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Challenges and interpersonal dynamics during a two-person lunar analogue Arctic mission

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Introduction: This case study was designed as an analog for aspects of NASA's planned Artemis missions to the lunar surface. The specific aims were to examine emerged mission challenges and dyadic affective and process dynamics over the course of a three-month lunar habitat analog Arctic mission.

Methods: Participants were two men who also had key roles in designing the habitat. Pre- and post- expedition interviews were conducted and daily satellite phone messages to mission control over the three-month mission were assessed. An integrated mixed methods approach was used to analyze challenges, group affect, and group processes, with the goal of furthering the understanding of coping and psychosocial work experiences in challenging conditions.

Results: The findings indicated that different challenges took distinct temporal trajectories across mission phases; based on the relational themes, several challenges were identified, primarily physical challenges related to the experience of coping in an ICE environment, and psychosocial challenges associated with the preparation and execution of mission tasks. Physical challenges, positive tone, and action processes were the themes most connected to each other. To deal with these challenges, the team adapted by more frequently engaging in action and transition processes. The specific training for the mission the participants engaged in, and prior knowledge about each other enabled team members to deal with mission exigencies while maintaining a positive outlook.

Discussion: Fostering strong positive relationships was an important mechanism to build resilience and effective performance while under ongoing, extreme conditions.

KEYWORDS

teamwork, challenges, lunar, analogue missions, Artic

1 Introduction

Teamwork in isolated, confined, and extreme environments has provided humankind with unprecedent achievements like reaching the bottom of Mariana's trench, climbing to the summit of Everest, and walking on the surface of the Moon. However, the adversity that characterizes these and other environments poses great challenges to human collaboration and survival, including the ability to successfully cope and adapt in the face of uncertainty (e.g., Bell et al., 2015; Salas et al., 2015). Hence, the extent to which humans will become an interplanetary species capable of thriving in a planet with environmental and socio-political conditions that are more extreme than Earth conditions, poses unanswered questions and challenges.

Psychological research in the polar regions has been carried out for more than half-a-century, providing important contributions for identifying the drivers of optimal individual and team performance in isolated, confined, and extreme environments on Earth and in space (Love and Bleacher, 2013; Tafforin, 2015; Landon et al., 2018; Nicolas et al., 2021; Palinkas and Suedfeld, 2021). Isolated, confined, and extreme (ICE) environments provide a natural, living laboratory to conduct social sciences research because the contextual features of these environments make human behaviors more salient and potentially more observable; this facilitates the identification of human and social phenomenon that would be otherwise unobservable (e.g., psychological hibernation Sandal et al., 2018). Research in ICE environments also has the potential to enhance existing knowledge about individual and group dynamics during short and long duration space missions (e.g., Leon et al., 2011; Love and Bleacher, 2013; Tafforin, 2015; Peuker and Faller, 2021; Palinkas and Suedfeld, 2021; Käosaar et al., 2022). Further, the COVID-19 pandemic has shown how the lessons learned from social sciences studies in ICE environments can aid in the development and implementation of biological and psychosociological protocols to preserve physical and mental health amidst isolation and confinement amongst general population (Nash et al., 2022; Van Cutsem et al., 2022).

Although there are elements of the space environment that cannot be reproduced on Earth (e.g., microgravity, exposure to space radiation, distance from Earth), the small number of astronauts available to study, even with the aggregation of data from multiple space missions, encourage the pursuit of research in analogue contexts such as the polar regions (Bruguera et al., 2021). Longitudinal studies of team functioning during polar expeditions and confined polar work settings have highlighted the importance of appropriate communication, adequate decision-making, and conflict resolution to foster positive team outcomes related to effective task performance, team cohesion, and satisfaction (Kjærgaard et al., 2013; Corneliussen et al., 2017; Blackadder-Weinstein et al., 2019). Agreement on the daily objectives of the endeavor and congruence between personal and team goals are also factors that have a significant influence on optimal team performance (Kjærgaard et al., 2013; Kjærgaard et al., 2015; Blackadder-Weinstein et al., 2019; Kjærgaard et al., 2022).

In contrast to analogue studies conducted in confined laboratory settings, lunar or Mars analogue case studies and research with a larger number of participants, carried out in extreme ICE environments, provide prime conditions to learn how individuals, dyadic teams and larger groups adapt to realistic extreme and potentially dangerous mission challenges. Although human adaption takes place on the individual-level, most individuals, especially in extreme contexts, are nested in teams (Golden et al., 2018; Käosaar et al., 2022)—i.e., two or more individuals who dynamically interact to adapt to the changes in their environment (Mathieu et al., 2019). Therefore, the behaviors, affect, and eventual adaptation of the individual is highly dependent on the respective reactions of their team members, and *vice versa*, creating a new team-level dynamic system of human adaptation (Blight and Norris, 2018). Thus, for understanding the mechanisms of adaptation to adversity in ICE environments, a multilevel level approach that focuses both on individual and collective processes needs to be applied.

Based on the notion of individuals nested in teams, existing team adaptation models focus simultaneously on individual- and team-level attributes that enhance adaptation effectiveness–i.e., the extent to which adaptation leads to positive outcomes for individuals and teams, including task related and team related outcomes such as goal accomplishment and cohesion (Burke et al., 2006; Christian et al., 2017; Palinkas and Suedfeld, 2021). For example, Blight and Norris (2018) introduced a temporally dynamic model of Adaptive Team Performance in which individual characteristics (e.g., knowledge and abilities) become a team-level variable through emergence and job design characteristics. Shared mental models, team situation awareness, and psychological safety were introduced as the three most influential emergent states affecting the adaptation cycle. Later, Maynard et al. (2015) introduced a Team Adaptation Nomological Network including individual-, team-, and organizational-level factors feeding into team adaptation processes mediated by communication, coordination, cognition, and empowerment. These factors indicate the efficacy of team adaptive outcomes, i.e., team performance, decision effectiveness, affective reactions, and creativity.

