

Brief Report

Supplemental Oxygen and Sleep at Altitude

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ABSTRACT

Windsor, Jeremy S., and George W. Rodway. Supplemental oxygen and sleep at altitude. *High Alt. Med. Biol.* 7:307–311, 2006.—The purpose of this study was to examine the effect supplemental oxygen has on the respiratory and cardiovascular system of a mountaineer during sleep at high altitude by using a novel ambulatory, multisensor, continuous monitoring device. Supplemental oxygen was administered to a healthy subject via a nasal demand system (0, 16.7, 33.3, or 50 mL/sec per pulse dose delivered over 1 sec) during the first three nights of sleep at 4900 and 5700 m. Increases in pulse dose resulted in a consistent rise in SaO₂ and a fall in minute ventilation ($p < 0.05$). The 50-mL pulse dose resulted in the greatest changes, with an increase in SaO₂ from 68.5% to 81% ($p < 0.05$) and a fall in minute ventilation from 13.1 to 10.9 L/min ($p < 0.05$) being noted. Changes in SaO₂ and minute ventilation also coincided with a fall in apnea/hypopnea index (AHI). At 4900 m the AHI fell from 12.5–52.3 (breathing air) to 0–7.5 (50-mL oxygen pulse), whereas at 5700 m a decrease from 49.1–80.4 to 3.5–10.0 was observed. No changes in respiratory rate or heart rate were identified when different pulse doses were compared ($p < 0.05$). The multisensor monitoring device proved to be a highly effective system, demonstrating marked improvements in SaO₂, tidal volume, and AHI in our participant when supplemental oxygen was administered via a nasal demand system.

Key Words: periodic breathing; nasal demand breathing system; mountaineering

INTRODUCTION

ON ASCENDING TO ALTITUDE, unacclimatized lowlanders typically complain that they take longer to get to sleep, wake frequently, often have unpleasant dreams, and do not feel refreshed in the morning. The resultant difficulties are not confined to the night because, as a result of poor sleep, people often feel somno-

lent and fatigued during the following day, their productivity is reduced, and they are more liable to make errors (West, 2002).

These changes stem from exposure to the low partial pressures of oxygen at altitude, which trigger cycles of periodic breathing during sleep (Fig. 1) and result in a shift away from sleep stages 3 and 4 and a reduction in REM sleep (Weil, 2004). At moderate altitudes, un-

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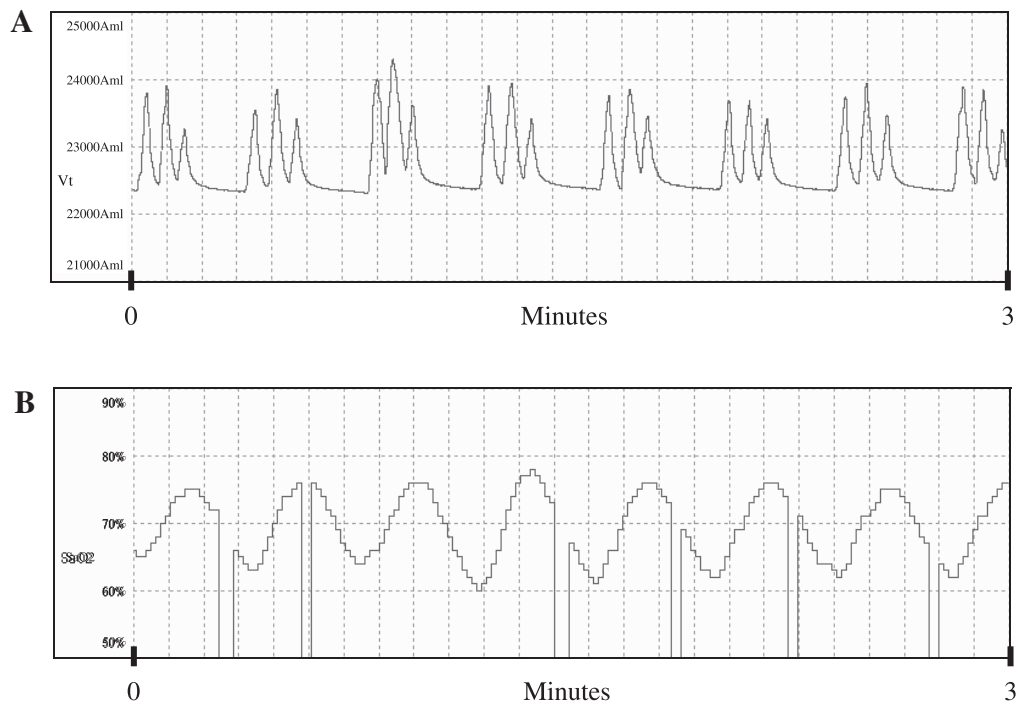


FIG. 1. Example of periodic breathing seen while breathing air during night 1 sleep at 4900 m. In this example, seven apneic episodes lasting between 12 and 14 sec were recorded over 3 min. These episodes were interrupted by pronounced bursts of irregular breathing.

acclimatized lowlanders have been treated successfully by enriching rooms with supplemental oxygen. This has resulted in a fall in both the frequency of apneas and the duration of periodic breathing, leading to longer periods of time being spent in deeper sleep stages and improvements in subjective sleep quality (Luks, 1998; Barash et al., 2001). The intention of this study is to demonstrate for the first time the effect of a nasal demand oxygen delivery device on the cardiovascular and respiratory systems of a healthy participant during sleep at high altitude. It is hoped that this will prompt comparisons between supplemental oxygen and pharmacological agents such as acetazolamide in treating sleep disorders at altitude.

