Confinement vs. Isolation as Analogue Environments for Mars Missions from a Human Ethology Viewpoint

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INTRODUCTION: This study compares observational data from two situations designed as planetary exploration missions: the Tara expedition and the Mars-500 experiment. We examined the issue of distinct environmental factors, isolation vs. confinement, which may have different or similar impacts on crews' behavioral manifestations for long-term adaptation, such as on a Mars mission. The Tara expedition was a 507-d polar drift of the Tara schooner embedded in the Arctic ice with two successive periods of summer and winter-over in an isolated environment. The Mars-500 experiment took place in Moscow and was a 520-d simulation of a trip to Mars, the Mars landing, and the return trip to Earth in a confined environment.

METHODS: We used the ethological method based on observation, description, and quantification of individual and interindividual behaviors. These events were scored from video recordings made during daily life activities and aggregated according to the summer period and to the outgoing trip for the whole crew ($N = 6$) for each situation, respectively.

RESULTS: We did not observe differences in the frequency of facial expressions and in the duration of body interactions. Conversely, there were differences in the frequency of collateral acts and in the duration of personal actions with the highest levels during the Mars-500 experiment (0.52 /min and 41,799 s); the highest level of visual interactions was observed during the Tara expedition (33,167 s).

DISCUSSION: We found that confinement generates stress manifestations vs. isolation, that isolation enhances social relashionships vs. confinement, and that the crew adapted positively to both environments.

KEYWORDS: behavior, adaptation, social group, isolated and confined environment, space exploration, polar missions.

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Planetary exploration missions lead human crews to adapt to two main environmental factors: isolation and confinement. Along with physical and mental health, crewmembers' behavioral adaptation on a long-term mission becomes one key to the success of these missions. A mission to Mars would last more than 500 d. It has been previously stated that the time and human factors are of prime importance in the adaptive process.[10] Cultural influences and individual differences were observed in multinational crews' communications. We proposed to study the effects of the more specific environmental factors of isolation and confinement on behavioral manifestations. It is a challenge to separately study these variables in analogue environments and there is a need to find terrestrial substitutes. In recent literature, numerous psycho-physiological works have been performed on isolated and confined crews,[12] but there have been no obvious findings on the extent to which isolation vs. confinement have an influence on individual and interindividual behaviors from an ethological viewpoint.

Isolation can be defined as an open space with climatic variations, external dangers, and restrictive living conditions that can become monotonous, is far from any civilization, and is an environment in which the crewmember is somehow socially isolated. Examples of analogue environments are the transpolar expeditions and the polar stations located in the Arctic and the Antarctic regions. The Fram drift at the North Pole (1893-1896) has been a precursory expedition to get

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psychological information from the discussions between participants. Human performance in polar environments[6] as an analogue for space missions is a new goal for researches that would integrate psycho-social and neuro-biological adaptation. For negative impacts, results showed that both polar conditions and human relationships generated decrements in mood, sleep deprivation, problems in concentration, and interpersonal tensions. However, in term of salutogenic adaptation,[7] the positive aspect was personal growth associated with greater self-confidence that lead to improved human performance in the polar regions.[6]

Other works conducted at the Flashline Mars Arctic Research Station (FMARS) on Devon Island, Canada, contributed to the design of missions for exploring the Moon and Mars.[1] Results showed that human experiences in the conditions of prolonged real isolation and hostile natural environments appear to provoke true demands for adaptation rather than temporary situational accommodation.[2] These are the current methods of investigation that support scientific knowledge of behavioral manifestations that we have previously studied at the Concordia station, Adelie Land, Antarctica. We found social cohesion when observing winterers' behavior, expressed by an increase in visual relationships during summer periods[9] and cyclic changes of the collective time to cope with the monotony of prolonged isolation.

Confinement can be defined as a closed space with regulated life-support, inner dangers, and restrictive living conditions that can be monotonous, with proxemics or crowding, and an environment in which the crewmember is somehow physically confined. Examples of these settings include a wide range of experiments in multichamber facilities and submarine missions. Ethological investigations made during campaigns of confinement such as the Isolation Study for European Manned Space Infrastructure (ISEMSI), Experimental campaign for European Manned Space Infrastructure (EXEMSI), Human Behavior in Extended Space flight (HUBES), and Simulation of Flight International Crew on Space Station (SFINCSS) described changes in social behavior over time according to environmental situations[8] and cultural background. On the basis of Hall's classification, the frequency of personal distances decreased and the frequency of public distances increased in small habitats. We also observed high levels of social distance and body mobility from the initial period to the final period of confinement.

