Exercise responses in normobaric and hypobaric hypoxia and prediction of acute mountain sickness – a pilot project in teaching

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Keywords: exercise responses; normobaric hypoxia; hypobaric hypoxia; acute mountain sickness

1. Introduction

High-altitude exposures are associated with a decrease in maximal aerobic power (i.e., maximal oxygen uptake – VO_2max) and capacity (Burtscher et al. 2006, Wehrlin & Hallen 2006) and with the risk of altitude-related disorders (e.g., acute mountain sickness – AMS) (Netzer et al. 2013). The decrease in aerobic power and capacity results in an impaired endurance performance during training and competitions but also in increased physiological responses to submaximal exercise intensities compared to sea level. The presence of AMS affects the well-being and performance of the suffering individuals and can even proceed to life-threatening conditions (e.g., high altitude pulmonary oedema) (MacInnis et al. 2015, Netzer et al. 2013, Tannheimer et al. 2009).

The altitude-related decrease in aerobic performance varies markedly among individuals and is a topic in competitive and recreational sports as well (Wehrlin & Hallen 2006). Therefore, assessments in simulated high-altitude conditions (e.g. in a normobaric hypoxic chamber) are used to estimate the individual exercise responses during a subsequent exposure to actual high altitude (hypobaric). However, it is still unclear, whether normobaric hypoxic conditions provoke the same physiological responses compared to hypobaric hypoxic conditions (i.e. actual high-altitude environments) (Faulhaber et al. 2020, Fulco et al. 2013).

Similar to the performance impairment, the AMS-susceptibility underlies a broad individual variation making the prediction of AMS development during a high-altitude exposure very difficult (Netzer et al. 2013). Several test procedures have been developed to predict the individual AMS risk during a subsequent exposure to high altitude. Among these, the procedure of Richalet and colleagues is relatively well evaluated (Richalet et al. 2012).

Thus, the goal of the present teaching project was to introduce Masters students to data collection in a laboratory and a field setting with subsequent data analyses. The project was conducted in the context of an official study course ("Seminar Problemanalyse und Forschung in der Trainingswissenschaft") in the Masters program "Sport Science". The students 1) compared submaximal exercise responses in normobaric and hypobaric hypoxia and 2) applied a test for AMS prediction.

2. Methods

Participants: 11 (5 females and 6 males) Masters students of the Department of Sport Science (participants of the "Seminar Problemanalyse und Forschung in der Trainingswissenschaft") comprised the study population. The characteristics of the participants were: age 25.5 ± 1.9 years, height 179.0 ± 8.2 cm, body weight 75.8 ± 10.4 kg). All participants were healthy, physically active and non-smokers and provided fully informed consent.

1) Submaximal exercise responses: Subjects performed three submaximal exercise tests in a fixed order in normoxia, normobaric hypoxia (NH) and hypobaric hypoxia (HH) whereat normoxia testing (Innsbruck) was used for familiarization and was not included in the analysis. The test in NH was performed in a normobaric hypoxic chamber (LowOxygen, Germany), located at the Department of Sport Science of the University Innsbruck (Austria, 590 m) at a simulated altitude of 3450 m (corresponding to 14.5 % inspired fraction of oxygen). Subsequent tests in hypobaric hypoxia were carried out at the High Altitude Research Station Jungfraujoch (Switzerland, 3450m) between 1 and 4 hours after arrival. In each condition, the participants performed a submaximal 3-minute step test (for details see Burtscher et al. 2018). Cardio-respiratory parameters were collected using a spirometric system (Metalyzer 3B, Cortex Biophysik, Germany). Arterial oxygen saturation (finger pulse oximeter, 9550 Onyx II, Nonin, USA), blood lactate concentration (L1, TaiDoc, Taiwan) and subjective ratings of perceived exertion (RPE) according to the Borg Scale (Borg 1982) were determined immediately after test termination.

