

# Team Effectiveness and Person-Environment Adaptation in an Analog Lunar Habitat

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- BACKGROUND:** Maintaining psychologically adaptive relationships among team members operating in an isolated, confined, and extreme (ICE) environment for an extended period continues to be a challenge, with relevance for long-duration missions to the Moon and beyond.
- METHODS:** Two male architects were studied who lived and worked over a 60-d period in a polar ICE environment in a lunar analog habitat they designed and helped construct. Psychological measures were completed at different points of the mission, including a post-mission debriefing interview.
- RESULTS:** Team members were highly different from each other on a number of personality traits, personal values, and stress and coping factors. Marked differences were noted on NEO-PI-3 Agreeableness and Extraversion personality traits, and Portrait Values Questionnaire (PVQ) Stimulation, Power, and Achievement values. Team Effectiveness Questionnaire (TEQ) findings showed consistency between team members with high ratings on the Passion and Commitment and Purpose and Goals scales, and low ratings on the Roles scale. The leveling influence of decision authority and its deleterious effect on interpersonal interactions and work performance was evident. The interior design with attention to materials that made it more Earth-like and the circadian lighting system were associated with ease of work performance and promotion of relaxation and privacy.
- DISCUSSION:** The study findings demonstrated the impact of incompatibility in personality traits and values on team performance, challenges regarding decision authority in a long-term dyadic relationship, and highlighted the human factors components of the habitat that facilitated effective individual and team functioning.
- KEYWORDS:** lunar habitat, team effectiveness, decision processes, conflict resolution, circadian lighting.

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Personality and team process findings evaluating a dyadic team living and working in a lunar analog habitat in an isolated, confined, and extreme (ICE) environment have the potential to inform about team effectiveness in a range of ICE environments, including the planned NASA Artemis mission to the Moon. Human factors information about the comfort and work performance within a habitat specifically designed for a lunar mission has direct application for current space agency design efforts.

Overall, team effectiveness in groups of different sizes encompasses performance, attitudes, and behavior, including interpersonal compatibility and task cooperation.<sup>15</sup> Previous research has indicated that optimal interactions in elite same-sex men and women dyadic sports teams centered on a sense of balance and partnership in the relationship; this was fostered by

effective communication that led to feelings of cohesion and agreement on specific goals.<sup>26</sup> Individual personality factors also contribute to team effectiveness. Military action teams with higher mean levels of conscientiousness and agreeableness received higher performance ratings.<sup>8</sup>

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Studies of team conflict have differentiated between task conflict and relationship conflict, with different implications for team performance.<sup>1,9,25</sup> In addition, team conflict may exhibit a positive timeline; beneficial over time in improving team performance as team members share task-related information regarding different options for performing specific tasks.<sup>9</sup>

Team conflict has also been studied at a more granular level. A concept mapping analysis of team conflict was carried out on a series of four-person crews living and working in an isolated and confined chamber on tasks that simulated a space mission.<sup>14</sup> Four types of conflicts were identified: noted discords (annoyances that were resolved), work disagreements, interpersonal tensions, and interpersonal breakdowns. This more nuanced analysis of team conflict showed differences among crews in the timing or emergence of specific types of conflict.

The importance of adequate communication, adaptive processes of conflict resolution, and congruence in personal and team goals on team effectiveness has been documented in expedition and work groups in polar ICE environments.<sup>2,4,11</sup> Compatibility in personal and social values in ICE environments is also associated with team interactions and team effectiveness. The Mars-105 simulation study found tensions among team members who were viewed as having dissimilar values.<sup>18</sup> Over the course of the following Mars-500 study, crewmembers attributed group tension to individual differences in benevolence.<sup>17</sup>

Although team conflict has a significant influence on team effectiveness, team members having an overriding goal for their particular mission has a strong motivational influence on performance.<sup>2,7,21</sup> The salience of a defined goal therefore mitigates what might otherwise be highly negative influences on team performance.

Team performance is influenced by person-environment (P-E) fit, including the habitat.<sup>19</sup> A basic principle of fit theory posits that a lack of congruence between personal and environmental attributes lowers positive outcomes. Congruent with P-E fit theory, in 2016 the NASA Human Research Program (HRP) convened a panel to evaluate progress and future directions on the research plan for Deep Space Habitat: Livability, Well-being, and Performance.<sup>16</sup> The concept of Human System Interaction Design (HSID) of a deep space habitat required that the habitat would be highly compatible from a human rather than primarily from an engineering perspective.

The current analog lunar habitat project provided the opportunity to assess a dyad over a 60-d period who lived and worked in a habitat specifically designed for the lunar surface. A specific aim of our investigation was to examine personality and other psychological and interpersonal factors within the confines of a lunar-designed habitat, and the influence of these factors on team effectiveness. An additional aim was to evaluate the design features of the habitat in terms of comfort and facilitation of task activities, with relevance for human-centered design of habitats for space exploration and for ICE environments on Earth.

