Acta Astronautica 219 (2024) 220–235

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

The right stuff: Salutogenic and pathogenic responses over a year in Antarctica

Barbara Le Roy [a,b,c,*], Charles Martin-Krumm [a,b,c,d], Jérémy Rabineau [e], Sandrine Jacob [a], Céline Dupin [f], Marion Trousselard [a,b,c,g]

[a] *Stress Neurophysiology Unit, French Armed Forces Biomedical Research Institute, Brétigny-sur-Orge, France*
[b] *CNES, Paris, France*
[c] *University of Lorraine, Inserm, INSPIIRE, UMR 1319, F-54000, Nancy, France*
[d] *École de Psychologues Praticiens, Catholic Institute of Paris, EA Religion, Culture et Société, Paris, France*
[e] *Laboratory of Physics and Physiology, Université Libre de Bruxelles, 1070, Brussels, Belgium*
[f] *French Southern and Antarctic Lands, Reunion Island, France*
[g] *French Military Health Service Academy, Paris, France*

ARTICLE INFO

Keywords:
Adaptation
Antarctica
Health
Neurosciences
Selection
Third-quarter phenomenon

ABSTRACT

Introduction: Ever since the first human reached the South Pole, studies have sought to explore the impact of an isolated, confined, and unusual environment on human adaptation. The findings have highlighted both negative and salutogenic effects on crews. Although several studies have focused on adaptation in the polar regions, we still do not fully understand its mechanisms. Thus, the objectives of the present study are: (1) to investigate the impact of a one-year stay in Antarctica on health adaptation; and (2) to assess recovery from this experience two days later.

Method: Seventeen healthy participants were recruited to stay for one year at the French Dumont d'Urville station in Antarctica. Psychological, physiological, and exteroceptive measures were recorded on the day of arrival at the station (baseline), during each quarter of the wintering season (M4, M7, M10, M12), and two days after the return to the continent (D+2). Subjects were allocated to two groups according to their scores on the General Health Questionnaire at baseline, as follows: very limited or no existence of minor non-psychiatric or psychotic disorders (higher than normal, HN); and standard values for non-psychiatric or minor psychotic disorders within the general population (ordinary range, OR).

Results: Our results highlight both an adaptative response during the winter months, and pathogenic states during the last quarter of the mission and at recovery (D+2), which are still below normal values for psychological disorders and stress. The analysis of OR and HN groups during overwintering highlights a decrease in psycho-sensory responses, and thus poorer adaptation.

Conclusion: Spending a year in Antarctica no longer has harmful consequences (except during the third quarter of the mission), and the harshness of the environment in midwinter does not seem to be an aggravating factor for the winterers included in this study. Nevertheless, the General Health Questionnaire indicates two levels of adaptation during the mission. The latter observation suggests that there is a need to select the most-adaptable crews to maintain high performance during overwintering, and to prepare for the return to the continent. Taken together, our results contribute to a better understanding of adaptation in extreme environments, notably future dark space exploration.

1. Introduction

"Dreams are not what you have when you sleep. The true dreams are the ones that don't let you sleep", Dr Abdul Kalam (2021). The dream of discovering white expanses extending as far as the eye can see was what motivated men to answer the call of Ernest Shackleton, published in the Times in 1913. Nowadays, while his pioneering expedition is part of history, polar missions remain a challenge to human life, despite

---

* Corresponding author. Stress Neurophysiology Unit, French Armed Forces Biomedical Research Institute, Brétigny-sur-Orge, France.
E-mail address: barbara.m.le.roy@gmail.com (B. Le Roy).

https://doi.org/10.1016/j.actaastro.2024.03.001
Received 8 September 2023; Received in revised form 25 February 2024; Accepted 2 March 2024

technological evolution, improvement of equipment, and selection of winterers based on their general somatic health and psychological functioning. To improve their health during their wintering, it seems crucial to explore their ability to cope to the environmental and mission's constraint. This is particularly important considering the risk to health and safety in the polar environment, and to provide preparation support for space travel. Thus, the main interest of conducting studies in Antarctica is twofold: (1) exploring the impact of environmental constraints on the body's homeostasis; and (2) providing a natural laboratory to study all the components of human adaptation. Thus, the main aim of the present study is to investigate the impact of a one-year stay in Antarctica on health adaptation.

1.1. Symptomatology and health adaptation in polar stations

Antarctica is not only an isolated and confined environment (ICE), but also an extreme and unusual environment (EUE). It is a harsh, hazardous place for the human organism to live [1,2]. Polar stations are isolated from the rest of the world, crews are confined in small spaces, life-support systems mean that they are unusual, and extreme temperatures limit access to the outer environment. While many of these characteristics are unique (e.g., cold, dry, light/dark cycles), other, inherent features are even more complex to manage, notably physical (e.g., sensory monotony, isolation, inability to escape, potential sudden disaster, physical discomfort, lack of privacy), or psychological (e.g., cultural differences, empty time, interpersonal issues, distance from loved ones, personal crises) demands. However, the body's response to a long stay in an extreme environment changes over time [3–7]. Data from polar research suggest that overwintering induces symptomatology that ranges from psychosomatic (e.g., fatigue, weight gain, pains, headaches, digestive complaints), to psychological (e.g., depression, anxiety, sleep disturbances, loneliness, fatigue, negative affect, irritability), and psychosocial (e.g., tensions, interpersonal conflicts). This symptomatology is frequent, and tends to follow a non-linear pattern during the mission [8–12], leading to different syndromes: (1) overwinter syndrome (i.e., sleep disturbance, depression, hostility, negative affect, irritability, distraction, and impaired cognition during the winter period); (2) third quarter phenomenon (i.e., an increase in symptomology after the midpoint of the mission, with a reduction toward the end); (3) polar T3 syndrome (i.e., variation in thyrotropin-stimulating hormone concentrations with impacts on performance and mood); (4) subsyndromal seasonal affective disorder (i.e., depressed mood, lethargy, somatic complaints, change in appetite, fatigue, decreased performance linked to photoperiodicity), and, more recently; (5) polar wintering (i.e., psychological hibernation, including a decrease in resources as winter begins, and their reconstruction in the second half of the mission). Living in the white lands of Antarctica presents many challenges. Response patterns to environmental and psychosocial stressors in polar regions have been highlighted in the literature [4,13–18]. However, findings from studies of their apparition or frequency are inconsistent [16, 19–22].

At the same time, a salutogenic response has also been demonstrated (e.g., friendship, personal achievement, resilience, coping, sense of humanity, courage, improved health, personal growth) [4,23–25]. Thus, the experience in ICE/EUE may be positive [4,7,17,20]. Notably, Palinkas and Suedfeld [4] observe that signs of maladaptation may coexist with salutogenic effects, which have significant impacts on overwintering, and may affect crews after returning to the continent. Under stress, an individual implements mechanism to cope with the environment, and thus maintain optimal health and operational capacities [3]. They are dependent on the crew, the mission, and environmental characteristics, as interactions with the environment influence the way crews act on it, and cope with its demands [26]. Overall, adaptation may occur at three points: the initial anxiety stage (at the beginning of the mission); a stage of increased depression and boredom (as the mission progresses), and a stage of anticipation, including euphoria/aggressiveness (the last period of the mission) [27,28]. Palinkas and Houseal [29] propose that these stages are similar to Selye's general adaptation syndrome. Nevertheless, it is important to keep in mind that individual responses can vary, and human adaptation in polar regions seems to be motivated by a complex intersection of several factors: seasonal, situational, social, and salutogenic [30]. These findings suggest that it may be complex to identify the adaptation mechanisms that play a role during an overwinter campaign in Antarctica, especially since there is substantial inter-individual variability [3]. However, a better understanding of these mechanisms is critical, not only for mission planning, but also to prevent and promote factors that support successful psychological, social, physiological, and sensory adaptation.

1.2. Brain-body regulation lies at the heart of homeostasis

A prolonged period of sensory deprivation and monotony may have an impact on the body's sensory functioning, including exteroception and interoception. Both interoceptive and exteroceptive abilities contribute to the construction of body awareness, and thus the *body matrix* [31]. While impaired visual function has been found in some Antarctic stations, due to the high altitude [1,17,32–34], Stahl et al. [35] found no evidence of pathological change in ophthalmology among overwinterers (visual acuity, contrast sensitivity, color vision, auto-refraction, subjective refraction, retinal examination, retinal autofluorescence and retinal thickness, or intraocular pressure). A loss of appetite has been reported in some studies [4,36], while others have demonstrated an increase [37–39].

Interoception has been less studied. Defined as the perception of the body's internal signals, it has been shown to play a crucial role in the regulation of physiological processes, and appears to be linked to adaptive coping strategies [40,41]. It also supports the maintenance of a state of balance (i.e., homeostasis) that implied autonomic nervous system (ANS). ANS can be assessed using the heart rate variability (HRV) whose changes have been associated with an increase in the ability to maintain function homeostasis [42]. Higher HRV and interoception are both associated with better adaptation in terms of emotion regulation [43]. In line with the latter finding, studies in ICE/EUE have shown that the cardiac biosignal profile, based on parasympathetic activity and cardiac flexibility, and measured by HRV, is consistent with different levels of adaptation among a patrol onboard a nuclear submarine [44, 45]. The latter authors show that differences in terms of interoception and exteroception have an impact on the health of submariners, as a function of baseline parasympathetic activity. The observation that HRV plays a role in the body's adaptive response to external environmental constraints highlights the role of the mind-body connection.

The mind-body connection refers to embodied, embedded (the relation with the environment), and extended (relational) experience [46], and impacts the multi-sensory representation of the lived experience [47]. As defined by Siegel (p. 52) [48], "The human mind is a relational and embodied process that regulates the flow of energy and information". Mindfulness is a mind-body framework that is often used as an umbrella term to characterize functioning that supports adaptation [49]. Mindfulness disposition (MD) is characterized by an intentional awareness and non-judgmental acceptance of the moment-by-moment experience. It refers to body awareness [50,51] and interoception [49], and has been related to flow (i.e., a feeling of being entirely absorbed) [52]. It has been associated with improved resilience, flexibility, emotional regulation, and attention in stressful situations [53–56]. A recent study by Lefranc et al. [44] explored the association between MD, interoception and exteroception, and found that high MD is associated with better interoceptive abilities, positive emotions, and subjective extra-sensor acuity. MD appears to protect against the negative effects of long-term containment in a professional environment, such as a submarine patrol [57]. MD and HRV have been proposed as indicators of an organism's flexibility, promoting the ability to constantly adapt to changing internal and external environments. Although few studies have examined their relationship, an increase in MD has been associated with an improvement in ANS flexibility measured using HRV self-similarity indicators [42].

1.3. Considerations of the present study

Although several studies have focused on adaptation in ICE/EUE, there are still some missing pieces of the puzzle. This is a real challenge in the context of Long-Duration Space Flight (LDSE), as Antarctica is widely considered to be the most suitable analog for Mars [58]. Thus, the objectives of the present study are: (1) to investigate the impact of a one-year stay in Antarctica on health adaptation; and (2) to assess recovery from this experience two days later. Health adaptation is defined as health functioning (overall health, sleep, energy, physical activity), psychological resources (mindfulness disposition, interoceptive awareness, emotions, mood, flow, sleep, energy, perceived stress, group cohesion), and perceived extrasensors (the sensory hierarchy and acuity). Mechanistic aspects are evaluated using physiological (HRV), and sensory (olfaction, hearing, visual accommodation, taste) responses highlighted through brain-body regulation mechanisms. The evaluation considered, among others, scores on the Goldberg's General Health Questionnaire (GHQ). The GHQ [59] aims to assess psychological distress by targeting the least-differentiated level of mental illness, in other words, the lowest common denominator, shared by all psychiatric diagnoses. The purpose is to detect individuals who may develop non-psychotic mental health problems as a function of four factors (depression, anxiety, somatic symptoms, and social dysfunction). GHQ-12 scores indicate the level of distress: a score of 11 or 12 has been proposed as neurotypical; scores above 15 have been associated with psychological distress; and scores above 20 with severe psychological distress [60]. During the golden age of scientific studies in Antarctica, researchers used the GHQ-12, over the course of a year, to study the psychological profiles of winterers at the British Rothera station, and to assess the relevance of using the GHQ in an ICE [61]. Although their results revealed greater psychological distress than the control group (who stayed on the continent) during the winter months, this did not persist, with scores remaining relatively stable over the year. Nevertheless, the three winterers who had the highest GHQ scores left earlier than planned. Consequently, the authors of the study noted that the GHQ could be a tool for detecting individuals at risk of psychological distress, and highlighted the added value of the scale for measuring mental health in Antarctica [61]. More recently, Khandelwal et al. [62] used the 28-item GHQ over the course of a year to study psychological adaptation at Maitri, an Indian polar station in Antarctica. Their results revealed a significant increase in somatic symptoms, and scores on social dysfunction subscales in midwinter, followed by a decrease. Anxiety and depression subscales were also highest during the winter peak.

Given the sparse, and often inconsistent results reported in the literature about the impact of a one-year stay in Antarctica on health adaptation, it is difficult to propose hypotheses regarding the evolution of physiological and sensory responses. Nevertheless, our hypotheses are as follows: (1) subjects with very low GHQ-12 scores at the beginning of the polar mission will be less impacted; (2) health functioning, and psychological (resources, perceived extrasensors) and sensory responses will deteriorate as wintering progresses, particularly during the coldest month, and the third quarter; (3) the sympathovagal balance may be modified, and follow either a linear deterioration or phased worsening. The second exploratory aim is to evaluate short-term recovery, 48-h after the polar mission ends. Here, we hypothesize that winterers' health functioning, and their psychological, physiological, and sensory responses will not have returned to their baseline state (i.e., prior to departure for Antarctica).

2. Materials & methods

2.1. Participants

Seventeen participants (two women and 15 men) were recruited for this study. They were among the crewmembers selected by the French Polar Institute Paul-Émile Victor to participate in the 2021–2022 overwinter campaign at the Dumont d'Urville station, after medical and psychological screening. Demographics are given as mean ± standard deviation. Mean age was 31.73 ± 10.56 years (range 19–55). One of the two women (50%) was using contraception (a copper intrauterine device). Two participants were smokers (11.76%), and one was taking 10 mg RAMIPRIL for the treatment of hypertension. Average height was 174.95 ± 6.36 cm, and weight was 73.82 ± 10.81 kg. Thirteen participants were single (76.47%), four were in a stable relationship (23.52%), among which two (11.76%) had children. Three (17.64%) had previous experience in the Southern and Antarctic Lands. Upon return, five (29.41%) reported that they encountered major stressful events during the mission.

Table 1 reports sociodemographic characteristics.

2.2. Data collection

2.2.1. Subjective measurements

Sociodemography. A 20-item sociodemographic questionnaire was developed to collect general information on the participant's family situation, medical history, current health status, hobbies, and familiarity with extreme environments.

