of time for peak sprinting power across 10 sprints  $F(9,27) = 16.78$ ,  $p < .01$ ,  $d = 1.77$ . There was no main effect of condition in peak power  $F(3,12) = 0.37$ ,  $p = .99$ ,  $d = 0.46$ . No interaction effect was evident.



Legend:  $O_2Supp - O_2Supp$ ; HH,  $O_2Supp - Normoxia$ ; HN, Normoxia -  $O_2Supp$ ; NH, Normoxia - Normoxia; NN, Number; No.

Figure 1. Percentage change in sprint performance from sprint one across nine subsequent sprints in the four conditions ( $n = 10$ ).

Percentage decline in performance (Figure 1). There was a significant main effect of time across the 10 Sprints  $F(8,72) = 24.42, p < .01, d = 7.22$ . No significant effect for sprint performance according to condition was found  $F(3,23) = 1.19, p = .33$ , although there was a moderate to large effect size,  $d = 0.72$ . No interaction effect was evident.



Legend: oxygen supplementation – O<sub>2</sub>Supp; HH, O<sub>2</sub>Supp -Normoxia; HN, Normoxia - O<sub>2</sub>Supp; NH, Normoxia – Normoxia; NN, Number; No, Millimole per Litre; mmol·L<sup>-1</sup>.

Figure 2. Mean lactate at rest and over ten sprints in four conditions (n = 10).

Lactate accumulation during sprint (Figure 2). There was no main effect in lactate accumulation for the four different gas mixtures,  $F(3,12) = 1.22, p = .21, d = 0.87$  (Figure 2). However, HH ( $7.15 \pm 0.77$  mmol·L<sup>-1</sup>) had an average lower lactate level than HN condition ( $9.45 \pm 0.71$  mmol·L<sup>-1</sup>). Whilst HH was also meaningfully lower (change greater than 10%) than both NH (mean differences (MD) =  $-2.13$  mmol·L<sup>-1</sup>) and NN conditions (MD =  $-2.13$  mmol·L<sup>-1</sup>). (Figure 2).

## DISCUSSION

The aim of this research was to determine the effect of O<sub>2</sub>Supp on sprint cycling performance, with a specific focus on the timing of administration of supplementary oxygen. The current study found that administering supplementary oxygen to a sprint cycling athlete has no statistically significant benefits for mean and peak power output (W) but a large effect size was noted in the effect of continual oxygen (HH) on attenuating performance decline. Further, meaningful reduction in blood lactate concentration was evident in the HH condition compared to the other conditions.

We speculated that the two conditions that have frequent changes in oxygen concentration (NH, HN), would evoke a decline in all performance variables compared to continual oxygen (HH), and this was evident within the data. Changes that occur with additional oxygen are include decreased blood flow (Macdonald et al., 1997), vasoconstriction (Pedersen et al., 1999; Welch et al., 1977), and increased arterial oxygen content

(Stellingwerff et al., 2006). It is possible that such rapid changes in oxygen concentration in the NH and HN conditions resulted in alterations in the internal environment that were not conducive to good performance.

Repeat changes in oxygen consumption, leads to changes in the internal homeostatic responses which cannot react to the rapid changes fast enough; performance capabilities are reduced as a result. The response to oxygen consumptions is detected by the peripheral chemoreceptors, signals the medulla oblongata to increase/ decrease the stimulation of either the parasympathetic or sympathetic nerves (decrease/ increase heart rate respectively) (Lumb and Horner, 2013). Even though this study did not measure these responses, they may explain the performance declines during each successive sprint, even in comparison to the 'control' condition.