During NASA Extreme Environment Mission Operations (NEEMO) missions, the crew that lived inside the divers' undersea habitat with strict life-support experienced training that had an enduring value, a beneficial effect, and an optimized success for space missions. During submarine missions, the rigorous and very long crew training as well as the strong hierarchical rules led to behavioral stereotypes and over-learned responses[3] that did not permit uncertain outcomes in the adaptive process. Considering the isolated and confined crew as a whole, high autonomy would be the common feature for future exploratory missions.[4,5]

Two analogue environments are of prime interest in the field because they are exceptional paradigms that offered, on the same 500-d long-term mission, actual isolation conditions during a transpolar Tara expedition in the Arctic vs. actual confinement conditions during the Mars-500 experiment inside a multichamber facility. In the present study, our general hypothesis was that the comparison of the crews' behavioral manifestions, from observable events, would show differences of impacts between an isolated environment and a confined environment. We worked from an ethological perspective that included the analysis of obvious events (personal actions, interactions, facial expressions, collateral acts) occurring in the crewmembers when adapting to their environments (Tara expedition and Mars-500 experiment). Our working hypothesis was that the occurrences would change from one situation to the other.

METHODS

Subjects

The subjects of the Tara expedition for the study were on the partial relieving team ($N = 6$) of the second summer period (1 May 2007 to 18 September 2007) and were composed of four French, one Estonian, and one Norwegian, all men. They were between 23 and 34 yr old. The subjects of the Mars-500 program for the comparative study were the entire crew ($N = 6$) and were composed of three Russians, two Europeans, and one Chinese, all men. They were between 26 and 38 yr old. All the subjects in each situation gave their consent to participate in the study.

Equipment

The Tara expedition was a 507-d polar drift of the Tara schooner in the Arctic Ocean with two successive periods of summer and winter-over. It was embedded in the pack-ice from a northeastern latitude (79.53°N 143.17°E) on 3 September 2006, crossed 5200 km, and was released from the ice at a northwestern latitude (74.08°N to 100.04°W) on 21 January 2008. The schooner is 36 m long and 10 m wide with 14 berths, a quarterdeck, a cooking area, a communication area, a technical area, storage areas, and a navigation area on the upper deck. In the summer period, the temperature could reach +9°C and in winter during the polar night, the coldest temperature could reach −41°C. Therefore, the crew could go outside; the crewmembers were isolated, but not actually confined. After a first wintering with summer period (September 2006 to April 2007), relieving teams ($N = 10$) boarded the Tara schooner for the following 236-d period of summer and winter-over (May 2007 to January 2008).

The Mars-500 program was a 520-d experimental paradigm that simulated different phases of a mission to Mars: a 250-d interplanetary flight from Earth to Mars, a 30-d orbital stay that included the Mars landing, and a 240-d interplanetary flight from Mars to Earth. It began 3 June 2010 and ended 4 November 2011, and took place at the Institute of Biomedical

Problems (IBMP) in Moscow, Russia. The facility was composed of four hermetically sealed, interconnected modules: the habitable module, the medical module, the storage module, and the Mars landing module. The total volume of the modules was 550 m^3 and the volume of the Martian surface was 1200 m^3. In the habitable module, there were a living room, a dining room, and six private cabins with berth and a single toilet/shower. The artificial atmospheric environment was set at a normal barometric pressure. Therefore, the crew could not go outside; the crewmembers were confined, but not actually isolated. The period chosen for the comparative study was on the outgoing trip to Mars (3 June 2010 to 26 October 2010).

Procedure

The ethological approach is a noninvasive method based on observation, description, and quantification of spontaneous individual and interindividual behaviors in daily life activities or specific tasks. Firstly, the observation protocol was on the collective meals: the evening meal for the Tara expedition and the morning meal for the Mars-500 experiment (observational data collection in the evening was not authorized). The advanced logistic support was the subjects' video recordings incorporated into the protocol of data collection. Analyses of video recordings were performed on two Thursdays a month over the first 145 d, totaling 10 points of observation for each situation.

Secondly, descriptive analysis was carried out on nonverbal behavior and focused on personal actions (any body segment movements, postural changes), visual interactions (any gazes directed to one subject), body interactions (any body contacts between two subjects), object interactions (any manipulations from one subject to another), facial expressions (any face movements such as smiling, laughing), and collateral acts (any small movements with no manifested functions such as scratching the head, scratching the nose).

Thirdly, the quantitative analysis consisted of scoring these behavioral events with The Observer XT® (Noldus, Netherlands). It is a software-based solution for collecting, organizing, and processing observational data from synchronized video files.[11] The scoring system was to list the events as the video progressed in a sequential process.