Health. The 12-item GHQ evaluates psychological and psychotic disorders in the general population [63]. Cronbach's alpha was acceptable, with scores between 0.571 and 0.914 for all measurement times. The 10-item Leeds Sleep Evaluation questionnaire (LEEDS) evaluates perceived sleep changes, as a function of four sub-factors: getting to sleep (Cronbach's alpha between .147 and .701 for all measurement times), sleep quality (Cronbach's alpha between .378 and .855 for all measurement times), awake following sleep (Cronbach's alpha between .543 and .891 for all measurement times), and performance following wakening (Cronbach's alpha between .573 and .954 for all measurement times) [64]. We added two questions concerning sleep time and time to get-up. Four additional Visual Analogue Scales (VAS) were added from the Buguet sleep questionnaire to evaluate the individual's overall status after sleep: desire to work; physical shape; morale; and mood [65]. These four scales were considered to be an indicator of the individual's perception of their energy level. Physical activity was assessed monthly using a bespoke questionnaire (type of activity, intensity, duration).

Psychology. The 14-item Freiburg Mindfulness Inventory (FMI) evaluates mindfulness disposition [66]. The scale is divided into two sub-factors that measure presence (Cronbach's alpha between .662 and .821 for all measurement times) and non-judgmental acceptance

Table 1
Socio-demographic characteristics of participants.

Measurements	Data[a]
N	17
M age	31.73 ± 10.56
M height	174.95 ± 6.36
M weight	73.82 ± 10.81
Gender (women/men)	11.76%/88.23%
Single	76.47%
In couple/with children	23.52%/11.76%
Contraception	50.00%
Major stressful events during wintering	29.41%
Previous experience in Southern and Antarctic Lands	17.64%

[a] Mean and standard deviation are reported when relevant. Other figures show the ratio of the number of subjects.

(Cronbach's alpha between .370 and .805 for all measurement times).

The 32-item Multidimensional Assessment of Interoceptive Awareness (MAIA) evaluates interoceptive awareness [67]. The scale is divided into eight sub-factors that measure awareness of uncomfortable, comfortable, and neutral body sensations, the response to sensations of pain and discomfort, the ability to regulate attention to body sensations, and awareness of mind-body integration. It is divided into noticing (Cronbach's alpha between .428 and .796 for all measurement times), not-distracting (Cronbach's alpha between .324 and .705 for all measurement times), not-worrying (Cronbach's alpha between .521 and .902 for all measurement times), attention regulation (Cronbach's alpha between .792 and .898 for all measurement times), emotional awareness (Cronbach's alpha between .733 and .916 for all measurement times), self-regulation (Cronbach's alpha between .750 and .897 for all measurement times), body listening (Cronbach's alpha between .739 and .892 for all measurement times), and trusting (Cronbach's alpha between .914 and .968 for all measurement times).

The 12-item Scale of Positive and Negative Experience (SPANE) assesses subjective feelings of positive and negative affect, based on how frequently they are felt over the previous four weeks [68]. The scale is divided into two-subfactors that measure positive (Cronbach's alpha between .844 and .935 for all measurement times) and negative affect (Cronbach's alpha between .828 and .917 for all measurement times).

The 28-item Activation-Deactivation Adjective Checklist (ADAC) evaluates the level of awareness and emotional disposition [69]. The scale is divided into two sub-factors: Energetic Arousal (EA, from energy to tiredness) and Tense Arousal (TA, from tension to calmness). EA is further divided into two subscales: general activation (Cronbach's alpha between .695 and .971 for all measurement times) and deactivation (Cronbach's alpha between .401 and .887 for all measurement times). TA is subdivided into general tenseness (Cronbach's alpha between .506 and .913 for all measurement times) and calmness (Cronbach's alpha between .702 and .845 for all measurement times).

The 14-item Perceived Stress Scale (PSS) assesses subjective stress [70]. Cronbach's alpha was good, with scores between 0.764 and 0.882 for all measurement times.

The experience of flow was assessed using the 12-item Educational Flow Questionnaire 2 (EduFlow2) [71]. The scale is divided into four dimensions: cognitive control (Cronbach's alpha between .715 and .879 for all measurement times); immersion and time transformation (Cronbach's alpha between .746 and .909 for all measurement times); loss of self-consciousness (Cronbach's alpha between .867 and .976 for all measurement times); and autotelic experience (Cronbach's alpha between .873 and .949 for all measurement times). Cognitive absorption (the sum of the first three dimensions) was added as a fourth scale.

The Standard Model of Military Group Cohesion (SMMGC) evaluates social cohesion in groups of military personnel [72]. The scale is divided into two dimensions: horizontal (Cronbach's alpha between .865 and .959 for all measurement times) and vertical (Cronbach's alpha between .857 and .935 for all measurement times).

Extrasensors. We also developed three, bespoke questionnaires. The 1-item Personal Hierarchical Sensory (PHS) questionnaire assesses subjective perceptions of vision, sound, touch, olfaction, taste, and equilibrium, and the 6-item Sensory Acuity (SA) questionnaire measures subjective exteroceptive acuity for each of the same six extrasensors. The 6-item Appetite (A) questionnaire evaluates several aspects of appetite: level, satiety, taste of food, hunger at the beginning of meals, hunger outside meals, and number of meals per day.

2.2.2. *Exteroceptive measurements*

Olfaction. The European Test of Olfactory Capabilities (ETOC) assesses olfactory sensitivity. There are 16 sets of four bottles, and individuals are asked to identify bottles that contain an odor (a discrimination task), and state the nature of this odor (an identification task). In our experiment, participants were also asked to evaluate the hedonic value of the detected odor.

Hearing. Pure Tone Testing (PTT) is commonly used to test hearing sensitivity in patients, using the Electonica Auditest CE system that enables air conduction measurements. In subjects with normal hearing, it is evaluated using pulsed tones at frequencies of 125 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 6000 Hz and 8000 Hz, until the individual reports hearing the lowest frequency. The instructions that are given to subjects are determinant in the type and quality of the response. In our study, all volunteers were placed in the same quiet room and told: "You will hear sounds at different frequencies. Please raise your hand when you hear a sound. The aim of the test is to identify your hearing sensitivity, and not to distinguish if the sound is loud or weak". Each stimulus was presented for approximately 2 s, with an interval of approximately 1 s between each presentation, until the subject reported discomfort.

Vision. The Parinaud scale (the French equivalent to the Jaeger chart) measures the natural accommodation distance (from the tip of the nose to the reading surface, measured with a tape measure), in other words, the distance at which the subject holds a text to read it comfortably. Paragraphs of text are presented in decreasing font size. The recommended reading distance to test visual acuity is 33 cm, with a tolerance of 30–35 cm. Luminance was controlled with a luxmeter to ensure that the lighting environment was the same for all subjects.

Taste. Burghart Taste Strips measure an individual's taste abilities. The kit is composed of 16 containers with four concentrations of sweet, salt, sour, and bitter, and three containers that contain blank strips. The subject is asked to place a strip on the tip of the tongue, and indicate whether the identified taste is sweet, salt, sour, bitter, or neutral. Thus, the test evaluates both the taste detection threshold, and the identification of flavors.

2.2.3. *HRV*

An electrocardiogram (ECG) was recorded for a 10-min period to extract heartbeat interval (RR) data. Subjects were in a sitting position, and a Kino® wearable cardiac monitoring device (Heartkinetics, Belgium) was used, at a sampling frequency of 500 Hz. Data were stored on a SD card and analyzed offline. The HRV analysis followed guidelines reported in Refs. [73,74], which take into account potential circadian variation, and used the *PyHRV* python library [75].

The following data were also recorded: weight; height; waist-to-hip ratio; smoking habits; most recent alcohol intake (>24 h); most recent caffeinated (coffee/tea) intake (>1 h); most recent meal (>2 h); most recent physical activity (>12 h); and quality of sleep on the day of the experiment and the preceding day.

Raw ECG data were filtered using a bandpass filter (0.5–80 Hz). The order of the filter was set at 54 (0.3 times the sampling frequency). R peaks were automatically detected using the *BioSPPy* Python library [76]. A Hamilton segmentation was performed on the filtered signal, followed by R-peak correction with tolerance set to 0.05. R-waves were manually examined to ensure correct detection. If an ECG sequence was overly noisy when visualizing the superposition of all QRS complex, the time interval was manually removed to improve data quality. RR intervals were automatically detected with the *hrvanalysis* module using linear interpolation, and manually corrected for artifacts and ectopic beats.

Time domain analysis. Time domain HRV metrics included mean RR (the mean interbeat interval), SDNN (Standard Deviation of the Normal-to-Normal RR interval), RMSSD (Root Mean Square of Successive Differences between adjacent RR intervals), and pNN50 (percentage of adjacent NN intervals that differ from each other by more than 50 ms).

Frequency domain analysis. Frequency domain HRV metrics complemented time domain metrics, and included oscillatory components of heart rate dynamics. Spectral density was estimated using Welch's method: low frequencies (LF, sympathetic and parasympathetic activity) in the range 0.04–0.15 Hz; high frequencies (HF, parasympathetic activity) in the range 0.15–0.4 Hz; and the LF/HF ratio as absolute power (ms^2).

Nonlinear analysis. Nonlinear HRV metrics reflect dynamic and chaotic internal states that other metrics cannot capture. The following, most representative metrics were used: SD1 (the standard deviation of instantaneous interbeat interval variability), SD2 (the standard deviation of continuous, long-term RR variability) extracted from the Poincaré plot (a graphical representation of the correlation between successive interbeat intervals), α1 (a detrended fluctuation analysis of the self-similarity parameter that represents short-term fluctuations), α2 (a detrended fluctuation analysis of the self-similarity parameter that represents long-term fluctuations), and sample entropy (the regularity and complexity of the time series).

2.3. Experimental procedure

This prospective cohort exploratory study (ID-RCB: 2017-A01329-44) was approved by the Committee for the Protection of Individuals (CPP Sud-Est VI, Clermont-Ferrand, France), and was conducted according to the standards given in the Declaration of Helsinki. After comprehensive verbal and written presentations, all participants gave their written consent to participate.

The experiment was conducted during the 2021–2022 overwintering season at the Dumont d'Urville station (DDU). DDU is a French polar station located on the coast of Adélie Land, in the East of Antarctica facing Tasmania (66°39′S–140°0′E). The climate was mild, with an annual mean temperature of −10.4 °C, and records of −31.1 °C in June and 5.2 °C in December. There were 369.1 h of sunshine in January, and 9 h in June. Due to the climate, DDU is only accessible between October and March, using the Astrolabe ice-breaker. Thus, the station is isolated from the rest of the world for approximately seven months each year.

Psychological, physiological, and exteroceptive responses were evaluated at different times over the one-year mission. Measures were performed by the station's medical doctor during the wintering period. Baseline psychological assessments were run on the day of arrival at the station (M0). During wintering, all measures were recorded at months 4, 7, 10 and 12 (M4, M7, M10, and M12). Recovery assessments took place two days after the return from DDU (D+2) on eight participants (this was because winterers did not return to the continent on the same rotation). Psychological data were assessed at M0, M4, M7, M10, and D+2. Physiological and exteroceptive data were assessed at M4, M7, M12, and D+2. No pre-mission baseline measurements were recorded due to Covid-19 sanitary restrictions applied by the Institute Paul-Émile Victor. Recovery data were only recorded at D+2 as subjects ended their contract with the Institute at that time.

Fig. 1 summarizes the experimental design of the study at DDU.

2.4. Statistical methods

Statistics are computed for all outcome measures. Data analyses are performed with JASP (Amsterdam, version 0.16.3), an open-source software package that is used for both classical and Bayesian analyses. Descriptive statistics are expressed as mean ± SD. The Shapiro–Wilk test is used to determine whether data are normally distributed. When the analysis is significant, effect sizes are reported. Psychological adaptability is evaluated using the GHQ score, notably our hypothesis that groups could be distinguished based on their score on the GHQ scale. Thus, the median GHQ score is used as a threshold to separate the overall population into two profiles: the Higher than Normal (HN) profile is characterized by a lower GHQ score (very limited or no evidence of minor non-psychiatric or psychotic disorders), and the Ordinary (OR) profile is characterized by a standard GHQ score (standard values for non-psychiatric or minor psychotic disorders within the general population) at baseline.

Psychological, physiological, and exteroceptive responses are

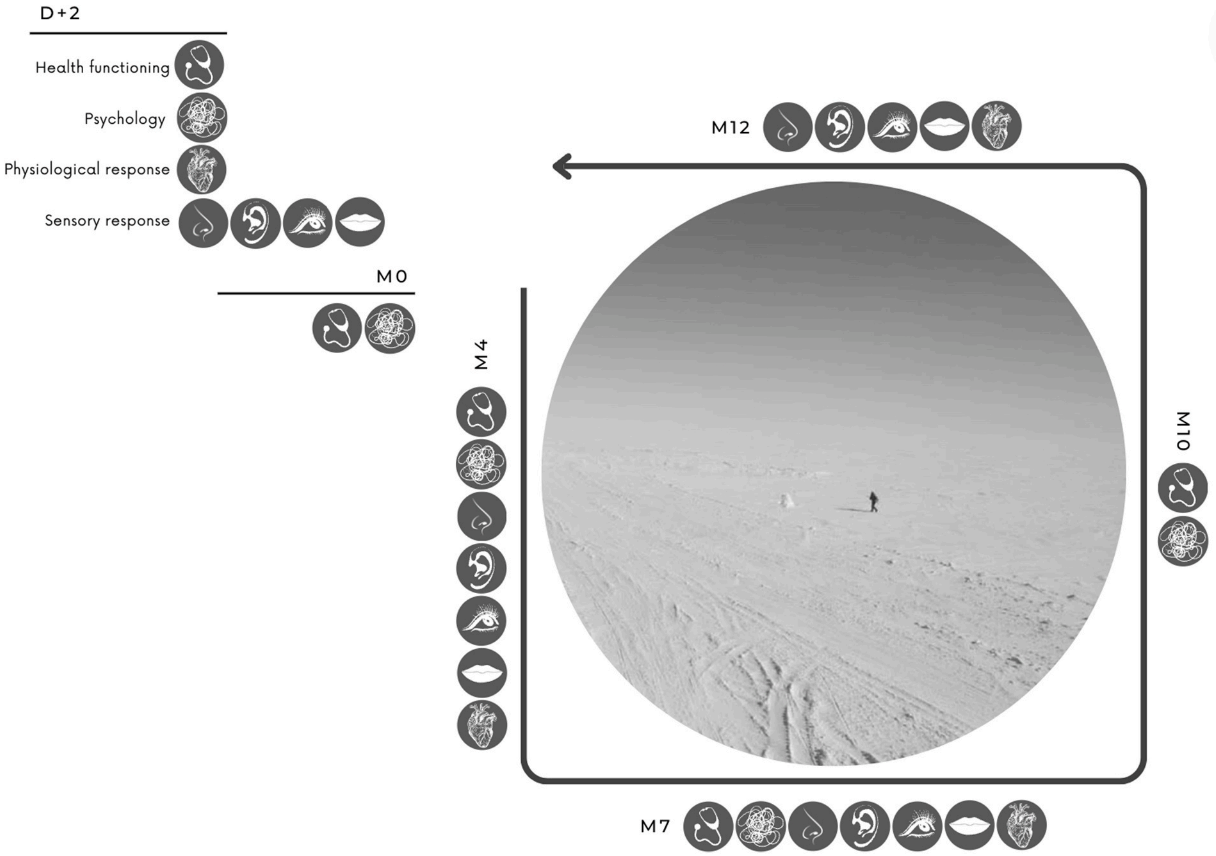

Fig. 1. Timeline of the one-year experimental evaluation of health adaptation. M0: Month 0; M4: Month 4; M7: Month 7; M10: Month 10; M12: Month 12; D+2: two days after the return from the polar station.

evaluated using repeated-measures ANOVA of data recorded at M0 to M12, and D+2. Holm *post hoc* analyses are performed when the *p*-value is significant. Bayesian analyses are performed by applying equivalent analyses for repeated-measures ANOVA. The Bayesian Factor (BF) is calculated if no significant effect is detected. A low value is understood as supporting the null hypothesis, and a high value indicates evidence in favor of the alternative hypothesis (BFs are presented in the Supplementary Material, and do not include recovery measures). For all analyses, statistical significance is set at $p < .05$. A *p*-value between .05 and .07 is considered as evidence of a trend. Only significant or trend results are presented.

