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Effects of normobaric hypoxic bed rest on the thermal comfort zone

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ABSTRACT

Future Lunar and Mars habitats will maintain a hypobaric hypoxic environment to minimise the risk of decompression sickness during the preparation for extra-vehicular activity. This study was part of a larger study investigating the separate and combined effects of inactivity associated with reduced gravity and hypoxia, on the cardiovascular, musculoskeletal, neurohumoural, and thermoregulatory systems. Eleven healthy normothermic young male subjects participated in three trials conducted on separate occasions: (1) Normobaric hypoxic ambulatory confinement, (2) Normobaric hypoxic bedrest and (3) Normobaric normoxic bedrest. Normobaric hypoxia was achieved by reduction of the oxygen fraction in the air ($F_iO_2=0.141\pm0.004$) within the facility, while the effects of reduced gravity were simulated by confining the subjects to a horizontal position in bed, with all daily routines performed in this position for 21 days. The present study investigated the effect of the interventions on behavioural temperature regulation. The characteristics of the thermal comfort zone (TCZ) were assessed by a water-perfused suit, with the subjects instructed to regulate the sinusoidally varying temperature of the suit within a range considered as thermally comfortable. Measurements were performed 5 days prior to the intervention (D-5), and on days 10 (D10) and 20 (D20) of the intervention. no statistically significant differences were found in any of the characteristics of the TCZ between the interventions (HAMB, HBR and NBR), or between different measurement days (D-5, D10, D20) within each intervention. rectal temperature remained stable, whereas skin temperature (T_{sk}) increased during all interventions throughout the one hour trial. no difference in T_{sk} between D-5, D10 and D20, and between HAMB, HBR and NBR were revealed. subjects perceived the regulated temperature as thermally comfortable, and neutral or warm. we conclude that regulation of thermal comfort is not compromised by hypoxic inactivity.

1. Introduction

In contrast to the International Space Station, which maintains a normobaric normoxic environment, it is envisaged that future Lunar and Mars habitats will maintain a hypobaric hypoxic environment to minimise the risk of decompression sickness during the preparation for extra-vehicular activity (EVA). Namely, the pressure within the space suits during EVAs is approximately one third of normal atmospheric pressure, and astronauts preparing for EVAs must conduct a lengthy decompression procedure in their space suits to prevent venous gas emboli. Maintaining a hypobaric hypoxic environment in future planetary habitats will eliminate the need for lengthy decompression procedures, and consequently the risk of decompression sickness (Bodkin et al., 2006; Norcross et al., 2013). Due to exposure to reduced gravity and hypobaric hypoxia, the main concern is how these conditions will affect the function of physiological systems.

It is well documented that hypoxia alters behavioural and autonomic thermoregulation in a variety of species, such that they choose a cooler environment during hypoxic exposure and lower their preferred body temperature (Barros et al., 2004; Dupré and Wood, 1988; Gordon and Fogelson, 1991; Hicks and Wood, 1985; Pertwee et al., 1990; Tattersall and Milsom, 2009). The reduction in

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Abbreviations: ANOVA, analysis of variance; BR, bedrest; $\Delta T_{forearm-fingertip}$, forearm–fingertip skin temperature gradient; $\Delta T_{calf-toe}$, calf–toe skin temperature gradient; DAP, Diastolic Arterial Pressure; D-5, measurements performed 5 days prior to the intervention; D10, measurements performed on day 10 of the intervention; D20, measurements performed on day 20 of the intervention; EVA, extra-vehicular activity; F_iO_2, fraction of inspired oxygen; HAMB, hypoxic ambulatory confinement; HBR, hypoxic bedrest; HR, heart rate; NBR, normoxic bedrest; P_iO_2, partial pressure of inspired oxygen; RH, ambient relative humidity; SAP, Systolic Arterial Pressure; SpO_2, capillary oxyhemoglobin saturation; T_a, ambient temperature; T_c, core temperature; TCZ, thermal comfort zone; T_{low}, lower limit of the thermal comfort zone; T_{high}, upper limit of the thermal comfort zone; T_{re}, rectal temperature; T_{sk}, skin temperature; T_{wps}, temperature of the water perfusing the suit; WPS, water perfused suit

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body temperature seems to be mediated by two autonomic thermoregulatory responses: peripheral vasodilation, which occurs as the circulatory system attempts to deliver more blood to the oxygen-starved tissues, and a reduction in metabolic rate, reflecting the reduced activity of aerobic respiration. Lowering body temperature reduces tissue oxygen requirements, thus prolonging survival and affording protection to the hypoxic tissues (Gordon, 1993). Numerous studies observing the effects of hypoxia have also been performed on humans. The autonomic thermoregulatory responses were shown to be altered, with enhanced core cooling due to a delay in the onset of vasoconstriction and shivering and increased respiratory heat loss (Johnston et al., 1996). Malanda et al. (2008,) investigated the effects of hypoxia in overweight altitude acclimatised subjects, using a thermal stimulator, and reported that exposure to normobaric hypoxia (4200 m) induces slowing of neural activity in the sensor-to-effector pathway, but does not affect cutaneous sensation threshold for either warm or cold detection, suggesting it is unlikely that the thermal comfort zone is affected by hypoxia under normobaric circumstances. The effect of hypoxia on the cutaneous thresholds for thermal sensation of the toes of unacclimatised subjects was also evaluated by Golja et al. (2004). They reported a reduced sensitivity to cold during the hypoxic exposure, suggesting that alteration in thermal perception may affect the individual's perception of thermal comfort and consequently attenuate thermoregulatory behaviour during cold exposure at altitude. The few studies that have investigated the effect of hypoxia on behavioural thermoregulatory responses in humans have reported that hypoxia does not seem to affect human behavioural thermoregulation (Golja and Mekjavic, 2003; Golja et al., 2005).

