Clinical

Resting and exercising cardiorespiratory variables and acute mountain sickness

T J Hooper, D Z H Levett, A J Mellor, M P W Grocott

Abstract

Introduction: The incidence of Acute Mountain Sickness (AMS) is increasing. In a military context our current operational areas include mountainous regions with the implications of AMS including loss of operational tempo and logistical overstretch. Oxygen saturation and heart rate variability have in some studies been predictive of AMS while in others not. No single factor has been demonstrated consistently to be predictive of developing AMS.

Methods: During an expedition to climb Mt Aconcagua (6959m) we explored the relationship between cardiorespiratory variables and AMS. In 11 subjects we measured simple physiological variables and Lake Louise Score both pre and post a standardised exercise challenge at on arrival at different altitudes and after a period of acclimatization.

Results: The changes in cardiorespiratory variables we observed with altitude were consistent with previous studies. Heart rate, respiratory rate and blood pressure increased whilst oxygen saturation reduced. Over time at altitude, respiratory rate and heart rate were maintained whilst there was a reduction in blood pressure towards sea level values. Oxygen saturations improved over time at altitude and the change in heart rate on exercise was reduced with acclimatization. In this small pilot study individuals with AMS may have a greater heart rate response to exercise than non-AMS subjects and this may warrant further investigation.

Conclusions: The incidence of AMS in our study was low reflecting a conservative ascent profile. Further larger studies are necessary to fully assess the predictive value of cardiorespiratory variables in AMS.

Introduction

Acute Mountain Sickness (AMS) has been defined by the Lake Louise Consensus Group as the presence of headache in an unacclimatized person who has recently arrived at an altitude above 2500m plus one or more of the following; gastrointestinal symptoms, insomnia, dizziness, and lassitude or fatigue (1). It is uncommon at altitudes of less than 2500m becoming more common above 3500m, especially in those who have rapid ascent profiles. The incidence of AMS has been quoted as 22% at altitudes of between 1850 – 2750m (2) and 42% at altitudes of 3000m (3) rising to as high as 60% in those ascending to 4800m(4). The incidence is increasing with millions of people travelling to high altitude each year for both work and leisure, especially skiing. In a military context our current operational areas include mountainous regions well above 2000m (50% of Afghanistan is above 2000m) with the implications of AMS including loss of operational tempo and logistical overstretch. The ability to predict AMS would allow the identification of individuals at high risk and implementation of prevention strategies.

Environmental risk factors such as rate of ascent, altitude reached and sleeping altitude are well documented and can be modified to prevent AMS (5). However individual physiological risk factors are less well understood. A number of factors have been identified as being associated with or predictive of AMS including age (2,6,7), gender (2,8), pulse oximetry (SpO2) (8) and over the age of 65 (9). It is clear that young adults are less affected by AMS, while women are less affected than men. Pulmonary O2 uptake, oxygen saturations, and AMS are less predictive of AMS for young adults (10). However, age is one of the most important predictors of AMS (11). Several studies have suggested that the heart rate response to exercise is predictive of AMS (12). However, a recent study found that the heart rate variability during high altitude exposure was predictive of AMS (13). Further studies are needed to confirm these findings.

In conclusion, factors such as age, gender, and physiological responses to exercise may be predictive of AMS. Future studies are needed to further investigate these factors and to develop strategies to prevent AMS in high altitude environments.
Resting and exercising cardiorespiratory variables and acute mountain sickness

gender (2,6), peripheral oxygen saturations (SpO2) (8) and heart rate variability (8). Adults over the age of 50 are less susceptible to AMS (2,6,7), whilst the incidence in children and young adults is similar (9). Men and women are equally prone to AMS, although women are less susceptible to High Altitude Pulmonary Oedema (HAPE) (2,6). Peripheral oxygen saturations (used to estimate arterial oxygen saturation) have been associated with AMS, with lower saturations in the AMS groups (8). In one study resting SpO2 at 4200m predicted the subsequent incidence of AMS during further ascent (10). However, other studies have reported conflicting results (11). Several studies have reported that cardiac responses (heart rate variability) to hypoxic exercise in the laboratory are predictive of AMS in the field (12,13).

