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Mindfulness disposition as a protective factor against stress in Antarctica: A potential countermeasure for long-duration spaceflight?

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ABSTRACT

Background: Long-duration missions in isolated, confined, and extreme environments, including Antarctica and upcoming deep-space operations, can be a source of increased stress. The identification of countermeasures and protective factors is required to support health and performance in similar contexts. Mindfulness disposition is an optimal candidate, but no research has ever explored this potential association.
Methods: Twenty-four crew members from two Antarctic expeditions at the Concordia base were repeatedly assessed over the course of a 12-month mission for stress (Perceived Stress Scale) and mindfulness, using multiple assessment measures, including the Mindful Attention and Awareness Scale (MAAS), the Langer Mindfulness Scale (LMS), the Breath Counting Task, and the Triangle Task.
Results: Results indicate a strong negative association over time between mindfulness and stress, particularly when measured with the MAAS and the LMS. Higher MAAS baseline values were also good predictors of lower stress patterns during the mission.
Conclusions: Mindfulness disposition was negatively associated with stress over time, suggesting that it can play an important role in stress mitigation in isolated and confined environments, including long-duration space missions. Furthermore, a mindfulness assessment could be added to the crew selection procedure.

1. Introduction

Transitioning from low-earth orbit operations to long-distance exploration, the crews of space missions will encounter a distinct set of experiences and stressors. Astronauts will be subjected to various challenges that can significantly impact their well-being, including isolation and confinement within small working environments, long distances from home, friends, and relatives, communication delays, adaptation to microgravity, exposure to radiation, and monotony (Pagnini, Manzey, et al., 2023; Stahn et al., 2023). These stressors can lead to detrimental effects on mood and performance, making it essential to develop preventative countermeasures that promote cognitive and behavioral health, manage stress, and prevent performance loss (Crucian et al., 2018; De La Torre et al., 2012).

Developing and testing countermeasures directly in space poses significant challenges due to limited resources, including time and space, as well as the small number of astronauts who can participate in these studies. Therefore, most research about medical and psychological countermeasures are preliminarily tested in analog environments, which simulate some of the key stressors that astronauts will experience during space missions, including confinement, isolation, and limited communication. Examples of analog environments include dedicated facilities and platforms, such as NEEMO (NASA Extreme Environment Mission Operations) (Todd & Reagan, 2004), HERA (NASA Human Exploration Research Analog) (Vessey, Cromwell, & Platts, 2017), the MARS-500 (Feichtinger et al., 2012) and SIRIUS (Belakovsky, Voloshin, & Suvorov, 2019) projects, as well as research stations located in extreme and remote environments, such as deserts, caves, or polar regions like Antarctica. A recent systematic review (Le Roy, Martin-Krumm, Pinol, Dutheil, & Trousselard, 2023) on analog

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environments has emphasized the need for additional analog studies, in particular in longer duration contexts and in extreme condition contexts. Analog environments such as the Antarctic bases are considered the ideal laboratory for the study of "positive capsule psychology" (Suedfeld & Steel, 2000, p. 229). This analog can provide insights into how psychological resources can be fostered in a confined and isolated environment, turning a stressful setting into a healthy and adaptive one (Palinkas, 2003).

