

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

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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 (O₂Supp) 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⁻¹). There was no significant effect of O₂Supp 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 O₂Supp 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. O₂Supp can be applied to training programmes that have extended (>1min) periods of recovery.

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

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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 [O₂Supp]). 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 O₂Supp within training for a competitive sport, resulting in its increasing application (World Anti-Doping Agency, 2009).

O₂Supp 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 O₂Supp (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 O₂Supp condition compared with partial O₂Supp or control conditions. Additionally, it was hypothesised that the continuous O₂Supp 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 ± 0.05 m, 74.7 ± 10.5 kg, 22.8 ± 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; O₂Supp (FiO₂ 1.00) or normal air (FiO₂ ~ 0.21). Laboratory tests were completed at the same time of the day (± 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

O₂Supp 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 O₂Supp (FiO₂ 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; O₂Supp in sprint and normoxia in recovery (HN), normoxia in sprint and O₂Supp in recovery (NH), O₂Supp in both sprint and recovery (HH), and finally normoxia in both sprint and recovery (NN).

A pre-exercise 20 μ 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 (%) $((\text{Best sprint} - \text{worst sprint})/\text{best sprint}) * 100$.

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 α -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⁻¹) 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

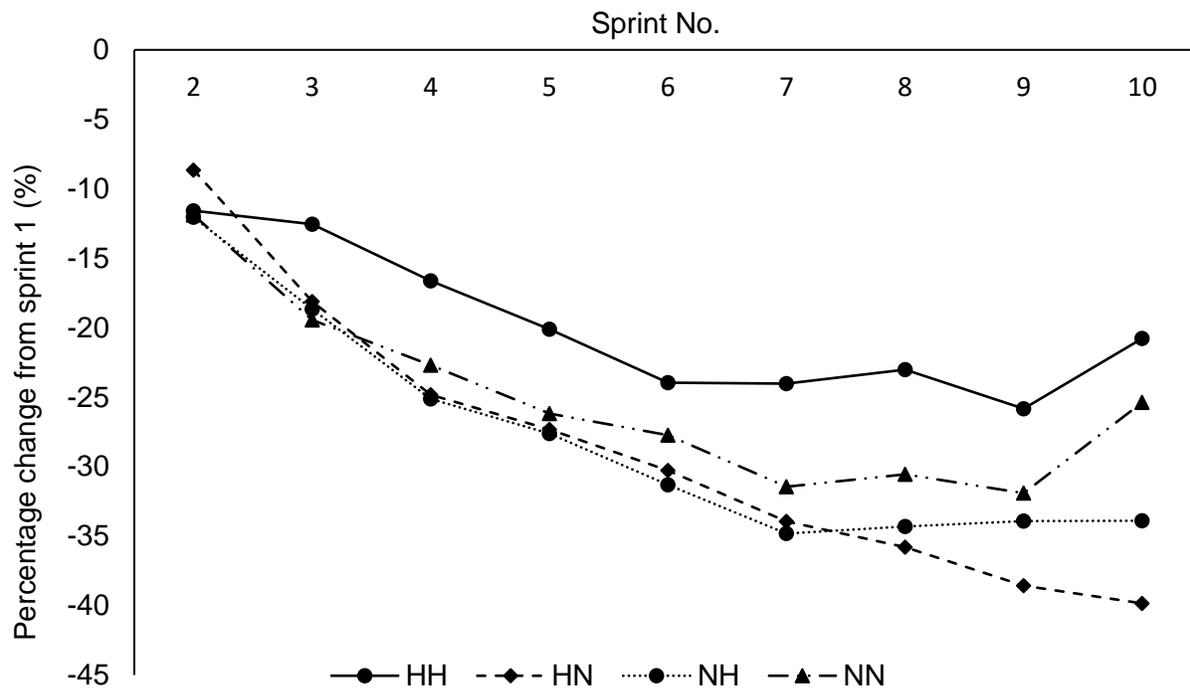
Mean Power (Table 1). There was a significant main effect of time across the 10 Sprints $F(9,27) = 35.73$, $p < .01$, $d = 2.61$. There was no significant main effect for sprint performance according to condition $F(3,12) = 0.21$, $p = .99$, $d = 0.35$. No interaction effect was evident.