## METHODS

### Subjects

Two Danish men, ages 24 and 26, respectively, participated in this research. Both were prize-winning space architects who designed and had major roles constructing the lunar habitat they lived in over the course of the study. They began working together on space architecture projects in early 2018 while completing their academic degrees in architecture.

### Procedure

Subjects completed the NEO-PI-3,<sup>5</sup> Portrait Values Questionnaire (PVQ),<sup>20</sup> Connor-Davidson Resilience Scale (CD-RISC 25),<sup>6</sup> Levenson Control Scale (LOC),<sup>13</sup> and Team Effectiveness Questionnaire (TEQ)<sup>3</sup> approximately 3 mo and again 1 wk prior to their departure for Greenland. They also practiced the subtests of the Spaceflight Cognitive Assessment Tool for Windows (WinSCAT)<sup>10</sup> to reach a baseline level of performance and participated in a joint pre-expedition interview with the first author 58 d before departure to Greenland. They completed the Danish version of the NEO-PI-3; the other measures and their individual comments were completed in English.

All mission data were completed during the second and third months on the ice, i.e., the 60-d period at their site in Greenland when the team lived and worked in the habitat. In addition to the Weekly Rating Form (WRF),<sup>11,12</sup> the TEQ and WinSCAT were completed biweekly. Subjects participated in independent debriefing interviews 3 d after their return to Denmark; they also completed the Human Factors Questionnaire and several other measures. The study was approved by the University of Minnesota Institutional Review Board. Informed consent was obtained.

### Mission

The subjects lived in a safety hut for the first 4 wk of arrival on the northwest coast of Greenland, near the uninhabited settlement of Moriusaq. During this period, they finished and set up the lunar structure nearby. There were no other people at the site during any time of their stay.

Following the completion of the habitat setup and the move inside, the team's primary activities were to produce a documentary, maintain the habitat, and engage in daily communications with mission control. Total darkness occurred at the start of Week 5, at which point outside filming was not possible. Team members working on the ice wore Arctic survival suits and a helmet that included a visor, headlamp, and headphones for radio communication.

### Habitat

The habitat was designed following architectural concepts for a lunar habitat. It followed an origami model of a foldable structure consisting of lightweight foldable panels for storage and transport. The habitat was folded into a shipping container and transported by ship to the site of the mission. The teammates



**Fig. 1.** Habitat and team members on the ice.

unfolded the habitat and set it onto struts that were anchored into the ice surface (**Fig. 1**).

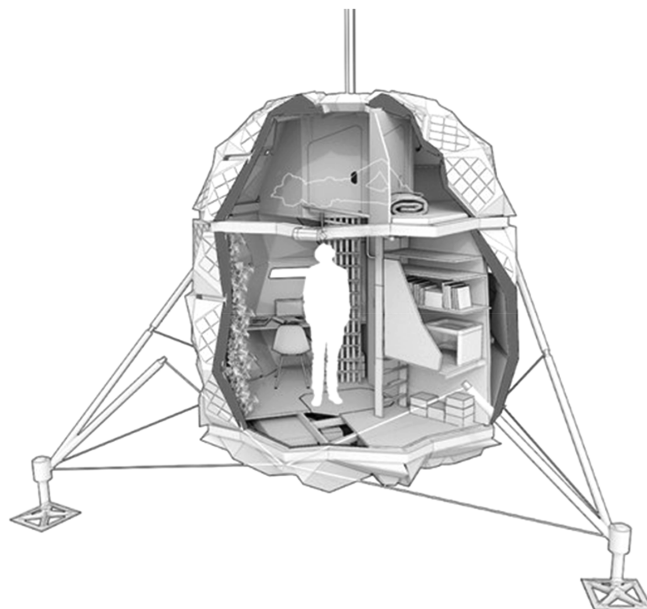
The two-level structure consists of an outer skin covered by solar panels. There also was a spotlight to make it easier to navigate and work in the dark. The first level of the interior is divided into two workspaces and a small galley; an airlock with a toilet is adjacent to the main room. The main room floor space is 3.57 m<sup>2</sup> and includes two desks, storage shelves, and a 3D printer; the airlock is 0.80 m<sup>2</sup>. To make the habitat more home-like, the interior design was composed of materials and surfaces with more natural desaturated Earth colors and textures - nuances of blue and green that they chose themselves. Most of the interior contact surfaces were either textiles, wood treated in different paint, or raw. The walls were covered with furniture textiles, rough and durable, but also a bit soft to the touch. The sleeping pods were fashioned with textiles on one side and acoustic felt made of wool fibers on the other side to provide a cozy feeling that promoted relaxation (**Fig. 2**).