The NH and HN conditions had changes in gas content every 15 and 45 s respectively, whilst the HH and NN conditions the gas content is continuous throughout the full session. In hypoxia research the detection of the internal change in oxygen content of the artery by the chemoreceptors has been reported as occurring between 3-15 s after its administration (Alberti, 1977; Lumb and Horner, 2013). The timing of the response could be purported to be similar in hyperoxia. Resultantly the continuous manipulation in oxygen levels leave the medulla oblongata continuously trying to respond to fluctuations in the blood oxygen levels, by altering peripheral blood flow (Macdonald et al., 1997), and peripheral vasoconstriction (Pedersen et al., 1999; Welch et al., 1977). Supplementary oxygen may be better suited when administered during longer periods of work/rest to allow for changes in internal equilibrium to occur before reverting to different gas contents.

Power responses in the HH and NN conditions were as expected, whereby the full oxygen condition resulted in greater performance (albeit non-significant) than the normoxia condition (NN) (Balsom et al., 1994; Cardinale et al., 2019; Porter et al., 2019). Performance decline followed a similar trend across each condition until sprint 6, when HH condition stabilises. The exponential decline in mean cycling power is replicated across repeated sprint literature and previous research in O<sub>2</sub>Supp (Glaister, 2005; Porter et al., 2019). Pilot work in our lab found that supplementary oxygen has significant performance benefits during the final five sprints of a ten-sprint programme.

The performance enhancing effects of O<sub>2</sub>Supp have been credited, in part, to the reduction in the accumulation of lactate in the blood (Sperlich et al., 2011). Despite this study only resulting in small changes in performance during the HH condition, lactate is also lowest in this full oxygen condition. It could be suggested that the metabolic cost of producing more power was attenuated by the consumption of oxygen (Balsom et al., 1994). Hogan et al (Hogan et al., 1983) suggest lactate accumulation can explain the differences in performance during varied oxygen conditions. O<sub>2</sub>Supp can also lead to an increased 'lactate threshold' or an increased ability to attenuate the accumulation of lactate, resulting in potential positive performance outcomes (Hogan et al., 1983; Maeda and Yasukouchi, 1998; Zinner et al., 2015).

It is evident that O<sub>2</sub>Supp is effective at improving performance during cycling, when administered over a longer duration. O<sub>2</sub>Supp should therefore be applied to training and or recovery periods that last over 1min in duration, with more investigation needed to identify the exact minimum time to elicit improvements in performance. Currently canisters that are available to the public only last for between 20-220 breaths may not be optimum in a training programme, as each canister may only last less than 200s during periods of exercise or recovery.

The novel findings of this study suggest short term use of supplementary oxygen is potentially detrimental to subsequent performance. It would appear reasonable for further studies to identify the specific microvascular

and biochemical changes experienced by simultaneously exercising whilst manipulating the oxygen content for very short durations (<15 s).

### **Limitations**

We acknowledge several limitations to this study. Participants fitness level was not accounted for which could potentially mediate the response to O<sub>2</sub>Supp (Malette et al., 2018). Additionally, the physical dead space in the breathing tubes, meant one to two breaths were needed to fully inhale the gas mixture stored in the reservoir bags. This may have stunted the response during the mixed conditions (NH, HN).

### **CONCLUSION**

In conclusion, the present study demonstrates that when supplementary oxygen is used during longer duration (recovery and sprints) bouts it can be effective. During short interchangeable periods it is less effective at increasing cycling performance and may in fact have a detrimental effect on performance. O<sub>2</sub>Supp has shown its ability to be applied to training programmes that can cater for continuous supplementation of oxygen, or programmes that have extended (>1 min) periods of recovery. These both result in a sufficiently long administration to see stable internal changes and as a resultant, performance improvements. Over the counter O<sub>2</sub>Supp cannisters should be used with caution within an exercise programme.

### **AUTHOR CONTRIBUTIONS**

Dr. Michael Porter, and Dr. Kate Reed developed the study design. Dr. Michael Porter undertook the data collection with Dr. Kate Reed supervising the findings of this work. All authors discussed the results and contributed to the final manuscript.

### **SUPPORTING AGENCIES**

No external funding was provided for this project.

### **DISCLOSURE STATEMENT**

The authors have no conflicts of interest that are directly relevant to the content of this manuscript.