Recently, several authors highlighted the importance of considering the nature of the adaptation triggers, or challenges, for understanding the factors that predict the success of team processes and emergent states in driving team adaptation (e.g., Maynard et al., 2015). Salas (2017), for example, theorized on how the timing of adaptation triggers (i.e., events that once perceived, lead teams to modify their team processes) within the team's lifecycle; the duration of the adaptation processes, and the frequency of occurrence of the trigger(s) determine how well teams adapt. Alliger et al. (2015) also laid out a set of common team challenges that may disrupt a team's performance (e.g., time pressure, challenging conditions, and unclear team roles), emphasizing the importance of considering triggers as part of the system of teams dealing with adversities.

Sandal et al. (2006) designated four main categories of inputs affecting adaptation in ICE environments: physical conditions (e.g., temperature and weather conditions), habitability and life support (e.g., space and noise), crew characteristics (e.g., heterogeneity and member attributes), and mission attributes (e.g., workload and duration). Because of its relevance to ICE environments, and the limited number of empirical studies that explicitly address the role these challenges on individual and team adaptation, the current study assessed how these four main categories of adaptation challenges proposed by Sandal et al. (2006) influence the adaptation dynamics of a two-person lunar analogue Arctic mission over the course of a 3-month period.

However, one of the less studied phenomena related to team adaptation is group affect (Maynard et al., 2015), defined as an emergent state of a group driven by both top-down and bottom-up processes influencing affective states such as emotions and moods (Barsade and Knight, 2015). In the context of team adaptation, group affect may act as an input (Rico et al., 2020), a boundary condition to team adaptation processes, and even function as an outcome of team adaptation (Maynard et al., 2015). Existing research has found significant relationships between affective states and performance (Barsade and Gibson, 2007), team efficacy (Kaplan et al., 2013), and reaction to stimuli (SAGA, 2023). Nonetheless, current empirical findings remain insufficient to make precise statements about causality. The extent to which individuals and teams engage in collective group processes to adapt to triggers or challenges during missions in ICE environments likely will have a positive effect on the individual and on collective affective reactions, with immediate implications for the improvement of the overall team environment (Barsade and Gibson, 2007; Maynard et al., 2015). This process, in turn, should minimize team related conflict and other challenges, and therefore enable further adaptation (Bell et al., 2019; Larson et al., 2019; Zhang et al., 2021).

The successful modification of different individual and collective processes has been positively associated with adaptation. Individual psychological adaption, group dynamics, performance, error management, safety, and individual health and wellbeing, and the interplay of these processes, have been identified as determining team adaptation outcomes (Sandal et al., 2006; Golden et al., 2018). Situation assessment, plan formulation and execution (Delben et al., 2020), together with interpersonal processes, coordination, and cognition (Maynard et al., 2015), have been identified as the processes driving team adaptation performance. Relevant team processes that contribute to adaptation include action processes–task execution behaviors such as performance monitoring and backup behaviors; transition processes–task organization behaviors such as mission analysis and goal specification; and interpersonal processes–which enable positive team member interactions through conflict and affect management (Maynard et al., 2015). Over the last 2 decades, research findings have demonstrated positive impacts that each of these processes have on teamwork outcomes (e.g., LePine et al., 2008), while also demonstrating that team process categories have distinct and unique effects on performance (Mathieu et al., 2019). However, research on team adaptation processes in ICE environments, particularly as stated by Maynard et al. (2015), remains sparse.

Therefore, consistent with recent calls for additional studies on the temporal and contextual dynamics of teamwork in ICE environments (e.g., Golden et al., 2018; Käosaar et al., 2022), the current study adopted a temporal, integrative mixed-methods approach (Paoletti et al., 2021) to characterize the ongoing dynamics of team adaptation processes and affective states of a two-person team as their mission evolved. This study used qualitative longitudinal data supplemented by interviews to investigate the relationships between the environmental and task conditions, i.e., challenges, team affect and other adaptation-related processes, to shed light on the dynamic process of team adaptation in an extreme environment. The following research questions were assessed:

Research question 1. What were the challenges that arose during the mission and how often did they occur?

Research question 2. What were the affective and behavioral responses to those challenges and how often did they occur?

Research question 3. What is the relationship between challenges and affective and behavioral responses over the course of the mission?

2 Materials and methods

2.1 Mission description

Data collection was carried out over the course of SAGA's Space Arctic Moon analogue experiment in NW Greenland, where the LUNARK habitat was deployed and assembled (see Figure 1). The overriding goal of this case study mission was to serve as an analogue for aspects of the planned NASA Artemis missions to the Moon (Artemis, 2023). The SAGA group designed a prototype lunar habitat to house a two-person team in an ICE environment as an analogue for the planned Artemis III mission during which a two-person astronaut team will live on the lunar surface for a short period of time. The specific aims of the case study LUNARK mission were to study the psychological adaptation of a dyadic team living and working over a 3-month period inside a structure specifically designed as a lunar habitat. A second aim was to test the adequacy of the habitat, including infrastructure, materials, habitability, and technology under extreme environmental conditions (https://saga.dk).

The habitat was in NW Greenland near the uninhabited settlement of Moriusaq. This Arctic region presents some of Earth's harshest conditions for life during the winter season when the mission took place, with challenges such as −40°C (104°F) temperatures, hurricane-like wind speeds, extended darkness period, solitude, and the constant threat of polar bears (SAGA, 2023). The mission lasted for approximately 90 days, during which participants were isolated from the outside world. Three critical phases of the mission were designated, each lasting 4 weeks: Phase 1—habitat assembly; Phase 2—sunlight; Phase 3—long night (see Figure 2). During Phase 1, team members lived inside a metal container where all relevant equipment, tools, and supplies were stored. The objective was to complete the deployment of the LUNARK habitat. The container also served as a storage facility during Phases 2 and 3. The second and third phases differed primarily in terms of activities during the presence vs. absence of sunlight. During Phase 2, the team performed several walks around the habitat to explore the region; during Phase 3, the team did not carry out any recreational activities outside of the habitat, although they still performed daily tasks such as walking to the container for supplies, chopping ice blocks to melt for water, or repairing any external equipment. In Phases 2 and 3, the team's primary tasks included the recording of video material to produce a documentary, implement multiple research protocols, maintain the habitat, and text daily messages via satellite to mission control in Denmark.