One of the most prominent psychological constructs currently studied is mindfulness (Alvear, Soler, & Cebolla, 2022). While not amenable to an absolute definition, the concept is multifaceted and is studied in multiple domains. Two general approaches frame the "mindfulness" construct (Siegel, 2007): one that defines mindfulness in terms of present-moment awareness, as originally rooted in the Buddhist tradition, and a second construct that frames mindfulness as a cognitive process of novelty-seeking. The Buddhist-tradition construct developed as a scientifically testable, westernized construct by Jon Kabat-Zinn (Kabat-Zinn, 1990). He defines mindfulness as "the awareness that emerges through paying attention on purpose, in the present moment, and nonjudgmentally to the unfolding of experience moment by moment" (Kabat-Zinn, 2003, p. 145). It centers on awareness of the present moment with a non-evaluative perspective. The second approach focuses on the cognitive process of novelty seeking, including openness as a core construct. While in harmony with the principles of meditation-based mindfulness, this approach uses a socio-cognitive framework for understanding and achieving mindfulness and has in more recent years been tied to cognitive abilities, personality, and cognitive styles (Sternberg, 2000). It developed in social psychology and comprised over 40 years of studies conducted primarily by Ellen Langer (Langer, 1989; Langer, Blank, & Chanowitz, 1978). This construct of mindfulness focuses more on the process (*being* mindful) rather than focusing on an outcome (*achieving* mindfulness through meditation and similar interventions). Being mindful means that we observe the world as always changing and, therefore, exists in a state of uncertainty; embracing uncertainty facilitates being present (Langer & Moldoveanu, 2000). When mindful, people are sensitive to what is happening in the current situation, welcome what is new, create new ways of thinking about things by using new categories for structuring perception, and formulate multiple solutions through the use of differentiated and broad perspective-taking when problem-solving (Langer & Moldoveanu, 2000). This awareness of multiple perspectives helps reduce the need for previously established categories, promoting mind-openness (Langer, 1992). As a consequence, our inclination to judgments also changes; instead, a mindful perspective suggests that an event is not "good" or "bad" in itself because it depends on the individual's point of view (Langer, 1989). Mindfulness can be considered as the opposite of "mindlessness", when a person acts on an automatic pilot, with limited or no awareness (Langer, 1989). Mindfulness has been reported in a variety of studies as a protective factor against stress (Pagnini & Phillips, 2015), by fostering a mental framework characterized by present-moment awareness (Donald, Atkins, Parker, Christie, & Ryan, 2016) and non-judgmental acceptance (Lindsay, Young, Smyth, Brown, & Creswell, 2018). Individuals with a predisposition toward mindfulness exhibit an enhanced ability to observe and engage with their thoughts and emotions in a balanced manner, transforming overwhelming challenges to manageable experiences (Iani, Lauriola, Chiesa, & Cafaro, 2019). Mindful attention reduces the impact of negative priors (expectations and beliefs), increasing the salience of current experience (Pagnini, Barbiani, et al., 2023) and leading, as a consequence, to a more adaptive response to the stressors (Finkelstein-Fox, Park, & Riley, 2019).

In a study commissioned by NASA (Pagnini, Phillips, Bercovitz, & Langer, 2019), several subject matter experts (e.g., psychiatrists) as well as current and former astronauts considered mindfulness as a particularly relevant construct for space exploration. Mindfulness-based practices are considered applicable in the space context and have high potential for astronauts' health and performance. In line with these conclusions, mindfulness training has been reported as one of the most promising countermeasures to mitigate the psychological demands of spaceflight but still needs further analog-based research before being implemented in space (ESA, 2021). However, the current level of evidence for mindfulness applications in space only relies on expert opinions, with no direct empirical data to support it. While there is no study to date that has specifically investigated the role of mindfulness in space or in analog environments (Pagnini et al., 2019), some findings on related psychological constructs seems to confirm the positive role of mindfulness core components. For example, Palinkas and Suedfeld (Palinkas & Suedfeld, 2008) reported positive psychological effects in polar expeditions when the person mindfully recognizes the variety or novelty in the experience and the differences in the current situation from the past. Moreover, Antarctic personnel who were considered exceptionally well adapted according to station commanders showed high levels of openness, which is a central component of mindfulness Grant et al., 2007). Conversely, mindlessness can have negative impacts on task performance during long-term missions (Nicolas, Suedfeld, Weiss, & Gaudino, 2015): while considerable variations exist in how individuals respond to extreme environmental challenges (Mairesse et al., 2019), cognitive decrements have been observed in people who have spent prolonged periods in polar stations (Kanas et al., 2009), frequently reporting experiencing prolonged lapses of attention, colloquially referred to as the "Antarctic stare" or the "Long Eye" (Palinkas & Browner, 1995). Only one research study has investigated the potential role of mindfulness in an isolated and confined environment, in the context of a nuclear submarine (Aufauvre-Poupon et al., 2021). In this study, mindfulness was strongly associated with reduced stress, although the effects were only explored for approximately 2 months. No information on this topic for a longer duration mission is currently available.

Considering the potential role of mindfulness and the absence of studies that have directly explored it in analog and extreme environments, the MINDFUL-ICE study aimed to:

1. Investigate dispositional mindfulness as a predictor for lower stress over the course of long-term missions in isolated, confined, and extreme (ICE) environments;
2. Explore time-related changes of mindfulness in this context;
3. Understand which assessment strategy is the best predictor for lower stress.

