The effect of breathing an ambient low-density, hyperoxic gas on the perceived effort of breathing and maximal performance of exercise in well-trained athletes

L Ansley, D Petersen, A Thomas, A St Clair Gibson, P Robson-Ansley, T D Noakes

Background: The role of the perception of breathing effort in the regulation of performance of maximal exercise remains unclear.

Aims: To determine whether the perceived effort of ventilation is altered through substituting a less dense gas for normal ambient air and whether this substitution affects performance of maximal incremental exercise in trained athletes.

Methods: Eight highly trained cyclists (mean SD) maximal oxygen consumption (VO2max) = 69.9 (7.9) (mlO2/kg/min) performed two randomised maximal tests in a hyperbaric chamber breathing ambient air composed of either 35% O2/65% N2 (nitrox) or 35% O2/65% He (heliox). A ramp protocol was used in which power output was incremented at 0.5 W/s. The trials were separated by at least 48 h. The perceived effort of breathing was obtained via Borg Category Ratio Scales at 3-min intervals and at fatigue. Oxygen consumption (VO2) and minute ventilation (V'E) were monitored continuously.

Results: Breathing heliox did not change the sensation of dyspnoea: there were no differences between trials for the Borg scales at any time point. Exercise performance was not different between the nitrox and heliox trials (peak power output = 451 (58) and 453 (56) W), nor was VO2max (4.96 (0.61) and 4.88 (0.65) l/min) or maximal V'E (157 (24) and 163 (22) l/min). Between-trial variability in peak power output was less than either VO2max or maximal V'E.

Conclusion: Breathing a less dense gas does not improve maximal performance of exercise or reduce the perception of breathing effort in highly trained athletes, although an attenuated submaximal tidal volume and V'E with a concomitant reduction in VO2 suggests an improved gas exchange and reduced O2 cost of ventilation when breathing heliox.

Sensations of respiratory discomfort are consciously monitored during exercise, and, at higher workloads, sensations of dyspnoea are closely related to perceived exertion. This evidence indicates a potential role for afferent sensory feedback of ventilatory exertion from the respiratory muscles in regulating maximum performance of exercise in humans. However, the role of perceived respiratory effort in the regulation of maximal performance of exercise remains unclear.

Perception of respiratory effort can be manipulated by altering the work of breathing. This effect has traditionally been achieved by either using a pressure-assisted ventilation (PAV) device, in which a demand valve senses pressure changes at the nose and mouth and reactively assists the breathing, or altering the properties of the inspired air so that it is less dense than normal air and therefore reduces the work required to move the air in and out of the lungs.

A serious limitation to the PAV method is the potential to disrupt the normal breathing pattern of the subjects, as the novelty of the task requires subjects to “train” to breathe on the apparatus before undergoing testing. A further limitation is the delayed response time of the demand valve to pressure changes at the mouth. The result is that the PAV method can only be used effectively during steady-state exercise and therefore cannot assess the role of ventilatory work or its associated sensations as a factor limiting progressive maximal exercise to exhaustion. Studies have produced mixed results regarding the effects of unloading the work of the respiratory muscles on exercise capacity possibly as a result of these limitations.

By contrast, the performance benefits of breathing a less dense gas have produced more consistent results. However, the increased breathing resistance imposed by the external gas delivery and collection systems used in these studies creates a potential difficulty in differentiating between the effects of the lighter gas on the anatomical respiratory tree and on the external respiratory tubing. Furthermore, altering the properties of the inspired air may result in altered ventilatory dynamics. Although some researchers have suggested that a less dense carrier gas might increase the alveolar–arterial partial pressure of oxygen (pO2) gradient, thereby reducing arterial blood oxygen saturation, Nemery et al reported that the physical properties of the inspired gas do not affect ventilatory dynamics. Indeed, more recent studies have found that breathing a helium–oxygen mix improved arterial saturation.