Statistics

We used nonparametric descriptive statistics for the quantification of point events (facial expressions and collateral acts) in terms of frequency of occurrence and for the quantification of state events (personal actions and interactions) in terms of duration of occurrence, completed with Chi-squared tests to assess the significant differences (P-values). Institutional Review Boards specific to the Tara expedition and to the Mars-500 program approved the research proposals.

RESULTS

We compared the quantitative results between the two situations observed. The observational data were aggregated according to the same total analyzed time, which was 15 h (10 d $\times$ 6 subjects $\times$ 15 min $=$ 900 min). Findings were based on the total occurrences of acts per minute defined as behavioral flow (personal actions + body interactions + object interactions + visual interactions + facial expressions + collateral acts). The results showed that the overall behavioral flow (BF) of the crewmembers during the Tara expedition was lower (BF $=$ 3.0 acts/min; SD $=$ 0.6) than during the Mars-500 experiment (BF $=$ 4.6 acts/min; SD $=$ 0.8). This means that the crew would increase actions and interactions in confinement, whereas the crew would reduce them in isolation.

Fig. 1 presents the average frequency of crewmembers' facial expressions. We did not observe a significant difference between the Tara expedition and the Mars-500 experiment. Facial expressions (smiling and laughing) are indicators of well-being or team spirit and the results showed positive impacts of both isolation and confinement factors on the crews' behavioral adaptation. However, there was a significant difference in the average frequency of collateral acts as presented in **Fig. 2**. These are indicators of stress or tension and the results showed a higher level during the Mars-500 experiment than during the Tara expedition. Even if both situations induce positive adaptation, they can have distinctive impacts. This means that confinement would be a stressful environment vs. isolation.

Fig. 3 focuses on the total duration of personal actions evaluated in each situation. Again, there is a significant difference. The results showed individual behavior that was twice as long during the Mars-500 experiment than during the Tara expedition. This means that isolation would generate an interindividual behavior with longer interactions vs. confinement. Results displayed in **Table I** illustrate this tendency qualitatively and quantitatively. We observed the same durations of body interactions, whereas visual interactions were longer and object interactions were much longer during the Tara expedition than during the Mars-500 experiment. The significant difference in the duration of total interactions confirms that isolation and confinement do not have the same impact on individual and interindividual behaviors. As a result, the behavioral manifestations of crews' adaptation

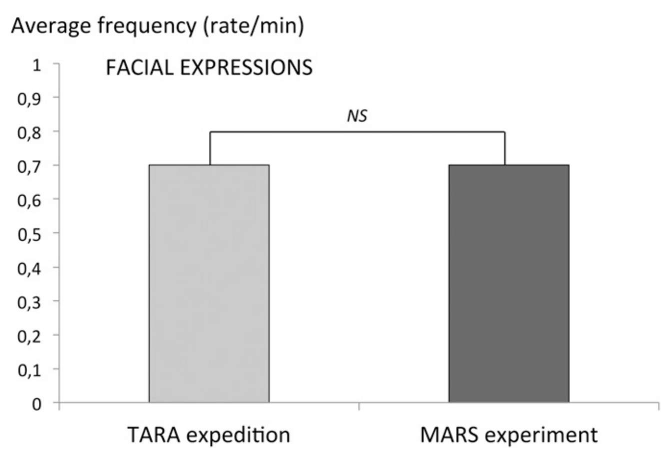

Fig. 1. Comparison of the frequency of occurrences of crews' facial expressions between the Tara expedition and the Mars-500 experiment.

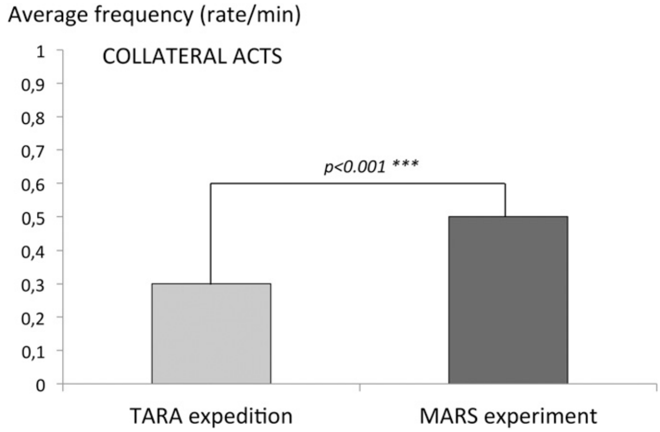

Fig. 2. Comparison of the frequency of occurrences of crews' collateral acts between the Tara expedition and the Mars-500 experiment.

depend on the environmental factors and support our working hypothesis.

