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Humans' 3*R*-adaptation for Space Colonization

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ABSTRACT

Starting with the unprecedented situation resulting from 2020 springer pandemic that constrained people on Earth to a period of lockdown, we analyzed a panel of studies findings on humans in Space based on a step-by-step positive adaptation emerging from optimal relationships of the individual with the environment, be it in weightlessness, in confinement or in insolation. We observed, described and quantified the subjects' orientations, actions, interactions, expressions and positions with the ethological method, science of behavior, implemented in parabolic flight, in orbital flight, during Sirius-19, Mars-500 and CELSS-180 experiments, and at Concordia polar station. We found that the physical and social environment had impacts on the motor, social and cultural behaviors. The behavioral strategies developed over short-term to extended periods of time are based on new *Referentials*, *Rhythms* and *Rituals* of self-organized crews for autonomous missions to the Moon or Mars. Adaptive tools for humans on Earth are to strike a new balance of usual activities and tasks for mitigating psycho-physiological stress and to create new living and working habits for well-being in extreme conditions.

Introduction

By the end of March 2020, 2.6 billons of inhabitants on Earth were confined that was 1/3 of the world population. During the period of lockdown, people were not allowed to move freely outside their home. Restrictions on social gatherings, on interactions and increase in the digitization of society will have a definitive-sociological impact (Vermaa, Saharanb, Polcumpally & Biswasb, 2020). Beside other impacts on economy, ecology, policy and healthy states, necessary demands to maintain physical distancing and to stay in confined habitats have affected men and women in their living and working conditions. This is the case for all the countries of the world affected by the pandemic resulting from transmission of the Covid-19 virus. Such extreme conditions are the consequence of unpredicted events to which humankind has to adapt individual and collective behaviors. That gives the opportunity to emphasize humanities and social science studies. A few investigations were performed at the terrestrial scale. In the present paper, we open the horizon of humans on Earth to humans in Space.

Research Questions

This study seeks t answer the following questions:

a. What are the impacts of physical and social environment on behaviors?
b. What are the behavioral strategies of humans in Space?
c. What are the adaptive tools for humans on Earth?

Literature Review

Adaptation to unexpected, unusual or exceptional situations is regulated through optimal relationships of the individual with his/her environment whose emerging positive behaviors are indicators of well-being and group-spirit in daily life activities (Tafforin, 2020). This definition reflects a specific meaning that underlies the notion of salutogenesis (Ritsher, Kanas Ihle & Saylor, 2007; Suedfeld & Brcic, 2011). It refers to the health-promoting, growth-enhancing effects of a challenging situation (Kanas, 2015). The Covid-19 health crisis could be new challenges at the personal and societal level to transform negative stressors in capturing benefic experiences of what has been lived through isolation and confinement, week by week. It is a dynamic process that contends with time as adaptive sequential steps. During the growing pandemic, people developed various strategies to adapt new living and working habits agreed upon social constraints and spatial restrictions. General principles of adaptation according to Christian Clot (2020) are the evolution from a state to the other one through resilience, stabilization and influence over the crisis. This mobilizes cognitive capacities for changing behaviors in a positive way. Applied to social sciences, resilience means the ability to successfully live and develop wonderfully despite stress or adversity to get over negative outcomes (Cyrulnik, 2002). Stabilization is related to the homeostasis mechanism that is a return to initial states. Influence involves knowledge and implementation of new tools in the future.