2.2 The LUNARK habitat

The LUNARK habitat is an origami-like foldable structure made of lightweight solar panels. The habitat was designed and constructed in Denmark, then loaded into a shipping container and transported by ship to the mission site in Greenland. After the habitat was offloaded, both team members, without any external help, assembled

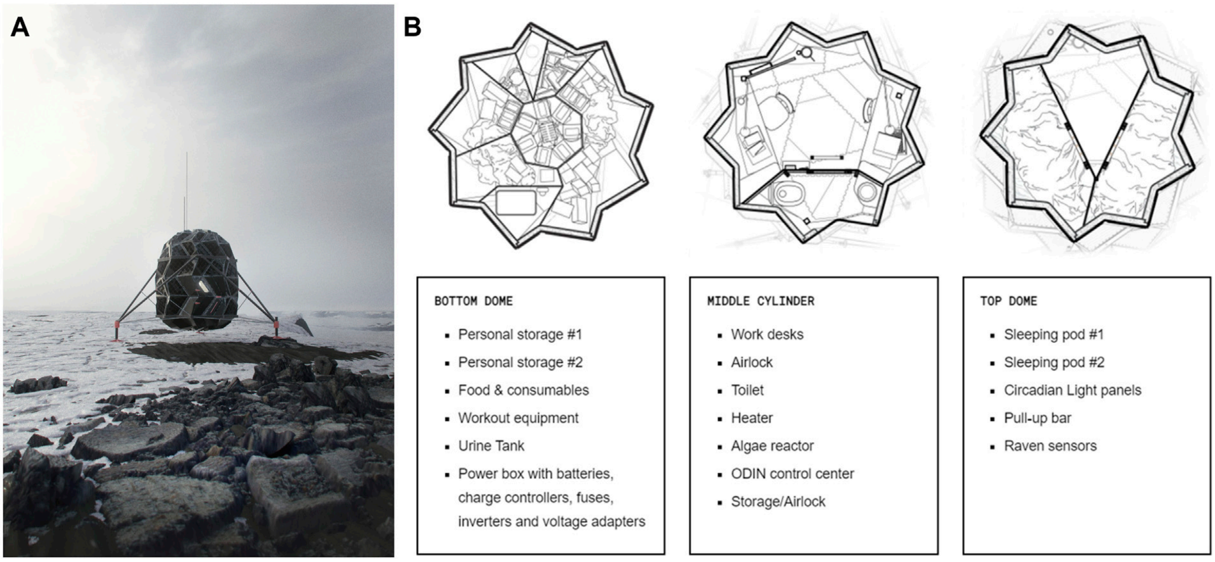

FIGURE 1
Image **(A)** shows the habitat. Image **(B)** is a top-down schematic of the habitat interior (SAGA, 2023). Image source [SAGA Space Architects], reproduced with permission.

FIGURE 2
Photos showing the three phases of the mission (SAGA, 2023). Photo **(A)** regards Phase 1—Habitat assembly. Photo **(B)** regards Phase 2—Sunlight. Photo **(C)** regards Phase 3—Long night. Image source [SAGA Space Architects], reproduced with permission.

the habitat and made it fully operational (Figures 1, 2). The habitat consists of two interior levels. The lower level is divided into two workspaces, one for each team member, a small galley, and an airlock with a toilet. The space in the main room floor is 3.57 m^2, with two desks, storage shelves and a 3D printer; the airlock space is 0.80 m^2. The interior was constructed with materials and surfaces consisting of natural Earth colors and textures, while the interior contact surfaces were either textiles, or painted or natural wood. The walls were covered with furniture textiles. The upper level had two separate sleep areas and a dynamic circadian rhythm lighting system. One sleep pod is 1.53 m^2, the other 1.38 m^2, providing the greatest privacy within the habitat. The acoustically insulated dividing walls and padded exterior walls promoted a feeling of protection and safety, according to the habitat designers. The habitat was specifically designed for this lunar analogue mission, with applications of the design and technology for other structures in ICE environments.

2.3 Participants and activities

Participants were self-selected two male Danish architects, ages 26 and 24. Both were part of the SAGA Space Architects company. They had been working together on the development of the habitat and the mission preparation for over 2 years, and were highly committed to developing and launching the mission. They also had some practice experience in short duration isolation in a desert setting. Much like what happens at the International Space Station, and unlike other polar facilities where the crew is often divided into scientists who implement research protocols and staff who engage in maintenance and repair, during the LUNARK mission the two team members were responsible for conducting the research as well as maintaining the habitat. They were fully autonomous on-site and had no face-to-face interaction with other humans over the course of the mission. The only exception was a 1-h encounter with a local resident who brought them via a small boat a needed

TABLE 1 Coding scheme and frequency.

Category	Frequency							
	Sub-code	Pre-mission interview	Phase 1	Phase 2	Phase 3	Post-mission interview	Total	Pre/actual ratio[a]
Affective tone Russell (2003)	Negative	6	4	11	8	31	60	-
	Positive	11	19	35	16	17	98	-
Challenges Sandal et al. (2006)	Team	0	1	1	0	5	7	n/a
	Habitat	0	1	7	9	6	23	n/a
	Health	3	3	5	7	6	24	1.49
	Mission	8	7	6	3	19	43	3.73
	Physical	2	19	16	12	10	59	0.32
Team processes Maynard et al. (2015)	Interpersonal	7	0	8	2	11	28	-
	Action	4	18	17	8	12	59	-
	Transition	8	8	4	5	7	32	-
Total		49	80	110	70	124	433	-

[a]To compare the proportions between expected challenges and experienced challenges, proportions of total challenges expected/experienced per challenge were calculated. For the ratio, proportion of expected challenges was divided by the proportion of the same experienced challenge. One equals an exact match between expectations and actual experiences; values < 1 indicate that the team experienced more of the challenge than expected; values > 1, challenge less than expected. There were no related expectations for Team and Habitat challenges.

piece of equipment. The team engaged in daily phone contact with mission control in Denmark. The rationale for the choice of a two-person team was its comparability with the number of crew members that will live on the lunar surface during the planned Artemis III mission.