To reach these aims, we have conducted a study in the Concordia station, a research base located in Antarctica that is a high-fidelity analog environment, sometimes defined as the "White Mars" (Van Ombergen, Rossiter, & Ngo-Anh, 2021). Based on current literature considerations, the general study hypothesis is that mindfulness would be negatively associated with stress.

2. Methods

2.1. Study design

The study design is a longitudinal cohort study with a multimodal assessment of mindfulness in the Concordia winter crew, compared against self-reported stress values. Participants were assessed at the pre-departure baseline and every three months while at the station (months 1, 4, 7, and 10, as depicted in Fig. 1), with a one-week flexible window to accommodate the various duties for each crewmember. They also received a post-mission assessment about 6 months after their return, which was the first post-mission meeting of the crew. The data collection time points were flexible, allowing for a one-week timeframe to account for crew duties. The assessment was conducted through a local computer, and data were locally stored. The ESA MDs (ST and NS), trained physicians responsible for conducting studies supported by the European Space Agency, oversaw data collection on site. They received

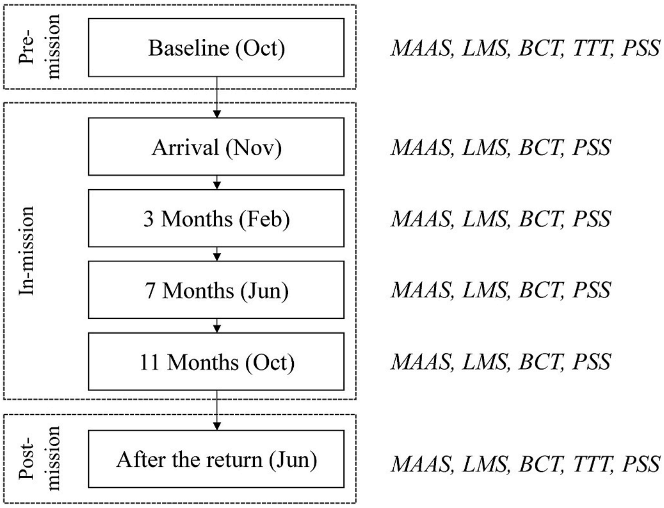


Fig. 1. Assessment times and study flow (MAAS = Mindful Attention and Awareness Scale; LMS=Langer Mindfulness Scale; BCT=Breath Counting Task; TTT = The Triangle Task; PSS=Perceived Stress Scale).

specific training to answer any participants' questions on the instruments, although the assessment was completely self-conducted. The assessment times are summarized in Fig. 1.

2.2. Setting

Concordia Station is a research base located in Antarctica, specifically on the Antarctic Plateau at an altitude of 3233 m (10,607 ft) above sea level, at Dome C (Van Ombergen et al., 2021). It was created by the Institut Polaire Français Paul-Emile Victor (IPEV, the French Polar Institute) and the Consorzio per l'Attuazione del Programma Nazionale di Ricerche in Antartide (PNRA, the Italian Antarctic Programme), and it has been staffed since November 2004. The station is jointly operated by France and Italy and primarily serves as a hub for scientific research in areas including astronomy, glaciology, and climate science. During winter, the station accommodates up to 16 crew members, including technicians and scientists, and becomes completely isolated from the rest of the world for 9 months, making it a more remote outpost than the International Space Station. Its unique location, the extreme cold (temperatures can drop as low as −80 °C), dryness, altered day-night cycles, isolation, and confinement, offer an exceptional opportunity for researchers to study the effects of such living conditions on human health and performance. Concordia Station stands as one of the few places on Earth that closely simulates the extreme environment astronauts may encounter during long-duration space missions. Consequently, it has been utilized as an analog environment for testing technologies and psychological countermeasures that could be employed during space missions.

2.3. Participants

Twenty-four crew members from two winter-over Concordia missions (WO2020 and WO2021) participated in the study. Among them, there were 5 (19%) women, and the average age at the baseline assessment was 39.96 (SD = 11.42). The educational backgrounds of the participants included middle/high school diplomas (N = 4, 15%), Bachelor's degrees or equivalent (N = 11, 42%), and advanced degrees (Master's, Ph.D., MD; N = 11, 42%). Seven participants (27%) reported prior meditation experiences. All participants underwent psychological testing during the selection process to exclude existing psychiatric conditions. Participants were selected by IPEV and PNRA in the months before the deployment, based on the mission requirement. The crew included technical staff (e.g., electricians, mechanicals, cooks) and scientists. All crew members agreed to join the study.

