Baseline Psychological Traits Contribute to Lake Louise Acute Mountain Sickness Score at High Altitude

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Abstract

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Background: Interoception refers to an individual’s ability to sense their internal bodily sensations. Acute mountain sickness (AMS) is a common feature of ascent to high altitude that is only partially explained by measures of peripheral physiology. We hypothesized that interoceptive ability may explain the disconnect between measures of physiology and symptom experience in AMS.

Methods: Two groups of 18 participants were recruited to complete a respiratory interoceptive task three times at 2-week intervals. The control group remained in Birmingham (140 m altitude) for all three tests. The altitude group completed test 1 in Birmingham, test 2 the day after arrival at 2,624 m, and test 3 at 2,728 m after an 11-day trek at high altitude (up to 4,800 m).

Results: By measuring changes to metacognitive performance, we showed that acute ascent to altitude neither presented an interoceptive challenge, nor acted as interoceptive training. However, AMS symptom burden throughout the trek was found to relate to sea level measures of anxiety, agoraphobia, and neuroticism.

Conclusions: This suggests that the Lake Louise AMS score is not solely a reflection of physiological changes on ascent to high altitude, despite often being used as such by researchers and commercial trekking companies alike.

Keywords: acute mountain sickness; altitude; breathlessness; exercise; filter detection task; interoception

Introduction

Acute Mountain Sickness (AMS) is a common feature of ascent to altitude, affecting ~25% of individuals ascending to moderate altitudes (2,000–3,000 m) and up to 58% of individuals at 4,500 m (Honigman et al., 1993; Schneider et al., 2002). Ascent rate also plays a key role in AMS prevalence, with rapid ascent profiles on
Mount Kilimanjaro (5,895 m) resulting in an AMS incidence as high as 75% (Karinen et al., 2008). Individual susceptibility is another important determinant, with more experienced mountaineers tending to suffer less AMS (Mairer et al., 2010).

Lake Louise AMS Score, a self-reported symptom score, is the most widely used measure of AMS (Roach et al., 2018). It is well recognized that symptoms of Lake Louise AMS score are not fully explained by measures of hypoxic insult, including arterial oxygen saturations, respiratory rate, and heart rate (Chen et al., 2012; Wagner et al., 2012). Direct measures of hypoxia on brain function also fail to explain this disparity, including matched regional oxygen saturations, electroencephalography, cerebral blood flow velocity, and cerebral edema (Mairer et al., 2012; Feddersen et al., 2015). Given the diverse array of subjective symptoms induced by ascent to high altitude (Hall et al., 2014), it may be that discrepancies in symptoms reporting between individuals can be explained by differences in their perceptual sensitivity or behavioral profiles.

Interception refers to an individual’s ability to sense the internal state of their body (Simmons and Land, 1987; Barret and Simmons, 2015). The “Bayesian Brain” hypothesis of perception, including interception (Barret and Simmons, 2015; Stephan et al., 2016), is a popular neuroscientific theory. In brief, the Bayesian Brain Hypothesis proposes that to interpret numerous noisy sensory stimuli (e.g., vision, pain, nausea), the brain generates an internal model of the world, against which it constantly tests new sensory inputs against.

The second-order process assessing the accuracy of this predictive model is known as metacognition, a term used to describe “cognition about cognition” (Stephan et al., 2016), or “insight” into your own perceptions. By extension, as all symptoms are produced centrally in the brain, they cannot be fully explained by measures of peripheral physiology alone. Differences in interception may help explain the discrepancies in AMS symptomology between individuals on ascent to high altitude.

Ascent to high altitude is associated with an array of physiological and behavioral stressors, including the disruption of multiple physiological symptoms due to AMS (Hall et al., 2014), hypoxia, and its associated systemic inflammatory response (Eltzschig and Carmeliet, 2011), and fatigue resulting from travel across multiple time zones (Stephan et al., 2016). Such stressors have the potential to impair interceptive performance either independently or in combination. Interestingly, habitual exercise is thought to improve interceptive performance, with athletes demonstrating better matching between ventilation and perceived breathlessness than sedentary controls (Faull et al., 2016). Furthermore, functional magnetic resonance imaging of brain networks associated with anticipating breathing stimuli has shown brain activity that reflects subsequent interceptive perceptions in athletes compared with sedentary controls (Faull et al., 2018), and changes in activity in patients with chronic respiratory disease after a course of pulmonary rehabilitation (exercise and education) on exposure to breathlessness cues (Hergistad et al., 2017). Therefore, this study aimed to test the hypothesis that initial ascent to high altitude would impair interceptive performance, while daily exercise in the form of an 11-day trek at high altitude would act as interceptive training and thus improve performance.