2.4 Measures

The data analyzed in this study consisted primarily of single daily short text message sent by the two team members via satellite phone, and pre and post mission interviews. The messages contained words, icons, and emoticons to summarize the most relevant events, experiences, thoughts, or feelings experienced by the team each day. As an additional data source, a detailed analysis was carried out of pre-expedition and follow-up semi-structured interviews conducted for a separate concurrent LUNARK research project (Kjærgaard et al., 2022). The pre-expedition interview was conducted 1 week before the mission, the post-expedition interview, 1-week post-mission. The team members were interviewed together and provided a more detailed understanding of the challenges and associated affect and processes experienced by the team members.

2.5 Coding and analytical procedure

An integrated mixed methods approach was adopted in this case study, defined as an interconnected mix of quantitative and qualitative characteristics. Beyond classic approaches such as triangulation of multiple data sources (e.g., archival data, surveys, and interviews), where a qualitative approach is used to support quantitative ones (and *vice versa*), adopting an integrated mixed methods approach combines qualitative and quantitative elements to analyze and interpret data in a way that generates results otherwise inaccessible (Paoletti et al., 2021). Examples of integrated mixed methods approaches include interaction analysis, content analysis, and cluster analysis (Paoletti et al., 2021). In the current study, the focus was on content and cluster analyses. Content analysis allows the categorization of large amounts of data in a systematized fashion using codes and subcodes generated from existing theory, prior to performing the coding itself. Cluster analysis enables the grouping of relevant factors by degree of proximity or similarity. MAXQDA20 Pro (MAXQDA20 2020) was used to perform data coding and analysis of the daily messages. The data were analyzed following a two-step approach. First, a focus on the overall mission to answer the study's first two research questions related to challenges and affective and behavioral responses. Next, a focus on the three stages of the mission to answer the study's third question regarding the frequency of these responses by phases of the mission, and possible relationships according to phase.

The analysis of the daily satellite messages was performed by the first and second authors of this study, taking a two-step approach. First, each author went through all the daily satellite messages separately, using the code system shown in Table 1. Second, the two authors met to discuss the codes they had assigned to different messages, share their individual interpretations, and reach a consensus. The pre-mission and post-mission interviews were coded by the second author and three research assistants, using the same codebook that was used for coding the daily messages (see Table 1). Once the research assistants were familiar with the coding scheme, the pre and post-expedition interviews were divided into two parts; the second author coded the full interviews, and each assistant coded a third of each interview. As with the daily satellite

	NegativeT	PositiveT	TeamC	MissionC	HealthC	PhysicalC	HabitabilityC	InterpersonalP	ActionP
NegativeT	0								
PositiveT	16	0							
TeamC	2	0	0						
MissionC	5	6	2	0					
HealthC	2	6	0	4	0				
PhysicalC	19	31	0	13	13	0			
HabitatC	4	13	0	6	4	13	0		
InterpersonalP	5	7	2	0	0	0	0	0	
ActionP	6	25	2	15	9	24	6	0	0
TransitionP	2	13	2	4	2	13	2	0	10

FIGURE 3
Code relations table showing the co-occurrences between pairs of codes. White coloring indicates no co-occurrences; blue coloring indicates occasional co-occurrences; grey coloring indicates frequent co-occurrences; red coloring indicates highly frequent co-occurrences. "T" stands for tone, "C" stands for challenges, and "P" stands for processes.

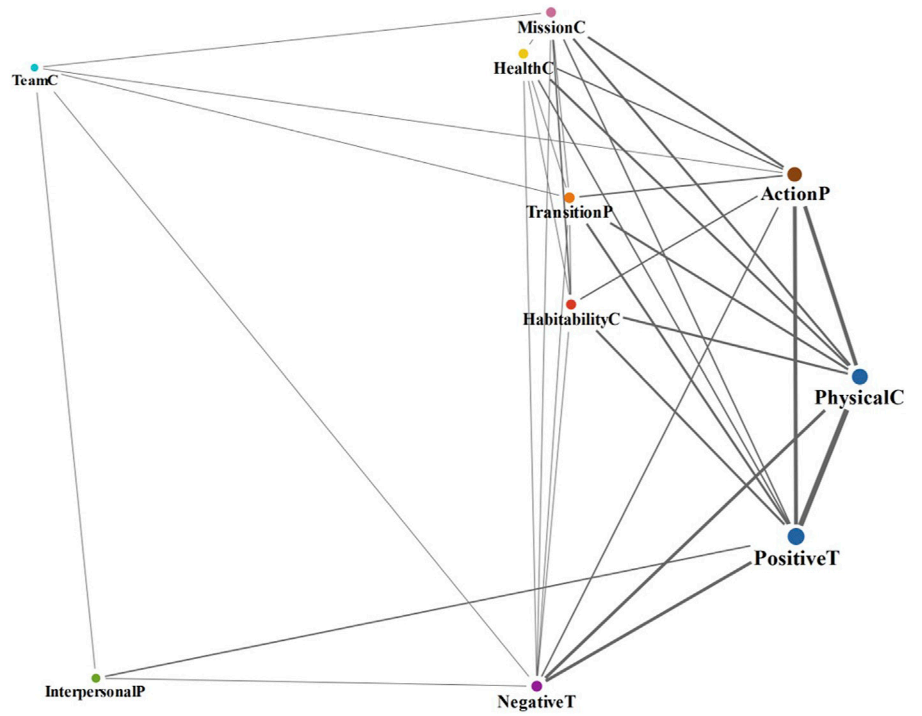

FIGURE 4
Code map showing the association between codes based on frequency of co-occurrences. Thicker lines indicate more co-occurrences between two codes. Bigger font sizes indicate higher code frequency. Code colors highlight clustering (distance matrix) in such a way that two or more codes with the same color were assigned to the same cluster. Capital "C" stands for challenges. Capital "T" stands for tone. Capital "P" stands for processes (SAGA, 2023).