The upper level consists of two separate sleep areas and a dynamic circadian rhythm lighting system; one sleep pod is 1.53 m<sup>2</sup>, the other 1.38 m<sup>2</sup>. The sleeping pods provided the most privacy within the habitat. There were acoustically insulated dividing walls and padded exterior walls that provided a soft and safe cocoon which the designers felt promoted a sense of protection and safety.

### Measures

**NEO-PI-3.** The NEO-PI-3 is a 240-item standardized Danish version of the NEO PI-R.<sup>5</sup> It measures five independent personality traits: Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness.

**Portrait Values Questionnaire.** The Portrait Values Questionnaire (PVQ) is a 40-item measure assessing 10 major distinct values and the extent to which the individual self-identifies with these values.<sup>20</sup> The value scales are as follows: Tradition, Universalism, Self-Direction, Simulation, Hedonism (Enjoyment), Achievement, Power, Security, Conformity, Benevolence. The



**Fig. 2.** The interior layout of the habitat.

individual scales are scored by applying a correction for individual differences in response style. The mean of the raw score on each scale is “centered” by subtracting the mean score of the rankings on all 40 items.

**Connor-Davidson Resilience Scale.** The CD-RISC 25 is a measure of stress coping/resilience.<sup>6</sup> Items are rated on a 5-point scale from 0 (not at all true) to 4 (true nearly all the time). A mean score of 73.4 was found in a European community sample.

**Levenson Control Scale.** The LOC assesses the self-perception of the control the individual has over the events in their life.<sup>13</sup> The 11-item measure consists of three scales: Internality, Powerful Others, and Chance. The latter two scales differentiate between discrete facets of an external orientation. Items are rated on a six-point scale ranging from +3 (Agree Strongly) to -3 (Disagree Strongly).

**Team Effectiveness Questionnaire.** The TEQ is a 56-item measure consisting of eight dimensions: Purpose and Goals (tasks outcome); Roles (position taken for a specific task); Team Processes (group collective goal-directed task work); Team Relationships (connection or interdependence among the team members); Intergroup Relations (interactions between and among group members); Problem Solving (analysis and effective solution); Passion and Commitment (strength and positive feeling related to team identity and performance); and Skills and Learning (development and understanding of different activities).<sup>3</sup> Items are rated on a five-point scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

**Spaceflight Cognitive Assessment Tool for Windows.** WinSCAT is a computer performance test consisting of five subtests assessing different cognitive functions.<sup>10</sup> The subtests are:

Symbol Memory (Learning), Repeating Numbers, Mathematical Processing, Pattern Matching, and Symbol Memory (Memory). The Index of Cognitive Efficiency is a weighted score with the four included tests weighted equally. The index of Cognitive Efficiency scores typically range between 300 and 600, according to the experience of the test developers (Seaton KA. Personal conversation; September 24, 2016).

**Weekly Rating Form.** The WRF is a 76-item measure that has been used in previous expedition studies and was modified as needed for the specific circumstances and focus of the current mission.<sup>2,11,12</sup> The individual sections are: Feelings and Emotions (Positive and Negative Affect Schedule; PANAS)<sup>24</sup>; Environmental and Physical Status Factors; Positive and Negative Event Checklist; Coping Checklist; Strategy/Decision Processes; and Other Important Events. PANAS ratings range from 1 (not at all, very little) to 5 (extremely).

**Post-Mission Debriefing Form.** The Post-Mission Debriefing Form is a semi-structured interview that assessed in greater detail the research questions posed in this investigation. There was a particular emphasis on team interactions and decision processes and possible changes in these factors over the course of the mission.

**Human Factors Questionnaire.** The Human Factors Questionnaire assessed comfort level within the habitat regarding its livability; sections included work performance and overall wellbeing, privacy, sleep, ventilation, noise level, food, and mealtimes.

### Statistical Analyses

Given the small number in this study, descriptive statistics (means, standard deviations) were the primary means of data analysis. The Events and Coping item ratings for each subject were analyzed by the percentage of time a particular rating was endorsed across the eight weekly ratings.

## RESULTS

### Pre-Mission Interview

Team member (TM) #1 felt that the most positive aspect of preparing for the mission was a “very primal” feeling in terms of building one’s own habitat. TM #2 discussed a sense of comfort in having complete insight into all of the details of the habitat and confidence in the habitat because they built it themselves. Both agreed the most stressful aspect of the preparation was the time factor, the strict deadline for departing to Greenland because of the weather and light/darkness conditions for setting up the habitat and doing the planned documentary.