Individuals’ psychology can also play a significant role in their experience of symptoms—framing their internal model of the world according to the Bayesian Brain Hypothesis. In particular, fatigue and anxiety may be the brain’s manifestations of poor perceived self-efficacy and control, presenting as a state of learned helplessness (Stephan et al., 2016). Indeed, 1 study of breathlessness in 100 patients with Chronic Obstructive Pulmonary Disease demonstrated different behavioral profiles and brain activity in the anterior insula (a likely key interceptive center) between a high and low symptom burden group, in the absence of any differences in spirometry between the two groups (Finnegan et al., 2021). Therefore, we also hypothesized that self-report questionnaires characterizing individuals’ baseline psychological state may correlate with their symptom burden over the expedition.

**Methods**

**Study design**

This study was a two-group repeated measures design, consisting of equally sized altitude and control groups. Both groups completed interceptive testing at three time points 2 weeks apart. The control group completed all three tests in Birmingham, United Kingdom (140 m). The altitude group completed baseline testing in Birmingham, United Kingdom (140 m); after arrival at high altitude in Lachung, India (2,624 m); and after completing a 11-day trek at altitude in Lachen, India (2,728 m). The ascent profile of the trek is shown on Figure 1, with the highest camp situated at 4,800 m. This study was approved by the Central University Research Ethics Committee of the University of Oxford (Ref: R60699/RE001). All participants provided written consent.

**Study participants**

The altitude group was composed of members of the Birmingham Medical Research Expeditionary Society (n = 18; 11 males, 7 females; median age ± interquartile range = 30.5 ± 15 years, age range = 23–74 years) taking part in a 2-week trek in Sikkim, India. An age- and sex-matched control group was recruited through advertisement on the University of Birmingham campus (n = 18; 11 males, 7 females; median age ± interquartile range = 31 ± 10 years, age range = 23–72 years).

![FIG. 1. The ascent profile of the altitude group in Sikkim, India. Days of travel by motor vehicle are plotted in a dashed line and days of trekking by foot are plotted with a solid line. The times of the two interceptive tests on the expedition are marked by arrows.](image_url)
Exclusion criteria for participating in the study included significant medical comorbidities, smoking history, recent travel across multiple time zones, and recent ascent to high altitude (see Supplementary Information S1 for full criteria). Inclusion criteria included being an acceptable age- and sex-match to one of the expedition participants (same sex and ≤8 years age difference).

There was no significant difference in age between the two groups (Wilcoxon Rank-Sum Test, \( p = 0.3353 \)), with a median age difference of 2 years and interquartile range of 3 years between the two groups.

**Primary outcome measures**

Respiratory interoceptive test. A respiratory threshold detection task, the filter detection task (Harrison et al., 2021a), was used as a measure of respiratory interoception. In this task, the participant breathes through a simple breathing system, and following three baseline breaths, either an inspiratory load is added through the addition of clinical breathing filters, or an empty filter (sham) is used (Fig. 2). After each trial, participants are asked to decide whether or not resistance was added, as well as reporting their confidence in their decision on a confidence scale from 0 to 10. The number of filters is varied according to an algorithm that tracks performance, until a threshold is found at which the participant is 60%–85% confident in their response. The task is then repeated at this threshold for 60 trials.

The filter detection task can then be used to determine perceptual sensitivity (number of filters), perceptual bias in symptom reporting (bias toward yes or no), metacognitive bias (average confidence), and metacognitive performance (Mratio, calculated from meta-d’/d)—that is, the ability to accurately reflect upon and thus control cognitive or perceptual processes (Garfinkel et al., 2016a, 2016b).

Cardiorespiratory physiology. Basic measures of cardiorespiratory physiology were made noninvasively using pulse oximetry and an automatic sphygmomanometer, measuring oxygen saturations, heart rate, and blood pressure. These measures were collected each morning on the expedition as part of a daily medical review.