2) Prediction of AMS: Participants performed cycle ergometer testing in Innsbruck (590 m) according to the protocol of Richalet et al. (2012). In brief: The test included four 4-minute periods: a) rest in normoxia (RN), b) rest in hypoxia (RH), c) exercise in hypoxia (EH), and d) exercise in normoxia (EN). During the hypoxic period, the participant received hypoxic air via a face mask (simulated altitude ca. 4800 m). Minute ventilation (VE) was measured by a spirometric system (Oxycon Pro, Viasys, Germany) and arterial oxygen

saturation (SpO_2) was determined by finger pulse oximetry (9550 Onyx II, Nonin, USA) at the end of each period.

Since exercise parameters seem to be predictive for AMS development the following two parameters were calculated:
$\Delta SpO_2 = SpO_2\text{-EN} – SpO_2\text{-EH}$
HVR = VE-EH – VE-EN

An AMS-development during the subsequent exposure to real high altitude was predicted for individuals with $\Delta SpO_2 \geq 22$ % or with an HVR ≤ 0.78 $l*min^{-1}*kg^{-1}$. The exposure to actual high altitude took place at the High Altitude Research Station Jungfraujoch (Switzerland, 3450 m). AMS symptoms were recorded using the Lake Louise Score (Roach et al. 2018) after 6, and 12 hours. AMS was defined as a Lake Louise Score ≥ 3 at one or more time points.

Statistical analyses were performed using SPSS Statistics 26 (IBM, Austria). All data were checked for normal distribution (Shapiro-Wilk-Test), before paired t-tests were applied to compare submaximal exercise responses of the 2 conditions. In addition, sensitivity and specificity were calculated for the accuracy of the AMS prediction model. Values are expressed as means ± SD or frequencies. P-values < 0.05 were considered to indicate statistical significance.

3. Results und Conclusions

1) Submaximal exercise responses are shown in Table 1. Breathing frequency tended to be about 7 % higher in HH compared to NH. This observation was reported in previous studies comparing NH and HH (Faulhaber et al. 2020) indicating that breathing patterns during exercise could be different in NH and HH. In addition, SpO2 was significantly lower in HH compared to NH.

Table 1. Submaximal exercise responses in normobaric (NH) and hypobaric hypoxia (HH). P-values refer to the comparison of NH and HH. SpO_2 = Arterial oxygen saturation.

	NH	**HH**	**p-value**
Heart rate (bpm)	129.8 ± 15.4	137.6 ± 18.5	0.124
Ventilation (l/min)	62.9 ± 14.8	64.8 ± 14.5	0.556
Breathing frequency (1/min)	28.7 ± 4.3	30.8 ± 3.6	0.094
Blood lactate (mmol/l)	3.4 ± 0.9	3.9 ± 1.3	0.058
SpO_2 (%)	81.5 ± 5.0	78.8 ± 4.8	0.003
RPE	12.1 ± 1.3	12.5 ± 0.9	0.341

2) Prediction of AMS: The test procedure for AMS prediction was conducted in 10 of the 11 participants. Therefore, results refer to data of 10 participants. Based on the threshold values for ΔSpO_2 and HVR, AMS development was predicted for 3 of the 10 individuals. In fact, 4 of the 10 participants developed AMS during the high-altitude exposure at the High Altitude Research Station Jungfraujoch. Sensitivity and specificity of the prediction model amounted to 75 % and 100 % respectively. In other words, 3 of the 4 AMS-positive individuals were correctly classified and all 6 AMS-negative individuals were correctly classified by the prediction model. These values are in line with or even exceed those of evaluations of other prediction models for AMS development (Burtscher et al. 2008; Faulhaber et al. 2014).

This pilot project, including Master students in planning and conducting a high-altitude physiology project, provided results that are comparable to data of published research projects. The feedback of the students about their competence benefit was positive. A special highlight for the students was the sojourn at the High Altitude Research Station Jungfraujoch because it broadened their experiences in personal responses to hypoxia and gave insights into other scientific disciplines at high altitude (e.g., climatology, meteorology). Future projects in this setting are planned, potentially with a slightly longer (i.e. 2 nights) exposure at high-altitude with the option of comparing acute responses as well as short-term acclimatization in NH and HH.

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