3. Results

Baseline measurements from the day of arrival at the station (M0) are presented for the two groups of participants (OR and HN) in Table 2. Overall, no inter-group differences are found for psychological, physiological, and sensory measurements, apart from: subjective stress ($p = .023$), calmness ($p = .035$), loss of self-consciousness of flow ($p = .059$), cognitive absorption of flow ($p = .045$), and performance following wakening ($p < .001$). GHQ scores for our participants range from 3 to 14 (8.44 ± 3.32), and the two groups are distinguished based on the median for the general population (8.00).

3.1. Health and psychological changes as a function of the GHQ profile

Mindfulness disposition. The analysis found a significant effect of group on acceptation [F (1,15) = 7.599, $p = .015$, $\eta^2 = 0.166$]. Acceptation is lower among participants with an OR profile than those with a HN profile.

Affect. There is a significant effect of group [F (1,15) = 19.484, $p < .001$, $\eta^2 = 0.277$] and a trend over time [F (3,45) = 2.648, $p = .060$, $\eta^2 = 0.074$] for negative affect. Negative affect is higher among the OR group than the HN group. *Post hoc* analyses found that winterers tend to have less negative affect at M7 compared to baseline ($p = .072$).

Thymia. There is a significant effect of time for tiredness [F (3,45) = 2.695, $p = .057$, $\eta^2 = 0.063$], and group effects for tension [F (1,15) = 40.147, $p < .001$, $\eta^2 = 0.324$] and calmness [F (1,15) = 8.426, $p = .011$, $\eta^2 = 0.324$]. *Post hoc* analyses found that tiredness increased at M10 compared to baseline ($p = .041$). Moreover, tension was higher, and calmness was lower, among the OR group compared to the HN group.

Sleep quality. There is a significant effect of time [F (3,45) = 4.175, $p = .011$, $\eta^2 = 0.159$] on time to get-up, together with a time*group effect [F (3,45) = 2.775, $p = .052$, $\eta^2 = 0.045$], and a group effect [F (1,15) = 8.222, $p = .012$, $\eta^2 = 0.173$] on performance following wakening. *Post hoc* analyses show that winterers get up earlier at M10 ($p = .024$) compared to M7. Those with an OR profile rate their performance following wakening as worse at M4 ($p = .030$) and M10 ($p = .013$) compared to those with an HN profile, and at M10 compared to M4 ($p =$

Table 2
Health & psychological measures during wintering.

	Baseline		Month 4		Month 7		Month 10		p-value*
	OR	HN	OR	HN	OR	HN	OR	HN	
GHQ									
Hc	6.250 ± 1.961	11.571 ± 2.070	6.700 ± 3.561	12.143 ± 7.537	8.900 ± 3.178	10.429 ± 5.255	8.200 ± 2.898	11.143 ± 2.854	<.001
FMI									
Ac	25.400 ± 2.591	23.286 ± 3.147	25.100 ± 3.281	20.429 ± 4.117	24.256 ± 3.217	22.286 ± 2.928	23.400 ± 1.955	21.143 ± 3.436	.015
SPANE									
Nc	1.967 ± .874	2.381 ± 1.145	1.467 ± .429	2.405 ± .526	1.650 ± .461	2.073 ± .470	1.700 ± .375	2.405 ± .607	.003
AD-ACL									
Tia	2.100 ± 1.197	3.527 ± 2.242	1.500 ± 1.716	6.000 ± 3.830	3.000 ± 2.981	4.857 ± 2.734	3.400 ± 1.897	6.429 ± 3.867	.057
Tec	.900 ± 1.101	2.661 ± 2.239	.200 ± .422	3.286 ± 3.546	.000 ± .000	2.571 ± 2.820	.463 ± .958	2.857 ± 2.116	<.001
Cc	11.100 ± 2.132	8.580 ± 2.306	10.200 ± 2.251	7.286 ± 3.039	10.800 ± 1.317	8.429 ± 2.760	9.100 ± 2.331	7.429 ± 2.699	.011
LEEDS									
Tga	7.600 ± 2.119	2.045 ± 2.379	6.700 ± 2.710	.857 ± 4.947	3.500 ± 5.563	3.714 ± 2.690	4.000 ± 4.667	.286 ± 4.680	.011
Pb,c	−.600 ± 1.713	.402 ± 1.148	.800 ± 1.476	1.143 ± 1.464	.500 ± 1.434	2.000 ± 2.708	−.500 ± 1.581	−.571 ± 1.988	.052
BUGUET									
Da	.000 ± .000	.455 ± .773	.600 ± 1.075	1.857 ± 1.952	1.100 ± 1.197	1.143 ± 1.773	1.000 ± 1.491	2.000 ± 1.291	.009
Mfc	4.900 ± .994	4.536 ± 1.262	5.200 ± .789	3.857 ± 1.574	4.900 ± 1.101	4.429 ± 1.512	5.000 ± 1.054	3.571 ± 1.718	.025
Ma,c	5.500 ± .707	5.196 ± .692	5.200 ± .919	4.429 ± .976	5.100 ± .994	4.286 ± 1.254	5.100 ± 1.101	3.571 ± 1.618	.004
PSS									
Sc	11.700 ± 4.832	18.196 ± 5.714	9.400 ± 4.477	20.571 ± 9.199	10.512 ± 6.525	18.143 ± 6.986	11.900 ± 5.547	21.857 ± 6.203	<.001
SIEBOLD									
TCa	15.287 ± 2.671	14.267 ± 3.143	17.000 ± 2.404	17.143 ± 3.185	16.300 ± 2.869	16.857 ± 3.288	15.188 ± 2.430	13.714 ± 4.645	.015
PHS									
Va	8.000 ± 2.309	8.304 ± 1.250	1.400 ± .699	1.857 ± 1.464	1.100 ± .316	1.571 ± 1.134	1.444 ± .956	1.429 ± 1.134	<.001
SA									
Va	9.000 ± 1.054	9.000 ± .816	8.300 ± 1.059	8.714 ± 1.254	8.600 ± 1.776	7.857 ± 2.410	8.500 ± 1.581	7.571 ± 2.440	.059
Ha	8.300 ± 1.252	8.482 ± .502	7.700 ± 1.703	8.000 ± .816	7.200 ± 1.989	7.857 ± 1.952	7.000 ± 1.886	6.857 ± 2.116	.010
Taa	7.100 ± 2.378	8.375 ± 1.013	6.300 ± 2.263	7.571 ± 1.718	6.000 ± 1.826	6.857 ± 1.676	5.900 ± 2.183	6.286 ± 1.380	.026
A									
LA	3.991 ± .578	3.900 ± .876	4.143 ± .690	3.700 ± .675	4.143 ± .690	3.700 ± .675	3.286 ± .488	3.000 ± 1.247	<.001
TF	4.161 ± .373	4.100 ± .373	4.714 ± .488	3.800 ± .632	4.714 ± .488	3.800 ± .632	3.571 ± 1.272	3.200 ± .789	<.001
MD	3.835 ± .687	3.850 ± .747	4.000 ± .816	3.600 ± .699	4.000 ± .816	3.600 ± .699	3.286 ± .488	3.300 ± .675	.001

Note. OR = standard values for non-psychiatric or minor psychotic disorders within the general population; HN = very limited or no existence of minor non-psychiatric or psychotic disorders; H = health; A = acceptation; N = negative emotions; Ti = tiredness; Te = tension; C = calmness; Tg = time to get-up; P = performance following wakening; D = desire to work; Mf = moral feeling; M = mood; S = subjective stress; TC = team cohesion towards leader; V = vision; H = hearing; Ta = taste; LA = level of appetite; TF = taste of food; MD = meals per day.

*p-value used in the analysis of effects. Means and standard deviations are shown for each variable. All variables were recorded at four times, apart from proprioception where baseline and recovery were collected. Only significant interactions were reported ($p < .05$).

a Significant effect of time.

b Significant effect of time*group.

c Significant effect of group.

.047). Moreover, those with an OR profile rate their performance following wakening as worse than those with an HN profile.

Perceptions of energy. There is a significant effect of time for desire to work [F (3,45) = 4.381, $p = .009$, $\eta^2 = 0.120$], and mood [F (3,45) = 5.071, $p = .004$, $\eta^2 = 0.097$], and a significant effect of group for morale [F (1,15) = 6.231, $p = .025$, $\eta^2 = 0.121$], and mood [F (1,15) = 4.519, $p = .051$, $\eta^2 = 0.134$]. *Post hoc* analyses found that winterers had a greater desire to work at M10 compared to M4 ($p = .008$), and a decrease in mood at M10 compared to baseline ($p = .002$). Moreover, those with an OR profile have poorer morale and mood than those with an HN profile.

Subjective stress. There is a significant effect of group [F (1,15) = 23.22.459, $p < .001$, $\eta^2 = 0.348$] on stress perception. Winterers with an OR profile perceive higher subjective stress than those with an HN profile.

Team cohesion. There is a significant effect of time regarding interactions with the leader [F (3,45) = 3.877, $p = .015$, $\eta^2 = 0.005$]. *Post hoc* analyses reveal poorer leader/subordinate relationships at M10 compared to M4 ($p = .044$).

Sensory evaluation. There is a significant effect of time on preference for vision [F (3,45) = 121.390, $p < .001$, $\eta^2 = 0.064$]. *Post hoc* analyses reveal that the preference for vision compared to the other senses fell at M4 ($p < .001$), M7 ($p < .001$), and M10 ($p < .001$) compared to baseline.

Subjective exteroceptive acuity. There is a significant effect of time on vision [F (3,45) = 2.670, $p = .059$, $\eta^2 = 0.051$], hearing [F (3,45) = 4.266, $p = .010$, $\eta^2 = 0.101$], and taste [F (3,45) = 3.385, $p = .026$, $\eta^2 = 0.096$]. *Post hoc* analyses show that winterers lose confidence in their ability to hear (p=.010), and taste ($p = .027$), and there is a trend for vision ($p = .065$) at M10 compared to baseline.

Appetite. There is a significant effect of time on the level of appetite [F (3,45) = 8.331, $p < .001$, $\eta^2 = 0.160$], taste of food [F (3,45) = 8.364, $p < .001$, $\eta^2 = 0.200$], and number of meals per day [F (3,45) = 1.384, $p = .001$, $\eta^2 = 0.097$], and a significant effect of group on taste of food [F (1,15) = 6.828, $p = .020$, $\eta^2 = 0.122$]. *Post hoc* analyses show that at M10, the level of appetite fell compared to baseline ($p < .001$), M4 ($p = .001$), and M7 ($p = .001$). Scores for the taste of food fall compared to baseline ($p = .003$), M4 ($p < .001$) and M7 ($p < .001$), and there is a decrease in the number of meals per day compared to baseline ($p = .003$), M4 ($p = .006$), and M7 ($p = .006$). Scores for taste of food are higher among participants with an OR profile compared to those with an HN profile.

A summary of these psychological differences during wintering is presented in Table 2.

Fig. 2 shows inter-group differences in acceptation (a facet of mindfulness). Fig. 3 shows differences associated with thymic functioning. Fig. 4 shows inter-group differences related to other psychological factors.

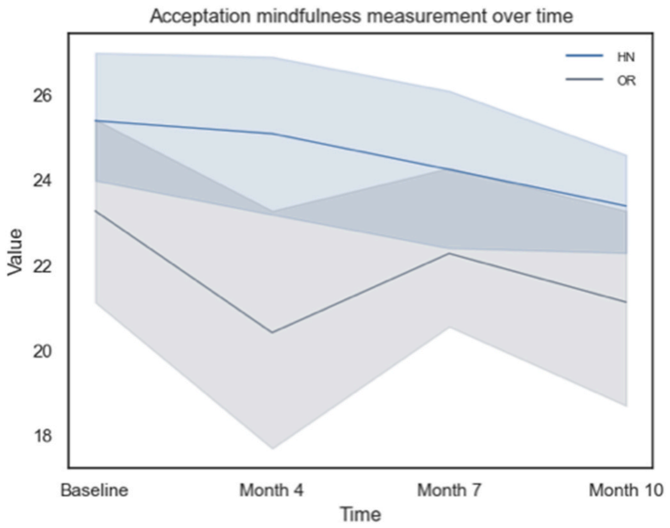

Fig. 2. Inter-group differences in acceptation (a facet of mindfulness) during the one-year mission in Antarctica.

3.2. Physiological and exteroceptive changes as a function of group profile

HRV. There is a significant effect of time for the RR interval [F (3,30) = 5.316, $p = .011$, $\eta^2 = 0.291$]. *Post hoc* analyses show that RR intervals are higher at M7 compared to M12 ($p = .009$).

Olfaction. There is a significant effect of group for hedonic value [F (1,15) = 12.567, $p = .003$, $\eta^2 = 0.350$]. Participants with an OR profile score higher for hedonic value than those with an HN profile.