However, a more recent study reported that heart rate variability in exercise was not predictive of AMS (8). This study did replicate the finding that SpO2 values at high altitude were predictive of AMS and reported that the inclusion of blood lactate levels improved the ability of SpO2 to predict AMS. Factors which have been excluded as predictors of AMS include sea level aerobic fitness, coronary artery disease and mild chronic obstructive pulmonary disease (5). The hypoxic ventilatory response (HVR) although initially thought to be a possible predictor of AMS has subsequently been shown in a number of studies not to be related to AMS (14-18).

In summary, it is apparent that no single factor has been demonstrated consistently to be predictive of developing AMS. The picture is further confused by apparently conflicting evidence in the literature. These inconsistencies may be explained by variations in study design, for example, some studies were performed in laboratories using altitude chambers and relatively acute hypoxic exposures which may not replicate the conditions in the field (8). In order to further explore the relationship between cardiorespiratory variables and AMS, we studied the response to a standardised exercise challenge (the CXE Step Test), during an expedition to climb Mt Aconcagua (6959m). We aimed to describe changes in resting and exercising cardiorespiratory variables on standardised altitude exposure and whether these were related to the incidence of AMS.

Materials and Methods
The protocol was approved by the University College London ethics committee (in accordance with the Declaration of Helsinki), and written informed consent was obtained from each subject.

Subjects
All members of a Tri-Service Defence Medical Services expedition to climb Mt Aconcagua in Argentina in January 2007 were recruited. No exclusion criteria were used. The expedition lasted 21 days with an initial ascent of Mt Vallecitos (5500m) for training and acclimatization followed by an ascent of Mt Aconcagua (6959m) via the Horcones Valley route. Data was collected throughout this period.

Symptoms Diary/Data Collection Book
Subject characteristics were collected for each team member (age, sex, weight, past medical history and medication).

A symptoms diary/data collection booklet was completed by each subject during the expedition every morning within 1 hour of waking before oral intake, exercise or cigarettes. For each day of the expedition, date, altitude, time, location, planned activity for the day, and medication/alcohol/cigarettes were recorded along with the Lake Louise Score and physiological variables at rest and after an exercise challenge (the CXE Step Test).

Lake Louise Score
AMS was assessed using the Lake Louise Scoring system (LLS) (1). For each symptom (headache, gastrointestinal symptoms, fatigue/weakness, dizzy/light-headedness, difficulty sleeping) a score of 0 to 3 was given. If the symptom was not present a score of 0 was given. If the symptom was present then a score of 1 to 3 was given depending on severity; mild = 1, moderate = 2 and severe = 3. AMS was defined as a LLS score of more than 3 with a headache (1).
Cardiorespiratory Variables
Heart rate, respiratory rate, non invasive blood pressure and oxygen saturation were recorded every morning within 1 hour of waking before oral intake, exercise or cigarettes. The subjects rested for 5 minutes in a seated position before making measurements. Heart rate and oxygen saturation were measured using a finger pulse oximeter (Nonin Onyx 9500) on the right index finger. The data was recorded after 30 seconds of the probe being on the finger. Respiratory rate was measured by counting the number of breaths per minute and blood pressure was measured using a manual non invasive analogue gauge blood pressure cuff with stethoscope over the brachial artery. All measurements were taken by an investigator and the subjects were blinded to the results during testing. The subject then performed the CXE step test (see below) and the measurements were repeated in the 60 seconds following the standardised exercise challenge.

Exercise Challenge
The CXE step test is a standardised, reproducible exercise challenge. The subjects stepped on and off a 20cm step for 1 minute. The cadence was standardised to 1 complete step (both feet) on ground to both feet back on ground every 4 seconds (15 reps/min). An investigator called the timing and recorded the physiological variables during the minute following exercise.

Results
16 subjects were recruited. Data capture was incomplete for 5 subjects who were subsequently excluded from the analysis (2 symptom diaries were lost, 2 team members dropped out of the study and 1 member developed AMS early in the expedition, on day 4 at 4250m, and returned to a lower camp where data collection was unavailable). Baseline age, sex, weight, chronic medical conditions, drug history and the maximum altitude attained are recorded in Table 1.