Therefore, it seems that breathing a less dense gas during high-intensity exercise may improve alveolar ventilation or the alveolar–arterial O2 difference or both, thereby enhancing the oxygen content of arterial blood.

To fully elucidate any potential role for the perceived effort of breathing in regulating maximal exercise, the confounding effects of breathing a gas less dense than air need to be considered. Conducting a trial on the performance of exercise in an environment in which “lighter” air is substituted for the ambient air will negate the need for external breathing

Abbreviations: ANOVA, analysis of variance; COPD, chronic obstructive pulmonary disease; CR10, Category-Ratio Scale; Fo2, fractional inspired oxygen; PAV, pressure-assisted ventilation; RPE15, 15-point rating of perceived exertion
apparatus, and hence the confounding effects of unloading the added respiratory resistance caused by such an apparatus. Furthermore, any ergogenic benefits derived from improved pulmonary dynamics can be minimised by increasing the fraction of oxygen in the inspired air.19

Young et al20 showed that physically active subjects are able to differentially assess feelings of effort pertaining to the respiratory and cardiovascular systems. Therefore, we aimed to investigate the perceptual and performance effects of breathing a low-density, hyperoxic gas during a graded maximal exercise test to exhaustion in a young, physically fit population. We hypothesised that breathing a less dense gas would attenuate the perceived effort of breathing and improve incremental exercise time to exhaustion.

METHODS

Subjects

Eight highly trained cyclists (mean standard deviation (SD)) maximal oxygen consumption (VO2max) = 69.9 (7.9) ml O2/ kg/min) were recruited for this study, which was approved by the university research and ethics committee. This study complied with the Declaration of Helsinki as adopted at the 52nd World Medical Association General Assembly, Edinburgh, October 2000. The nature of the study, including the risks associated with exercising in oxygen and helium-enriched conditions, was clearly explained to the subjects, from whom informed consent was obtained before the initiation of testing. The mean (SD) age, height and weight of the subjects were 20.1 (1.2) years, 184.4 (5.6) cm and 69.6 (5.1) kg, respectively. Subjects were excluded from the study if they smoked, had breathing disorders, or had experienced a respiratory illness within 2 weeks of the start of the study.

Experimental protocol

After a habituation trial in normoxic conditions, each subject was required to perform an incremental ramp test to exhaustion on a Lode cycle ergometer (Excalibur, The Netherlands) on two separate occasions, while breathing a helium (heliox) mixture (FiO2 of 35% and the balance helium). The tests lasted on average 605 s (range 437–757). The hyperoxic concentration was required to perform an incremental ramp cycle test to exhaustion on a Lode cycle ergometer (Excalibur, The Netherlands) on two separate occasions, while breathing a helium (heliox) mixture. The concentration in the chamber was continuously monitored. Oxygen content was maintained at the prescribed level for all the trials.

Occupancy specifications. There were internal CO2 scrubbers; O2, temperature and humidity were continuously monitored. Oxygen content was maintained at the prescribed level for all the trials.

Peak power achieved was not significantly different between trials (nitrox = 451 (58) W; heliox = 453 (56) W; p = 0.4). The

RESULTS

Maximum values of power output, VO2 and VE

Peak power achieved was not significantly different between trials (nitrox = 451 (58) W; heliox = 453 (56) W; p = 0.4). The
VO₂ max was also similar for both conditions (nitrox = 4.96 (0.61) l/min; heliox = 4.88 (0.65) l/min; p = 0.6), as was max-
imal minute ventilation (nitrox = 157 (24) l/min; heliox = 163 (22) l/min; p = 0.3). The percentage bias between the means of
the nitrox and heliox trials for peak power, VO₂ and Vₑ are
−0.55 (1.77), 1.67 (9.19) and −4.02 (11), respectively (fig 1).