The study received ethical approval from the Ethics Commission of the Department of Psychology at Università Cattolica del Sacro Cuore (cod.36-18), and all participants provided informed consent before participating.

2.4. Measures

The assessment battery, which was available in three languages (English, Italian, and French) based on the participants' preferences, included:

- The *Mindful Attention Awareness Scale* (MAAS) is a 15-item self-report measure designed to assess a core characteristic of mindfulness, specifically one's receptive awareness of and attention to the present moment (Brown & Ryan, 2003). It has demonstrated excellent psychometric properties, with factor analyses conducted among undergraduate, community, nationally sampled adult, and adult cancer populations confirming a single-factor scale structure (Osman, Lamis, Bagge, Freedenthal, & Barnes, 2016). The scale is available in multiple languages, including Italian (Veneziani & Voci, 2015) and French (Jermann et al., 2009). Scores range from 1 to 6, with higher numbers associated with higher mindfulness.
- The *Langer Mindfulness Scale* (LMS) is a 14-item questionnaire that assesses three domains describing mindful thinking: novelty seeking, engagement, and novelty producing (Pirson, Langer, Bodner, & Zilcha-Mano, 2012). It demonstrated reliable psychometric validity (Haigh, Moore, Kashdan, & Fresco, 2011). The LMS has been translated and validated in Italian (Pagnini, Bercovitz, & Phillips, 2018), and the French version underwent a rigorous process of back translation. Scores range from 1 to 7, with higher numbers associated with higher mindfulness.
- The *Breath Counting Task* (BCT) was developed as an "objective" assessment of mindfulness skills (Levinson, Stoll, Kindy, Merry, & Davidson, 2014), and a measure of present moment awareness. Participants use a computer or smartphone to count breaths from 1 to 9 repeatedly for 18 min. They press one button for breaths 1–8 and another for breath nine. The number of accurately tracked groups of nine breaths is associated with mindfulness disposition (Davidson & Kaszniak, 2015). The scores is represented by the number of mistakes, with higher number associated with lower mindful attention.
- *The Triangle Task* (TTT) is an instrument developed as a direct assessment of mindfulness (Bercovitz, Pagnini, Phillips, & Langer, 2017) to overcome the limitations of declarative knowledge (Bergomi et al., 2012). It consists of 50 words with varying levels of abstraction (e.g., "kite," "fire," "happiness," and "infinity"). Participants are instructed to check the box next to all the items they believe are related to the word "triangle" and encouraged to provide a short description of the relationship in an adjacent textbox. The scoring system reflects the number of items marked as having a relationship with "triangle," with higher scores indicating more connections identified. The TTT was only administered at the baseline assessment and at the participants' return. Scores range from 0 to 50, with higher scores indicating higher mindful creativity.
- The *Perceived Stress Scale* (PSS), developed by Cohen and colleagues (Cohen, Kamarck, & Mermelstein, 1983), is arguably the most commonly used tool for assessing stress. It consists of 10 items and has been validated in English, Italian, and French. Individual scores range from 0 to 40, with higher scores indicating higher perceived stress.

2.5. Statistical analyses

Time trends were analyzed using general linear models for repeated measures. Post-mission scores were excluded from these analyses. Pre/post-mission changes were evaluated using paired t-tests. The longitudinal association between mindfulness and stress was examined through mixed-effects models, applied individually for each relevant instrument, and employing PSS values as the dependent variable. Time points were organized as time-varying elements to accommodate temporal shifts, and a random effect was introduced to address variations among individual subjects. The covariance matrix was chosen as autoregressive (AR), incorporating diverse variances across the three assessment times. Additionally, mixed-effect models were employed to ascertain whether baseline mindfulness scores could predict stress levels over time. Missing data were handled per protocol, and the analyses have been run on all the available data. For illustrative purposes, the sample was divided by utilizing median baseline mindfulness scores, and sub-cohorts were compared using repeated measures GLMs. These analyses were carried out using SPSS and R statistical software.