messages, agreement meetings were held for each interview to reach full consensus about the codes. In addition, besides content analyzing our data and in line with the integrative mixed methods approached, frequency analysis (Table 1), co-occurrence tables (Figure 3) and relational graphs (Figure 4) were generated to visualize the relations between codes using MAXQDA20 Pro. This enabled obtaining additional detailed information about the association between codes and how their occurrence changed across mission phases.

3 Results

This section allowed for answering Research questions 1 and 2 and is organized into six themes: anticipated challenges (Pre-Mission); challenges the team encountered (Challenges); emotional responses to those challenges (Group affect); behavioral responses to those challenges (Group processes); integration of challenges, affect, and processes (Integration) themes; findings from post-expedition interview (Post-Mission).

3.1 Pre-mission

Team members were excited, enthusiastic, and optimistic about the mission. *"It is been a theoretical project for almost 2 years from the very early stages. And now we finally . . . see real physical things and prove that it is going to happen"* (P1). Team members mentioned that prior to the LUNARK mission, they had engaged in two short isolation experiences (2 weeks and 4 weeks) living in a tent in the desert to gain a better understanding of the exigencies of isolation in a harsh environment. While this was primarily a solo endeavor, for a short period there was an overlap where the two lived together in the tent. From these experiences, both felt they had learned a great deal about how to adapt to an ICE environment. They also indicated that they believed themselves to be resilient enough to be willing to accept that they can get tired of each other, but still "*have mutual respect, and respect each other's privacy*" (P2).

During the pre-mission interview, team members also acknowledged how they had learned to deal with conflict with each other over the time they had been working together prior to the mission. P2 stated that they just need to relax a bit to reduce tension when in a state of conflict with each other. On the other hand, they also indicated that although they felt prepared, the LUNARK mission had a lot more at stake than any of their previous experiences: "*The weight on our shoulders is definitely more extreme . . . but it is also more exciting*" (P1). P2 stated "*We had to do a crowdfunding campaign . . . and that means that all our family and friends and people . . . have invested a little bit in the mission. So, it is kind of . . . we owe it to them*". Furthermore, they indicated that although they knew that missions in ICE environment are dangerous, they did not feel like daredevils—they had gone through extensive training about how to handle a rifle, administering first aid, communications, and other training procedures, and that training made them feel more confident. Finally, at this early stage, before the mission began, the participants anticipated they would mainly face sleeping problems and small habitability issues (e.g., leaks in the habitat). Of interest, P1 indicated that as a coping mechanism, it was important to have no specific expectations about potential stressors: *"I think it is hard to predict really, I try not to really have too much of . . . an idea in my mind of how it is going to be. Because then you get disappointed"*.

3.2 Mission

3.2.1 Challenges

Five different themes were used to capture data associated with challenges from the daily messages sent during the mission: 1) Team (e.g., low morale amongst the team), 2) mission (challenges associated with tasks and workload), 3) health (challenges associated with physical health), 4) physical (challenges associated with physical environment), and 5) habitability (challenges associated with the habitat). These challenges were previously identified by Sandal et al. (2006).

As detailed in Table 1, the most prevalent challenge theme extracted was physical challenges (n = 47). The main specific stressors related to physical challenges were the cold, storms, and the lack of sunlight from the mid-point of the mission. As the team wrote on Day 66: "*Temperatures are falling fast now, without sunlight. Today we had -21 C [-6°F], but the windchill effect is -28 C [-18°F]. One month left, it will only get colder.*" While physical challenges were common, habitat (n = 17), mission (n = 16) and health (n = 15) were less so. Habitat challenges included vibrations within the habitat and noise during storms; the confinement of the habitat (Day 65: *"When one works out, the other sits in his sleeping pod"*), and other aspects related to the hardships of living in a remote and small space (Day 16: *"Started melting ice for water. We each use 7.5 L a day here. That's much less than the 105 L an average person uses in DK [Denmark]. Not showering helps"*). The challenges associated with mission tasks were primarily related to several problems with the mechanical/technological part of the habitat and general maintenance work, e.g., on Day 32 the team reported: *"Oh and Technology has not been with us today, lots of challenges."* On one occasion, the team also realized they forgot one important piece of equipment, which eventually ended up being delivered to them by a local (Day 27: "*we'd forgotten the pump for our algae reactor in DK. Now it finally came. It was a long journey by ship, planes and finally in the boat of an Inuit hunter.*"). Interestingly, the highest discrepancy between expected challenges and actual challenges was for mission challenges, as shown in Table 1.