**Self-report scores.** Participants were asked to complete a number of self-report scores during each of their three testing sessions, including the Lake Louise AMS Scale (Roach et al., 2018), Multidimensional Assessment of Interceptive Awareness (Mehling et al., 2012), Fatigue Severity Scale (Krupp et al., 1989), Epworth Sleepiness Scale (Johns, 1991), State-Trait Anxiety Inventory (Spiegelberger et al., 1983), Center for Epidemiological Studies Depression Scale (Radloff, 1977), Positive and Negative Affect Scale (Watson et al., 1988), Mobility Inventory for Agoraphobia (Chambless et al., 1985), Anxiety Sensitivity Index (Reiss et al., 1998), U.K. Biobank Neuroticism Scale (Smith et al., 2013), and WHO Global Physical Activity Scale (World Health Organization, 2002) reported in metabolic equivalent minutes.

The altitude group also completed daily Lake Louise AMS scores throughout the trek each morning as part of daily medical review.

**Statistical analysis**

Statistical analysis was performed according to the pre-published statistical analysis plan (https://osf.io/zgj9c/).

Examining interoceptive performance. The respiratory threshold task was analyzed using the hierarchical HMeta-d statistical model (Harrison et al., 2021a); model fits were implemented in MATLAB (Mathworks, Natick) with sampling conducted using JAGS (Plummer, 2003). The HMeta-d model was fitted separately for each pair of tests in the control group and altitude group to look at the effect of initial ascent to high altitude (visit 1 and 2) and of an 11-day trek at altitude (visit 2 and 3).

Mratio was compared between each visit by calculating a one-tailed 95% highest density interval (HDI) across the distribution of samples for each visit, a significant difference was defined as a HDI not spanning zero. The effect of ascent to high altitude and exercise at altitude were examined by looking at the interaction effect between the control and altitude group for the aforementioned paired time points.

Additional variables of the filter detection task, including perceptual sensitivity, perceptual bias, and metacognitive bias, are not fit hierarchically within the Hmeta-d model, so can be compared using standard frequentist statistics. Repeated measures analysis of variance (RANOVA) was used to compare these measures between visits with a 5% significance level. To compare the self-report scores between the altitude and control groups for each visit, responses were first tested for normality using an Anderson–Darling test, then if normal compared using a two-tailed \( t \)-test and if nonparametric compared using a Wilcoxon rank-sum test. Uncorrected \( p \)-values are presented and a Bonferroni correction for multiple comparisons between the two groups has been used to adjust the significance level, \( p = 0.05/20 = 0.0025 \).

To investigate the relationship between metacognitive ability and AMS, linear regression models were used to compare metacognitive performance from baseline (visit 1) and arrival at high altitude (visit 2) with AMS symptom burden over the trek. A significant relationship between the covariate and log of Mratio was defined as a two-tailed HDI that does not span zero across the beta samples for the covariate.

Examining baseline psychology. Hierarchical cluster analysis, similar to the method outlined by Abdallah et al.
(2019), was used to assess the relationship between measures of symptoms of AMS on ascent to high altitude and baseline psychological state. Means of the daily measures of Lake Louise AMS score and oxygen saturations from the trek were included to represent AMS symptom burden. Only self-report scores that referred to individuals’ “usual state” rather than the present moment or preceding week were included in the cluster analysis to best represent their baseline psychological state. Additionally, the Multidimensional Assessment of Interoceptive Awareness was excluded because it only strongly clustered with itself.

Subsequently, baseline psychological state was represented using State-Trait Anxiety Inventory—Trait only, Anxiety Sensitivity Index, Mobility Inventory for Agoraphobia, U.K. Biobank Neuroticism Scale, and Epworth Sleepiness Scale. These questionnaires were all completed during the baseline test at sea level in Birmingham. Before clustering, all variables were adjusted so that larger numbers represented a “worse” result and normalized through a z-transformation. The ability of the above variables to predict Lake Louise AMS score was further investigated using linear regression modeling.