MATERIALS AND METHODS

This project was completed with ethical approval from University College London and the participant provided written, informed consent.

Participant

The sleeping pattern of a 46-year-old male was studied during the first three nights spent at Chinese Base Camp (4900 m) and Advanced Base Camp (5700 m) on the 2005 Anglo Irish Xtreme Expedition to Cho Oyu (ACXE). Within the previous 12 months the participant had undertaken a full-night polysomnograph for research purposes that confirmed the absence of both obstructive and central sleep apnea at sea level. In addition, there was no other significant medical history or any evidence of acute mountain sickness (AMS).

Instrumentation

The LifeShirt® System (Vivometrics, Venture, CA, USA) is an ambulatory, multisensor, continuous monitoring system that was used to collect data on pulmonary function (tidal volume, respiratory rate, and minute ventilation) via respiratory inductive plethysmography (RIP), electrical activity of the myocardium via three-lead electrocardiography (EKG), and arterial blood



FIG. 2. Pulse dose meter of the Summit Oxygen PD110 nasal demand system. The device detects a negative pressure during inspiration and delivers a fixed pulse of oxygen.

oxygen saturation (Sa_{O_2}) via an ear-clip oximeter. The apnea/hypopnea index (AHI) is a record of the number of apneas and hypopneas occurring during each hour of monitoring. For this study, an apnea was defined as a tidal volume less than 25% of the running baseline for at least 10 sec; a hypopnea was defined as a tidal volume of less than 50%, but greater than 25% of the running baseline for a similar period of time (AASM Task Force Report, 1999).

The sensor array of the LifeShirt System is embedded in a sleeveless undergarment made of Lycra material that fits snugly against the skin and can be worn comfortably for extended periods. RIP sensors for monitoring a variety of pulmonary signals are contained within the shirt. Prior to each use, the LifeShirt system was calibrated using a fixed bag volume provided by Vivometrics®. An on-board PDA continuously encrypted and stored the subject's physiological data on a compact flash memory card. A proprietary PC-based software, VivoLogic™, was used to decrypt and process recorded data.

Equipment and procedure

The participant received supplemental oxygen through a nasal demand breathing system (PD 110, Summit Oxygen, UK) (Fig. 2). The system consists of two nasal prongs that are inserted into the entrance of both nostrils and attached to a battery-operated pulse dose meter. The pulse dose meter triggers the release of oxygen into the nasal cavity when a fall in pressure is sensed along the connecting tubing. A dial on the pulse dose meter controls the volume of oxygen delivered by each pulse. Throughout the study the participant was accommodated in a comfortable, well-ventilated two-man tent. The first 8 h of sleep were divided into 4 periods lasting 2 h each, with all the data from each 2-h period being averaged for analysis purposes. During each 2-h period a pulse volume of oxygen was chosen at random and remained unknown to both the participant and those undertaking data analysis. Four treatment modalities were chosen: (1) 0 mL/sec, (2) 16.7 mL/sec, (3) 33.3 mL/sec, and (4) 50 mL/sec. These volumes coincided with flow rates marked 0, 1, 2 and 3 L/min on the pulse dose meter and were each delivered over 1 s.

The nasal demand system and oxygen cylinders were manufactured and tested to U.K. safety specifications. The accuracy of the pulse dose was confirmed by manufacturer's tests prior to departure and following the return of the system to the United Kingdom.

Data analysis

Statistical significance was established at $p \leq 0.05$ a priori. SPSS statistical package version 11.5 was used for analysis. Because $n = 1$ in this study, physiological variables for each altitude, night, and oxygen pulse were analyzed via a

TABLE 1. PHYSIOLOGICAL PARAMETERS MEASURED DURING EXPOSURE TO SUPPLEMENTAL OXYGEN AT 4900 M AND 5700 M

Oxygen pulse (mL/sec)	0	16.7	33.3	50
Sa_{O_2} (%)	68.5 ± 2.4	77.2 ± 2.7	80.8 ± 4.9	81.0 ± 3.0
TV (L/sec)	852 ± 66	809 ± 96	742 ± 55	733 ± 57
RR	15.4 ± 1.3	14.1 ± 0.2	14.7 ± 1.4	14.9 ± 0.6
MV (L/min)	13.1 ± 0.8	11.4 ± 1.5	10.9 ± 0.6	10.9 ± 1.1

All data from each 2-h period were averaged to produce the reported values (mean ± SD). Sa_{O_2} , arterial blood oxygen saturation; TV, tidal volume; RR, respiration rate; MV, minute ventilation.

one-way ANOVA, with no attempt to look at interactions between factors. All data collected from each 2-h period were averaged to produce the values reported in this study.