3. Results

Descriptive statistics of the outcomes over time are reported in Table 1. The overall attrition rate was 10% over the mission, with 6 participants (23%) who did not participate in the post-mission assessment. There were no differences between the two mission crews on the MAAS ($F = 1.37$, $df = 1$, $p = .258$), the LMS ($F = 1.46$, $df = 1$, $p = .224$), the BCT ($F = 0.019$, $df = 1$, $p = .892$), or the TTT ($F = 0.682$, $df = 1$, $p = .420$). There was a significant correlation between the MAAS and the LMS scores ($r = 0.336$, $p=<.001$), and a negative correlation between these two measures and the PSS (respectively, $r = -0.519$, $p < .001$, and $r = -0.144$, $p = .094$). The other outcomes did not show any significant correlations.

Stress levels followed a quadratic trend ($F = 9.65$, $df = 1$, $p = .006$), with a slight decrease toward the sixth month, and an increase toward the end of the mission. Conversely, the opposite quadratic trend was observed on the MAAS ($F = 8.63$, $df = 1$, $p = .009$). The LMS did not show any changing trend. The BCT showed instead a linear reduction over time ($F = 10.85$, $df = 1$, $p = .004$). Time trends are reported in Fig. 2.

When comparing pre-departure and post-mission scores, there were no statistical differences, with the only exception of the TTT (see Table 2), which decreased in the post-mission.

The association between mindfulness and stress was particularly strong when mindfulness was assessed with the MAAS (F (1, 81.95) = 30.91, $p < .001$) and the LMS (F (1, 90.78) = 9.23, $p = .003$), but not with the BCT (F (1, 63.97) = 1.61, $p = .209$) (see Table 3).

The baseline MAAS values significantly predicted decreased PSS scores over time (F (1, 26.29) = 5.07, $p = .033$), while the other mindfulness assessments did not result in significant predictors (see Table 4).

When the cohort is split into two subgroups through the median of the baseline scores (MAAS = 4.6; LMS = 5.48; BCT = 2; TTT = 13.5), those with high MAAS scores show significantly different stress trends over time compared to others (F (1, 583.68) = 8.49, $p = .010$). No significant differences are shown when comparing the cohorts obtained by splitting with the LMS (F (1, 221.16) = 2.42, $p = .139$), the BCT (F (1, 51.68) = 0.51, $p = .487$), or the TTT (F (1, 0.001) = 0.00, $p = .998$). Fig. 3 illustrates the trends for the MAAS sub-cohorts.

4. Discussion

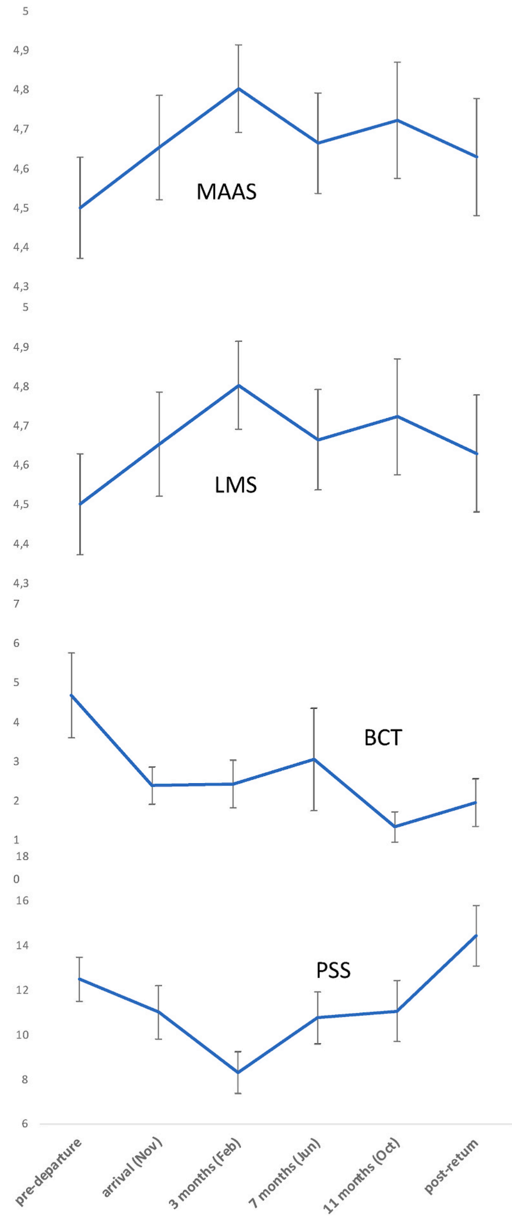
In this study, we collected data from two winter-over missions in the isolated, confined, and extreme Antarctic environment, specifically at the Concordia station, to investigate mindfulness disposition and stress over time. The results strongly support the initial hypothesis that mindfulness is associated with a lower level of stress, and mindfulness disposition can serve as an important protective factor in ICE missions. Initial mindfulness scores are predictive of lower distress levels during the mission. The association between mindfulness and reduced stress remained stable across time and different measurements. Among the instruments used, the MAAS emerged as the most predictive tool, followed by the LMS. These instruments evaluate different aspects of mindfulness disposition: the MAAS focuses on mindful attention and awareness, while the LMS evaluates the Langerian perspective on mindfulness, considering cognitive flexibility, openness, and creativity. The BCT and the TTT assess mindful attention and mindful creativity through direct tasks. As there is still a debate on mindfulness assessment tools (Baer, 2019), the divergence among the obtained results is interesting and relevant. Given the lack of correlations between the two assessment tasks and the two more well-established self-reported instruments, however, it can be argued that the former are not appropriate to evaluate mindfulness disposition in this context. The MAAS and the LMS both consider mindfulness as a disposition, but the scores can change over time. Consistent with its nature, mindfulness is something intrinsically flexible and changeable over time (Pagnini & Phillips, 2015), consistent with the changes reported during the study.