Initial ascent was to 4250 metres over 4 days from Mendoza (750m) followed by descent to 2700 metres and re-ascent to 4300 metres on Day 9. All subjects followed an identical ascent profile during the initial 9 days but following arrival at 4300 metres ascent profiles diverged and data collection became less consistent. We analysed 11 subjects during the first 9 days (ascent and re-ascent). The ascent profile is illustrated in Figure 1.

The resting cardiorespiratory data is summarised in table 2. Following initial ascent from sea level to 4250m (Day 4), resting heart rate (HR), respiratory rate (RR), blood pressure (SBP) and diastolic blood pressure (DBP) increased. Following further ascent to 4300m (Day 9), resting heart rate and DBP were reduced compared to sea level. Changes in HR and SBP are illustrated in Figure 1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Weight/ kg</th>
<th>Sex</th>
<th>Medical History</th>
<th>Medication</th>
<th>Altitude reached/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34</td>
<td>97</td>
<td>M</td>
<td>Fit and well</td>
<td>Nil</td>
<td>6959</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>90</td>
<td>M</td>
<td>Hypertension - untreated</td>
<td>Nil</td>
<td>6959</td>
</tr>
<tr>
<td>3</td>
<td>29</td>
<td>65</td>
<td>F</td>
<td>Fit and well</td>
<td>Nil</td>
<td>6959</td>
</tr>
<tr>
<td>4</td>
<td>34</td>
<td>100</td>
<td>M</td>
<td>Fit and well</td>
<td>Nil</td>
<td>6700</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>78</td>
<td>M</td>
<td>Fit and well</td>
<td>Nil</td>
<td>6700</td>
</tr>
<tr>
<td>6</td>
<td>56</td>
<td>90</td>
<td>M</td>
<td>NIDDM, Hypertension</td>
<td>Nifedipine, Losartan, Metformin, Aspirin</td>
<td>6200</td>
</tr>
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<td>Nil</td>
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</tr>
<tr>
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<td>88</td>
<td>M</td>
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<td>35</td>
<td>54</td>
<td>F</td>
<td>Fit and well</td>
<td>Nil</td>
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</tr>
<tr>
<td>11</td>
<td>29</td>
<td>64</td>
<td>F</td>
<td>Fit and well</td>
<td>Nil</td>
<td>5400</td>
</tr>
</tbody>
</table>

Table 1. Subject Characteristics and Maximum Altitude Reached

| Sea Level (Pre) Mean (sd) | HR 64 (7.7) | SpO2 98 (1.4) | RR 12 (1.3) | SBP 120 (15.2) | DBP 75 (11.8) |

Table 2. Resting Cardiovascular Data
Data capture was performed by 2 team members who were present on the analysis (2 team members and 1 member of the expedition, on day 4 we were at lower camp where data was collected). Baseline age, height, weight, smoking status, drug intake and altitude attained are detailed in Table 1.

- 3000 metres over 4 days followed by a rest day and re-ascent to 4300 metres the next day. Data points followed an ascent pattern with the initial 9 days of ascent reaching approximately 1000 metres ascent per day. The altitude collection became more frequent during the final ascent and re-ascent. The data is presented in Figure 1. Coronary data is presented showing initial ascent (Day 1), resting heart rate (HR), respiratory rate (RR), systolic blood pressure (SBP) and diastolic blood pressure (DBP) increased, whilst oxygen saturations (SpO2) decreased.

Following further acclimatization and re-ascent to 4300m (Day 9), SBP and DBP were reduced compared with 4250m (Day 4). There was an increase in HR between 4250m (Day 4) and 4300m (Day 9).

Changes in HR, RR, SpO2, SBP and DBP following exercise at each altitude are summarised in Table 2. HR and RR increased following exercise at sea level and at altitude, whilst SpO2, SBP and DBP decreased. The changes observed in all variables following exercise at 4250m (Day 4) were of a greater magnitude than at sea level. After a period of further acclimatization, the fall in SBP and DBP on exercise at 4250m was reduced and the heart rate increase on exercise was less.