Regarding their expectations about living and working together, TM #1 indicated that they had mutual respect for each other and each other’s privacy. TM #2 stated that they were resilient enough so if they became tired of each other, they

could accept “that was the way it was.” Both felt if there were conflicts, they would just talk about the situation to resolve the disagreement. Neither team member viewed himself as a high risk-seeking person. They indicated the expedition was a calculated risk, but they had been trained to follow the best practices for safety, such as rifle training. Also, they had two backup huts to retreat to in case of an emergency.

### Personality and Personal Attitudes

The NEO-PI-3 findings indicated the most predominant trait for both team members was Openness, reflecting their creativity and imagination as architects. However, there were considerable differences between the two individuals in their overall personality structure; TM #1 scored relatively high on Conscientiousness (T = 57) and low on Agreeableness (T = 32); TM #2 scored relatively high on Agreeableness (T = 56) and low on Extraversion (T = 40). Complete details are presented in **Table I**.

The CD-RISC 25, administered both pre- and post-mission, indicated an increase in resilience following the successful completion of the mission. TM #1’s pre- and post-mission scores were 67 and 75, respectively; TM #2, 74 and 83. These scores are in contrast to a mean score of 73.4 found in a large community sample, indicating that TM #2’s score post-mission was above the mean in resilience in comparison to the standardization sample.

The findings on the PVQ, measuring personal and social values, demonstrated similarities between the two teammates on values related to independence and conformity, and differences in the strength of the following values: Stimulation, Universalism, Power, and Achievement related to social recognition. The

**Table I.** Personality Traits and Personal Values of Team Members.

FACTOR/SCALE	TEAM MEMBER #1		TEAM MEMBER #2	
NEO-PI-3 <sup>+</sup>				
Neuroticism	47		44	
Extraversion	52		40	
Openness	62		62	
Agreeableness	32		56	
Conscientiousness	57		51	
	PRE	POST	PRE	POST
PVQ <sup>++</sup>				
Tradition	-1.00	-1.08	-0.60	-0.83
Universalism	-0.25	-0.08	1.15	1.34
Self-Direction	1.00	0.93	1.90	0.93
Stimulation	0.08	0.93	2.15	1.18
Hedonism	-0.25	-0.41	-1.85	-0.16
Achievement	0.15	0.13	-0.45	-0.83
Power	0.08	0.59	-1.52	-1.16
Security	-1.25	-0.91	-1.35	-1.49
Conformity	-1.25	-1.33	-2.60	-1.58
Benevolence	0.50	-0.08	1.15	0.93
Levenson Control Scale <sup>+++</sup>				
Internality	0.75	0.38	2.0	1.13
Powerful Others	1.0	1.0	2.0	-1.0
Chance	0.5	-0.5	2.0	2.5

<sup>+</sup>T-scores: standardized score with Mean 50, SD 10.

<sup>++</sup>Centered scores: a correction for individual differences in response style applied by “centering” the mean of the raw score on each scale by subtracting the mean score of the rankings on all 40 items.

<sup>+++</sup>Scores range from -3 (Strongly disagree) to +3 (Agree strongly).

**Table II.** Team Effectiveness Questionnaire (TEQ) Ratings Evaluated Prior To, During, and Post-Mission.

DIMENSION	TEAM MEMBER #1			TEAM MEMBER #2		
	PRE	DURING	POST	PRE	DURING	POST
Purpose and Goals	4.57	4.39 (0.3)	4.14	4.29	4.11 (0.3)	3.57
Roles	4.43	3.86 (0.2)	3.57	3.57	3.39 (0.1)	4.14
Team Processes	4.14	4.00 (0.2)	3.57	3.57	3.68 (0.2)	3.86
Team Relationships	4.29	4.07 (0.2)	4.00	4.14	3.79 (0.1)	4.29
Intergroup Relations	4.29	4.11 (0.2)	3.71	3.29	3.32 (0.1)	3.14
Problem Solving	4.43	4.18 (0.4)	3.57	4.29	3.75 (0.1)	4.14
Passion and Commitment	4.86	4.46 (0.2)	4.14	4.57	4.14 (0.2)	4.14
Skills and Learning	4.57	4.21 (0.1)	3.86	3.86	3.82 (0.1)	3.86

Ratings: 1—Disagree strongly to 5—Strongly Agree.

pre- to post-mission analysis indicated changes in the strength of several values: pre-mission, TM #1 scored highest on Self-Direction and Benevolence and lowest on Security and Conformity; post-mission, there was a decline in Conformity and a marked decline in Benevolence. Pre-mission, TM #2 scored highest on Stimulation, Self-Direction, Benevolence, and Universalism, and lowest on Conformity, Power, and Security; post-mission, there was an increase in Universalism and a decline in Stimulation, Self-Direction, and Achievement.