The longitudinal association with the BCT did not yield significant results, possibly influenced by a learning effect that led to a decrease in average error numbers over time. While LMS values remained consistent throughout the mission duration, those assessed with the MAAS showed an increase toward the central months of the mission followed by a decrease toward the end. This pattern aligns with the idea of novelty and excitement upon entering a new and challenging environment, which gradually becomes more familiar and, in some ways, less stimulating. Consequently, the impacts of isolation and confinement on mental presence and awareness appear to vary based on timing and habituation.

When comparing pre-departure and post-mission mindfulness scores, the only notable difference that emerged was a decrease in scores on the TTT. This observation might suggest that prolonged exposure to an isolated and confined environment could potentially lead to a reduction in creative thinking. This seems in line with MRI data collected from the German Neumayer III station, before and after 14 months of Antarctic isolation, (Stahn et al., 2019). Although creativity was not specifically assessed in that study, hippocampal circuits, which showed a reduction

Table 1
Assessed outcomes over time (mean, SD; N = number of participants in each assessment; MAAS = Mindful Attention and Awareness Scale; LMS=Langer Mindfulness Scale; BCT=Breath Counting Task; TTT = The Triangle Task; PSS=Perceived Stress Scale).

	Min-Max score		pre-departure	arrival (Nov)	3 months (Feb)	7 months (Jun)	11 months (Oct)	post-return
N			24	24	24	24	21	21
MAAS	1–6	Mean	4.50	4.65	4.80	4.66	4.72	4.63
		SD	.61	.65	.55	.62	.67	.68
LMS	1–7	Mean	5.42	5.44	5.49	5.33	5.36	5.34
		SD	.44	.59	.37	.49	.43	.39
BCT	0 – no max	Mean	4.67	2.38	2.42	3.04	1.33	1.95
		SD	5.26	2.30	2.96	6.37	1.77	2.64
PSS	0–40	Mean	12.48	11.00	8.29	10.75	11.05	14.43
		SD	4.73	5.86	4.56	5.71	6.25	6.21
TTT	0–50	Mean	15.32					12.57
		SD	8.08					7.23



	F	df	p
Linear	2.395	1	.14
Quadratic	8.632	1	.009
Cubic	1.842	1	.192

	F	df	p
Linear	.338	1	.568
Quadratic	1.656	1	.215
Cubic	.256	1	.619

	F	df	p
Linear	10.848	1	.004
Quadratic	2.711	1	.117
Cubic	.183	1	.674

	F	df	p
Linear	2.983	1	.102
Quadratic	9.653	1	.006
Cubic	.199	1	.661

Fig. 2. Time trends of the considered outcomes.

Table 2
Paired-sample t-tests comparing pre-post mission scores.

	T	df	*p*
MAAS	−.703	17	.491
LMS	.44	17	.665
BCT	1.581	16	.134
TTT	2.239	18	.038
PSS	−1.438	17	.169

Table 3
Longitudinal associations between the mindfulness outcomes and PSS (mixed-model effects).