### **ACKNOWLEDGEMENTS**

The authors thank the athletes of the University of Essex for their participation in the study and the postgraduates that assisted with data collection.

### **REFERENCES**

- Alberti. (1977). The biochemical consequences of hypoxia. *Journal of Clinical Pathology*, S3-11, 14-20.  
<https://doi.org/10.1136/jcp.s3-11.1.14>
- Amann. (2011). Central and peripheral fatigue: Interaction during cycling exercise in humans. *Medicine and Science in Sports and Exercise*, 43(11), 2039-2045.  
<https://doi.org/10.1249/MSS.0b013e31821f59ab>

- Balsom, Ekblom, and Sjodin. (1994). Enhanced oxygen availability during high intensity intermittent exercise decreases anaerobic metabolite concentrations in blood. *Acta Physiologica Scandinavica*, 150(4), 455-456. <https://doi.org/10.1111/j.1748-1716.1994.tb09711.x>
- Buchheit, Abbiss, Peiffer, and Laursen. (2012). Performance and physiological responses during a sprint interval training session: Relationships with muscle oxygenation and pulmonary oxygen uptake kinetics. *European Journal of Applied Physiology*, 112(2), 767-779. <https://doi.org/10.1007/s00421-011-2021-1>
- Cardinale, Larsen, Lännerström, Manselin, Södergård, Mijwel, Lindholm, Ekblom, and Boushel. (2019). Influence of Hyperoxic-Supplemented High-Intensity Interval Training on Hemotological and Muscle Mitochondrial Adaptations in Trained Cyclists. *Frontiers in Physiology*, 10(June), 1-12. <https://doi.org/10.3389/fphys.2019.00730>
- Cohen. (1988). *Statistical Power Analysis for the Behavioural Sciences*. In Lawrence Erlbaum Associates (2nd ed., Vol. 2). Lawrence Erlbaum Associates.
- Glaister. (2005). Multiple sprint work: Physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sports Medicine*, 35(9), 757-777. <https://doi.org/10.2165/00007256-200535090-00003>
- Hauser, Zinner, Born, Wehrin, and Sperlich. (2014). Does hyperoxic recovery during cross-country skiing team sprints enhance performance? *Medicine and Science in Sports and Exercise*, 46(4), 787-794. <https://doi.org/10.1249/MSS.0000000000000157>
- Hogan, Cox, and Welch. (1983). Lactate accumulation during incremental with varied inspired oxygen fractions exercise. *Journal of Applied Physiology*, 55(4), 1134-1140. <https://doi.org/10.1152/jappl.1983.55.4.1134>
- Hogan, Haseler, and Richardson. (1999). Human Muscle Performance and PCr hydrolysis with varied Inspired Oxygen Fractions: A 31P-MRS Study. *Journal of Applied Physiology*, 86(4), 1367-1373. <https://doi.org/10.1097/00005768-199805001-00395>
- Karpovich. (1934). The Effect of Oxygen Inhalation on Swimming Performance. *Research Quarterly. American Physical Education Association*, 5(2), 24-30. <https://doi.org/10.1080/23267402.1934.10761607>
- Linossier, Dormois, Arsac, ... Lacour. (2000). Effect of hyperoxia on aerobic and anaerobic performances and muscle metabolism during maximal cycling exercise. *Acta Physiologica Scandinavica*, 168(3), 403-411. <https://doi.org/10.1046/j.1365-201X.2000.00648.x>
- Lumb, and Horner. (2013). Chapter 25 - Pulmonary Physiology. In *Physiology and Pharmacology for Anesthesia*. Elsevier Inc.
- Macdonald, Pedersen, and Hughson. (1997). Acceleration of VO<sub>2</sub> kinetics in heavy submaximal exercise by hyperoxia and prior high-intensity exercise. *Journal of Applied Physiology*, 83(4), 1318-1325. <https://doi.org/10.1152/jappl.1997.83.4.1318>
- Mach, Thimmesch, Pierce, and Pierce. (2011). Consequences of Hyperoxia and the Toxicity of Oxygen in the Lung. *Nursing Research and Practice*, 2011, 1-7. <https://doi.org/10.1155/2011/260482>
- Maeda, and Yasukouchi. (1998). Blood lactate disappearance during breathing hyperoxic gas after exercise in two different physical fitness groups--on the workload fixed at 130% AT. In *Journal of Physiological Anthropology* (Vol. 17, Issue 2, pp. 33-40). <https://doi.org/10.2114/jpa.17.33>
- Mallette, Stewart, and Cheung. (2018). The Effects of Hyperoxia on Sea-Level Exercise Performance, Training, and Recovery: A Meta-Analysis. *Sports Medicine*, 48(1), 153-175. <https://doi.org/10.1007/s40279-017-0791-2>
- Murray, K., Sommerville, A., McKenna, M., Edgar, G., & Murray, A. (2016). Normobaric hyperoxia training in elite female hockey players. *The Journal of sports medicine and physical fitness*, 56(12), 1488-1493.