PTT. Significant differences are found for both ears. For the right ear, there is a significant effect of time at 125 Hz [F (2,30) = 3.806, $p = .034$, $\eta^2 = 0.055$], 1000 Hz [F (2,30) = 3.864, $p = .032$, $\eta^2 = 0.083$], and 4000 Hz [F (2,30) = 5.041, $p = .013$, $\eta^2 = 0.083$]. At 125 Hz, there is a significant effect of group for both the right [F (1,15) = 7.805, $p = .014$, $\eta^2 = 0.292$], and the left ear [F (1,15) = 6.047, $p = .027$, $\eta^2 = 0.202$]. *Post hoc* analyses show that winterers have better sensitivity at 125 Hz at M12 compared to M7 ($p = .049$), with a trend at M4 ($p = .072$), and at 4000 Hz at M12 compared to M4 ($p = .011$). There is also evidence of a trend, with an increase in sensitivity at 1000 Hz at M12 compared to M4 ($p = .066$) and M7 ($p = .066$). For both right and left ears, participants with an OR profile have higher sensitivity at 125 Hz than those with an HN profile.

Vision. There is a significant effect of time for distant focus [F (3,45) = 12.682, $p < .001$, $\eta^2 = 0.181$]. *Post hoc* analyses show that the distant focus distance increases ($p < .001$) at M7 compared to M4.

Taste. There is a significant group effect for taste [F (1,15) = 9.072, $p = .009$, $\eta^2 = 0.155$]. Participants with an OR profile have poorer taste abilities than those with an HN profile.

Table 3 presents a summary of these physiological and exteroceptive differences during the mission. Fig. 5 shows exteroceptive differences between profiles.

3.3. Measures at recovery (D+2) as a function of group

Interoception. There is a significant effect of time for noticing [F (4,24) = 3.695, $p = .018$, $\eta^2 = 0.119$], and trends for self-regulation [F (4,24) = 3.196, $p = .031$, $\eta^2 = 0.079$] and attention regulation [F (4,24) = 2.536, $p = .066$, $\eta^2 = 0.286$]. The analysis found a time*group trend for self-regulation [F (4,24) = 3.308, $p = .027$, $\eta^2 = 0.081$]. *Post hoc* analyses show that at D+2, winterers have a decrease in their awareness of uncomfortable, comfortable, and neutral body sensations compared to baseline ($p = .012$), their ability to maintain and control attention to body sensations compared to M7 ($p = .059$), and tend to regulate psychological distress by paying attention to body sensations compared to M10 ($p = .064$). Moreover, participants with an OR profile tend to have a decrease in their ability to regulate psychological distress by paying attention to body sensations at D+2 compared to M10 ($p = .063$).

Perception of energy. There is a significant effect of time on the desire to work [F (4,24) = 6.888, $p < .001$, $\eta^2 = 0.304$], morale [F (4,24) = 6.430, $p = .001$, $\eta^2 = 0.412$], and mood [F (4,24) = 11.728, $p < .001$, $\eta^2 = 0.451$]. *Post hoc* analyses show that at D+2, winterers have: an increased desire to work compared to baseline ($p < .001$), M4 ($p = .010$), M7 ($p = .003$), and M10 ($p = .010$); improved mood compared to baseline ($p = .008$), M4 ($p < .001$), M7 ($p = .001$), and M10 ($p < .001$); and poorer morale compared to baseline ($p = .004$), M4 ($p = .030$), M7 ($p = .001$), and M10 ($p = .053$).

Flow. There is a significant effect of time [F (4,24) = 5.385, $p = .003$, $\eta^2 = 0.113$] and a time*group effect [F (4,24) = 3.373, $p = .025$, $\eta^2 = 0.071$] for loss of self-consciousness. *Post hoc* analyses show that winterers have a decrease in their ability to be absorbed by an activity at D+2 compared to baseline ($p = .022$). Moreover, the loss of self-consciousness is lower among those with an OR profile at baseline ($p = .003$), M4 ($p = .015$), M7 ($p = .013$), and M10 ($p = .027$) compared to

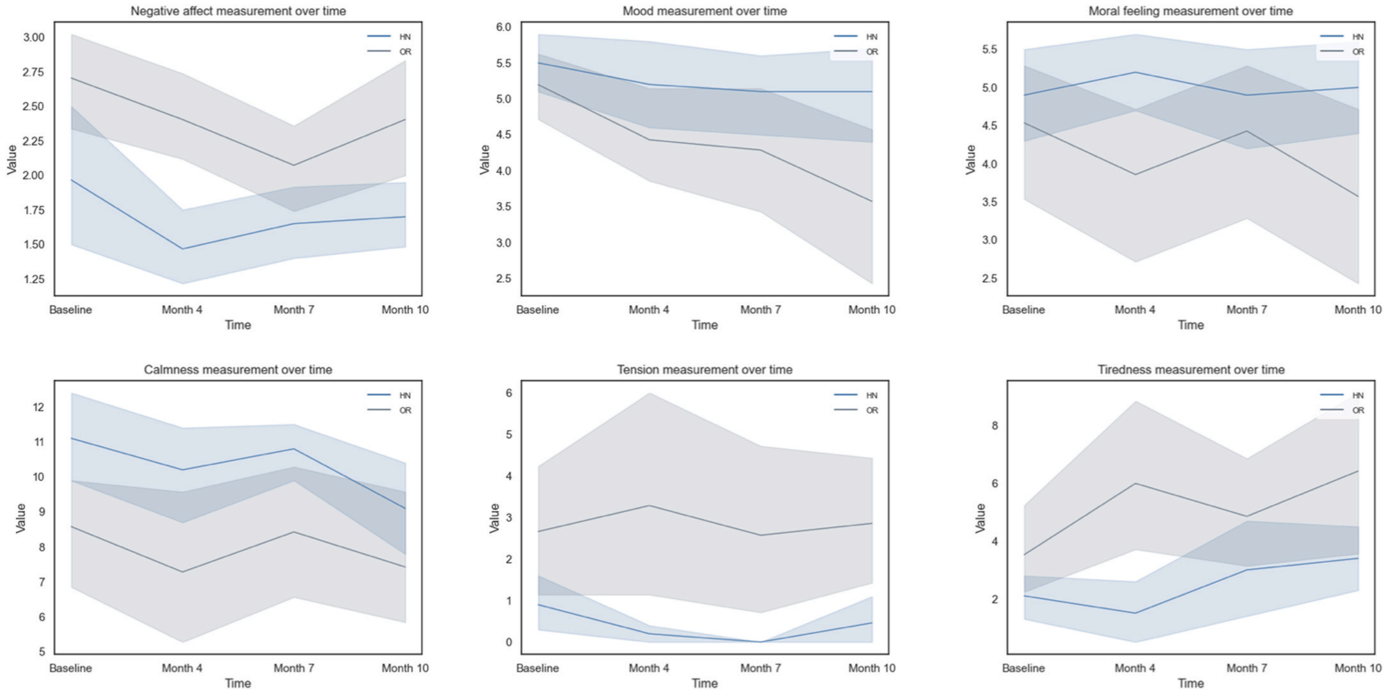

Fig. 3. Inter-group differences in thymic functioning during the one-year mission in Antarctica.

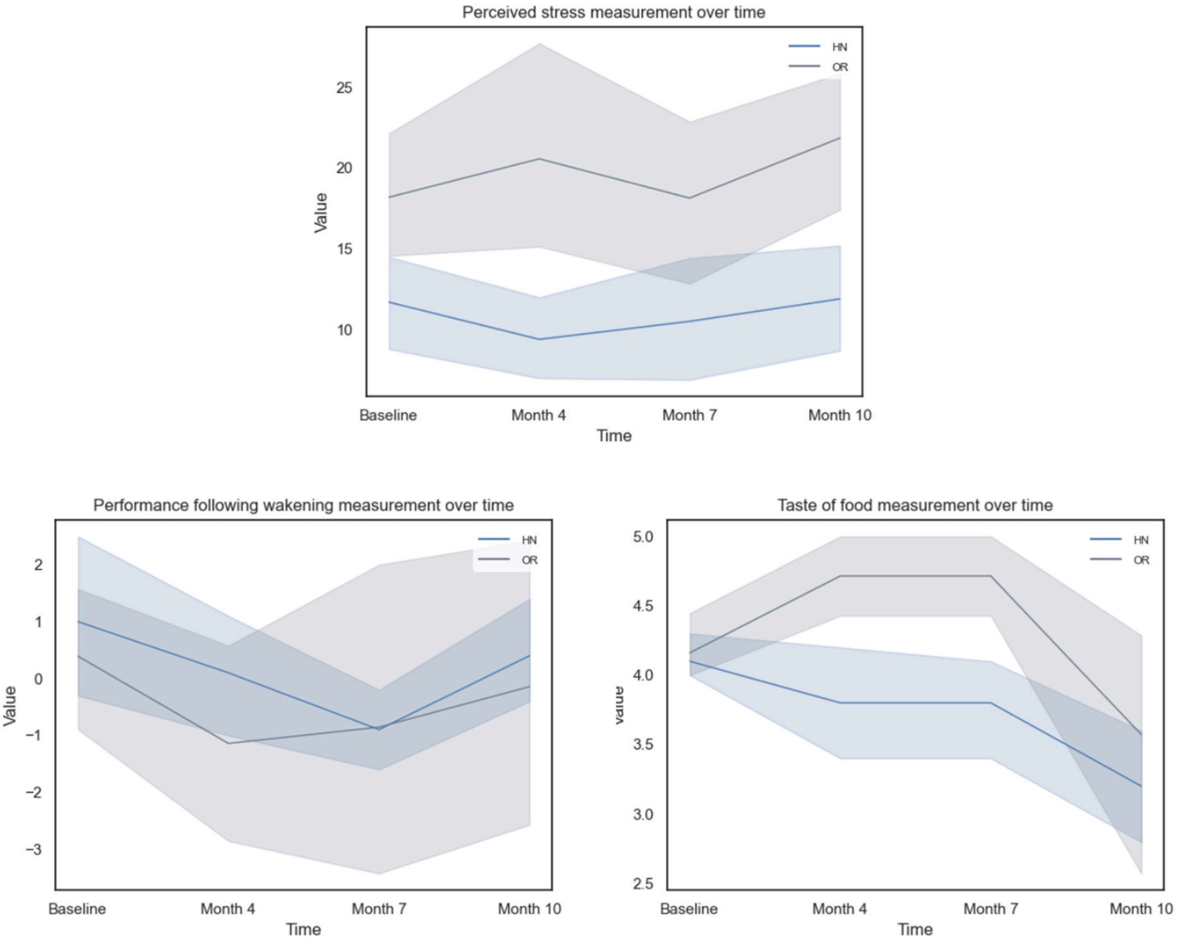

Fig. 4. Inter-group differences in other psychological factors during the one-year mission in Antarctica.

Table 3
Exteroceptive measures recorded during wintering.

	Month 4		Month 7		Month 10		*p*-value*
	OR	HN	OR	HN	OR	HN	
HRV							
NNI[a]	−4.000 ± 5.676	7.857 ± 15.774	−2.500 ± 7.546	12.143 ± 17.043	−5.500 ± 4.378	10.000 ± 16.073	.011
PTT							
125 Hz LE[a,c]	−4.000 ± 5.676	7.857 ± 15.774	−2.500 ± 7.546	12.143 ± 17.043	−5.500 ± 4.378	10.000 ± 16.073	.034
1000 Hz LE[a]	2.500 ± 9.789	6.429 ± 6.268	1.500 ± 11.559	7.143 ± 6.362	1.500 ± 11.559	2.857 ± 4.880	.032
4000 Hz LE[a]	3.000 ± 11.595	.000 ± 7.638	.000 ± 12.019	−4.286 ± 7.319	.500 ± 14.034	−2.857 ± 9.063	.013
125 Hz RE[c]	−2.500 ± 5.893	6.429 ± 15.999	−4.500 ± 7.619	10.000 ± 13.540	−6.000 ± 6.583	.000 ± 7.638	.027
PARINAUD							
Df[a]	85.900 ± 9.219	80.429 ± 21.298	98.000 ± 11.441	100.429 ± 14.797	87.300 ± 14.024	94.000 ± 16.042	<.001
Taste							
T[a]	12.900 ± 1.729	11.000 ± 3.416	13.900 ± 2.998	9.286 ± 4.461	13.100 ± 2.644	11.714 ± 3.546	.009

Note. OR = standard values for non-psychiatric or minor psychotic disorders within the general population; HN = very limited or no existence of minor non-psychiatric or psychotic disorders; NNI = mean of successive RR intervals; Df = distant focus; T = taste; LE = left ear; RE = right ear.

* *p*-value used in the analysis of effects. Means and standard deviations are shown for each variable. All variables were recorded at four times, apart from proprioception where baseline and recovery data were collected. Only significant interactions are reported ($p < .05$).

[a] Significant effect of time.

[b] Significant effect of time*group.

c Significant effect of group.

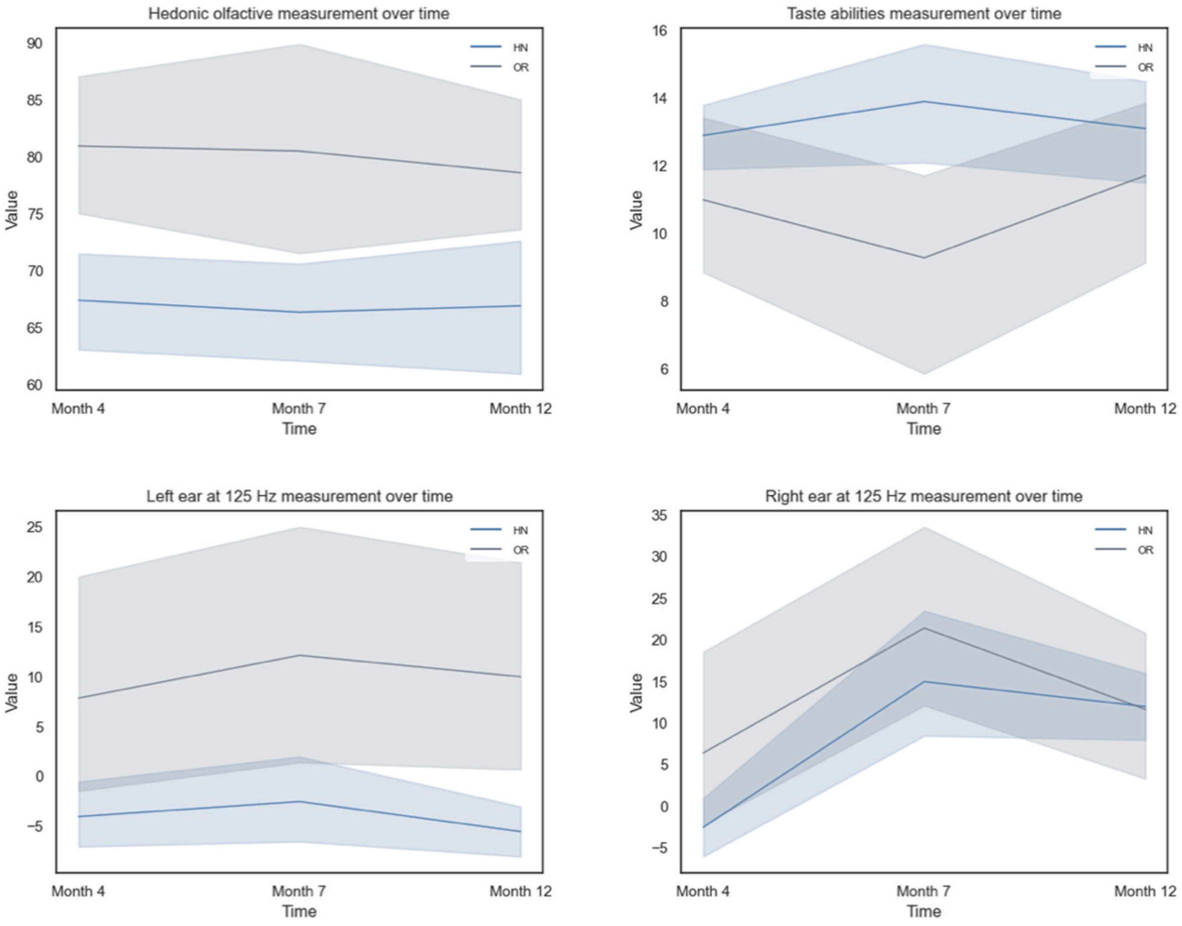

Fig. 5. Inter-group differences in exteroceptive measures during the one-year mission in Antarctica.

those with an HN profile at D+2. They also have less loss of self-consciousness at D+2 compared to those with an OR profile at M7 ($p = .016$) and M10 ($p = .004$). At D+2, winterers with an OR profile have a greater loss of self-consciousness compared to those with an HN profile ($p = .003$). Finally, the HN profile group has a greater loss of self-consciousness at D+2 compared to baseline ($p = .009$).