### Table 2: Resting Cardiorespiratory Variables

<table>
<thead>
<tr>
<th>Altitude reached/m</th>
<th>Sea Level (Pre) Mean (sd)</th>
<th>2980m (Day 1)</th>
<th>3550m (Day 2)</th>
<th>4250m (Day 4)</th>
<th>0 vs. 4250 (Paired t)</th>
<th>4300m (Day 9)</th>
<th>4250 vs. 4300 (Paired t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>64 (7.7)</td>
<td>80 (11.0)</td>
<td>82 (11.2)</td>
<td>82 (16.2)</td>
<td>0.008</td>
<td>94 (13.7)</td>
<td>0.018</td>
</tr>
<tr>
<td>SpO₂</td>
<td>98 (1.4)</td>
<td>91 (3.2)</td>
<td>89 (3.3)</td>
<td>84 (3.9)</td>
<td>0.000</td>
<td>86 (2.6)</td>
<td>0.129</td>
</tr>
<tr>
<td>RR</td>
<td>12 (1.3)</td>
<td>15 (3.2)</td>
<td>16 (2.9)</td>
<td>18 (4.1)</td>
<td>0.002</td>
<td>19 (3.3)</td>
<td>0.398</td>
</tr>
<tr>
<td>SBP</td>
<td>120 (15.2)</td>
<td>124 (14.8)</td>
<td>131 (19.4)</td>
<td>133 (14.1)</td>
<td>0.001</td>
<td>126 (13.0)</td>
<td>0.007</td>
</tr>
<tr>
<td>DBP</td>
<td>75 (11.8)</td>
<td>81 (8.7)</td>
<td>88 (14.3)</td>
<td>89 (12.8)</td>
<td>0.002</td>
<td>80 (10.5)</td>
<td>0.009</td>
</tr>
</tbody>
</table>
Table 3. Cardiorespiratory Variables after the Exercise Challenge

<table>
<thead>
<tr>
<th></th>
<th>Sea Level (Pre) Mean (sd)</th>
<th>2980m (Day 1)</th>
<th>3550m (Day 2)</th>
<th>4250m (Day 4)</th>
<th>4300m (Day 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔHR</td>
<td>-23 (18.1)</td>
<td>20 (19.1)</td>
<td>-47 (17.0)</td>
<td>-40 (17.2)</td>
<td>-2 (10.8)</td>
</tr>
<tr>
<td>ΔSaO₂</td>
<td>0 (0.6)</td>
<td>1 (4.4)</td>
<td>6 (4.5)</td>
<td>7 (4.1)</td>
<td>5 (3.0)</td>
</tr>
<tr>
<td>ΔRR</td>
<td>-5 (3.6)</td>
<td>-3 (3.5)</td>
<td>-4 (3.0)</td>
<td>-7 (4.5)</td>
<td>-6 (3.2)</td>
</tr>
<tr>
<td>ΔSBP</td>
<td>39 (8.6)</td>
<td>35 (11.4)</td>
<td>44 (14.3)</td>
<td>53 (14.4)</td>
<td>39 (11.1)</td>
</tr>
<tr>
<td>ΔDBP</td>
<td>-6 (5.0)</td>
<td>-8 (7.5)</td>
<td>1 (13.4)</td>
<td>9 (12.7)</td>
<td>-7 (11.6)</td>
</tr>
</tbody>
</table>

Discussion

Principal findings

The changes in cardiorespiratory variables we observed with altitude were consistent with previous reports (5,8,10,12,13,15). Heart rate, respiratory rate and blood pressure increased whilst oxygen saturation reduced. Over time at altitude, elevations in respiratory rate and heart rate were maintained whilst there was a reduction in blood pressure towards sea level values. Increased ventilation with acclimatization (ventilatory acclimatization) led to a trend towards improved oxygen saturations over time at altitude. The change in heart rate on exercise was reduced with acclimatization.

The incidence of AMS in our study was low reflecting a conservative ascent profile. Although this was a prudent approach to acclimatization, it limited the power of our study to detect associations between cardiorespiratory variables and AMS. From the limited data available it appears individuals with AMS may have a greater heart rate response to exercise than non-AMS subjects. However no variables or changes in variables measured at lower altitudes were able to predict subsequent AMS in this group.

The greater heart rate response to exercise in the AMS group is consistent with other studies that have looked at heart rate variability with exercise and altitude (12,13). However our study did not find oxygen saturations seen in other studies the findings of one association (8) but low incidence of AMS limited power of analysis.