On Earth, humanities have to cope with critic situations as well as humans in extreme conditions with hostile climate in the Polar Regions. Four decades of research in Antarctica proposed distinct characteristics of psychosocial adaptation to isolation and confinement (Palinkas, 1963-2003). Adaptation is cyclic because of the altered diurnal periods associated to the segmentation of summer campaigns and winter-over. Adaptation is situational because of unique features of the station's social and physical environment and the lack of resources typically used to cope. Adaptation is social because the structure of the group directly impacts individual well-being. Adaptation becomes salutogenic because it results from a positive effect for individual seeking experiences in new or unique environments. Nevertheless, difficulty may occur in adjusting to the novelties of living in confined and isolated polar bases and during trans-polar expeditions. The behavioral adaptive process could lead to negative psychological reactions. Manifestations of expeditioners' maladjustment are typical symptoms of winter-over mental syndrome described in three successive phases that are alarm reaction, stage of resistance and stage of exhaustion (Rivolier, Goldsmith, Lugg & Taylor, 1988). Considering time factor in the process of adaptation, prolonged residence in Antarctica is currently examined. The third quarter phenomenon with mood reduction, irritability and interpersonal tension at midpoint accordingly differentiates three periods (Smith & Sandal, 2018). It is particularly emphasized in the view of long-duration space missions. A recent study of Indian expeditioners at the Maitri station showed externalized psychological reactions peaked during the midwinter period (Khandelwal, Bhatia, Mishra, 2017). The behavioral observations of French winterers at Dumont d'Urville station showed periodic changes in increasing inter-individual distances over time and in decreasing social orientations at the half time (Tafforin, 2004). Chinese expeditioners who were deployed to Great Wall Station and Zhonghan Station for over a year showed different change patterns in mood and endocrine hormones (Chen, Wu, Li, Zhang & Xu, 2016). Despite psycho-physiological issues that are common occurrences in earthling from remote continents on Earth, socio-cultural heterogeneity of a small group like the international crews going in Space is benefic for the success of missions. Adaptation is cultural because diversity value of the group-members helps to break up the boring conditions of repetitive activities during extended periods of time in isolation and confinement (Tafforin, 2018; Tafforin, 2020).

In Space, men and women have to adapt to such environmental factors aboard the International Space Station in synergy with new sensorial-motor conditions generated by the microgravity factor. They have to live and work as they use to do in 1-g terrestrial gravity but weightlessness generated by 0-g orbital gravity modifies the movements, postures and orientations. Adaptation is thus a change of perception of environmental cues whose motor responses eliminate discrepancies within sensory modalities (Parker & Parker, 1990). The visual system is strongly activated vs. the vestibular system. The vestibulo-ocular reflex may provoke motion sickness (Clément & Reschke, 2018). It appears contradictions between ocular inputs and otolithic inputs that induce space adaptation syndrome during the first day of orbital missions until astronauts have acclimated to the new physical environment. The early adaptive stages of humans in Space are physiological. A long-term interplanetary travel to go to Mars will be more than 500-day duration and Space colonization beyond. The following stages of humanities to explore the universe will be based by culture enhancing complex behaviors rather than by biology, on evolutionary principles specifically to human species (Smith, 2016). For a complete behavioral adaptation, the space travelers will have to evolve in new social environment as a self-organized system with its own living habits, working rules and structural laws. Adaptability of the interplanetary crew will be of prime importance. In space literature (NASA, 1985), adapting to unusual physical state and social context is the goal of today’s astronauts and tomorrows’ marsionauts. They will be extracted from the ongoing relationships that are usual macro-society on Earth, and will be trust into a new micro-society

with its own social deprivation and cultural organization. In anthropology studies, the concept of space colonies (Melchionne & Rosen, 1986) is related to these small and isolated confined groups. Autonomy is fostered (Goemaere, Brenning, Beyers, Vermeulen, Binsted & Wansteenkiste, 2019) and monotony is challenged (Peldszus, Dalke, Pretlove & Welch, 2014).

The impacts of physical and social environment on behaviors result from multi-variables, i.e. health - perceptive - cognitive - cultural - situational - organizational - experiential - temporal, that modify more often positively the human physiological and psychological systems and answer to our first question.

Protocols and Methodology

We propose to analyze what are the resulting behavioral strategies from ethological data collected in real and experimental conditions of microgravity, isolation and confinement. The goal is to investigate some of the environmental variables mattering in the adaptation process.

Parabolic flight and orbital flight

Protocols designed in parabolic flight were performed to study initial moments of adaptation of the human orientation behavior to reduced gravity. It is a unique paradigm since for each time unit, the observed motor activity is the manifestation of new relationships between body referentials and spatial referentials. The profile of a parabolic flight consisted of alternating phases of normal gravity (g=1) for 3-5 minutes, of macrogravity (g=1.8) and of microgravity (g=0) for successive periods of 20 seconds. Each flight aboard the CNES 0-g Caravelle accounted 30 parabolas. The experimental test was to compare, during a goal-directed orientation task, the body orientations of 12 subjects with a past experience of 0, 30 or more than 300 parabolas. During each microgravity phase, the subjects were asked to reach four colored targets arranged in up, down, right and left positions on the aircraft walls.

