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Brief Report

120-DAY SIMULATION OF A MOON MISSION (SIRIUS-19): CONTEXT OF BEHAVIORAL OCCURRENCES

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ABSTRACT

Ethological observations in extreme living and working contexts are relevant for interdisciplinary investigations and methodological applications on human adaptation in experimental settings, as offered in The Scientific International Research in Unique Terrestrial Station (SIRIUS) program. Observational data collected from video recordings during the Moon mission crew's collective activities over a 120-day simulation (n=6, mixed gender and culture) produced ethological results according to mission days, major events and environmental factors. We reviewed key behavioral outcomes in such a context of occurrences and in extended periods of time. The emphasis is on Moon landing at mid-period with positive facial expressions and increased flow of merged behaviors as adaptive strategies. Analysis of the results in this brief report follows the original article on "individual diversity and temporal stability during a 4-month confinement experiment (SIRIUS-19) for human space exploration" (Tafforin et al., 2021).

Keywords: *adaptation, interdisciplinary, spaceflight, time, Isolated and Confined Environment (ICE)*

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INTRODUCTION

Space and human ethology deploys observation tools in a wide range of environments: in real situations (space shuttle and orbital station), in simulations (parabolic flight, water immersion and bedrest), in isolation analogs (Antarctic, Arctic and Mars Desert Research Station) and during confinement campaigns (ISEMSI, EXEMSI, HUBES, CELSS and MARS-500) (Tafforin, 2015). Such investigations are concerned with studies of individual and social behaviors in daily life activities (meal time and leisure time) and working tasks (experimental tests and remote operations). The aim is to highlight dynamics of actions with regard to theoretical accounts on how internal and external information processes interact (Hoffmann et al., 2019). The goal is to look at human performance through the behavioral strategies leading to it. Specificities are to analyze spontaneous manifestations (personal and interpersonal actions, communications and expressions), what emerges from the optimal relationships between the crews and their living and working contexts. We assume that it is an optimizing process. Limitations are the observable field based on objective criteria. The general problematic is to emphasize a multisystem adaptation (Yuan et al., 2019) with psychophysiological demands (Gushin et al., 2012, Basner et al., 2014) and harmonious crew dynamics (Bell et al., 2019) for long-duration space missions. Ethological studies are part of a wide spectrum of experiments performed for the preparation of remote operations from Earth and autonomous manned journeys on planets (Moon and Mars). MARS-500 was an exceptional paradigm used to develop devices for monitoring changes in crew relations during a 520-day simulated mission to Mars (Johannes et al., 2015) or methodological tools for analyzing adaptive strategies of the interplanetary crew in extended periods of time (Tafforin, 2013).

METHODS

The Scientific International Research in Unique Terrestrial Station (SIRIUS) program offers a new opportunity to investigate human behavior in an operational environment simulating interplanetary mission scenarios. SIRIUS-19 took place from 19th March 2019 to 17th July 2019 at the Institute of Biomedical Problems (IBMP) in Moscow, Russia. The experiment was completed like MARS-500 in the Ground Test Complex (NEK) over a 120-day isolation and confinement period to design a Moon mission (Table 1). The NEK is a multichamber facility consisting of 5 units of 550 m^3: an EU-50 landing module, an EU-100 working module, an EU-150 living module, an EU-250 storage module and a PSS planetary surface simulator. A set of 38 control crew cameras (CCTV) covers the experimental area.

Table 1: Major events designed in the IBMP-NASA project for the SIRIUS-19 mission.

Scenario per day	**Events duration**	**Mission days** **Module**	**Observation days** **EU150: BF/*GD***
Launch and insertion into near-Earth orbit	3 days	MD 1-3 EU150	
Transit and dock with the Moon orbital station	7 days	MD 4-10 EU150	MD 5
Orbital operations	50 days	MD 11-60 All modules	MD 20, **MD 34**,48 *MD 17,48*
Landing and on-surface operations	10 days	MD 61-70 EU50	**MD 62**
Departure and dock with orbital station	8 days	MD 71-79 All modules	MD 76
Orbiting the Moon, control rovers remotely and dock with transport vehicles	30 days	MD 80-110 All modules	MD 89, **MD 104** *MD 101*
Transit to Earth	7 days	MD 111 – 117 EU150	***MD 114***
Reaching near-Earth orbit and landing	3 days	MD 118 –120 EU150	**MD 118**

BF= Breakfast/*GD=Group Discussion*.
In blue: low behavior-impacted periods; in red: key events; in bold: key days

The ethological method (Tafforin, 2017) was applied on video recordings collected twice a month for daily life activities at breakfast and once a month during group discussions in the living module. We analyzed the nonverbal and verbal behaviors observed, described and quantified according to the subjects (three Russian women, one Russian man and two American men) and the mission days (MD). The crew (mean age = 34.5; SD = 6) provided informed consent before participating in the SIRIUS-19 mission.