Strengths and limitations

Many previous studies suffer from an acute exposure to the laboratory setting (e.g. may differ from the often do not permet over prolonged periods. As a field study, we changed with increased time at a similar after further acclimatization.

We have demonstrated that collecting simple physiological variables whilst still achieving Compliance with diving equipment. This was achieved with the monitoring of individuals and their monitor data deviate from the to the important subgroup those most susceptible. A lesson is that who have the priority over scientific studies (e.g. due to limiting comparisons).

Limitation

A number of subjects lack of complete data for some of the divergent ascent profiles in each individual. Comparisons between individual and non-AMS groups showed the lack of data at higher altitudes does not allow for an assessment of the variation in cardiorespiratory variables of AMS.

Future studies might explore differences in cardiorespiratory variables between AMS and non-AMS groups in more detail.
our study did not find an association between oxygen saturations and AMS that has been seen in other studies (8,10). This agrees with the findings of one study that has not found an association (8) but could equally represent the low incidence of AMS and therefore the limited power of our study to detect a difference.

**Strengths and limitations of the study**

Many previous studies investigating physiological variables and AMS have used acute exposure to simulated altitude in a laboratory setting (8,12). Chamber studies may differ from the situation in the field and often do not permit observation of changes over prolonged periods of acclimatization (8). As a field study, we were able to assess acute changes with increasing altitude and changes over time at a similar altitude (4250/4300m) after further acclimatization.

We have demonstrated the feasibility of collecting simple physiological data in the field whilst still achieving a climbing goal. Compliance with data collection would have been improved with multiple sets of equipment. This would permit the continued monitoring of individuals who are forced to deviate from the team ascent profile – an important subgroup as these probably include those most susceptible to AMS. An important lesson is that where climbing goals have priority over scientific goals data collection will suffer (e.g. due to divergent ascent profiles limiting comparison between groups).

Limitations of our study include the small number of subjects (this was a pilot study), the lack of complete datasets on all individuals, divergent ascent profiles (limiting intra-individual comparisons), the conservative ascent profile (reduced incidence of AMS) and the lack of data at high altitude (due to equipment shortages and focusing on the goal of summiting) where differences in the physiological variables between the AMS and non-AMS groups may have been greater.

Future studies should focus on larger groups to clarify the ability of changes in cardiorespiratory variables to predict the onset of AMS. The importance of a systematic study (same ascent profile all the way through) and priority of scientific goals should be emphasized early in the expedition planning process, if good results are to be achieved. A longitudinal field study at higher altitudes would be interesting; changes in physiological variables would be more pronounced and incidence of AMS greater.

There is a tension between a slow ascent profile (for ethical reasons – to reduce incidence of AMS) and a faster ascent profile. The faster ascent profile will produce a higher incidence of AMS and therefore a greater likelihood of identifying true differences between AMS sufferers and non-sufferers. It may also identify predictive patterns of cardiorespiratory variables which could have utility in identifying individuals who will go on to suffer from AMS. Clearly if a faster ascent profile is adopted then risk management and medical cover need to be of the highest quality.

**Conclusion**

A standardised exercise challenge and simple cardiorespiratory variables can be effectively collected at altitude. The heart rate response to exercise may be greater in individuals with AMS than those without AMS. Further data is necessary to fully assess the predictive value of cardiorespiratory variables in AMS.

**References**

5. Hackett PH, Roach RC. High-Altitude Illness,

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**Introduction**

Recently there has been an increase in the number of endurance hours and the affected by the number of people outside their typical “dead” time as part of their training programme. The discussion regarding the importance of the role of the physician assistant in the current multi-disciplinary approach to the practice of medicine is a necessary one. The role of the physician assistant involves the physician assistant working as a member of a health care team to ensure that the patient receives the best possible care. The physician assistant provides a wide range of services, including medical examinations, diagnosis, and treatment of patients. The physician assistant also provides care to patients during the admission, discharge, and follow-up phases of care. The physician assistant is an integral part of the health care team and contributes to the quality and efficiency of the care provided to patients.

**Administrative**

In order to facilitate the necessary to undertake a doctor's day to day activities, this may be fully appreciated that which may have been the "old style". A shift rotation to a roster of shifts(5). Therefore, this involvement and a