Sensory evaluation. There is a significant effect of time on vision [F (4,24) = 3.577, $p = .020$, $\eta^2 = 0.031$]. *Post hoc* analyses reveal that winterers decrease their subjective preference for vision compared to the other senses at D+2 compared to M4 ($p = .020$).

Appetite. There is a significant effect of time on taste of food [F (4,24) = 7.264, $p < .001$, $\eta^2 = 0.409$]. *Post hoc* analyses reveal that winterers have a decrease in the subjective taste of food at D+2 compared to M4 ($p = .019$).

HRV. There is a significant effect of time for the RR interval [F (3,18) = 3.013, *p* = .057, η^2 = 0.225]. *Post hoc* analyses show that winterers have lower RR intervals at D+2 compared to M7 (*p* = .051).

Olfaction. There is a significant effect of time for detection [F (3,18) = 6.687, *p* = .003, η^2 = 0.416]. *Post hoc* analyses show that winterers have a decrease in their ability to detect odors at D+2 compared to M4 (*p* = .007), M7 (*p* = .007) and M12 (*p* = .036).

Vision. There is a significant effect of time for distant focus [F (3,18) = 5.584, *p* = .007, η^2 = 0.358]. *Post hoc* analyses show that winterers have a longer focal distance at M7 compared to D+2 (*p* = .026).

Table 4 reports a summary of the recovery measures recorded at D+2.

4. Discussion

Antarctica is one of the most inhospitable locations on Earth, but it is also one of the most exciting places to live and work. Since the first expeditions, scientific studies have reported on the challenges of living at remote polar stations. For years, research has focused on understanding the psychophysiological and cognitive impacts of wintering [3,4,20]. More recently, a new dynamic has emerged, which acknowledges the salutogenic effects of the environment. A one-year mission in Antarctica is, therefore, no longer necessarily considered pathogenic but, on the contrary, could support improved health and personal development for the individual [3,20,58]. A growing body of literature is exploring the mechanisms underlying adaptation in these unique environments [77–80]. This is important not only to improve living conditions in polar regions, but also to benefit crews exploring outer space. Even if environmental and mission conditions make it an imperfect analogue, the characteristics of Earth's polar regions remain unique, and make them comparable to those encountered during LDSE [58,77–84]. Thus, research in Antarctica is a unique opportunity to reduce health risks before they jeopardize the mission.

Table 4
Recovery measures at D+2.

	Recovery		*p*-value*
	OR	HN	
MAIA			
N[a]	3.000 ± .433	3.333 ± 1.181	.018
SR[a,b]	2.550 ± 1.095	3.750 ± .661	.031
AR[a]	2.714 ± 1.187	2.762 ± .577	.066
BUGUET			
D[a]	4.333 ± 3.512	6.200 ± 4.382	<.001
Mf[a]	1.333 ± .577	3.000 ± 1.581	.001
M[a]	7.667 ± 2.517	7.600 ± 1.817	<.001
FLOW			
L[a,b]	19.000 ± 3.464	9.400 ± .894	.003
PHS			
V[a]	1.000 ± .000	1.600 ± 1.342	.020
A			
TF[a]	3.600 ± .548	4.000 ± .000	<.001
HRV			
NNI[a]	821.672 ± 28.890	781.179 ± 140.439	.057
ETOC			
V[a]	14.111 ± 1.836	15.333 ± .408	.003
PARINAUD			
Df[a]	77.667 ± 15.567	73.700 ± 14.721	.007

Note. OR = standard values for non-psychiatric or minor psychotic disorders within the general population; HN = very limited or no existence of minor non-psychiatric or psychotic disorders; N = noticing; SR = self-regulation; AR = attention regulation; D = desire to work; Mf = morale; M = mood; L = loss of self-consciousness; V = vision; TF = taste of food; NNI = mean of successive RR intervals; Df = distant focus.

*p-value used in the analysis of effects. Means and standard deviations are shown for each variable. All variables were recorded at four times, apart from proprioception where baseline and recovery data were collected. Only significant interactions are reported ($p < .05$).

a Significant effect of time.

b Significant effect of time*group.

Therefore, the aims of this study were: (1) to investigate the impact of a one-year stay in Antarctica on health adaptation; and (2) to assess recovery from this experience, two days after the crew's return to civilization. Mental health was evaluated using the GHQ-12. Our results highlight that a one-year stay does not represent a serious threat for the health and psychological, physiological, and sensory functioning of winterers. Furthermore, crew remain in a stable state during winter, indicating adaptability, while the last part of the mission seems to constitute a challenge. Two days after returning to the continent, we found evidence of psychophysiological and sensory stress. Our baseline results for the OR group underline the importance of pre-departure screening, and that those who have no risk of psychological disorders are better-able to adapt.

4.1. *Overwintering and the third-quarter phenomenon*

Winterers tend to experience less negative affect during the depths of winter. Our results suggest that the mind-body connection is maintained, with only small changes in mindfulness functioning, mainly for the OR group. We also observed a decrease in appetite (level, taste of food, number of meals per day). Furthermore, there is an increase in the RR interval during midwinter. These results suggest that the harshest winter months have a positive effect on winterers. Many studies have shown that winter is a crucial time in ICE/EUE, and it has been found to be consistent with sleep disturbances [40,85–87], mood changes [7,29,39,40], and interpersonal disorders [7,77,88–91]. Collectively, these changes have been referred to as *overwinter syndrome* [36]. Nevertheless, our results are in line with evidence which suggests that ICE and EUE do not necessarily induce a pathogenic state, but support normal, stable functioning.

Contrary to other studies [2–4,15,20,77], our findings do not identify any salutogenic effects in terms of mindfulness functioning or positive affect. Anthonovsky [92] was the first to suggest that stress could be beneficial, and induce positive health outcomes. Palinkas and Suedfeld [20] highlight that the severity of the environment is inversely correlated with negative mood, while a more recent study [80] found that symptoms of depression and anxiety did not exceed the threshold for mental disorders throughout the year. Palinkas and Suedfeld [4] point out that psychological disorders are rare in Antarctica, and that there is a decrease in their rate of occurrence. They go as far as to claim that a stay in Antarctic improves the individual's ability to deal with stress, and thus enhances coping strategies. Levine and Ursin [93] underline that the body's response is motivated by the meaning attached to the experience, rather than environmental stressors alone.

Furthermore, our results demonstrate that winterers have a lower preference for vision compared to their other senses during the winter months, and that their focal distance increases during midwinter. Midwinter corresponds to the month with the fewest hours of sunshine. At this time, the temperature ranged from −18.2 °C to −13.3 °C, with 0 mm of precipitation, and 00 min/1 kWh/m^2 of sunshine. This can be compared to the beginning of winter, where the temperature ranged from −16.5 °C to −10.8 °C, with 0 mm of precipitation, and 115 h 40 min/23 kWh/m^2 of sunshine. Therefore, winterers seem to have better distance vision during midwinter, when there is least sunshine. This result appears to reflect an adaptation of visual accommodation. A 2013 overwintering study [35] explored ophthalmological changes before and upon return from an 8-month expedition. No damage to the eye was evident, suggesting that visual function remained unchanged after exposure to an ICE/EUE.

Nevertheless, we found evidence of non-linear patterns of adaptation. Our results show that the last quarter of the mission (from October [M10] onwards) seems to constitute a period of stress. On the psychological level, there is an increase in tiredness and a decrease in mood, despite an increase in desire to work. Furthermore, crew get up earlier. On the social level, there is a decrease in cohesiveness with the leader compared to the beginning of winter. Nevertheless, despite the increased tension [20,77,94], t here is relatively little conflict over the year [18]. The leader and the crew form the primary group, and cohesion-based trust and teamwork are associated with performance [94]. A study [95] analyzing cohesion in a US army medical unit found an inverted-U pattern over the course of a 6-month mission. Cohesiveness was initially low, reached its highest point at mid-deployment, and decreased during the third quarter of the deployment. The late decrease appeared to be associated with relationships, boredom, and trust in leaders.

On the sensory level, our study found a reduced preference for vision compared to the other senses, reduced subjective acuity for hearing and taste, and a trend for vision. Furthermore, crew are more sensitive to sound stimuli in the right ear at 125 Hz, 1000 Hz and 4000 Hz at the end of the wintering compared to the winter months. Our findings are consistent with those reported in previous studies in extreme environments [44,45,96]. Other research shows a decrease in the auditory discomfort threshold for the right ear at 500 Hz, 1000 Hz, and 2000 Hz in submarine patrols during the third quarter of a mission [44,45], and at 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz during a 5-day simulation at sea [96]. Therefore, participants seem to develop auditory hypersensitivity to sensory stimuli. Other authors have pointed out that the right ear plays an important role in hearing processing [97,98].

Our study seems to confirm a third-quarter phenomenon, in the form of a critical period during the last quarter of the mission (mainly M7 and M10), on psychological and sensory levels [99,100]. Several authors have identified a cluster of symptoms during the last quarter of a mission, notably increased fatigue, interpersonal tension, and decreased mood [8,21,100–102]. Another study showed that the third-quarter phenomenon reflected interpersonal hypersensitivity [29]. Nevertheless, Palinkas et al. [91] found that the third-quarter syndrome was not inherent to environmental factors, but was the result of psychosocial factors and mission time awareness. Other authors add that the psychological changes that emerge during this period could presuppose the impact of the Antarctic mission, or even reflect the anticipation of returning to normal life [92,103]. Wilson [104] hypothesized that the third-quarter phenomenon could persist until the end of the mission, and Kokun et al. [105] reported a major decrease in psychological, performance, and health responses during the last two months in an ICE/EUE. Our results confirm the hypothesis that the third-quarter phenomenon coincides with an anticipatory period, as highlighted by Rohrer [28], particularly in the case of long-duration ICE/EUE missions.

4.2. Selection based on psychological abilities

Our study sheds light on psychological profiles, defined using a baseline assessment of mental health. While there is evidence of minor non-psychiatric or psychotic disorders in the OR group, with scores within the norm for the general population, individuals in the HN group score beyond the norm, suggesting very little, or no risk of minor non-psychiatric or psychotic disorders. At baseline, people in the OR group reported higher perceived subjective stress, less calmness, a loss of self-consciousness, cognitive absorption, and decreased performance following wakening compared to people in the HN group. In general, winterers are a healthy population, and are selected based on their ability to work in an ICE/EUE. It is possible that wintering is insufficient to highlight any differences, due to their overall aptitude. Flow experience has been found to be correlated with salutogenic outcomes [91], and provide active adaptation [106]. Our one-year study of Antarctica winterers found that those with a greater prevalence of minor non-psychiatric or psychotic disorders (the OR profile) were more impacted by the mission. Compared to the HN group, they reported more psychological and sensory problems: a lower ability to live in the present moment (acceptation), poorer interoceptive abilities (regulation of psychological distress by paying attention to the body), greater tiredness, poorer performance following wakening (notably at the beginning of winter, and during the last quarter of the mission), higher negative affect, more tension, less calmness, lower mood and morale, and higher perceived and subjective stress. They experience a decrease in energy, a higher level of arousal, a higher level of fatigue that affects performance, less stable mood, and a higher level of perceived stress. They are less connected to both their body sensations, and the present moment.

Their sensory abilities are also impacted by the mission. They report an increase in the taste of food, better hedonic value for olfaction, poorer taste abilities, and higher sensitivity to sound for both ears at 125 Hz. Thus, it appears that members of the OR group are more sensitive than those with an HN profile. Since ambient noise is often low-frequency, it is possible that individuals develop hypersensitivity during their time at the station; in particular, the machines that operate the station can be heard by some members of the crew. The results presented here confirm earlier findings in ICE/EUE [45,96], and it is reasonable to ask if changes in hearing might be the best indicator of the state of stress of crews. It seems that the more extreme the environment, the more individuals develop a hypersensitivity to auditory stimuli. Consequently, they may pay more attention to the surrounding noise.

It appears that GHQ scores that are within the norm of the general population are insufficient as an indicator of adaptation in ICE/EUE. Our results suggest that people with an OR profile could be more at-risk than those with an HN profile, as the latter have psychological characteristics that are better than normal. Our study thus sheds light on what we might focus on when we are looking for people with the ‘right stuff’ [107].

The literature highlights several characteristics that support optimal performance (e.g., age, emotional stability, personality traits, coping skills, social compatibility, tolerance for monotony) [4,20,108]. Palinkas et al. [4] highlight the need for flexibility and adaptability in ICE/EUE. They note that crews who are flexible are likely to perform best in these environments. Currently, crew selection does not seek to identify people with the most adaptable profiles. Instead, aptitude criteria are used to eliminate those individuals who are most at-risk of psychological maladjustment and clinical decompensation. Screening aims to find critical pathologies that increase the risk of decompensation, or non-pre-existing pathologies. However, the discovery or pre-existence of a pathology is not a direct reason for exclusion. Certain pathologies, which are controlled, may be allowed, while those that require regular follow-up or ongoing treatment are excluded (e.g., hypertension, asthma). An examination consisting of questionnaires and an interview with a psychologist excludes individuals with psychological, psychopathological, behavioral, and addictive disorders that would present a risk during wintering. During this process, the motivation and social skills of candidates are assessed.