RESULTS AND DISCUSSION

With the addition of small volumes of supplemental oxygen from the nasal demand system, our participant experienced three significant physiological changes:

1. An increase in SaO_2 ($p < 0.05$)
2. A fall in tidal volume and minute ventilation ($p < 0.05$)
3. A fall in the apnea/hypopnea index (AHI)

Because altitude and duration of stay were not shown to have any effect on the values of SaO_2 , respiratory rate, or tidal volume in our participant, the mean of the combined values are presented in Table 1. These changes also coincided with a marked fall in the apnea/hypopnea index (AHI) at both altitudes. These results are displayed in Tables 2 and 3.

Although a change in heart rate was not observed between different oxygen pulse doses or altitudes, there was a significant fall in heart rate with each night spent at altitude ($p < 0.05$). At 4900 m, the mean heart rate fell from 67 to 57 beats/min, and at 5700 m a decrease from 63 to 57 beats/min was observed ($p < 0.05$).

Nasal demand systems are widely used in patients with chronic obstructive pulmonary disease (COPD) who are dependent on supplemental oxygen. During sleep and sedentary activities, demand systems consume up to 31% to 56% less oxygen than continuous-flow systems without any difference in SaO_2 being ob-

TABLE 2. APNEA/HYPOPNEA INDEX (AHI) FOR EACH OF THE OXYGEN PULSES DELIVERED DURING THE THREE NIGHTS SPENT AT 4900 M

Oxygen pulse (mL/sec)	Night 1	Night 2	Night 3
0	52.3	14.1	12.5
16.7	33.5	28.1	5.5
33.3	5.0	22.1	1.5
50	0.0	7.5	0.0

All data from each 2-h period were averaged to produce the reported values.

TABLE 3. APNEA/HYPOPNEA INDEX (AHI) FOR EACH OF THE OXYGEN PULSES DELIVERED DURING THE THREE NIGHTS SPENT AT 5700 M

Oxygen pulse (mL/sec)	Night 1	Night 2	Night 3
0	49.1	49.1	80.4
16.7	1.6	14.5	49.4
33.3	3.6	4.5	5.5
50	5.8	10.0	3.5

All data from each 2-h period were averaged to produce the reported values.

served (Mecikalski and Shigeoka, 1984; Yaeger et al., 1994; Bower et al., 1998). The administration of 33.3 mL of oxygen per breath resulted in the use of approximately 500 mL/sec of gas per minute (33.3 mL/sec \times 15 breaths per minute). This represents a considerable saving over constant-flow devices that may be set to deliver up to 2 L/min during sleep. The 3-L cylinder used by our participant was pressurized to 300 bars and therefore contained approximately 900 L of oxygen. By setting the pulse dose meter to deliver 33.3 mL/sec, the system could provide enough oxygen for more than 30 h of continual use. Alternatively, a smaller 1-L cylinder could provide sufficient oxygen for more than 10 h of use. In addition, the nasal demand system has the advantage over face-mask systems of avoiding the problems of claustrophobia and the accumulation of heat and moisture that are typically seen.

The LifeShirt System used in this study proved highly effective. Unlike previous sleep studies at altitude that have often needed an array of monitors, the multisensor LifeShirt provided continuous, detailed monitoring in a single lightweight device for 8 h. The device also proved easy to maintain and simple to calibrate, making it ideally suited for field experiments in extreme environments. Although not employed in this study, electroencephalography (EEG) can also be undertaken with the LifeShirt device and can therefore provide additional information to researchers.

Naturally, the results from just a single participant should be interpreted with considerable caution. Indeed, the unexpected changes seen in the AHI highlight the considerable variation that can occur in one individual sleeping at altitude. Nevertheless, we believe that this

brief report successfully illustrates the use of a nasal demand system during sleep at high altitude. But, despite the physiological benefits seen here, supplemental oxygen is both expensive and difficult to transport. The nasal demand system used in this study cost approximately 675 pounds sterling (\$1250) to hire and weighs 3.25 kg. Therefore, it seems reasonable to ask what cheaper and more portable alternatives are available. At present, acetazolamide is probably the agent most individuals utilize to alleviate sleep disturbance at altitude. This carbonic anhydrase inhibitor is capable of reducing periodic breathing by approximately 50%, resulting in both subjective and objective improvements in sleep quality (Sutton et al., 1979; Nicholson and Stone, 1986). However, no published studies have directly compared the cardiovascular and respiratory response of healthy subjects receiving either supplementary oxygen or acetazolamide during sleep at high altitude. The results of any such work would not only influence the treatment of sleep disorders at altitude, but would also help to further unravel the physiological mechanisms that are responsible for this fascinating phenomenon.

DISCLOSURE STATEMENT

The nasal demand system was loaned by Summit Oxygen. Dr. Rodway has participated in speaking engagements supported by Vivometrics. Dr. Windsor has indicated no financial conflict of interest.

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