The LOC scale pre- and post-mission findings showed changes in attitude by both teammates about the extent of control they have over life events. TM #1 showed a decline on the Internality scale and the Chance scale; TM #2 also showed a pre- to post-mission decline in Internality and on Powerful Others.

**Team Effectiveness**

The findings on the TEQ, administered pre, biweekly during, and post-mission, showed consistent differences between teammates on their ratings of the effectiveness of their working together. In addition, both showed a consistent decline in the perception of team effectiveness over the three rating periods.

**TM #1.** Across the mission, the highest rated dimensions of team effectiveness were Passion and Commitment; item

example – “My team has a strong sense of accomplishment relative to our work,” and Purpose and Goals, “Our team has a meaningful shared purpose.” The lowest rated dimensions were Roles, “Team members understand one another’s roles,” and Team Processes, “Team problem solving results in effective solutions.”

**TM #2.** Similar to TM #1, the highest rated dimensions of team effectiveness were Passion and Commitment and Purpose and Goals; however, the lowest ratings were on Intergroup Relations, “Our collaborations with other teams are productive, worthwhile, and yield good results,” and Roles (Table II).

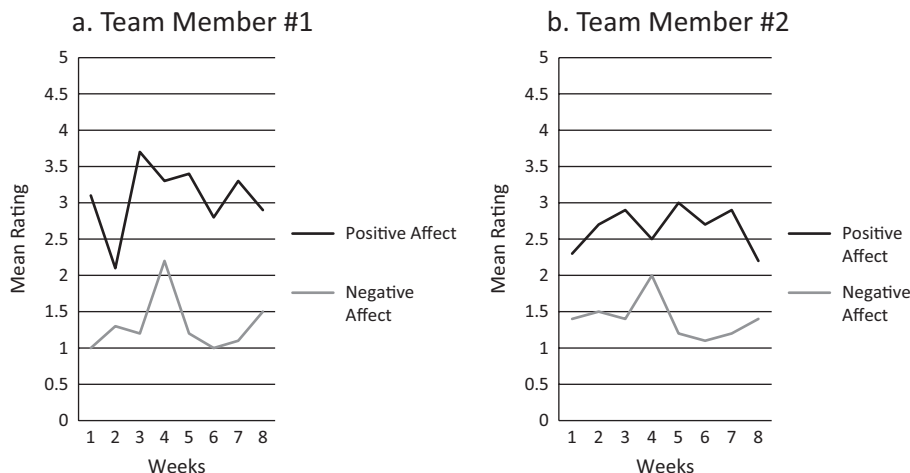
**Weekly Rating Form**

The PANAS results demonstrated consistently higher Positive Affect (PA) compared to Negative Affect (NA) ratings across the mission for both participants; TM #1: PA mean = 3.08 (0.49), NA mean = 1.31 (0.39). The Week 4 ratings showed a decline in PA and a noted increase in NA for both teammates. This change was likely related to a major disagreement, detailed in a later section of the paper (Fig. 3).

The Events data, analyzed in terms of the mean percentage of rating periods in which an item was endorsed, indicated that the following items were strongly endorsed by both teammates over the course of the mission: “Feelings of camaraderie/closeness with teammate,” “Enjoyment of the Arctic environment,” “Satisfaction in making good progress today,” “Satisfaction that equipment is working properly,” and “Satisfaction that I am able to cope with the challenges.”

Teammates differed in their endorsements of several work-related and personal items: “Concern about how effective my teammate and I are working together,” “Tension or argument with teammate,” “Loneliness, homesickness,” and “Lack of privacy, time for myself.” These ratings point to substantial differences in the experiences of each of the participants during the mission (Table III).

The Coping data reflected the individual differences in personality and behavior between the teammates. There were



**Fig. 3.** Positive affect and negative affect scores over the 8 wk of the expedition. Items are rated on a scale of 1 (very slightly, not at all) to 5 (extremely).

**Table III.** Mean Percentage of Significant Events Endorsed While Living in the Habitat.

ITEM	TEAM MEMBER #1 (% <sup>+</sup> )	TEAM MEMBER #2 (% <sup>+</sup> )
Problems with gear and equipment	12.5	62.5
Feeling of camaraderie/closeness with teammate	87.5	100
Concern about the well-being of my teammate	37.5	38
Enjoyment of the Arctic environment	87.5	87.5
Concern about how effectively my teammate and I are working together	25.0	62.5
Feeling down/low or stressed because my teammate is feeling that way	12.5	12.5
Tension or argument with my teammate	25	37.5
Satisfaction in making good progress today	100	100
Satisfaction that equipment is working properly	87.5	87.5
Satisfaction that I am able to cope with the challenges	87.5	87.5
Concerns about the effectiveness or safety of decisions I made today	0	0
Fear of being injured	37.5	25.0
Worried about family, friends	25.0	25.0
Worried about encountering bad weather	25.0	37.5
Loneliness, homesickness	0	62.5
Lack of privacy, time for myself	25.0	62.5
Personal Hygiene (wanting to be cleaner)	12.5	0
Muscle or joint ache	25.0	12.5
Headache	25.0	0
Other physical problems	12.5	0