Finally, themes associated with health challenges were primarily associated with fatigue (Day 12: *"Our bodies are getting more tired"*) and being ill–both crewmembers fell ill over the course of the mission, one team member for a few days. The crew reported very few team challenges that arose because of low morale (Day 37: *"Messy surroundings area a symptom of low morale"*) and the fact that some things are difficult to execute as a two-person team–Day 6: *"It was heavy, only two people."*

3.2.2 Group affect

To capture affective tone, two codes were used following Russell (2003): positive tone (n = 55), and b) negative tone (n = 21). Positive tone was the predominant affective state for this mission. The reports reflecting positive tone were primarily indicative of a prevalent positivity; the team viewed even the challenges through this lens. For example, on Day 67 there was a problem with a toilet tank due to extremely cold weather. The team reported: *"When* [P1] *found out he looked at me and said: Urine big trouble."* The way the team member communicated the problem reflected coping by means of humor, and thus maintains a positive attitude. A similar humor theme occurred in the Day 55 report: *"The neighbors did not even complain about the music [of yesterday's party],"* or on Day 68: *"Oh and today's update: Still very cold here."*

Many of the reports related to positive tone were also associated with friends and family when, e.g., the team opened care packages that their loved ones had sent with them to boost morale (Day 59: "*Words cannot describe how moved and grateful we are*"). Finally, there were several references to salutogenesis, which might help explain the prevalence of positive tone over negative tone. This suggests that despite the harshness of the environment and the general ICE context, the team was resilient in dealing with these stressors and tended to enjoy the context (Day 60: *"Tomorrow is the last day the Sun comes above the horizon. But the days have never been more beautiful"*).

The main themes stemming from negative tone were related to missing friends and family, and the feeling of missing out on experiencing life with them, illustrated by this report on Day 68: *"Marius from the SAGA team became a dad recently! What else are we missing?."* Another prevalent theme was related to the polar night that began on Day 61: *"We're entering the dark period of the mission. It is both scary and exciting."* Amongst other less frequent themes, the acknowledgement of being in a remote location was captured on Day 50: *"Here, even a small accident is no joke. Who's gonna help?."* The team also reported some form of "ICE blues" or thoughts of home near the end of the mission; Day 84: *"As architects we think a lot about what makes a home, a home. One thing that's clear now more than ever: it is the people;"* Day 85: "*We've been here for such a long time that the outside world seems like a dream. A good dream that we long to return to."*

3.2.3 Group processes

To capture relevant group processes, Maynard et al. (2015) was followed; three main codes were identified: interpersonal processes ($n = 10$), action processes ($n = 43$), and transition processes ($n = 17$). The interpersonal processes referred to the activities carried out together related to having fun and therefore were mainly oriented towards building shared motivation (Day 62 they wrote: "*We celebrated Halloween and our first day of darkness*"), boosting morale and strengthening the social ties between team members (Day 55: "*Had a slow day on top of last night's party. Which btw was great. Everyone was dancing.*"). Action processes were related to tasks and activities focused on the mission, including assembling and maintaining the habitat (Day 15: "*8 of 15 trusty Spirafix ground anchors installed. Each anchor takes up to 3 h for us to hammer into the freezing ground.*") and conducting research (Day 63: "*Testing some new colors on our circadian lights. We're both the lab rats and the researchers in this experiment. It creates some bias, but also opportunities!*"). The transition processes were primarily oriented towards organizing work and activities and were the most critical during initiating and transition periods of the team mission, e.g., arriving at the site of the mission (Day 3: "*We surveyed the area and found a potential location for the hab! Gentle breeze makes it feel colder despite only -1C [34°F]. The Sun skips the horizon.*"); the transition from emergency shelter to the habitat (Day 31: *(P2) l did not leave the hab at all. Everything appears to be working. We're focusing on getting on track with research and documentation.*"), and end of the mission (Day 87: "*We have not taken a real shower in 3 months. The list of things we are looking forward to is long.*").

3.2.4 Visualizing relationships among themes

To understand the connections between the challenges encountered by the team and the affective and process-related reactions to those challenges during the mission, a relational map of the codes was generated (Figure 3). In MAXQDA20, this is achieved by estimating a similarity matrix between codes, which is then converted into a distance matrix (Figure 4). For the conversion, the column sums are calculated first, so each code is checked to see how often it occurs together with any other code. The maximum of these column sums is determined and defined as the maximum possible similarity. In each cell, the similarity of two codes is subtracted from this maximum. If 0 is obtained, this means that two codes always happen together. The greater the distance, the less two codes occur together. Through classic multidimensional scaling, relational maps in MAXQDA20 display the frequency of occurrence for each theme, combined with the frequency of co-occurrences in the text. The closer two themes are on the relational map and the thicker the line that connects them, the more related they are (Artemis, 2023).

The most frequent theme to co-occur with other themes was positive affective tone, which co-occurred with health challenges (Day 12: *"Our bodies are getting more tired every day [health challenge] . . . But morale is top [positive tone]"*); physical challenges (Day 61: *"We're entering the dark period of the mission [physical challenge]. It is both scary and exciting [positive tone]"*); and habitat challenges (D58: *"Woke up to a freezing Hab [habitability challenge]. Never has the bed felt more comfy [positive tone]"*). Positive affective tone also co-occurred with action processes (Day 28: *"We are happy to say that the habitat is finally alive [positive tone]. Electronics are working well, heating and toilet too, not much left [action processes]"*). Apart from the co-occurrence with positive tone, physical challenges also co-occurred also with action processes (Day 69: *"We're going through the hab looking for cold spots and adding extra Armaflex insulation where we can [action processes]. The inside-outside temperature difference is now 50C [90°F]! [physical challenge]"*); and transition processes (Day 21: *"Minus 8C [18°F] today [physical challenge]. Stepping up to warmer gloves from Ewool so our fingers do not go numb when working outside"*). Of interest, team challenges and interpersonal processes were the furthest distance from the denser map region on the right, as well as amongst each other. This finding seems related to the scarce references to any team challenges occurring during the mission as transmitted in the daily-satellite messages by the team.

A close inspection of the map depicted in Figure 4 shows a strong association between physical challenges, positive emotions, and action processes. This reflects the finding that team members often saw the physical challenges of their mission from a positive outlook. Also, action processes are related to the execution of mission plans, including implementing experiments within and outside the habitat, hiking and doing documentation. These activities provide numerous opportunities to experience positive emotions, especially those related to the feeling of awe viewing the landscape, and the achievement of mission-related goals.