Results
The effect of altitude on metacognition
There was no significant difference in Mratio between visit 1 (140 m) and visit 2 (2,624 m), HDI −0.2095, 0.6285. Additionally, there was no significant interaction effect (the effect of altitude) for the difference between visit 1 and 2 in the altitude group using control group as a comparison dataset (HDI 0.5525, −0.5699). Neither was there a significant difference in the additional filter detection task variables between the two visits: perceptual sensitivity (RANOVA, \(F = 0.5435, p = 0.4660\)), perceptual bias (RANOVA, \(F = 1.1436, p = 0.2924\)), and average confidence (RANOVA, \(F = 0.0001, p = 0.9918\)).

The effect of a daily trek on metacognition
There was no significant difference in Mratio between visit 2 (2,624 m) and visit 3 (2,728 m, after an 11-day trek), HDI −0.5203, 0.4295. Additionally, there was no significant interaction effect (the effect of daily exercise) between visit 2 and 3 in the altitude group using the control group as a comparison dataset (HDI 1.6060, −0.1156). Neither was there a significant difference in the additional filter detection task variables between the two visits: perceptual sensitivity (RANOVA, \(F = 0.8250, p = 0.3701\)), perceptual bias (RANOVA, \(F = 0.3104, p = 0.5811\)), and average confidence (RANOVA, \(F = 1.9743, p = 0.1691\)).

Metacognitive ability and AMS
The first regression model fitting Mratio, Lake Louise AMS score, and oxygen saturations from visit 2 (2,624 m) in the altitude group showed no significant association between metacognitive performance at that particular time point and corresponding Lake Louise AMS score (HDI −6.293, 0.2354) or oxygen saturations (HDI −0.4579, 0.3530). The second regression model fitting Mratio from visit 1 in the altitude group and average Lake Louise AMS score, oxygen saturations, and heart rate from the highest camp on the expedition (4,800 m) found no association between metacognitive performance at baseline and measures of symptom burden at the highest camp on the expedition: Lake Louise AMS score (HDI −0.1647, 0.5173), oxygen saturations (HDI −0.2021, 0.4682), and heart rate (HDI −0.3988, 0.1996).

Questionnaires
The results of the self-report questionnaires from the baseline test of the control and altitude groups are shown in Table 1. There was no significant difference in baseline psychological measures or physical activity between the control and altitude groups, other than two subcomponents of the Multidimensional Assessment of Interoceptive Awareness questionnaire: noticing and not worrying. The daily measures of Lake Louise AMS score and cardiorespiratory function, recorded during a daily medical examination, are shown in Table 2. A total of 8/18 (44%) participants on the expedition developed AMS (defined as a Lake Louise AMS score ≥3), which was mild (Lake Louise AMS score <6) in all but 1 participant. This participant required premature evacuation from the highest camp due to concerns from the medical team.

Baseline psychology and AMS symptoms
The results of the hierarchical cluster analysis are illustrated in Figure 3; the optimal number of clusters for this model was two. The first cluster was composed of mean oxygen saturation from the trek, Anxiety Sensitivity Index, and Epworth Sleepiness Scale. The second cluster included mean Lake Louise AMS score from the trek, Mobility Inventory for Agoraphobia—Alone and Accompanied, State-Trait Anxiety Inventory—Trait, and U.K. Biobank Neuroticism Scale.

To explore whether any of these measures were predictive of the Lake Louise AMS score, they were fitted into a linear regression model: number of observations 16, degrees of freedom 8, root mean squared error 0.4546, adjusted \(R^2\) 0.7926, F-statistic 9.1879, and \(p = 0.0028\). The assumptions of linear regression, including normality of the residuals and homoscedasticity were met.

In this model, Epworth Sleepiness Scale (\(\beta_1 = 0.5170, p = 0.0314\)) and Mobility Inventory for Agoraphobia—Alone (\(\beta_1 = 1.1574, p = 0.0026\)) were predictive of Lake Louise AMS score. The other variables did not have a significant relationship with Lake Louise AMS score: mean oxygen saturation (\(\beta_1 = -0.0082, p = 0.9750\)), State-Trait Anxiety Inventory—Trait (\(\beta_1 = -0.0175, p = 0.9432\)), Anxiety Sensitivity Index (\(\beta_1 = -0.3495, p = 0.1750\)), Mobility Inventory for Agoraphobia—Accompanied (\(\beta_1 = -0.6083, p = 0.0675\)), and U.K. Biobank Neuroticism Scale (\(\beta_1 = 0.0314, p = 0.9064\)).