Parameter	b	SE	p	95% CI
Intercept	32.517	3.912	<.001	(24.732, 40.302)
MAAS	−4.617	.830	<.001	(-6.270, −2.965)
Intercept	30.877	6.701	<.001	(17.557, 44.196)
LMS	−3.735	1.230	.003	(-6.178, −1.293)
Intercept	10.472	.853	<.001	(8.744, 12.200)
BCT	.127	.100	.209	(-.073, .328)

in their volume, are thought to be involved in creative thinking (Bendetowicz, Urbanski, Aichelburg, Levy, & Volle, 2017; Madore, Addis, & Schacter, 2015).

The trends in stress over time were found to be opposite to those observed in mindfulness scores, following a U curve. This finding deviates from prior studies that have reported either a linear trend toward the worsening of stress symptoms (Nicolas et al., 2015, 2022), or a relative stability of stress levels over time (Strewe et al., 2018, 2019). A similar trend, however, was identified in another study conducted at Concordia, which focused on coping skills (Sandal, van deVijver, & Smith, 2018). Here, it is important to recognize that at Concordia station, the first few months of the mission happen during the summer season (November to February), with up to 70 or more individuals on site. This pre-isolation period is typically perceived as stressful, until departure of the last summer crew and start of the isolation period in

Table 4
Predictive values of the pre-departure mindfulness outcomes on stress scores over time (mixed-model effects).

Parameter	b	SE	p	95% CI
Intercept	24.265	5.843	<.001	(12.259, 36.271)
MAAS	−2.900	1.291	.033	(-5.552, −.248)
Intercept	7.416	10.625	.492	(-14.453, 29.284)
LMS	.742	1.960	.708	(-3.291, 4.775)
Intercept	10.692	1.139	<.001	(8.355, 13.029)
BCT	.087	.174	.621	(-.269, .443)
Intercept	10.032	1.925	<.001	(6.062, 14.003)
TTT	.077	.112	.499	(-.154, .307)

February, where our data shows a corresponding decrease of distress. Thus, while both the summer and the winter seasons may be highly stressful (as anecdotical reported by the participants), the trend after February would be more reflective of the long-term exposure to space-like living conditions, including the isolation, confinement, lack of novelty, being far from "Earth", interpersonal conflicts, and stressful conditions living in Concordia for various months.

Individuals with higher dispositional mindfulness scores, as assessed with the MAAS prior to departure, experienced an overall lower level of distress in comparison to those with lower mindfulness scores. Notably, the disparities between the two cohorts became more pronounced during the latter part of the mission, as those with a more mindful disposition consistently maintained lower distress levels. While the correlational design does not allow for causal inferences, these results strongly suggest that, as stress levels increased over the course of the mission, a mindful disposition proved to be a crucial resource for mitigating stress and maintaining low distress levels. Therefore, interventions promoting mindfulness could represent a potential countermeasure against stress in isolated, confined, and extreme environments.

These results not only align with but also extend findings from another study that explored the relationship between mindfulness and psychological adaptation within a subsurface ballistic missile nuclear submarine during a 60-day period (Aufauvre-Poupon et al., 2021). However, our results suggest that this association may endure for considerably longer durations.

5. Strengths and limitations

This is the first study to explore the potential role of mindfulness disposition on long-term missions in isolated, confined, and extreme environments. Data suggest a clear trend, emphasizing a negative association between mindfulness and stress, both cross-sectionally and over time. Nevertheless, several limitations must be considered that are inherent in conducting research within ICEs, including the small sample size available, the flexible agenda for data collection (which would be less typical for a study conducted in space), and the length of the follow-up assessment, which was conducted on a convenience basis after 6 months (i.e., the first chance for the crew to be together after their return). Another potential source of bias arises from reliance on subjective surveys, where individual tendencies in self-reporting could confound the observed relationship between mindfulness and stress levels (e.g., through social desirability). The lack of an immediate post-mission assessment must be considered a study limitation. Finally, the limited sample sizes across all these studies and the varying conditions for each mission (e.g., the MINDFUL-ICE study was conducted during the coronavirus pandemic) present challenges to making direct cross-mission comparisons.