3.3 Follow-up interview: Post-mission

The primary challenge from Phase 1 mentioned in the post-mission interview was the fact that setting up the habitat lasted 30 days instead of 6 days as planned. This time delay had three main effects: intense chronic stress because of uncertainty whether they would eventually be able to set up the habitat and continue with the mission; sustained workload over the period of setting up the habitat; time pressure stemming from the lost days. The latter affected the entire mission regarding other projects and goals that the team had to accomplish, e.g., installing and testing the solar panels because at a specific point in the mission, there would not be any more sunlight. As P2 explained: *"The biggest pressure . . . was not so much that . . . it had to be 6 days. It was more that . . . we had done so much work in the past 2 years–how much of the value disappeared by not being there for the 20 extra days . . . I was stressed* *about the idea of losing that value of the mission."* The main reason for the delay was the challenging weather conditions and fatigue resulting from the workload—*"It is hard to explain exactly why things were going so slow . . . We were fatigued. And the cold and harsh climate just slows things down. Because we could unfold the habitat in . . . 2 days . . . in the workshop".* Both team members indicated that acceptance was the primary way to deal with the immense stress and pressure from this situation. In addition, maintaining high moral and humor, being optimistic and trying to deal with the situation in a rationale way were mentioned *"just make sure that I put as much work as I can into every day without . . . doing anything stupid or exerting myself too much"* (P1).

The single most stressful event that team members indicated from Phase 2 was discovering large polar bear footprints outside of their habitat. They spent a large portion of the day searching the area for the bear, rifles in hand, to be sure that the bear was not in the area so they could work outdoors in peace and safety—*"And we were between the building, and you were wondering what was behind the corner . . . That was the most stressful part"* (P2). Regarding coping with this stressor, P2 stated: *"There was not that much to do . . . You kind of just had to deal with it,"* and then added: *"That was the only moment in the entire expedition where I was thinking–I wish I was not here right now".*

For Phase 2, the main stressors mentioned by P2 were the indoor climate and the effect it had on his sleep. Experiencing a first strong storm was highly stressful because they did not know how durable their habitat was. In addition, the low communication bandwidth the team had for contacting and getting information from mission support personnel was a chronic stressor for the team throughout the mission. For P1, sleep problems were a major stressor; despite tinkering with different habits (e.g., not drinking coffee) and trying to understand the issue, he felt that sleep problems clearly affected his performance. Both team members also mentioned several smaller stressors (e.g., lack of privacy, hearing the other person snore during night), but indicated that instead of letting the small irritations affect them, they kept a positive attitude and worked actively on not getting irritated. This suggests why there were so few references to team challenges throughout the mission, and why humor often showed in the team satellite messages when they made references to challenges that were affecting mission performance and team wellbeing. It also is consistent with the positive relationship between interpersonal processes and team challenges, reinforcing the idea expressed here that team members actively adopted humor as a potent affect management strategy to resolve tension and preserve a positive relationship with each other.

For Phase 3, the biggest stressor indicated was the time pressure resulting from the approaching end of the mission. They explained that they had lots of documentation (e.g., pictures and films) planned, a film project they had promised to carry out, and procedures they wanted to test out about the habitat; however, at the same time, they had to continuously fix and maintain the habitat. Dealing with the stressors related to low bandwidth communication such as receiving instructions very slowly, along with perceptions of time pressure, feelings of stress became more pronounced. These factors may have had an influence on the continuous increase in health challenges towards the end of the mission. In the team's view, the primary outcome of these stressors was mediocre energy levels. However, they also indicated that toward the end of the mission, the effect of the end approaching had an opposite effect on each of them–for P1, more energy *"just from the knowledge of the mission being over soon;"* on the other hand, P2 said: *"I felt that [motivation] dropping and my commitment to the expedition decreased a bit. I started to let go in the last week"* (P2).

Team members stated that looking back, they were surprised how well the mission proceeded, how normal they felt throughout the mission, and the fact that they were able to deal with each other so well over the entire time. Moreover, they found that their ability to work together increased over the mission, since *"we kind of ironed out wrinkles . . . So, I felt coming out of the expedition, we are working even better together".* They also indicated that this process of 'ironing out the wrinkles' was quite intentional–e.g., one evening they threw a party and drank alcohol; they found that this was quite effective in reducing stress/tension.

4 Discussion

This investigation adopted an integrated mixed method approach to characterize the challenges, group affect, and adaptation processes experienced by a two-man team during a 3-month lunar analogue mission high above the Arctic circle in Greenland. The research questions included the quantification of the challenges that occurred, how often they occurred, the affective and behavioral responses to those challenges, and the relationship between challenges and affective and behavioral responses over the course of the mission.

Our findings from this case study indicated that the expectations both team members had about the mission did not fully align with how events proceeded. Different challenges took distinct temporal trajectories across the mission phases; physical and habitat challenges were the most frequent and in which changes across mission phases were highly significant. One of the biggest challenges mentioned was the extended time and exhausting nature of assembling the habitat because of the extreme environmental conditions in which they were immersed. The team did not expect this, as they were not aware of the extent to which cold temperatures can damage electronic devices. Because of these initial challenges, they had to exert much greater effort to successfully accomplish their tasks. When they finally entered the habitat, they were more physically tired than they expected; in addition, they both were experiencing a high level of stress since they were 3-weeks behind schedule, given all the technical and scientific activities that were planned for the mission.

The team adapted to these challenges by more frequently engaging in action and transition processes–they changed how they coordinated tasks, monitored their own performance, and frequently provided back-up and support to each other. Team members adjusted mission plans across mission stages and therefore exhibited high adaptability across the mission (Anglin and Kring, 2016). One important factor that may have contributed to this adaptability was that both team members were prepared to experience the unexpected, and continuously adapt (LePine, 2003; Maynard et al., 2015). The challenges associated with the deployment to the Arctic site and the longer than expected time to prepare the habitat supports comments by Harris et al. (2023) regarding the challenges construction teams deployed to the lunar surface will face.