Discussion
AMS is a poorly understood condition, in which symptoms are inadequately explained by measures of peripheral physiology. Interoceptive performance, as measured by the filter detection task, was not impaired on ascent to high altitude and did not demonstrate any relationship with AMS symptoms. Average Lake Louise AMS score at high altitude clustered with self-reported measures of anxiety, agoraphobia, and neuroticism taken at sea level, but not average
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### Table 1. Self-Report Questionnaire Measures from Baseline Testing (in Birmingham, 140 m) for the Control and Altitude Group

| Questionnaire                                      | Control group, median±interquartile range | Altitude group, median±interquartile range | Normally distributed | p     |
|---------------------------------------------------|------------------------------------------|--------------------------------------------|----------------------|-------|
| MAIA—Noticing                                     | 3.6±1.3                                  | 2.9±1.3                                    | False                | 0.1824|
| MAIA—Not distracting                              | 3.0±1.3                                  | 1.8±1.3                                    | False                | <0.001*|
| MAIA—Not worrying                                 | 2.7±1.0                                  | 3.8±0.7                                    | False                | <0.001*|
| MAIA—Attention regulation                         | 3.0±0.7                                  | 2.7±1.6                                    | False                | 0.4955|
| MAIA—Emotional awareness                          | 3.4±1.4                                  | 3.0±1.8                                    | False                | 0.1196|
| MAIA—Self-regulation                              | 3.0±1.8                                  | 2.4±2.0                                    | False                | 0.3919|
| MAIA—Body listening                               | 2.3±1.3                                  | 2.2±1.7                                    | False                | 0.2020|
| MAIA—Trusting                                     | 4.0±0.7                                  | 4.0±1.0                                    | False                | 0.5091|
| Fatigue Severity Scale                            | 3.3±1.2                                  | 2.9±1.8                                    | False                | 0.1208|
| Epworth Sleepiness Scale                          | 7.5±6.0                                  | 7.0±3.0                                    | False                | 0.6912|
| State-Trait Anxiety Inventory—State               | 33.5±10.0                                | 29.0±14.0                                  | False                | 0.2218|
| State-Trait Anxiety Inventory—Trait               | 38.0±20.0                                | 30.5±8.0                                   | False                | 0.0443|
| Center for Epidemiological Studies Depression Scale| 11.5±9.0                                  | 5.0±6.0                                    | True                 | 0.0263|
| Positive and Negative Affect Scale—Positive       | 31.5±10.0                                | 39.0±11.0                                  | False                | 0.1130|
| Positive and Negative Affect Scale—Negative       | 14.5±6.0                                  | 13.0±6.0                                   | False                | 0.4842|
| Mobility Inventory for Agoraphobia—Alone          | 1.4±0.4                                  | 1.1±0.1                                    | False                | 0.0079|
| Mobility Inventory for Agoraphobia—Accompanied    | 1.2±0.3                                  | 1.0±0.1                                    | True                 | 0.0277|
| Anxiety Sensitivity Index                         | 21.5±14.0                                | 10.5±5.0                                   | False                | 0.0028|
| U.K. Biobank Neuroticism Scale                    | 2.5±6.0                                  | 1.5±4.0                                    | True                 | 0.2077|
| WHO Global Physical Activity Scale                | 3900.0±4580.0                            | 3660.0±3040.0                              | False                | 0.7879|

An Anderson–Darling test was used to check whether data for each questionnaire were from a normal distribution reported as “True” for parametric data and “False” for nonparametric data; the two groups were then compared using a two-tailed t-test or Wilcoxon rank-sum test respectively.

Uncorrected p-values are presented. A Bonferroni correction for multiple comparisons was used to adjust the level of significance to 0.0025; significant values are marked with an asterix (*).

MAIA, Multidimensional Assessment of Interoceptive Awareness.