Submaximum values of VO₂ and Vₑ
Figure 2 depicts changes in oxygen consumption and minute
ventilation for the first 6 min of the exercise test. An ANOVA
showed a significant condition effect for both VO₂ (p = 0.009)
and Vₑ (p = 0.001) during submaximal workloads. The average
for both variables was lower in the heliox condition (VO₂ = 2.77
(0.18) l/min; Vₑ = 68 (5) l/min) compared with the nitrox
condition (VO₂ = 3.02 (0.19) l/min; Vₑ = 79 (5) l/min). The
attenuation in Vₑ was attained through a reduction in tidal
volume, which was significantly lower during the heliox trial
than in the nitrox trial at all submaximal time workloads
(p = 0.011), whereas the breathing frequency remained
unchanged (p = 0.3). All submaximal ventilatory variables
increased as a function of workload (p<0.001), but there was
no condition×time interaction for VO₂ and Vₑ.

Ratings of perceived exertion
We found no difference in the ratings of perceived exertion for
either RPE₁₅ (p = 0.8) or CR₁₀ (p = 0.6) between trials, and both
variables increased as a function of workload (p<0.001) (fig 3).

DISCUSSION
The main finding of this study was that substituting helium for
nitrogen in the hyperoxic ambient air did not improve the
maximal performance of exercise of trained cyclists during an
incremental exercise test to exhaustion. This finding is contrary
to results from most previous studies that have evaluated the
effects of breathing a lighter gas on performance of exercise.⁵⁶ ⁴⁻⁵ Furthermore, the perceived ventilatory effort was not
When the patients breathe a hyperoxic gas even though both patients breathe a heliox gas mixture, but does not change with COPD, the submaximal tidal volume is increased when conditions of 30% O2:70% N2 (nitrox) and 30% O2:70% He (heliox) maximal incremental exercise performed in a sealed chamber under whole-body exertion (B, rating of perceived exertion (RPE 15)) during viscosity 1.12 times greater than the nitrox air, 26 the sensation although the work of the respiratory muscles was potentially significantly attenuated when subjects breathed heliox. Thus, et al showed that in patients with chronic obstructive pulmonary disease (COPD), Eves et al previously showed that in patients with COPD, the submaximal tidal volume is increased when patients breathe a heliox gas mixture, but does not change when the patients breathe a hyperoxic gas even though both gas mixtures improve exercise tolerance to the same extent. This suggests that the mechanisms through which heliox and hyperoxia improve performance are different, a postulate that is supported by their observation that a hyperoxic heliox mixture exhibits a performance improvement effect greater than either hyperoxia or normoxic heliox individually.

In healthy people whose ventilation is compromised through hypobaric exposure, the supplementation of helium for nitrogen in the ambient air in hypobaric conditions has a similar effect to the COPD studies of increasing submaximal ventilation towards normobaric values through an increase in tidal volume. 25 Furthermore Esposito and Ferretti reported that VO2max and peak power were improved in hypoxic conditions when a heliox gas was inspired; however, they did not find any difference in either VO2max or peak power when heliox was substituted in normoxic conditions. Interestingly, however, maximal expired and maximal alveolar ventilation were increased in both hypoxia and normoxia when heliox was substituted for nitrox. In people who have no pathological limitations to their ventilation, an effect of inspiring a less dense gas on respiratory work or ventilatory dynamics may be to reduce tidal volume at submaximal workloads. A lower ventilation and oxygen uptake at submaximum workloads, such as that observed in our study, implies superior gas exchange and unchanged airway resistance—that is, a lower ventilation is required to deliver oxygen, thus oxygen uptake is lower. Interestingly, the reduction in mean oxygen consumption at submaximum workloads observed during the heliox trial (about 8%) is similar to the oxygen cost that has been determined for breathing normoxic air during exercise (4.6–10%). 28 Although there was a reduction in submaximal VE, the perceived ventilatory effort remained similar between trials. This can probably be explained by the fact that the reduction in VE was attained through a reduced tidal volume and not a change in the breathing frequency. A change in the rate of breathing is the respiratory variable that has been associated with the perception of dyspnoea. 27