It is also important to recognize that even though the study was designed as a way to test hypotheses for long-duration space missions in an analog setting, differences between ICEs and their distinct characteristics could yield divergent outcomes (Suedfeld, 2018). For instance, while the current results offer valuable insights into human adaptation within a particular ICE, they may not be directly transferable to the space environment or other ICE environments due to the absence of microgravity, the presence of space radiation, variations in personal space, different crew compositions, among other factors. For the findings to be generalizable to similar contexts, replicating the study would be beneficial. Nevertheless, Concordia station is regarded as one of the highest-fidelity analogs available on Earth to help understand future life on a lunar or Martian base (Van Ombergen et al., 2021), and our study provides promising results to be tested in other isolated, confined, and extreme contexts.

6. Conclusions

Study results support the hypothesis that mindfulness exerts a protective role against stress in ICEs. The selection process of ICE mission crew members, including the identification of astronaut candidates, could include an assessment of mindfulness traits, by using the MAAS or a similar instrument. Furthermore, as in future long-duration space missions, these crews will face new challenges and risks, including stress and negative emotions, which in turn could develop into potentially

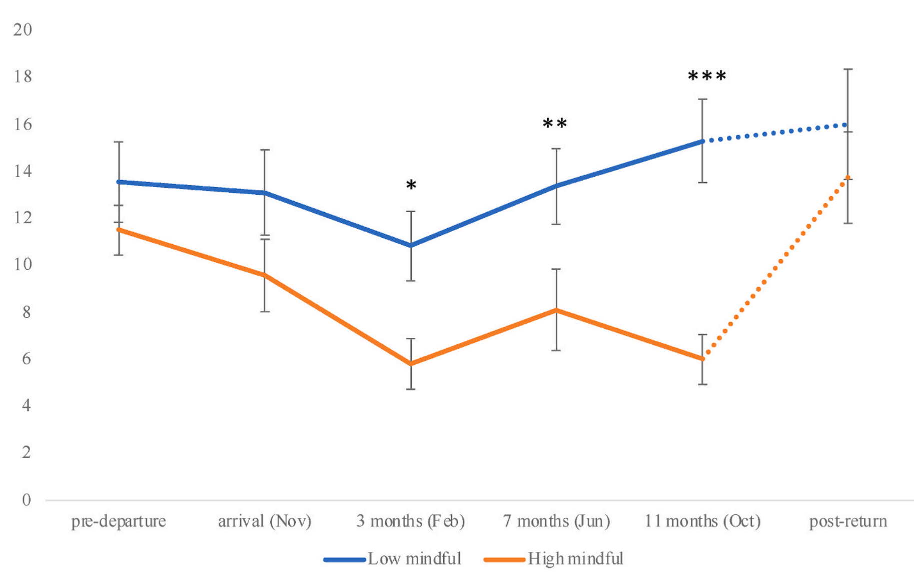


Fig. 3. Longitudinal stress values (PSS) distinguished by baseline MAAS value cohorts (* = p < .05; ** = p < .01; *** = p < .001).

dangerous cognitive or behavioral symptoms (Pagnini, Manzey, et al., 2023; Stahn et al., 2023). It is therefore important to develop preventive countermeasures to promote emotional and behavioral health, manage stress and prevent loss of performance. These results pave the way for the development of a specific mindfulness-based intervention for long-duration ICE missions, aimed to reduce stress and improve psychosocial adaptation. This is an empirical support to the published reflections and consensus among subject matter experts, recommending mindfulness training as an important tool to be considered for long-duration missions in outer space (Le Roy et al., 2023; Pagnini et al., 2019; Pagnini, Manzey, et al., 2023).

Author contributions

Francesco Pagnini: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. Francesca Grosso: Data curation, Methodology, Validation, Writing – review & editing. Angelique Van Ombergen: Conceptualization, Resources, Supervision. Nick Smith: Data curation, Investigation, Methodology, Writing – review & editing. Stijn Thoolen: Data curation, Investigation, Methodology, Writing – review & editing. Deborah Phillips: Conceptualization, Investigation, Methodology, Validation, Writing – review & editing. Ellen Langer: Conceptualization, Supervision, Writing – review & editing

Ethical approval

The study received ethical approval from the Ethics Commission of the Department of Psychology at Università Cattolica del Sacro Cuore (cod.36-18).

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Informed consent

All participants provided informed consent before participating.

Declaration of competing interest

None reported.

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