DISCUSSION

We found that features of analogue environments for Mars missions impacted human behavior from an ethological viewpoint that did not only consider the result of the behavior, i.e., crews' efficiency, but also considered facial expressions, collateral acts, personal actions, and interactions leading to it, i.e., crews' strategies. Similarities and differences between the isolation and confinement factors generated related behavioral manifestations that led to various strategies of adaptation. For instance, our study suggested that in a confined environment with decreased possibilities for physical activity, crewmembers increased behavioral flow. We failed to find changes in body mobility in a wide space because the observations were authorized only at meal times due to the constraints of protocol and privacy, but in an environment with proxemics that delimited close interpersonal distances, we found a high level of crewmembers' personal actions. Conversely, in an isolated environment where the crew is far from any large societal activities, i.e., civilization, the interactions were longer, as if the crewmembers increased social relationships, specifically through visual interactions. We noted that body interactions are neither dominant in nor different between isolation and confinement. Our findings revealed similar behavioral manifestations that depended upon the same environmental features. In these extreme settings with restrictive living conditions that can become monotonous, crews adapt positively through frequent facial expressions, which are shown in our previous studies to be indicators of well-being or team spirit. On the other hand, differences between the Tara expedition and the Mars-500 experiment may also be related to mission goals. Reaching Mars after 250 d or being released from the Arctic ice-pack after 236 d (for the relief crew) did not have the same impact on the crewmembers' behaviors. This resulted in behavioral manifestations of stress such as collateral acts that were more frequent in the confined crew compared to the isolated crew. Confinement (vs. isolation) would be a stressful environment despite the dangerous conditions of both analogue environments.

These distinct contributing factors should be considered in training, preventing, and optimizing daily life activities and work tasks, and for a better knowledge of human adaptation to future planetary exploration missions. We may then raise the question about synergies of environmental factors and other factors with strong impacts because future crews will have to deal not only with isolation and confinement, but also with extended periods of time. Other terrestrial campaigns of simulation exist such as those conducted at the Mars Desert Research Station (MDRS) in Utah in the United States. MDRS is not a strictly confined and isolated environment, but it was designed for extravehicular activities while working in a desert landscape and mimics a Mars landscape. Long-duration missions aboard the International Space Station (ISS) are the closest replication of interplanetary missions.

In all the situations, there are methodological limitations as we had in the present study. The major limitations were that we could not standardize the comparative data (synchronized days of observation, sessions of observation per day) and harmonize the observed subjects (size of the group, age, gender, task, background, days spent in the situation). It would have been effective to compare the crews over full 500-d periods of isolation and confinement, but that was only possible during the Mars-500 experiment. Nevertheless, each situation permitted a relevant transversal approach. In conclusion, for validating our preliminary research findings and for promoting further advances in space exploration, future studies need to better understand several perspectives of psycho-physiology, socio-psychology, and neuro-biology with ethology and need to explore diverse terrestrial and orbital environments in order to move closer to a Mars mission.

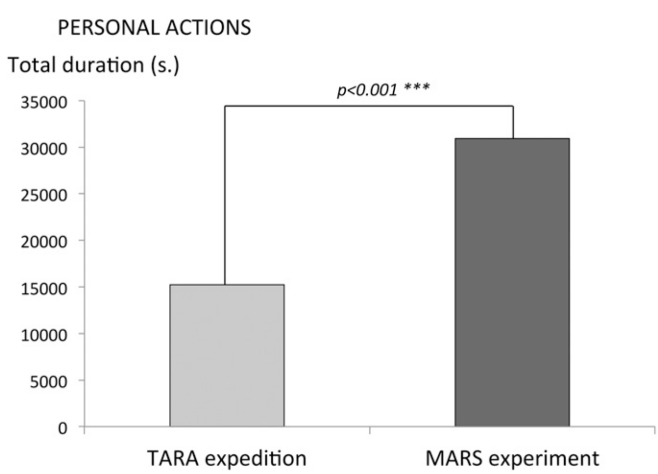

Fig. 3. Comparison of the duration of occurrences of the crews' personal actions between the Tara expedition and the Mars-500 experiment.

Table I. Comparison of the Duration of Occurrences of the Crews' Interactions Between the Tara Expedition and the Mars-500 Experiment.

	BODY INTERACTIONS	OBJECT INTERACTIONS	VISUAL INTERACTIONS	TOTAL INTERACTIONS	CHI^2 TEST
Tara	228 s	2231 s	33,167 s	35,626 s	$P < 0.001$***
Mars	230 s	580 s	19,767 s	20,577 s	

***Indicates strongly significant.

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