The bedrest experimental model is commonly used as a ground-based simulation model for studying the effects of microgravity on certain physiological systems (Fortney et al., 1996). Exposure to sustained bedrest has been shown to alter autonomic thermoregulatory responses. Specifically, it has been shown to induce a progressive decrease in skin temperature of the distal regions, reflecting reduced skin blood perfusion (Golja et al., 2002), attenuated responses of sweating and cutaneous vasodilation, with increased threshold core temperature for sweating onset and decreased sweating sensitivity (Michikami et al., 2004), attenuated cold-induced vasoconstriction and consequently greater heat loss, and attenuated shivering after the exposure (Mekjavic et al., 2005). As regards behavioural thermoregulation, we have previously reported that responses were not affected after 21 days of normoxic inactivity/unloading achieved with the bedrest experimental model (Yogev et al., 2010).

The present study extends the work of Yogev et al. (2010), by investigating the effect on behavioural thermoregulation of living in a hypoxic environment during sustained bedrest. Even though these two non-thermal factors, both known to induce peripheral vasoconstriction during the exposure, do not seem to affect behavioural thermoregulation when studied separately, information is lacking regarding their combined effect on the perception of thermal comfort in humans.

2. Methods

This study was part of a larger study investigating the separate and combined effects of inactivity/unloading and hypoxia on the cardiovascular, musculoskeletal, neurohumoural, and thermoregulatory systems. The study protocol was approved by the National Committee for Medical Ethics at the Ministry of Health of the Republic of Slovenia, and conformed to the guidelines of the Declaration of Helsinki. Fourteen healthy male subjects participated in the study. Prior to the onset of the study they had a medical examination, and their participation was subject to physician's approval. They were familiarised with the protocol of the study and gave their written consent for participation in the study. Their mean (SD) age, weight and height were 27 ± 6 years, 76.7 ± 11.8 kg and 179 ± 3 cm. The study was conducted at the Olympic Sport Centre Planica (Rateče, Slovenia) situated at an altitude of 940 m.

2.1. Protocol

The study was designed as a repeated measures study, such that the subjects participated in three separate trials conducted on separate occasions. During the first trial subjects were assigned to one of three experimental groups: (1) Hypoxic ambulatory confinement (HAMB; fraction of oxygen in the inhaled gas, $F_iO_2 = 0.141 \pm 0.004$; partial pressure of oxygen in the inspired gas, $P_iO_2 = 90.0 \pm 0.4$; ~4000 m simulated altitude), (2) Hypoxic bedrest (HBR; $F_iO_2 = 0.141 \pm 0.004$; $P_iO_2 = 90.0 \pm 0.4$;~4000 m simulated altitude), and (3) Normoxic bedrest (NBR; $F_iO_2 = 0.209$; $P_iO_2 = 133.1 \pm 0.3$). In the remaining two trials the interventions were crossed over. The three experimental trials were conducted over a one-year period. The interval between the experimental trials was a minimum of 3 months to ensure that the subjects' physical condition returned to baseline, pre-trial, values. The simulation of the target altitude of 4000 m was achieved by reduction of the oxygen fraction in the air (normobaric hypoxia), while the effects of bedrest studied by confining the subjects to a horizontal position in bed, with all daily routines performed in this position for 21 days. To ensure the safety of the subjects, staff and researchers, the oxygen level was continuously monitored. Once subjects arrived at the Olympic Sport Centre, they were assigned to one of the three experimental groups, with 7 days of baseline measurements before starting the assigned 21 day intervention. Following the 21-day confinement, subjects remained at the Olympic Sport Centre for a further 4 days of (post-) testing. During the study, subjects were provided with five meals (breakfast, snack, lunch, snack, dinner) each day with the total caloric intake corresponding to their daily energy requirements (Debevec et al., 2014). The same menu with identical meal order for each day was repeated in each campaign, in order to exclude the effects of the diet on measured variables. All experiments were performed on the same days in all three campaigns. A staff of nurses and physicians ensured the health and well-being of the subjects 24/7 during each 21-day intervention. The three confinement trials were conducted on one floor of the Olympic Sport Centre, which comprised 10 double bedrooms, living and dining areas. A barrier separating the floor into two parts, allowed both normoxic and hypoxic interventions to be conducted simultaneously.

2.2. Behavioural thermoregulation assessment

The assessment of behavioural temperature regulation was achieved with a water-perfused suit (WPS) made of mixed blend of synthetic fibres and mashed inner layer. Eight small-diameter (inner dia. = 4 mm; outer dia. = 5 mm) PVC tubes were woven in the mash of the suit and connected to a manifold. The length of each tube was 9 m, so that when the pump was activated, the equal length of the tubes ensured equal water flow (22 L/min) in all tubes connected to the manifold. The WPS was designed so that different regions of the body could be regulated together or separately. Therefore two of the 9 m tubes were woven into the arm segments, two in torso (one in front and one in back) segment and four in the leg (two in front and two in back) segments. The WPS covered the whole body except the hands, feet, neck and head. Each segment of the WPS was designed with a front and back segment that could be separated. A snug fit of the two parts on any given segment was achieved with Velcro® straps. Once instrumented, the subjects donned the WPS, and remained in the supine position for the duration of the test. The test commenced