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.

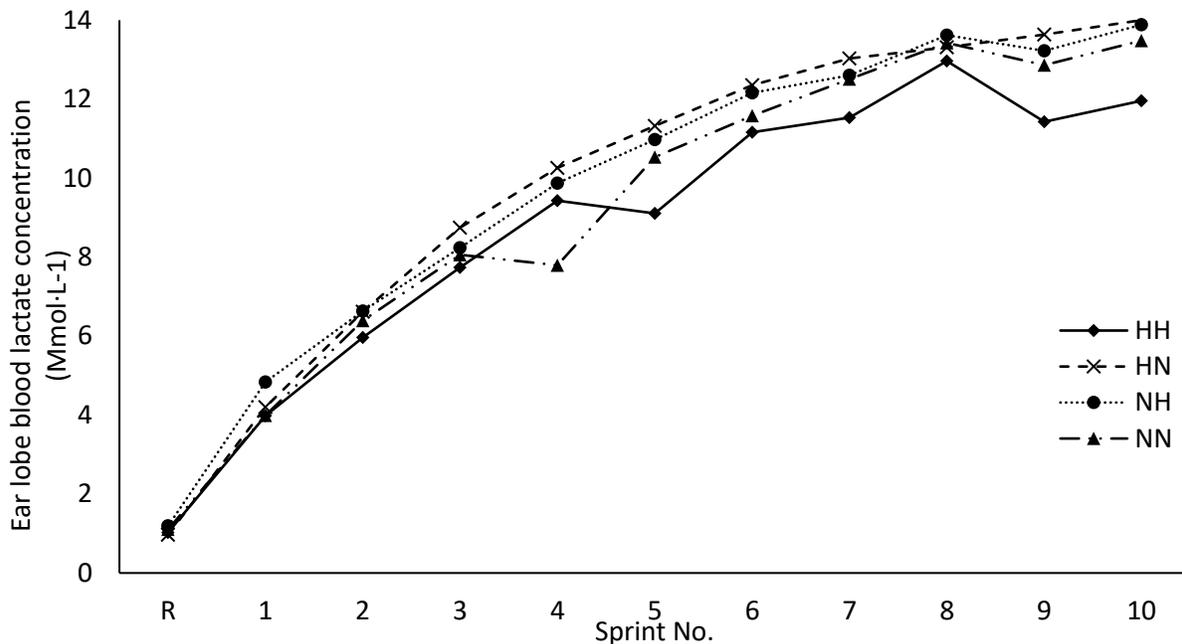
Peak Power. There was a significant main effect of time for peak sprinting power across 10 sprints $F(9,27) = 16.78$, $p < .01$, $d = 1.77$. There was no main effect of condition in peak power $F(3,12) = 0.37$, $p = .99$, $d = 0.46$. No interaction effect was evident.



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 – O₂Supp; HH, O₂Supp -Normoxia; HN, Normoxia - O₂Supp; NH, Normoxia – Normoxia; NN, Number; No, Millimole per Litre; mmol·L⁻¹.

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 ± 0.77 mmol·L⁻¹) had an average lower lactate level than HN condition (9.45 ± 0.71 mmol·L⁻¹). Whilst HH was also meaningfully lower (change greater than 10%) than both NH (mean differences (MD) = -2.13 mmol·L⁻¹) and NN conditions (MD = -2.13 mmol·L⁻¹). (Figure 2).

DISCUSSION

The aim of this research was to determine the effect of O₂Supp 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 O₂Supp (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 O₂Supp 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. O₂Supp 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 O₂Supp is effective at improving performance during cycling, when administered over a longer duration. O₂Supp 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 O₂Supp (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. O₂Supp 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 O₂Supp 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.

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DISCLOSURE STATEMENT

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

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