The software-based solution was the Observer XT 14.0 used to organize data per subject or per MD, to proceed to descriptive statistics (occurrences based on percentage or on frequency) and to visualize data. For example, it calculates the behavioral flow by the number of non-verbal behaviors on duration of observations (act/min).

RESULTS

Observational data were the dependent variables, i.e., behaviors, related to the independent variables, i.e., environment features (Table 2). Review of the results gives the main impacts.

Table 2: SIRIUS-19 environment and behavior.

Independent variables	Dependent variables	Examples
Isolation, confinement	Personal actions	"eat", "drink"
Life support	Visual interactions	"look at subject B", "look at all crew"
Social, familial privation	Body interactions	"touch subject E", "point at all"
Individuality	Object interactions	"give object to C", "take object from D"
Monotony	Facial expressions	"smile", "laugh"
Autonomy	Collateral expressions	"scratch the head", "scratch the noise"
Promiscuity, privacy	Body expressions	"relax", "speak with hands"
Ground control contacts	Body motions	"sit down", "stand up"
Danger, maintenance	Communications	"speak to subject A", "speak to all"
Workload, complex tasks		
Multicultural group		
Mixed gender composition		
Non-native language		

In blue: key environmental contexts; in red: key behavioral occurrences

We first observed that the SIRIUS-19 crew's behavioral profile had higher levels of personal actions and visual interactions and low body activity (interaction, expression and motion), with an emphasis on facial expressions rather than collateral expressions. At any time, the balance of facial expressions vs. collateral expressions was positive, with the highest level of such positive manifestations at mid-period (MD 62). The results showed the SIRIUS-19 crew's behavioral variations with salutogenesis-based expressions. Time-course changes in the occurrences of interactions over 40-day periods and of communications with the lowest level at the end of the SIRIUS-19 mission (MD 114) gave an overview of the ethological analysis (Tafforin, 2020).

Regarding the individuality variable, the results showed differences between subjects in the occurrences of interactions, motions, expressions and communications on specific mission days, such as on MD 118. The mean linear trend did not show significant associations with time, i.e., upward or downward continuum. We concluded that there was individual diversity and temporal stability (Tafforin et al., 2021).

Regarding gender and cultural variables, the results showed expressive and communicative behaviors in women and less active but more interactive behaviors in men, with specific adaptive strategies built by each of them. We observed more frequent communications between American crewmembers in the male subgroup. Conclusions were drawn regarding the personal value and diversity value that contributed to the heterogeneous quality of a mixed gender and culture group in a positive way for mission success (Tafforin, 2020a).

Related to psychological data, a comparison of individual values, based on Schwartz's classification (Schwartz et al., 2012), showed that in SIRIUS-19 baseline data, there were gender differences that tended to smooth out after the experiment, except for values such as benevolence, self-direction and hedonism, which were higher for women than for men. Evaluation of the group effectiveness and role distribution showed that subgroups mixed in gender most successfully solved tasks of medium complexity, and the highest leadership activity was noted for one woman and one man. Data visualization and quantification from ethological observations according to subjects and to mission days supported the results (Vinokhodova et al., 2021).

Overall, the behavioral flow results (merged non-verbal behaviors on whole observation duration) showed low levels on MD 34 and MD 104 and the highest levels on MD 62 and MD 118. In the 120-day mission scenario, we observed ascending and descending curves, such as rhythmic variations or cycles indicative of crew adaptation dynamics to environmental factors (Tafforin, 2020b).

Data visualization is displayed in Figure 1. The global results show (a) differences in the verbal behaviors per subject over time and (b) variations in the non-verbal behaviors during the MD and upon daily live activities duration (breakfast). Behavioral occurrences are at high levels over long duration meals but sometime over shorter duration. Temporal context is also to consider.