### Table 2. Daily Physiological Measures from the High-Altitude Expedition (Mean±Standard Deviation) and Prevalence of Acute Mountain Sickness (Lake Louise Acute Mountain Sickness Score ≥3) Recorded During the Daily Medical Review Each Morning

| Day of expedition | Altitude, m | Oxygen saturations, % | Heart rate | Respiratory rate | Systolic blood pressure, mmHg | Diastolic blood pressure, mmHg | Daily AMS prevalence |
|-------------------|-------------|-----------------------|------------|-----------------|-------------------------------|-----------------------------|---------------------|
| 1                 | 1,650       | 94.9±2.0              | 63.2±9.5   | 14.7±2.4        | 112.7±8.2                    | 69.1±7.4                    | 0                   |
| 2                 | 2,624       | 93.6±2.0              | 61.1±12.9  | 14.7±1.9        | 111.8±10.6                   | 72.2±7.9                    | 0                   |
| 3                 | 2,624       | 91.3±1.9              | 65.4±12.5  | 15.2±2.3        | 112.7±10.7                   | 72.9±8.6                    | 0                   |
| 4                 | 3,240       | 92.2±1.7              | 62.1±13.4  | 14.9±2.4        | 113.2±10.4                   | 74.4±5.3                    | 0                   |
| 5                 | 3,240       | 89.2±2.5              | 68.9±16.2  | 16.3±3.4        | 111.9±9.4                    | 70.4±6.3                    | 2                   |
| 6                 | 3,300       | 88.8±2.5              | 67.7±14.5  | 16.5±3.1        | 116.8±9.4                    | 72.4±6.3                    | 0                   |
| 7                 | 3,850       | 86.6±2.7              | 69.6±13.7  | 15.4±2.3        | 116.6±9.2                    | 74.3±6.1                    | 1                   |
| 8                 | 3,850       | 85.8±3.4              | 65.9±8.6   | 16.1±2.6        | 117.4±7.4                    | 75.6±6.2                    | 4                   |
| 9                 | 4,800       | 87.4±2.9              | 67.4±13.8  | 17.8±3.1        | 117.1±9.7                    | 75.1±6.4                    | 2                   |
| 10                | 4,800       | 81.1±4.5              | 71.8±10.3  | 19.4±3.5        | 120.4±10.3                   | 73.9±6.6                    | 5                   |
| 11                | 4,800       | 80.5±4.8              | 69.6±11.6  | 18.6±3.6        | 118.3±10.7                   | 73.1±7.6                    | 2                   |
| 12                | 3,850       | 82.6±3.1              | 68.6±12.4  | 18.7±4.1        | 130.1±11.2                   | 81.2±8.8                    | 1                   |
| 13                | 3,240       | 88.9±1.8              | 66.9±14.9  | 17.1±2.6        | 119.9±12.9                   | 75.9±8.7                    | 1                   |
| 14                | 2,728       | 91.2±2.4              | 66.1±13.3  | 17.8±2.7        | 116.7±10.9                   | 75.8±7.1                    | 1                   |
| 15                | 2,728       | 91.6±1.6              | 71.9±16.4  | 17.7±2.1        | 117.3±10.5                   | 73.2±7.3                    | 0                   |
| 16                | 1,650       | 92.2±1.2              | 67.2±11.5  | 17.5±2.5        | 113.3±9.7                    | 69.6±9.2                    | 0                   |
| 17                | 1,650       | 94.6±1.4              | 61.5±14.2  | 16.2±1.5        | 110.8±9.5                    | 69.1±8.2                    | 0                   |

AMS, acute mountain sickness.
hypoxic chamber studies at sea level (Niedermeier et al., 2017), which may reflect the different physiological responses to normobaric and hypobaric oxygen (Millet et al., 2012), or indeed the additional stresses of an expedition environment compared with a controlled laboratory environment.

There was no change in metacognitive performance between visit 1 at 140 m and visit 2 at 2,624 m; therefore, ascent to altitude did not act as an “interoceptive challenge.” This may reflect the low incidence of AMS in our expedition group of predominantly experienced mountaineers (Table 2); the mean group Lake Louise AMS score at visit 2 (2,624 m) was 0.83.