<sup>+</sup>Mean % of rating periods in which a particular item was endorsed.

substantial differences in the percentage of item endorsements on the majority of items, for example, “Discussed task concerns with my teammate,” “Kept my feelings to myself,” “Saw the situation in a positive way, what I’m learning, getting out of it,” “Tried harder. Pushed myself to do my best, told myself I can do it,” and “Negative feelings about my teammate” (Table IV).

### Disagreements, Conflict and Its Resolution

The frequency of differences of opinion in how a situation should be resolved, resolution through talking together and agreeing who has the responsibility for the task, coping by retreating to a different area of the habitat to diffuse tensions, and having a party that promoted positive feelings are noted in the WRF comments below.

Disagreements: Week 1. TM #2—“It happens all the time... Every decision to be made.” Week 3. TM #1—“It happens frequently. We talk about it until it’s solved. The person taking responsibility of the task has the right to decide which is best.” Comments from Week 4 are as follows: TM #2—“We had our first real argument. [#1] got angry with my lack of excitement about filming and documenting the expedition.”

Resolution: TM #1: “A medium sized conflict with teammate, we solved it quickly...I went to the airlock and closed the door to calm myself down and get some privacy. After a 10-minute break we talked again and apologized.”

**Table IV.** Mean Percentage of Coping Mechanisms Endorsed While Living in the Habitat.

ITEM	TEAM MEMBER #1 (% <sup>+</sup> )	TEAM MEMBER #2 (% <sup>+</sup> )
Told myself, “take it one day at a time. Live with it, accept it.”	75.0	100
Kept my feelings to myself.	50.0	100
Discussed task concerns with teammate.	50.0	100
Discussed personal/emotional concerns with teammate.	25.0	0
Tried harder. Pushed myself to do my best, told myself “I can do it.”	75.0	50.0
Wrote home or in a diary/journal.	87.5	62.5
Prayed (For God or others).	0	0
Saw the situation in a very positive way, what I’m learning and getting out of it.	87.5	37.5
Kept a positive attitude. Humor, joking around, having fun.	50.0	37.5
Relaxed, meditated, listened to music, daydreamed.	87.5	75.0
Kept the goal in sight. Thought about finishing the journey and why I’m here.	100	87.5
Thought of something pleasant such as good times to come.	75.0	87.5
Tried to figure out how to solve the situation that’s bothering me.	100	37.5
Negative feelings about myself.	0	0
Negative feelings about my teammate.	12.5	50.0
Yelled, stomped, threw things around.	0	0

<sup>+</sup>Mean % of rating periods in which a particular item was endorsed.

TM #2: End of Week 4. “Last Friday we had a “party” in the habitat. It was fun and definitely “rebooted” our camaraderie.”

### Other Significant Events

Positive events were associated with enjoyment of nature and receiving parcels from home; negative events related to illness and safety issues. TM #1, Week 4: “The dawn is just beautiful now. I enjoy being outside. I am also enjoying my personal work here.” Week 5: Care packages from girlfriend. Negative events referred to a Week 2 illness: “fever and in bed for three days.” TM #2’s positive events were associated with camaraderie, food parcels from home; negative events referred to environmental changes. Week 5: “We opened our family care packages.... It was one of the best things on the mission so far... It’s crazy how powerful sweets and snacks are in a deprived environment like this”. Negative events, Week 5: “The sun set for the season a few days ago. It was stressful because there was still unfinished work to be done that required sunshine.”

### Cognitive Performance

Scores on the WinSCAT showed a consistent increase across the biweekly assessments for both teammates, except for TM #1 at Week 7. He suffered a bicep injury during that week that might have interfered with speed of motion. Overall, these findings suggest that while a baseline level of proficiency was reached in pre-mission practice, there continued to be a learning curve during the mission (Table V).

**Table V.** Spaceflight Cognitive Assessment Tool for Windows (WinSCAT) Index of Cognitive Efficiency Baseline and Mission Scores.

TIME	TEAM MEMBER #1	TEAM MEMBER #2
Baseline	331	416
Week 1*	326	478
Week 3	381	499
Week 5	411	545
Week 7	354	559

\*Weeks in the habitat.