The study findings also demonstrated that the relationship between physical and habitat challenges, and action and transition processes, were central to the mission dynamics, as highlighted in the code map (Figure 4). This is consistent with the teamwork literature indicating that action and transition processes are particularly important to address regarding task-related problems such as continuing changes in task and environmental conditions (e.g., Mathieu et al., 2019; Connaboy et al., 2020; Schmutz et al., 2022). Our findings confirmed previous studies showing that teams engaged in interpersonal processes more frequently when there also were team challenges (e.g., Maynard et al., 2015). Other research in ICE environments has shown that effective team performance is associated with team members engaging in interpersonal interactions focused on building motivation, providing emotional support, and importantly, managing and resolving conflict (e.g., Sandal et al., 2006; Golden et al., 2018). Positive and satisfying interpersonal interactions can then facilitate the process of solving team challenges, preserving group cohesion, and enhancing positive affect (Atlis et al., 2004; Kjærgaard et al., 2013; Corneliussen et al., 2017; Bell et al., 2019).

Fostering strong positive relationships is an important mechanism to build resilience and effective performance while living and working in an ICE environment (Kahn and Leon, 1994). Team members thoroughly engaged in pleasant activities that fostered working together cooperatively and enabled their relationship to recover and improve after a conflict episode. They maintained a positive mental attitude, learned from their experiences when there were differences of opinion, moved on, and continued working together to accomplish the required tasks. This ability to maintain a positive working relationship was achieved in part because the teammates were a consolidated team before their departure to Greenland, as highlighted through their pre-mission interview (e.g., Mathieu et al., 2019). They began planning and working on the LUNARK project together well before the mission commenced, had similar expectations about the process of the mission, including how their relationship would unfold, and were highly motivated for success. These factors point to the strong commitment they had towards each other as a team and the project, including several clearly shared goals. The teammates also had well-defined boundaries, since they knew they could only count on each other while in Greenland, even though each team member had the necessary knowledge, skills, and abilities to perform the individual and collective tasks. This competence was achieved through multiple training activities in which they engaged in. Finally, the team was cohesive; both team members agreed that they would work together to manage the tensions that could arise between them. In so doing, the team established an informal team-charter that clarified goals, roles, norms, and expectations (Mathieu and Rapp, 2009).

Overall, our findings demonstrated that the team achieved its main performance goals, i.e., evaluate the functioning of the habitat, carry out other tasks, and complete a 3-month mission. Indeed, despite quite significant and some occasional setbacks (e.g., five times longer habitat assembly phase than expected; polar bear visit; sleep problems; disagreements about work schedules and allocations; illness) the team adapted to the challenges and successfully completed the mission.

4.1 Limitations and future directions

Conducting teamwork in ICE environments is methodologically challenging, primarily because study participants are not always accessible or cooperative; gathering enough data to perform sound statistical analysis is contingent on technology and participants' motivation and the location of research sites (Palinkas and Suedfeld, 2021). As a result, researchers may need to compromise methodological rigor in the face of the operational constraints of the mission and the research environment (Bell et al., 2019). Although in the current study these challenges were dealt with by adopting an integrated mix-method, multi-source approach, this study is not without limitations. The main data analysis was performed using the daily satellite messages sent by the team. This enabled the collection of nearly 90 daily messages that were content analyzed; however, the number of words in each message was short (±20 words on average). This precluded performing an in-depth examination of daily information, as well as carrying out quantitative analyses that would consider the nested structure of our data, since our sample size was $N = 1$ team (e.g., multilevel analysis; Schmutz et al., 2022). Ideally, future studies in similar conditions would benefit from larger sample sizes, as well as enrich temporal data collection by adding at least one specific time per week during which participants could provide longer mission logs.

Further, the N of 2 in our case study was deliberately chosen as an analogue for the two-person astronaut crew planned to live and work on the lunar surface for a short duration during the Artemis III mission. (The Artemis III mission plans to have two astronauts deployed on the surface of the Moon while two other astronauts will orbit the Moon during this time period). Analogue research supported by national space agencies have typically consisted of a relatively small number of participants—crews of 4–6 individuals, to be consistent with the crew numbers currently on the International Space Station or planned for future space missions (e.g., the HERA, HI-SEAS and NASA-Roscosmos SIRIUS missions; Marcinkowski et al., 2021; Anderson et al., 2016; https://www.nasa.gov). Therefore, following the Artemis III analogue, there were only two participants in this study, which precluded the evaluation of relevant social processes such as the role that diversity faultlines that might have had an influence on in shaping the formation of subgroups (Lau and Murnighan, 1998), and the emergence of group conflict during missions (e.g., Burke and Feitosa, 2015; Larson et al., 2019; Marcinkowski et al., 2021). In sum, despite the uniqueness of the research context and the analogue mission in which the participants were involved, this study had one single team as the sample. Therefore, the aggregation of data from a large number of N of 2 studies that follow the paradigm of the current study is required in order for the findings obtained to be generalized to future missions and to other ICE environments.

5 Conclusion

Effective teamwork during long-duration space missions is paramount for the success of future space exploration as well as the performance of activities in ICE environments on Earth. As an example, the fact that the assembly of the habitat was slower than expected raises the issue of whether some type of delay could happen during a future space mission, and how the crew would deal with this delay. Hence, this study provides an in-depth account of how different challenges emerged across mission stages, and the behavioral and affective responses to those challenges that enabled individuals and crews to adapt successfully. The findings of this study therefore are relevant not only for personnel on space missions (e.g., astronauts; mission control managers), but also for polar expeditioners, submarine crews, mountaineers and other teams functioning in ICE environments. Adaptation is not only one's ability to cope and accept their environment, but rather the motivation and capacity to anticipate and positively react to the challenges that otherwise would negatively impact mission success.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

PM-Q, AKä, and PD wrote the manuscript; PM-Q and AKä conducted the data analyses; AKj conducted and compiled the interviews; GL provided revisions to the paper. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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