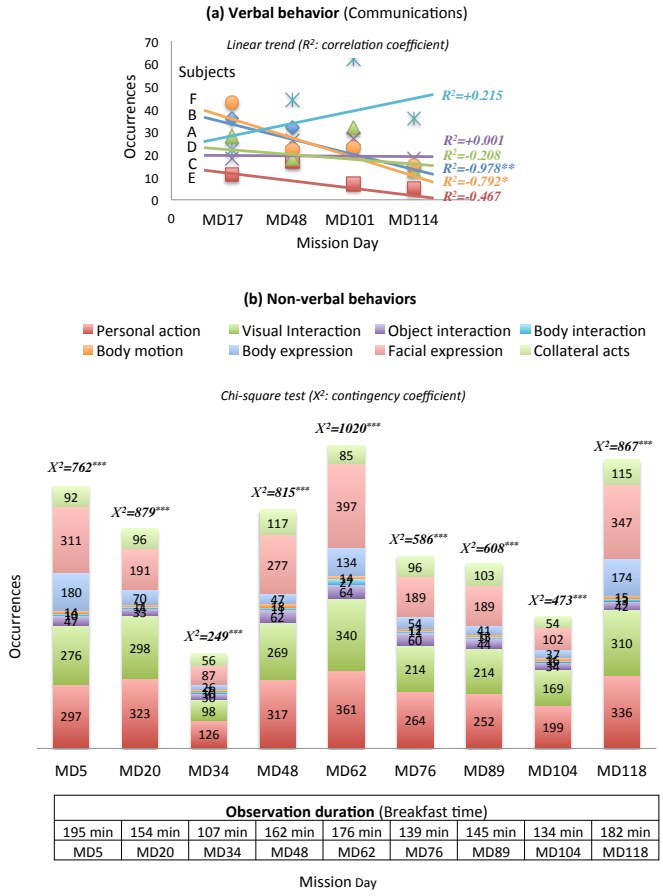

Figure 1: Row data given in absolute occurrences of behavioral variables (number of acts). (a) The flat lines give the linear trends associated to time variable, with R^2 determination levels (*p<0.05; **p<0.01). (b) The histogram gives the significant distributions (X^2 values for df:7; ***p<0.001) associated to the observation durations per MD.

Table 3: Levels of main behavioral occurrences with respect to mission days.

Mission days	Behavioral occurrences
MD 34	↘ Personal actions ↘ Behavioral flow
MD 62	↗ Facial expressions ↗ Behavioral flow
MD 104	↗ Visual interactions ↘ Behavioral flow
MD 114	↘ Communications ➡ Individual differences
MD 118	↗ Collateral expressions ↗ Behavioral flow

MD= Mission Day

DISCUSSION

The ethological results must be analyzed in the context of their occurrences for further interpretation. During the major events of the SIRIUS-19 mission, the launch phase to near-Earth orbit, the transit phase to the Moon orbital station, and the reaching near-Earth orbit then landing phase were low behavior-impacted periods. However, there were specific days with an emphasis during the Moon landing and on-surface operations phase. A review of the main impacted behaviors on key days is summarized in Table 3. On MD 62, increasing occurrences of facial expressions, as indicators of well-being, and increasing occurrences of merged behaviors, i.e., behavioral flow, as indicators of intensive activities, mean that the crew is adapting in a motivated and invested manner upon demanding tasks. This highlights that dynamics of action is a positive process in the temporal mechanism of adaptation. Additionally, low occurrences of collateral expressions are indicators of little stress and low fatigue, thus emphasizing optimal relationships to contextual factors expressly on workload and complex tasks. However, MD 34, MD 104 and MD 114 are critical days that could be related to monotony of the long-duration orbital operations phases (50 days and 40 days) or of prolonged isolation and confinement during the phase of transit to Earth. Finally, MD 118 is a specific active day for crewmembers prior to landing and mission completion. It is nevertheless a stress-induced situation as we observed increasing occurrences of collateral expressions. Globally, we observed temporal or situational points, period or cycle premises as a result. This supports previous findings of the MARS-500 crew's behavior over a 520-day simulation.

The present review of the SIRIUS-19 crew over a 120-day simulation in daily life activities and working tasks updates knowledge on field studies for earthlings' evolution in space and time. They will continue in the 8-month and one-year experimental program. Temporal stability could be an indicator of crew cohesion development and crewmember cooperation effectiveness. Cultural diversity could act against monotony and promote autonomy, and gender and individual differences could act against social privation and improve human performance. Here are examples of positive strategies of adaptation.

This brief report on human ethology gives the opportunity to study correlations between results from other physiology, psychology, sociology and anthropology investigations within the framework of interdisciplinary analyses of interplanetary crew scenarios.

ETHICS & DISCLOSURES

The author declares that there is not conflict of interest.
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[*] Erratum in papers: MD 118, MD 128 and MD 132 being replaced by MD 104, MD 114 and MD 118, respectively.