Neither was there a change in metacognitive performance between visit 2 and 3 after completion of an 11-day trek; therefore, daily exercise at altitude did not act as an “interoceptive training.” Unfortunately, the trek was not as arduous as anticipated by the researchers. Additionally, the altitude group had a highly variable level of baseline activity level, with 74% of the group reporting >2,000 minutes of metabolic equivalent time per week according to the Global Physical Activity Questionnaire (World Health Organization, 2002). Thus, it is possible that the trek did not present an adequate training stimulus to alter metacognition.

Metacognitive performance on arrival at altitude (visit 2) was not related to Lake Louise AMS score or oxygen saturations at that time point, neither was baseline metacognitive performance (visit 1) predictive of AMS symptom burden (Lake Louise AMS score, oxygen saturations, or heart rate) at the highest point of the trek. It is possible that the filter detection task was not sufficiently sensitive to detect subtle changes in metacognition, particularly given the low prevalence of AMS on the expedition. Although, this same task has previously proven sensitive enough to detect interoceptive differences between asthma patient subgroups experiencing different levels of symptom severity (Harrison et al., 2021c).

Previous work has validated the filter detection task in participant groups with asthma and anxiety (Harrison et al., 2021b, 2021c), with interoceptive ability appearing to relate to symptom burden in these two conditions. However, this is the first study that has investigated the contribution of interoceptive ability to AMS and as such warrants larger validation studies. Ongoing work is taking place to optimize the filter detection task to make it more amenable to further field research in larger cohorts (Harrison et al., 2021a; Nikolova et al., 2021).

Mood and physical fatigue appear to be important perceptual modulators impacting individuals’ symptom reporting (Finnegan et al., 2021; Harrison et al., 2021c), therefore, we investigated the impact of these factors on AMS symptom burden in our cohort with hierarchical cluster analysis. Average Lake Louise AMS score over the trek clustered with self-reported measures of anxiety, agoraphobia, and neuroticism taken at sea level. Agoraphobia is a type of anxiety disorder where individuals fear being in circumstances where escape may be difficult (American Psychiatric Association, 2013). It has previously been linked to dysfunctional interoceptive processes, where individuals have increased perceptual sensitivity paired with a propensity to misconstrue bodily sensations as dangerous, leading to panic (Breuniger et al., 2017).

Neuroticism has also been linked to interoceptive sensitivity (Pearson and Pfeifer, 2020) and certainly contributes to
Limitations

The study had a small sample size, with only 18 participants in each group. A larger sample size would allow for exploratory factor analysis and stratification of participants into behavioral phenotypes.

Furthermore, participation in high-altitude treks represents a rather niche interest that likely introduced some selection bias into this study. However, baseline questionnaires (shown in Table 1) demonstrated no significant difference in psychological measures or usual physical activity between the two groups.

We hypothesized that ascent to high altitude would impair interoceptive performance. However, the interoceptive tests took place at only moderate altitudes of 2,624 and 2,728 m, inducing low levels of AMS in our study group. This was largely for pragmatic reasons, to allow testing to take place in an indoor environment, as the trekking group camped at higher altitudes. The trek itself involved a high camp of 4,800 m though, which is comparable to many commercially available treks in the greater ranges.

Conclusions

AMS remains a poorly understood condition, in which symptom burden is inadequately explained by measures of peripheral physiology. Interoceptive performance, as measured by the filter detection task, was not impaired in this study on ascent to altitude, or improved by daily exercise, and did not demonstrate any relationship with AMS symptoms. However, AMS symptoms were more closely related to self-reported psychological measures than oxygen saturations, demonstrating the contribution of psychological factors to individuals’ experience of AMS symptoms. Therefore, we advise caution in the interpretation of Lake Louise AMS scores by researchers and commercial trekking companies alike to ensure serious cases of AMS are not missed.

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Authors’ Contributions

B.J.T. was involved in data collection, data analysis, and article drafting.
C.C., S.J.L., C.L., and L.M. were involved in data collection.
O.K.H. was involved in study design, data analysis, and article drafting.
S.L.F. was involved in data analysis and article drafting.
S.J.E.L. was involved in study design and overview.
K.P. was involved in study conception, study design, data collection, data analysis, and article drafting.
All authors were involved in final revision and approval of the article.

Preprint

An earlier draft of this article was posted as a preprint at bioRxiv (DOI: 10.1101/2021.07.22.451589v1).

Author Disclosure Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary Material

Supplementary Information

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