Nevertheless, our results highlight the need to orient the search towards individuals with ‘positive’ characteristics, notably well-developed coping strategies and psychological resources. This would disqualify individuals who present a risk, and select candidates with optimal adaptation characteristics. We recommend that crew selection for the French Southern and Antarctic territories should take this approach, and the literature suggests that all institutions should aim to adopt it [20]. There is clearly still a need to homogenize both ICE/EUE measurements and selection methods [3]. The GHQ-28 could be a relevant candidate for further discussions in countries that are considering questions of human adaptation in ICE/EUE.

4.3. Post-mission recovery processes

Our results show that two days after their return, winterers go through a difficult time. Interoceptive awareness tends to fall, especially among those with an OR profile. This group experiences more psychological distress during this period compared to both midwinter, and the last quarter of the mission. Our findings are comparable to a study onboard a sub-surface ballistic nuclear patrol, which reports decreased interoceptive awareness during recovery for submariners with a nonadaptive profile, based on their cardiac biosignal at baseline [44,45].

Moreover, the OR group experiences greater physiological stress on return, compared to the midwinter period. There is a fall in morale, despite improved mood and a desire to work. The return to normality seems to leave winterers ambivalent, lost, and lacking confidence. They report a reduction in flow with respect to their ability to be absorbed in a task (loss of self-consciousness) compared to midwinter and the last quarter of the mission. This suggests that polar stations may generate a flow experience. People in the HN group report better flow compared to those with an OR profile during overwintering. This may be due to their better adaptative abilities in Antarctica, and it should be noted that their ability to be absorbed in a task increased during the winter months and the last quarter of the mission.

The analysis of their sensory abilities shows that the distant focus of winterers returned to normative values, along with a preference for vision compared to the other senses, an increase in the taste of food compared to the beginning of winter, and their ability to detect odors compared to the winter months and the last quarter of the mission.

Our results seem to indicate short-term impacts that make the return to real life difficult. In the short term, recovery may be seen as a new stressor. In 2020, Salam [1] pointed out that despite the presence of a number of stressors in ICE/EUE, daily life also contains its own stressors. Crew need to re-adapt to the environment that they left behind for a year. The overall pathogenic impact of the return on psychophysiological and sensory responses may mirror the effects of overwintering. In this context, Nicolas et al. [77] reported an association between mature defense, perceived control, and recovery. The one year spent in Antarctica induced a high level of involvement, to adapt to the effects of wintering. The overwinterers grew up during their stay, as they learned how to successfully adapt to the harsh environment [1,3,20]. Long-term salutogenic outcomes have been reported in several studies, and support the idea that winterers may experience personal growth, self-confidence, find meaning in life, enjoy improved health, find strength, understand human values, have a feeling of accomplishment, improve their social skills, and increase their ability to deal with stressful situations [1,3,7,20,109,110]. This suggests that there is a need for follow-up, beyond the 48-h post-mission period.

Studies have hypothesized that psychological symptoms may correspond to coping strategies, and are not necessarily maladaptive [111,112]. Coping is a transaction between an individual's needs and environmental demands [113–115]. The resources available to the individual to cope with stressors support the development of pathogenic or salutogenic behavior. Salutogenic behavior requires accepting reality, while reacting to the surroundings [116]; the idea presupposes that interoceptive functioning and MD are optimal, but can evolve over time [20,117]. In conjunction with individual characteristics, this type of coping could be a good predictor of adaptation in extreme environments [20]. More specifically, mature defense mechanisms could contribute to efficient adaptation in ICE/EUE, and be linked to better recovery [77]. Overall, Le Roy et al. [3] highlight that multiple coping strategies are used in ICE/EUE, and therefore cannot be considered as a stable factor. This conclusion has been highlighted previously [29]. Coping strategies depend on multiple factors that need to be understood in order to determine the mechanisms that optimize adaptation [3].

Our results, combined with those reported in the literature, underline how complex it is to determine temporal patterns of symptomology [15]. Missions in polar regions no longer represent a major risk to crews [78]. Several factors justify the latter observation: (1) the screening process seeks to identify the most suitable crew members; and (2) living conditions onboard stations have improved. Nevertheless, identifying the best candidates is not enough. It is also necessary to determine how best to support and maintain adaptation. Despite the lack of negative effects of wintering, it is essential to provide countermeasures to prepare crews for their return to the mainland at the end of the mission. The recovery period is as stressful as the mission itself. It would be relevant to study the recovery of winterers over longer periods of time, in order to evaluate readaptation processes.

Our results also underline that the impact of the return is the same for our two groups, with the exception of a lower level of interoception and flow in members of the OR group. Reinforcing interoceptive and mindfulness capacities seems to be an interesting research axis, and could contribute to improving the adaptive capacities of crews. It could also be used during missions to improve recovery. Numerous studies have shown the benefits of mindfulness practice on interoceptive abilities, stress, emotion regulation, and resilience [118–120]. A neural network study has demonstrated an association between a high level of MD, emotional and interoceptive abilities [44], other elements involved in neuroplasticity, and, therefore, adaptive capacities [49]. More recently, a review highlighted its benefits as a countermeasure during future LDSE [121].

Furthermore, our analysis of physical activity shows that the level remained stable throughout the wintering period (Supplementary Material). No addictive behaviors, reflecting maladaptation, were observed, and this does not seem to have an impact on the psychophysiological and sensory responses of winterers. Nevertheless, it should be noted that all winterers engaged in regular physical activity. An extensive body of literature has highlighted its benefits in promoting psychological and physical well-being [122–124]. Physical activity is an efficient countermeasure in many extreme environments. Onboard the International Space Station, daily physical activity helps to limit the adverse effects of the environment on the body [125,126]. One study highlights that physical activity during the MARS500 simulation mission was able to limit confinement-related psychophysiological deconditioning [127], while another supports the hypothesis that physical activity at DDU would improve sleep quality [128].

Nevertheless, Martin-Krumm et al. [129] found that even if regular physical activity helped to maintain exteroceptive functioning, this was not sufficient to compensate for the thymic degradation induced by an ICE/EUE. The scientific community still has not reached a consensus regarding both their pathogenic and salutogenic effects. It is reasonable to ask whether the stability observed in the psychophysiological responses of winterers might not be salutogenic. While the underlying mechanisms remain an open question, they seem to be related to both environmental characteristics, the type of mission, the profile of the individual, and the characteristics of the group. It remains true that a long stay in an ICE/EUE is not harmful to the health of the crew. Our results provide a new, hopeful dynamic for adaptation during future LDSE. Further research would help to better-understand typical stressful environments, highlight their impact on the human body and behavior, and explore how humans adapt to them, against all odds.

5. Limitations

This study has several methodological shortcomings that are inherent to the ecological environment. They include the small sample size, an imbalance between male and female participants, and right- and left-handed subjects. Studying such a population is complex, both in terms of time constraints, and access to infrastructure and personnel (operational constraints, attendance). Notably, we were unable to access all of our subjects two days after their return to the continent, because they did not all come back on the same rotation of the Astrolabe. We therefore chose the rotation that included the highest number of subjects. Both the scientific team and participants must be flexible in order to run such an experiment, and an assessment of recovery would take more time. Institutions that organize wintering missions could help scientific teams to deploy a longitudinal study of recovery.

Secondly, our results are not reproducible beyond the specific experimental conditions, and cannot be generalized. Thirdly, some measures were not recorded. Due to the Covid-19 health crisis, we were unable to record baseline measurements for winterers before they left for the station. Moreover, control measurements should have been carried out onboard the Astrolabe, and compared with recovery measurements carried out on the crew's return to the mainland. These points should be considered in future studies. Fourth, effect sizes ranged from 0.005 to 0.451, and this may be relatively low for some variables. Further studies are therefore needed to confirm our results. Fifth, psychological and interoceptive data (collected through questionnaires) are subjective measures. Intelligent sensors would provide more objective measures of adaptation. Sixth, it would have been relevant to use scales developed specifically for ICE/EUE, notably the Isolated and Confined Questionnaire (ICE-Q) developed by Nicolas et al. [130], which measures social, emotional, occupational, and physical components of adaptation, and/or a mental health checklist to explore positive adaptation, self-regulation, and anxious apprehension [131]. Furthermore, team dynamics could have been evaluated, to explore all of the dimensions of adaptation. Finally, RR intervals were recorded with the Kino® wearable cardiac monitoring device (Heartkinetics, Belgium). The measured ECG signals contained artifacts that may have impacted their analysis.

6. Conclusion

The present study took place during a one-year mission in Antarctica. Our results highlight both salutogenic and pathogenic effects. Winterers are able to adapt to this harsh environment, and ICE/EUE no longer constitute a threat. Notably, many positive outcomes were observed during midwinter. Nevertheless, a third-quarter phenomenon, together with a degradation during recovery provides new insight into life in an ICE/EUE. We were able to characterize two profiles based on the non-psychotic and minor psychiatric disorders scale: the OR profile (scores within the norm of the general population), and the HN profile (few or no psychotic and minor psychiatric disorders compared to the general population). Our study underlines that the HN profile is most likely to develop a salutogenic adaptive coping strategy, and people with an OR profile are more susceptible to inner-exteroceptive and psychological dysfunction, which could, in turn, indicate poorer adaptation to long duration ICE/EUE missions. Thus, despite improvements in selection processes, wintering can impact the psychological and sensory responses of people with an OR profile. It is therefore essential that selection criteria identify those who can best-adapt as the mission progresses, and ensure its success. Finally, it is crucial to prepare crews for their return, because there is no doubt that living in an ICE/EUE can capture people's hearts.

Funding

The work was supported by the French Space Agency (CNES; n°4800001159) and the French Military Health Service.

Author contributions

BLR, MT designed the study. BLR, JR, CD collected, and analyzed the data (signal processing, statistics). BLR drafted the manuscript in collaboration with CMK and MT. All authors reviewed the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to thank the volunteers who took part in this study, and the data collection team. We also thank the French Space Agency (CNES) and the French Government Defense (AID) for their support. Moreover, we are grateful to the French Polar Institute Paul Émile Victor for their operational support during the campaign. Data used in this study are the property of the French Health Service. Any requests must be filed with, and evaluated by, the French Military Staff.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actaastro.2024.03.001.

References

[1] A.P. Salam, Exploration Class missions on Earth: lessons learnt from life in extreme Antarctic isolation and confinement, in: A. Choukèr (Ed.), Stress Challenges and Immunity in Space, Springer, 2020, https://doi.org/10.1007/978-3-030-16996-1_38.

[2] P. Suedfeld, Applying positive psychology in the study of extreme environments. Human performance in extreme environments, J. Soc. Hum. Perf. Extrem. Environ. 6 (1) (2001) 21–25, https://doi.org/10.7771/2327-2937.1020.

[3] B. Le Roy, C. Martin-Krumm, N. Pinol, F. Dutheil, M. Trousselard, Human challenges to adaptation to extreme professional environments: a systematic review, Neurosci. Biobehav. Rev. 146 (2023) 105054, https://doi.org/10.1016/j.neubiorev.2023.105054.

[4] L.A. Palinkas, P. Suedfeld, Psychological effects of polar expeditions, Lancet 371 (9607) (2008) 153–163, https://doi.org/10.1016/S0140-6736(07)61056-3.

[5] E.D. Rothblum, Psychological factors in the Antarctic, J. Psychol. 124 (3) (1990) 253–273, https://doi.org/10.1080/00223980.1990.10543221.

[6] C. Tortello, M. Barbarito, J.M. Cuiuli, D.A. Golombek, D.E. Vigo, S.A. Plano, Psychological adaptation to extreme environments: Antarctica as a space analogue, Psychology and Behavioral Science International Journal 9 (4) (2018) 1–4.

[7] M. Zimmer, J.C.C.R. Cabral, F.C. Borges, K.G. Côco, B. Hameister, Psychological changes arising from an Antarctic stay: systematic overview, Estud. Psicolog. 30 (3) (2013) 415–423, https://doi.org/10.1590/S0103-166X2013000300011.

[8] E.K. Gunderson, Mental health problems in Antarctica, Arch. Environ. Health 17 (4) (1968) 558–564, https://doi.org/10.1080/00039896.1968.10665281.

[9] N. Kanas, W.E. Feddersen, Psychiatric Behavioral, Sociological Problems of Long-Duration Space Missions, Johnson Spacecraft Center/National Aeronautics and Space Administration, 1971. NASA-TM X-58067.

[10] C. Le Scanff, J. Larue, E. Rosnet, How to measure human adaptation in extreme environments: the case of Antarctic wintering-over, Aviat Space Environ. Med. 68 (12) (1997) 1144–1149.

[11] D. Manzey, B. Lorenz, A. Schiewe, G. Finell, G. Thiele, Behavioral aspects of human adaptation to space: analyses of cognitive and psychomotor performance in space during an 8-day space mission, Clin. Invest. 71 (9) (1993) 725–731, https://doi.org/10.1007/BF00209727.

[12] R.E. Strange, W.J. Klein, Emotional and social adjustment of recent U.S. winter-over parties in isolated Antarctic stations, Antarctic Bibliography 7 (1974) 229.

[13] R.B. Bechtel, A. Berning, The third-quarter phenomenon: do people experience discomfort after stress has passed? in: A.A. Harrison, Y.A. Clearwater, C.P. McKay (Eds.), From Antarctica to Outer Space: Life in Isolation and Confinement Springer Verlag, 1990.

[14] K. Engel, The Winter-Over Syndrome and the Potential Lessons for Space Travel, University of Canterbury, 2019.

[15] G.R. Leon, G.M. Sandal, E. Larsen, Human performance in polar environments, J. Environ. Psychol. 31 (4) (2011) 353–360, https://doi.org/10.1016/j.jenvp.2011.08.001.

[16] L.A. Palinkas, J.C. Johnson, J.S. Boster, M. Houseal, Longitudinal studies of behavior and performance during a winter at the South Pole, Aviat Space Environ. Med. 69 (1) (1998) 73–77.

[17] H.R. Guly, Snow blindness and other eye problems during the heroic age of Antarctic exploration, Wilderness Environ. Med. 23 (1) (2012) 77–82, https://doi.org/10.1016/j.wem.2011.10.006.

[18] R.E. Strange, S.A. Youngman, Emotional aspects of wintering over, Antarct. J. U. S. 6 (1971) 255–257.

[19] O.G. Gazenko, Investigations in outer space conducted in the USSR during 1982, Aviat Space Environ. Med. 54 (10) (1983) 949–951.

[20] L.A. Palinkas, P. Suedfeld, Psychosocial issues in isolated and confined extreme environments, Neurosci. Biobehav. Rev. 126 (2021) 413–429, https://doi.org/10.1016/j.neubiorev.2021.03.032.