Our study differed from other studies that have looked at maximal exercise capacity in healthy subjects breathing a heliox gas 12 in two important ways: (1) our subjects were highly trained cyclists and (2) our subjects inspired a hyperoxic gas mixture. Esposito and Ferretti and Powers et al reported an increase in maximal minute ventilation while breathing a heliox mixture, but Powers et al only reported an increase in VO2max and workload under normoxic conditions. We have previously alluded to the fact that the effects of breathing a heliox gas may be twofold: an improved ventilatory capacity and improved ventilatory dynamics. With regard to the improved ventilatory capacity, the subjects in our study are accustomed to working close to their maximal capacity and therefore their respiratory system would be trained to cope with the volume of air that is moved in and out of the lungs at peak workloads. However, in less well-trained people, the respiratory system would be unaccustomed to the ventilatory volumes, especially at the higher workloads (which might explain why Powers et al and Esposito and Ferretti only noted differences in submaximal VE at higher

<table>
<thead>
<tr>
<th>Condition</th>
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<th>Peak exercise</th>
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<tr>
<td>pCO2 (mm Hg)</td>
<td>sO2 (%)</td>
<td>pCO2 (mm Hg)</td>
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<tr>
<td>21%</td>
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<td>98.6</td>
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<tr>
<td>30%</td>
<td>223</td>
<td>99.3</td>
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pCO2, mean arterial oxygen pressure; sO2, mean arterial oxygen saturation.

Figure 3 Mean (standard error) data for rating of perceived effort for localised respiratory exertion (A, Category-Ratio Scale (CR10)) and general whole-body exertion (B, rating of perceived exertion (RPE 15)) during maximal incremental exercise performed in a sealed chamber under conditions of 30% O2:70% N2 (nitrox) and 30% O2:70% He (heliox).
workloads) and therefore were not able to attain their functional maximal ventilation while breathing nitrox gas. However, as in the case of subjects with restricted breathing, heliox allowed them to ventilate closer to their maximal volume.

Additionally, we argue that the effects of the improved pulmonary gas exchange while breathing heliox, evidenced in this study by the lower submaximal ventilation, would have been even more pronounced had the exercise not been conducted in hypoxic conditions. This argument is indirectly supported by Esposito and Ferretti, who observed significantly improved maximal alveolar ventilation when heliox was inspired under hypoxic conditions as compared with normoxic conditions. Although alveolar ventilation did improve in normoxic conditions, it was to a lesser extent, and not statistically significant. Therefore, seemingly, breathing heliox may be beneficial to improve work capacity in subjects who have respiratory pathologies or are not habituated to high ventilatory volumes, as well as in conditions of low inspired oxygen concentrations.

It is well documented that exercise-induced arterial hypoxemia occurs at higher exercise intensities in some highly trained athletes. Therefore, it could be argued that a compromised oxygen delivery to the working muscles limited the exercise capacity of these subjects before they reached the ventilatory volumes that would terminate exercise. However, it has been shown that the arterial pO2 is better maintained during severe exercise when a heliox gas is inhaled compared with normal air. Furthermore, Dempsey and ourselves have shown that the arterial desaturation associated with maximal work is completely counteracted when subjects breathe a hyperoxic gas mixture (24% and 30%, respectively; table 1).

Therefore, it seems unlikely that in this study maximal exercise capacity was limited by arterial desaturation in either condition.

The Bland–Altman plots for peak power, VO2max and maximal VE show the close limits of agreement between the mixture (24% and 30%, respectively; table 1).

REFERENCES
This paper provides relevant data on furthering our understanding of cardiovascular dynamics during exercise, which may well impact on sporting performance and have clinical significance.

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Professor Mark Batt, BSc MB BChir MRCPG DM FFSEM FACSFM, is a consultant in sport and exercise medicine at The Centre for Sports Medicine, University Hospitals NHS Trust, Nottingham. He has a busy NHS practice and is physician for The English Institute of Sport.

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He is married with two children. He enjoys a variety of sports, outdoor pursuits and gardening, none of which he does tremendously well!
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