- Nummela, Hämäläinen, and Rusko. (2002). Effect of hyperoxia on metabolic responses and recovery in intermittent exercise. *Scandinavian Journal of Medicine and Science in Sports*, 12(5), 309-315. <https://doi.org/10.1034/j.1600-0838.2002.10157.x>
- Pedersen, Kiens, and Saltin. (1999). Hyperoxia does not increase peak muscle oxygen uptake in small muscle group exercise. *Acta Physiologica Scandinavica*, 166(4), 309-318. <https://doi.org/10.1046/j.1365-201x.1999.00575.x>
- Porter, Fenton, and Reed. (2019). The effects of hyperoxia on repeated sprint cycling performance & muscle fatigue. *Journal of Science and Medicine in Sport*. <https://doi.org/10.1016/j.jsams.2019.07.001>
- Sperlich, B., Zinner, Krueger, Wegrzyk, Mester, and Holmberg. (2011). Ergogenic effect of hyperoxic recovery in elite swimmers performing high-intensity intervals. *Scandinavian Journal of Medicine and Science in Sports*. <https://doi.org/10.1111/j.1600-0838.2011.01349.x>
- Sperlich, Billy, Zinner, Hauser, Holmberg, and Wegrzyk. (2017). The Impact of Hyperoxia on Human Performance and Recovery. *Sports Medicine*, 47(3), 429-438. <https://doi.org/10.1007/s40279-016-0590-1>
- Stellingwerff, LeBlanc, Hollidge, Heigenhauser, and Spriet. (2006). Hyperoxia decreases muscle glycogenolysis, lactate production, and lactate efflux during steady-state exercise. *American Journal of Physiology-Endocrinology and Metabolism*, 290(6), E1180-E1190. <https://doi.org/10.1152/ajpendo.00499.2005>
- Vanhatalo, Fulford, Dimenna, and Jones. (2010). Influence of hyperoxia on muscle metabolic responses and the power-duration relationship during severe-intensity exercise in humans: A 31P magnetic resonance spectroscopy study. *Experimental Physiology*, 95(4), 528-540. <https://doi.org/10.1113/expphysiol.2009.050500>
- Welch, Bonde-petersen, Graham, Klausen, and Secher. (1977). Effects of hyperoxia on leg blood flow and metabolism during exercise. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, 42, 385-390. <https://doi.org/10.1152/jappl.1977.42.3.385>
- World Anti Doping Agency. (2009). World Anti Doping Agency. World Anti-Doping Code 2010. <https://www.wada-ama.org/en/media/news/2009-09/wada-executive-committee-approves-2010-prohibited-list>
- Zinner, Hauser, Born, Wehrin, Holmberg, and Sperlich. (2015). Influence of hypoxic interval training and hyperoxic recovery on muscle activation and oxygenation in connection with double-poling exercise. *PLoS ONE*, 10(10), 1-12. <https://doi.org/10.1371/journal.pone.0140616>