[21] G.M. Sandal, F. Van DeVijver, N. Smith, Psychological hibernation in Antarctica, Front. Psychol. 9 (2018) 2235, https://doi.org/10.3389/fpsyg.2018.02235.

[22] A. Van Ombergen, A. Demertzi, A.E. Tomilovskaya, B. Jeurissen, J. Sijbers, I. B. Kozlovskaya, P.M. Parizel, P.H. Van de Heyning, S. Sunaert, S. Laureys, F. L. Wuyts, The effect of spaceflight and microgravity on the human brain, J. Neurol. 264 (Suppl 1) (2017) 18–22, https://doi.org/10.1007/s00415-017-8427-x.

[23] G. Décamps, E. Rosnet, A longitudinal assessment of psychological adaptation during a winter-over in Antarctica, Environ. Behav. 37 (3) (2005) 418–435, https://doi.org/10.1177/0013916504272561.

[24] E.K. Gunderson, Adaptation to extreme environments: the Antarctic volunteer, navy medical neuropsychiatric research unit, Rep No 66–4 (1966) 1–28, https://doi.org/10.21236/ad0632571.

[25] L.A. Palinkas, Psychosocial effects of adjustment in Antarctica: lessons for long-duration spaceflight, J. Spacecraft Rockets 27 (5) (1990) 471–477, https://doi.org/10.2514/3.26167.

[26] L. Quadt, H.D. Critchley, S.N. Garfinkel, The neurobiology of interoception in health and disease, Ann. N. Y. Acad. Sci. 1428 (1) (2018) 112–128, https://doi.org/10.1111/nyas.13915.

[27] N. Kanas, Psychological and interpersonal issues in space, Am. J. Psychiatr. 144 (6) (1987) 703–709, https://doi.org/10.1176/ajp.144.6.703.

[28] J. Rohrer, Interpersonal relationships in isolated small groups, in: B. Flaherty (Ed.), Psychological Aspects of Manned Spaceflight, Columbia University Press, 1961.

[29] L.A. Palinkas, M. Houseal, Stages of change in mood and behavior during a winter in Antarctica, Environ. Behav. 32 (1) (2000) 128–141, https://doi.org/10.1177/00139160021972469.

[30] L.A. Palinkas, The psychology of isolated and confined environments. Understanding human behavior in Antarctica, Am. Psychol. 58 (5) (2003) 353–363, https://doi.org/10.1037/0003-066x.58.5.353.

[31] G.L. Moseley, A. Gallace, C. Spence, Bodily illusions in health and disease: physiological and clinical perspectives and the concept of a cortical 'body matrix', Neurosci. Biobehav. Rev. 36 (1) (2012) 34–46, https://doi.org/10.1016/j.neubiorev.2011.03.013.

[32] A. Barabasz, M. Barabasz, Antarctic isolation and inversion perception: regression phenomena, Environ. Behav. 18 (1986) 285–292, https://doi.org/10.1177/0013916586182008.

[33] M.M. Bosch, D. Barthelmes, T.M. Merz, F. Truffer, P.B. Knecht, B. Petrig, K. E. Bloch, U. Hefti, G. Schubiger, K. Landau, Intraocular pressure during a very high altitude climb, Invest. Ophthalmol. Vis. Sci. 51 (3) (2010) 1609–1613, https://doi.org/10.1167/iovs.09-4306.

[34] D.V. Varyvonchyk, S.O. Rykov, A.O. Saliukov, A.B. Mishenin, H. Pyshnov, I. Moĭseienko, Morphological changes of the vision organ among winterers in Ukrainian Antarctic station "Academician Vernadskiĭ", Fiziol. Zh. 60 (1) (2014) 70–77.

[35] M.H. Stahl, A. Kumar, R. Lambert, M. Stroud, D. Macleod, A. Bastawrous, T. Peto, M.J. Burton, Antarctica eye study: a prospective study of the effects of overwintering on ocular parameters and visual function, BMC Ophthalmol. 18 (1) (2018) 149, https://doi.org/10.1186/s12886-018-0816-0.

[36] L.A. Palinkas, M. Cravalho, D. Browner, Seasonal variation of depressive symptoms in Antarctica, Acta Psychiatr. Scand. 91 (6) (1995) 423–429, https://doi.org/10.1111/j.1600-0447.1995.tb09803.x.

[37] N. Chen, Q. Wu, Y. Xiong, G. Chen, D. Song, C. Xu, Circadian rhythm and sleep during prolonged Antarctic residence at Chinese Zhongshan station, Wilderness Environ. Med. 27 (4) (2016) 458–467, https://doi.org/10.1016/j.wem.2016.07.004.

[38] C.S. Mullin Jr., Some psychological aspects of isolated Antarctic living, Am. J. Psychiatr. 117 (1960) 323–325, https://doi.org/10.1176/ajp.117.4.323.

[39] L.A. Palinkas, Sociocultural influences on psychosocial adjustment in Antarctica, Med. Anthropol. 10 (4) (1989) 235–246, https://doi.org/10.1080/01459740.1989.9965970.

[40] S.S. Khalsa, D. Rudrauf, C. Sandesara, B. Olshansky, D. Tranel, Bolus isoproterenol infusions provide a reliable method for assessing interoceptive awareness, Int. J. Psychophysiol. 72 (1) (2008) 34–45.

[41] A. Schulz, C. Vögele, Interoception and stress, Front. Psychol. 6 (2015) 993, https://doi.org/10.3389/fpsyg.2015.00993.

[42] S. Sun, C. Hu, J. Pan, C. Liu, M. Huang, Trait mindfulness is associated with the self-similarity of heart rate variability, Front. Psychol. 10 (2019) 314, https://doi.org/10.3389/fpsyg.2019.00314.

[43] T. Pinna, D.J. Edwards, A systematic review of associations between interoception, vagal tone, and emotional regulation: potential applications for mental health, wellbeing, psychological flexibility, and chronic conditions, Front. Psychol. 5 (11) (2020) 1792, https://doi.org/10.3389/fpsyg.2020.01792.

[44] B. Lefranc, C. Martin-Krumm, C. Aufauvre-Poupon, B. Berthail, M. Trousselard, Mindfulness, interoception, and olfaction: a network approach, Brain Sci. 10 (2020) 921, https://doi.org/10.3390/brainsci10120921.

[45] B. Le Roy, C. Aufauvre-Poupon, A. Ferragu, A. Vannier, C. Martin-Krumm, M. Trousselard, Cardiac biosignal in confined nuclear submarine patrol: heart rate variability a marker of adaptation, Acta Astronaut. 203 (2022) 469–482, https://doi.org/10.1016/j.actaastro.2022.12.014.

[46] E. Thompson, F.J. Varela, Radical embodiment: neural dynamics and consciousness, Trends Cognit. Sci. 5 (10) (2001) 418–425.

[47] W.J. Rejeski, L. Gauvin, The embodied and relational nature of the mind: implications for clinical interventions in aging individuals and populations, Clin. Interv. Aging 8 (2013) 657–665, https://doi.org/10.2147/CIA.S44797.

[48] D. Siegel, Mindsight, Bantam Books, New York, NY, 2010.

[49] J. Gibson, Mindfulness, interoception, and the body: a contemporary perspective, Front. Psychol. 10 (2012) (2019), https://doi.org/10.3389/fpsyg.2019.02012.

[50] A.W. Hanley, W.E. Mehling, E.L. Garland, Holding the body in mind: interoceptive awareness, dispositional mindfulness and psychological well-being, J. Psychosom. Res. 99 (2017) 13–20, https://doi.org/10.1016/j.jpsychores.2017.05.014.

[51] W.E. Mehling, C. Price, J.J. Daubenmier, M. Acree, E. Bartmess, A. Stewart, The Multidimensional Assessment of Interoceptive Awareness (MAIA), PLoS One 7 (11) (2012) e48230, https://doi.org/10.1371/journal.pone.0048230.

[52] M. Csikszentmihalyi, Beyond Boredom and Anxiety: Experiencing Flow in Work and Play, second ed., Jossey-Bass, San Francisco, CA, 1975.

[53] R.A. Baer, G.T. Smith, J. Hopkins, J. Krietemeyer, L. Toney, Using self-report assessment methods to explore facets of mindfulness, Assessment 13 (1) (2006) 27–45.

[54] E.L. Garland, N.A. Farb, P.R. Goldin, B.L. Fredrickson, Mindfulness broadens awareness and builds eudaimonic meaning: a process model of mindful positive emotion regulation, Psychol. Inq. 28 (4) (2017) 242–248.

[55] L.A. Kilpatrick, B.Y. Suyenobu, S.R. Smith, J.A. Bueller, T. Goodman, J. D. Creswell, K. Tillisch, E.A. Mayer, B.D. Naliboff, Impact of Mindfulness-Based Stress Reduction training on intrinsic brain connectivity, Neuroimage 56 (1) (2011) 290–298, https://doi.org/10.1016/j.neuroimage.2011.02.034.

[56] A. Lutz, A.P. Jha, J.D. Dunne, C.D. Saron, Investigating the phenomenological matrix of mindfulness-related practices from a neurocognitive perspective, Am. Psychol. 70 (7) (2015) 632–658, https://doi.org/10.1037/a0039585.

[57] C. Aufauvre-Poupon, C. Martin-Krumm, A. Duffaud, A. Lafontaine, L. Gibert, F. Roynard, C. Rouquet, J.-B. Bouillon-Minois, F. Dutheil, F. Canini, J. Pontis, F. Leclerq, A. Vannier, M. Trousselard, Subsurface confinement: evidence from submariners of the benefits of mindfulness, Mindfulness 12 (9) (2021) 2218–2228, https://doi.org/10.1007/s12671-021-01677-7.

[58] A. Van Ombergen, A. Rossiter, T.J. Ngo-Anh, 'White Mars' - nearly two decades of biomedical research at the Antarctic Concordia station, Exp. Physiol. 106 (1) (2021) 6–17, https://doi.org/10.1113/EP088352.

[59] D.P. Goldberg, V.F. Hillier, A scaled version of the general health questionnaire, Psychol. Med. 9 (1) (1979) 139–145, https://doi.org/10.1017/S0033291700021644.

[60] D. Goldberg, P. Williams, A User's Guide to the General Health Questionnaire, Nfer-Nelson, London, 1991.

[61] J. Bell, P.H. Garthwaite, The psychological effects of service in British Antarctica: a study using the General Health Questionnaire, Br. J. Psychiatr. : J. Ment. Sci. 150 (1987) 213–218, https://doi.org/10.1192/bjp.150.2.213.

[62] S.K. Khandelwal, A. Bhatia, A.K. Mishra, Psychological adaptation of Indian expeditioners during prolonged residence in Antarctica, Indian J. Psychiatr. 59 (3) (2017) 313–319, https://doi.org/10.4103/psychiatry.IndianJPsychiatry_296_16.

[63] M. Shevlin, G. Adamson, Alternative factor models and factorial invariance of the GHQ-12: a large sample analysis using confirmatory factor analysis, Psychol. Assess. 17 (2) (2005) 231–236, https://doi.org/10.1037/1040-3590.17.2.231.

[64] A.C. Parrott, I. Hindmarch, The Leeds sleep evaluation questionnaire in psychopharmacological investigations - a review, Psychopharmacology 71 (2) (1980) 173–179, https://doi.org/10.1007/BF00434408.

[65] A. Buguet, C. Raphel, R. Bugat, J. Fourcade, Etats de vigilance en opération continue (alertness pattern in SUSOPS), Inter Rev Army Navy Air Force Medicine Services 54 (1981) 101–102.

[66] M. Trousselard, D. Steiler, C. Raphel, C. Cian, R. Duymedjan, D. Claverie, F. Canini, Validation of a French version of the Freiburg Mindfulness Inventory - short version: relationships between mindfulness and stress in an adult population, Biopsychosoc. Med. 4 (2010) 8, https://doi.org/10.1186/1751-0759-4-8.

[67] W.E. Mehling, M. Acree, A. Stewart, J. Silas, A. Jones, The multidimensional assessment of interoceptive awareness, version 2 (MAIA-2), PLoS One 13 (12) (2018) e0208034, https://doi.org/10.1371/journal.pone.0208034.

[68] C. Martin-Krumm, F. Fenouillet, A. Csillik, L. Kern, M. Besancon, J. Heutte, Y. Paquet, Y. Delas, M. Trousselard, B. Lecorre, E. Biener, Changes in emotions from childhood to young adulthood, Child Ind Res 11 (2) (2018) 541–561, https://doi.org/10.1007/s12187-016-9440-9.

[69] R.E. Thayer, Measurement of activation through self-report, Psychol. Rep. 20 (2) (1967) 663–678, https://doi.org/10.2466/pr0.1967.20.2.663.

[70] S. Cohen, T. Kamarck, R. Mermelstein, A global measure of perceived stress, J. Health Soc. Behav. 24 (4) (1983) 385–396.

[71] J. Heutte, F. Fenouillet, C. Martin-Krumm, G. Gute, A. Raes, D. Gute, R. Bachelet, M. Csikszentmihalyi, Optimal experience in adult learning: conception and validation of the flow in education scale (EduFlow-2), Front. Psychol. (2021), https://doi.org/10.3389/fpsyg.2021.828027.

[72] R. Sundberg, C. Ruffa, Measurements for the institutional cohesion dimension of the standard model of military group cohesion, Mil. Psychol. 33 (2021) 92–103, https://doi.org/10.1080/08995605.2021.1897491.

[73] S. Laborde, E. Mosley, J.F. Thayer, Heart rate variability and cardiac vagal tone in psychophysiological research - recommendations for experiment planning, data analysis, and data reporting, Front. Psychol. 8 (2017) 213, https://doi.org/10.3389/fpsyg.2017.00213.

[74] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, Heart rate variability: standards of measurement, physiological interpretation and clinical use, Circulation 93 (5) (1996) 1043–1065.

[75] P. Gomes, P. Margaritoff, H. Silva, pyHRV: development and evaluation of an open-source python toolbox for heart rate variability (HRV), Proc Int conf On electrical, electronic and computing engineering (icetran) (2019) 822–828.

[76] C. Carreiras, A.P. Alves, A. Lourenço, F. Canento, H. Silva, A. Fred, BioSPPy: Biosignal Processing in Python, 2015. https://github.com/PIA-Group/BioSPPy/ [Online].

[77] M. Nicolas, P. Suedfeld, K. Weiss, M. Gaudino, Affective, social, and cognitive outcomes during a 1-year wintering in concordia, Environ. Behav. 48 (8) (2015) 1073–1091, https://doi.org/10.1177/0013916515583551.

[78] M. Nicolas, G. Martinent, L. Palinkas, P. Suedfeld, Dynamics of stress and recovery and relationships with perceived environmental mastery in extreme environments, J. Environ. Psychol. 83 (2022) 101853, 10.1016/j.jenvp.2022.101853.