### Post-Mission Debriefing Interview

The necessity to complete the outdoor filming of the habitat before total darkness set in was a continuing stressor. During the first month in Greenland while the team was living in a safety hut and working outdoors to construct the habitat, there was a concern about polar bears; tracks were spotted near the hut on Day 10 of arrival. Cold and wind conditions had an impact on their progress and amplified any irritation in terms of the pace of constructing the habitat. During the 8-wk period living in the habitat, both teammates mentioned the privacy advantages of rotating every 2 d working indoors or outdoors, although on some days both needed to work outside together. Another mode of privacy was to go into the airlock to do individual logs on the computer or to exercise.

The debriefing interview in part focused on perceptions of how a team could work together more effectively. According to TM #1, the most important factors for a work group to be effective in an ICE environment were as follows: *“Tolerance, self-awareness, sharing a clear goal, emotional intelligence... Talk it through, then shake hands.... Every argument brought us closer.”*

Physical well-being in the habitat also was assessed. TM #1 stated sleep was *“Good, minor difficulties falling asleep.”* The final 4th week: *“excellent.”* Appetite changes were noted; *“Due to illness, I completely lost my appetite for about a week. Other than that, I felt a healthy appetite.”*

Unusual experiences have occasionally been reported by expeditioners and others in isolated environments and occurred as well for TM #1:<sup>22</sup> *“Random visions of distant friends and relatives mostly from my childhood...I felt more spiritual than normal...as though there was someone looking over us.”*

TM #2 indicated that the most important factors for a work group to be effective in an ICE environment are *“Having structured days with time allocated to work as well as leisure.”* Regarding how to resolve disagreements, he stated that *“it would have made it more frictionless if we’d defined our areas of responsibility clearly before embarking.”* However, they resolved their disagreements *“through communication. We both learned to be better at saying sorry when we’d been wrong or unfair.”*

TM #2 indicated several physical difficulties regarding sleep and appetite. His sleep patterns in Month 2 were poor and in Month 3 were fair. Changes in appetite also were evident: *“Towards the end I started thinking a lot about food. I started craving a lot of food and dreaming about the dishes I couldn’t eat. In fact, I made a list of them just to get it out of my head.”*

### Human Factors

The features the team found most comfortable within the habitat were factors that increased floor space, such as desks that flipped up and collapsible chairs that could be stowed away when not in use, storage shelves next to their individual desks, and organized storage space. The team also freed up space by using the space beneath the floor for hardware, food, and equipment storage. There was versatility in using areas and furniture in different ways, such as working or relaxing in the sleeping pod or the airlock, which also enhanced privacy.

A highly important comfort and sleep feature was the installation of a circadian light system with daily variation, high color rendering, and simulated sunsets and sunrises. According to TM #2’s self-report, these features promoted a healthy sleep-wake cycle, a sense of time, something to look at, and made the habitat feel natural: *“It felt like we had large amounts of diffused sunlight flooding into the habitat, which in ways hard to define made it really pleasant to be there. The mornings especially were nice.”* TM #1 stated that another comforting aspect was *“the contrast between the interior and the exterior of the habitat. From the outside, the habitat shell is black with jagged edges and almost looks intimidating; the inside is the exact opposite - light colors, soft materials, and rounded edges.”*

Stated improvements in the habitat design were related to the ventilation system—the addition of fans or ducts to circulate the air more evenly throughout the habitat. Temperature regulation also was a challenge.

### DISCUSSION

The findings of this investigation demonstrated the interactive influence of the team and the habitat design on effective functioning in an ICE environment. The findings also showed the leveling influence of decision authority in a dyad living and working together in an ICE environment for an extended period, and its often-deleterious effect on work performance.

Individual differences between team members on personality traits and values clearly affected team effectiveness, resulting in disagreements on strategies for task completion that were evident throughout the mission. However, the crucial importance of the purpose and goals of the mission and the strong commitment to its successful completion were overriding factors in the exigencies of their daily activities.<sup>2,7</sup>

Examination of the differing personality trait configurations of the team members provides insight into team relationships. While they were similar to each other in their relatively high scores on Openness and creativity, they were incompatible on Agreeableness and Extraversion. Team members possessing high levels of conscientiousness and agreeableness have been viewed as optimal for effective team performance;<sup>8,23</sup> however, exhibiting high conscientiousness and an abrasive and contradictory behavioral style, interacting with a teammate who is low in energy and more passive and reserved, increases the likelihood of relationship and task disagreements.