[79] M. Nicolas, G. Martinent, P. Suedfeld, L. Palinkas, C. Bachelard, M. Gaudino, The tougher the environment, the harder the adaptation? A psychosocial point of view in extreme situations, Acta Astronaut. 187 (2021) 36–42, 10.1016/j.actaastro.2021.05.045.
[80] C. Tortello, A. Folgueira, M. Nicolas, J.M. Cuiuli, G. Cairoli, V. Crippa, M. Barbarito, C. Abulafia, D.A. Golombek, D.E. Vigo, S.A. Plano, Coping with Antarctic demands: psychological implications of isolation and confinement, Stress Health, J. Int. Soc. Investig. Stress. 37 (3) (2021) 431–441, https://doi.org/10.1002/smi.3006.
[81] A.A. Harrison, Y.A. Clearwater, C.P. McKay, The human experience in Antarctica: applications to life in space, Behav. Sci. 34 (4) (1989) 253–271, https://doi.org/10.1002/bs.3830340403.
[82] P. Suedfeld, K. Weiss, Antarctica natural laboratory and space analogue for psychological research, Environment and behavior 32 (1) (2000) 7–17, https://doi.org/10.1177/00139160021972405.
[83] R. Wharton, B. Roberts, E. Chiang, J. Lynch, C. Roberts, A. Buoni, D. Anderson, Use of Antarctic Analogs to Support the Space Exploration Initiative. NASA-TM-1080000, Johnson Spacecraft Center/National Aeronautics and Space Administration, 1990.
[84] D. Lugg, M. Shepanek, Space analogue studies in Antarctica, Acta Astronaut. 44 (7–12) (1999) 693–699, https://doi.org/10.1016/s0094-5765(99)00068-5.
[85] A. Folgueira, G. Simonelli, S. Plano, C. Tortello, J.M. Cuiuli, A. Blanchard, A. Patagua, A.J. Brager, V.F. Capaldi, A.E. Aubert, M. Barbarito, D.A. Golombek, D.E. Vigo, Sleep, napping and alertness during an overwintering mission at Belgrano II Argentine Antarctic station, Sci. Rep. 9 (1) (2019) 10875, https://doi.org/10.1038/s41598-019-46900-7.
[86] N. Pattyn, M. Van Puyvelde, H. Fernandez-Tellez, B. Roelands, O. Mairesse, From the midnight sun to the longest night: sleep in Antarctica, Sleep Med. Rev. 37 (2018) 159–172, https://doi.org/10.1016/j.smrv.2017.03.001.
[87] M. Steinach, E. Kohlberg, M.A. Maggioni, S. Mendt, O. Opatz, A. Stahn, H. C. Gunga, Sleep quality changes during overwintering at the German Antarctic stations neumayer II and III: the gender factor, PLoS One 11 (2) (2016) e0150099, https://doi.org/10.1371/journal.pone.0150099.
[88] R. Bhargava, S. Mukerji, U. Sachdeva, Psychological impact of the Antarctic winter on Indian expeditioners, Environ. Behav. 32 (1) (2000) 111–127, https://doi.org/10.1177/00139160021972450.
[89] N. Chen, Q. Wu, H. Li, T. Zhang, C. Xu, Different adaptations of Chinese winter-over expeditioners during prolonged Antarctic and sub-Antarctic residence, Int. J. Biometeorol. 60 (5) (2016) 737–747, https://doi.org/10.1007/s00484-015-1069-8.
[90] L.A. Palinkas, Effects of physical and social environments on the health and well-being of Antarctic winter-over personnel, Environ. Behav. 23 (6) (1991) 782–799.
[91] L.A. Palinkas, E.K. Gunderson, J.C. Johnson, A.W. Holland, Behavior and performance on long-duration spaceflights: evidence from analogue environments, Aviat Space Environ. Med. 71 (9 Suppl) (2000) A29–A36.
[92] A. Antonovsky, The salutogenic perspective: toward a new view of health and illness, Advances 4 (1) (1987) 47–55.
[93] S. Levine, H. Ursin, What is stress? in: M.R. Brown, G.F. Koob, C. Rivier (Eds.), Stress-neurobiology and Neuroendocrinology Marcel Dekker, New York, 1991.
[94] G.L. Siebold, The essence of military group cohesion, Armed Forces Soc. 33 (2) (2007) 286–295, https://doi.org/10.1177/0095327x06294173.
[95] P.T. Bartone, A.B. Adler, Cohesion over time in a peacekeeping medical task force, Mil. Psychol. 11 (1) (2009) 85–107, https://doi.org/10.1207/s15327876mp1101_5.
[96] B. Le Roy, C. Martin-Krumm, C. Poupon, C. Bouquet, C. Trouve, C. Jego, L. Giaume, M. Trousselard, Lost at Sea: Impact of an Ocean Survival Experience on Psychological, Physiological and Cognitive Abilities (RAD'LÔ). European Journal of Trauma and Dissociation ([under revision]).
[97] G. Prete, D. Marzoli, A. Brancucci, L. Tommasi, Hearing it right: evidence of hemispheric lateralization in auditory imagery, Hear. Res. 332 (2016) 80–86, https://doi.org/10.1016/j.heares.2015.12.011.
[98] I. Saliba, M.E. Nader, F. El Fata, T. Leroux, Bone anchored hearing aid in single sided deafness: outcome in right handed patients, Auris, nasal, larynx. 38 (5) (2011) 570–576, https://doi.org/10.1016/j.anl.2011.01.008.
[99] R.B. Bechtel, A. Berning, The third-quarter phenomenon: do people experience discomfort after stress has passed? in: A.A. Harrison, Y.A. Clearwater, C.P. McKay (Eds.), From Antarctica to Outer Space: Life in Isolation and Confinement Springer Verlag, 1990.
[100] J. Stuster, C. Bachelard, P. Suedfeld, The relative importance of behavioral issues during long-duration ICE missions, Aviat Space Environ. Med. 71 (9 Suppl) (2000). A17–A25.
[101] G.M. Sandal, Coping in Antarctica: is it possible to generalize results across settings? Aviat Space Environ. Med. 71 (9 Suppl) (2000). A37–A43.
[102] G.D. Steel, Polar moods: third-quarter phenomena in the Antarctic, Environ. Behav. 33 (1) (2001) 126–133, https://doi.org/10.1177/00139160121972909.
[103] K. Weiss, P. Suedfeld, G.D. Steel, M. Tanaka, Psychological adjustment during three Japanese Antarctic research expeditions, Environ. Behav. 32 (1) (2000) 142–156, https://doi.org/10.1177/00139160021972478.
[104] D. Wilson, The third-quarter phenomenon in Antarctic personnel, Gateway Antarctica, Lit. Rev. 285 (2011).
[105] O. Kokun, L. Bakhmutova, Dynamics of indicators of expeditioners' psychological states during long Antarctic stay, Int. J. Psychol. Psychol. Ther. 20 (1) (2020) 5–12.
[106] E. Langeland, H.F. Vinje, The significance of salutogenesis and well-being in mental health promotion: from theory to practice, in: C.L. Keyes (Ed.), Mental Well-Being: International Contributions to the Study of Positive Mental Health, Springer, New York, 2013.
[107] T. Wolfe, The Right Stuff, Farrar Straus & Giroux, 1979.
[108] P. Suedfeld, What can abnormal environments tell us about normal people? Polar stations as natural psychology laboratories, J. Environ. Psychol. 18 (1) (1998) 95–102, https://doi.org/10.1006/jevp.1998.0090.
[109] S. Blight, K. Norris, Positive psychological outcomes following Antarctic deployment, The Polar Journal 8 (2018) 351–363, https://doi.org/10.1080/2154896X.2018.1541552.
[110] H.R. Guly, Psychology during the expeditions of the heroic age of Antarctic exploration, Hist. Psychiatr. 23 (90 Pt 2) (2012) 194–205, https://doi.org/10.1177/0957154X11399203.
[111] L.A. Palinkas, Going to extremes: the cultural context of stress, illness and coping in Antarctica, Soc. Sci. Med. 35 (5) (1982) 651–664, https://doi.org/10.1016/0277-9536(92)90004-a, 1992.
[112] L.A. Palinkas, D. Browner, Effects of prolonged isolation in extreme environments on stress, coping, and depression 1, J. Appl. Soc. Psychol. 25 (7) (1995) 557–576.
[113] R.S. Lazarus, Coping strategies, in: S. McHugh, T.M. Vallis (Eds.), Illness Behavior, Springer, 1986, pp. 303–308.
[114] R.S. Lazarus, S. Folkman, Stress, Appraisal and Coping, Springer, 1984.
[115] R.S. Lazarus, S. Folkman, Stress and Coping, Springer, 1985.
[116] R.L. DeHart, Fundamentals of Aerospace Medicine, Lea & Febinger, Philadelphia, 1985.
[117] J. Leach, Psychological factors in exceptional, extreme and torturous environments, Extreme Physiol. Med. 5 (2016) 7, https://doi.org/10.1186/s13728-016-0048-y.
[118] K.W. Brown, R.M. Ryan, The benefits of being present: mindfulness and its role in psychological well-being, J. Pers. Soc. Psychol. 84 (4) (2003) 822–848, https://doi.org/10.1037/0022-3514.84.4.822.
[119] A. Chiesa, A. Serretti, Mindfulness-based stress reduction for stress management in healthy people: a review and meta-analysis, J. Alternative Compl. Med. 15 (5) (2009) 593–600, https://doi.org/10.1089/acm.2008.0495.
[120] J. Kabat-Zinn, Wherever You Go, There You Are: Mindfulness Meditation in Everyday Life, Hyperion, New York, 1994.
[121] B. Le Roy, C. Martin-Krumm, M. Trousselard, Mindfulness for adaptation to analog and new technologies emergence for long-term space missions, Frontiers in Space Technologies 4 (2023) 1109556, https://doi.org/10.3389/frspt.2023.110955.
[122] S. Biddle, K. Fox, S. Boutcher, Physical Activity and Psychological Well-Being, first ed., Routledge, 2000 https://doi.org/10.4324/9780203468326.
[123] S.N. Blair, H.W. Kohl 3rd, R.S. Paffenbarger Jr., D.G. Clark, K.H. Cooper, L. W. Gibbons, Physical fitness and all-cause mortality. A prospective study of healthy men and women, JAMA 262 (17) (1989) 2395–2401, https://doi.org/10.1001/jama.262.17.2395.
[124] H.W. Kohl 3rd, K.E. Powell, N.F. Gordon, S.N. Blair, R.S. Paffenbarger Jr., Physical activity, physical fitness, and sudden cardiac death, Epidemiol. Rev. 14 (1992) 37–58, https://doi.org/10.1093/oxfordjournals.epirev.a036091.
[125] K.S. Fraser, D.K. Greaves, J.K. Shoemaker, A.P. Blaber, R.L. Hughson, Heart rate and daily physical activity with long-duration habitation of the International Space Station, Aviat Space Environ. Med. 83 (6) (2012) 577–584, https://doi.org/10.3357/asem.3206.2012.
[126] I.B. Kozlovskaya, A.I. Grigoriev, V.I. Stepantzov, Countermeasure of the negative effects of weightlessness on physical systems in long-term space flights, Acta Astronaut. 36 (8–12) (1995) 661–668, https://doi.org/10.1016/0094-5765(95)00156-5.
[127] S. Schneider, V. Brümmer, H. Carnahan, J. Kleinert, M.F. Piacentini, R. Meeusen, H.K. Strüder, Exercise as a countermeasure to psycho-physiological deconditioning during long-term confinement, Behav. Brain Res. 211 (2) (2010) 208–214, https://doi.org/10.1016/j.bbr.2010.03.034.
[128] G. Collet, O. Mairesse, A. Cortoos, H.F. Tellez, X. Neyt, P. Peigneux, E. Macdonald-Nethercott, Y.M. Ducrot, N. Pattyn, Altitude and seasonality impact on sleep in Antarctica, Aerosp. med. hum. perform. 86 (4) (2015) 392–396, https://doi.org/10.3357/AMHP.4159.2015.
[129] C. Martin-Krumm, B. Lefranc, A. Moelo, C. Poupon, J. Pontis, A. Vannier, M. Trousselard, Is regular physical activity practice during a submarine patrol an efficient coping strategy? Front. Psychiatr. 12 (2021) 704981 https://doi.org/10.3389/fpsyt.2021.704981.
[130] J.L. Bower, M.S. Laughlin, C. Connaboy, R.J. Simpson, C.A. Alfano, Factor structure and validation of the mental health checklist (MHCL) for use in isolated, confined and extreme environments, Acta Astronaut. 161 (2019) 405–414, 10.1016/j.actaastro.2019.03.007.
[131] M. Nicolas, G. Martinent, M. Gaudino, P. Suedfeld, Assessing psychological adaptation during polar winter-overs: the isolated and confined environments questionnaire (ICE-Q), J. Environ. Psychol. 65 (2019) 101317, https://doi.org/10.1016/j.jenvp.2019, 101317.

Abbreviations

A: Appetite
ADAC: Activation-Deactivation Adjective Checklist
ANS: Autonomic Nervous System
BF: Bayesian Factor
DDU: Dumont d'Urville station
EA: Energetic Arousal
EduFlow: Educational Flow Questionnaire

ETOC: European Test of Olfactory Capabilities
FMI: Freiburg Mindfulness Inventory
GHQ: General Heath Questionnaire
HF: High-Frequency
HN: Very limited or no existence of minor non-psychiatric or psychotic disorders
HRV: Heart Rate Variability
ICE: Isolated and Confined Environments
LDSE: Long-Duration Space Flight
LEEDS: Leeds Sleep Evaluation questionnaire
LF: Low-Frequency
MAIA: Multidimensional Assessment of Interoceptive Awareness
MD: Mindfulness Disposition
OR: Standard values for non-psychiatric or minor psychotic disorders within the general population
PHS: Personal Hierarchical Sensory
pNN50: Percentage of adjacent NN intervals that differ from each other by more than 50 ms
PSS: Perceived Stress Scale
PTT: Pure Tone Testing
RMSSD: Root Mean Square of Successive Differences
RR: Successive variation of the intervals between two heartbeats
SMMGC: Standard Model of Military Group Cohesion
SA: Sensory Acuity
SD1: Standard Deviation of short-term RR variability
SD2: Standard Deviation of long-term RR variability
SDNN: Standard Deviation of the Normal-to-Normal RR interval (SDNN)
SPANE: Scale of Positive and Negative Experience
TA: Tense Arousal
VAS: Visual Analogue Scale
$\alpha 1$: detrended fluctuation analysis self-similarity parameter that represented short-term fluctuations
$\alpha 2$: detrended fluctuation analysis self-similarity parameter that represented long-term fluctuations