Teammates in the current study were also incompatible in personal values adaptive for dyadic task performance. Both team members highly valued self-direction. However, there were marked differences on other self-identified values: TM #2 had high scores on Stimulation and low scores on Power and Achievement (as related to social recognition); this is in contrast to TM #1's moderate scores on Stimulation, Power, and Achievement. Tensions among team members viewed as having dissimilar values noted in the Russian Mars-105 simulation and the current study appear related in part to differences in the approach to work performance, including the timeliness of task completion.<sup>18</sup>

The findings comparing the pre- and post-mission measures demonstrated that the experiences of two people living and working in an ICE environment for an extended period had an impact on psychological perceptions. Pre- to post-mission changes in personal attitudes were evident; both team members showed an increase in the perception of their resilience as they successfully completed their mission, and a decline in attitude about their ability to control the events that happen to them, likely related in part to the impact of the physical environment. There were also individual differences in changes on Stimulation, Benevolence, Achievement, and other values reflecting their experiences of isolation in an extreme environment. In retrospect, both team members viewed their team effectiveness in a less positive manner.

The events endorsed on the WRF indicated a number of substantial differences in daily experiences. TM #1's coping methods were more problem-focused, while TM #2's strategies were primarily emotion-focused and keeping feelings in. The latter's less adaptive coping strategies likely contributed to his feelings of loneliness; the need for more privacy allowed him to deal with his feelings through solitary activities.

Both teammates perceived difficulties in working together and importantly, the role or decision authority each would assume regarding the performance of specific tasks. However, despite the numerous disagreements about daily tasks, both reported strong feelings of camaraderie with their partner throughout the mission. This finding reflects their continuing report that disagreements were resolved through prolonged discussion until a resolution was achieved. "We talked through it." Typically, the resolution was to go along with the opinion of the team member who had primary responsibility for that particular task, although occasionally which team member had primary responsibility was not clearly understood or agreed upon.

By means of extended discussion, information was exchanged that potentially enhanced the effectiveness of the ultimate completion of the task. This discussion process reflects theoretical formulations proposing that across a timeline, task conflict has a positive outcome on performance.<sup>9,25</sup> In agreement with this formulation, the teammates reported that during the last several weeks of the mission, they were getting along quite well in their work and personal relationships despite initial differences in opinion on the performance of particular tasks.

However, the major conflict that occurred during Week 4 had a clear effect on the mood of both teammates. While a distinction has been made between task conflict and relationship conflict,<sup>9,25</sup> clearly the strong task disagreement spilled over into a negative effect on their relationship. The ability to obtain privacy or physical distance from each other by going to another area of the habitat or exiting the habitat helped diffuse the negative emotional arousal of the situation, as did the celebration several days later on the weekend.

Other experiences during the mission are of note. TM #1, high in Openness, reported visual images and memories from childhood and at times a sense of someone looking over him as he carried out various tasks. These sensed presence images have been reported by expeditioners and others in ICE environments and may be related to a propensity to fantasy and daydreaming while engaged in a challenging environment.<sup>2,22</sup>

The innovative design of the habitat has significant applications for the habitat that will be placed on the lunar surface during the Artemis missions. Living and working in a habitat specifically designed as a lunar analog had a continuing influence on team performance. The circadian lighting system was a highly important component of the habitat; self-reports by teammates indicated that the lighting system facilitated regular sleep/wake schedules, cognitive activation, comfort, and time orientation. The configuration of the workspace regarding the placement of individual desks, the ability to flip them up against the wall, multifunctional and collapsible furniture, storage space to avoid clutter, and the occasional use of the airlock for work and privacy facilitated task performance and mitigated interpersonal conflicts. Both team members' use of isolated areas of the habitat for privacy facilitated the diffusion of tension and thus served as a means of coping with stress. The interior materials, color scheme, and the designed comfort of the sleep pods promoted relaxation and made the habitat feel more like an Earth home. The comfortable sleep pods also facilitated individual privacy as needed.

This study has a number of limitations. The participants were an opportunity sample and were not selected to possess "astronaut-like" characteristics. They did not collect data while building the habitat because their specific focus was on the evaluation of the effectiveness of the structure of the habitat. In studies with a small number of participants, the data are necessarily descriptive.

Overall, the findings of this study demonstrated that compatibility of adaptive personality traits and personal values, the salience of the overriding goal of the mission, and clarity of role relationships are crucially important for effective team performance in ICE environments. It is important to note that conflicts can occur regarding strategies for carrying out specific tasks even when the decision authority of one of the team members is specified. This leveling process of decision making may be particularly problematic in a crew of two persons. Therefore, in developing countermeasures for dealing with crew conflict, the decrease of decision authority as a crew works together over an extended duration and its potential influence on crew



conflicts and work performance need to be considered. The effective methods of conflict resolution noted throughout this lunar habitat mission have application for other teams living and working in extreme environments. The human factors description of the components of the interior design of the habitat that facilitated or hampered team performance is relevant for a range of situations, particularly those involving dyadic teams living in small, confined spaces.

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