Studies performed in orbital flight were made during short-duration missions. Inside the Spacelab-1 aboard the NASA space shuttle, we analyzed the occurrence of head-down orientations as main changes in the astronaut's motor activity over a 7-day exposure to microgravity. The observed subject was manipulating racks during a working task. A transversal analysis of 20-minute sequences, day after day, allowed following the first step of adaptation to a new world of perceptions and actions within a tri-dimensional space. We described the body orientations about geo-centric cues, i.e. considering ceiling and floor of the space habitat, with head-up orientations for body tilt above the cabin's horizontal axis and head-down orientations below the horizontal axis. It was a case study given the limited number of astronauts assigned to a mission and the analysis protocols designed posteriori, upon the selection of adequate sequences at the laboratory.

SIrius-19 and Mars-500 experiments

A set of confinement campaigns was performed to study the social activity of small groups over long-duration missions. They took place at the Institute of Biomedical Problems in Moscow, Russia and offered exceptional paradigms in a multi-chamber facility. It was structured as four hermetically sealed, interconnected modules: the habitable module, the medical module, the storage module and the Mars/Moon landing module. Inside, the multinational crew consisted in 6 subjects who lived and worked together month after month, thus developing step-by-step adapted behaviors according to time in a dynamics process.

The protocol of Sirus-19 experiment was a 133-day lockdown that simulated a mission to the Moon with forth trip to the planet, docking to a lunar orbital station (a deep space Gateway analog), 2-month period of intra- and extra-vehicular activities whose 10-day landing on the Moon surface, several weeks of orbiting period for operating transport vehicles and back trip to Earth. During a daily life activity at breakfasts, we observed twice a month actions, interactions and expressions as nonverbal behaviors occurrences resulting from the synergy of social environment and temporal extended periods.

The full Mars-500 experiment was a 520-day lockdown that simulated three phases of a mission to Mars: 250-day interplanetary flight from Earth to Mars, 30-day orbital stay with 15-day Mars landing and 240-day interplanetary flight from Mars back to Earth. The crew was more strictly confined and isolated since it traveled at more and more remote distances from the ground control and with a 20-minute delay communication. We analyzed the behavioral data according to the same protocol of Sirius-19 experiment.

CELSS-180 experiment and Concordia station

Space-analog facilities were also built up for studies on physical environments related to Controlled Ecological and Life Support Systems (CELSS). The CELSS platform is located at the Space Institute of South China in Shenzhen, China. It consisted of 8 interconnected modules: three plant chambers, two crews' rooms, one low-pressure plant chamber, one life support chamber and one resource chamber. The facilities had functions of food production, atmosphere control and waste recycle, by using plants and microorganisms as central recycling components in a closed-loop life support model. They were designed to investigate multifactorial components of humans' adaptation to space stations and colonies typically in confinement conditions. The protocol of CELSS-180 experiment integrated a crew's behavioral monitoring over a 180-day lockdown. We focused our analysis on non-verbal interactions of the 4 subjects, all Chinese, during a daily life activity at lunchtime, once a month.

Space-analog environments are the polar stations. Concordia station in Antarctica was built in a double-cylinder structure like a Moon village concept. The quiet building houses the sleeping quarters, laboratories and hospital, and the noisy building houses the workshop, wastewater treatment plant, communication room, kitchen and cafeteria. This offers a relevant paradigm for studies of long-term isolated and confined groups' adaptation since during the 8-month wintering periods alternated with summer campaigns, the subjects have to live and work as a micro-society far from metropolitan customs and in hostile climatic conditions. We analyzed the spatial activities by checking once a week, the individual positions of 31 winterers and summer personals during a collective activity, at dinnertime. The goal was to emphasize cultural habits of a multinational team, predominantly French-Italian, as behavioral strategies developed in an unfamiliar social environment.

Ethological method

We applied the methodology used in ethology, science of behavior, to this panel of field settings. General analyses are observations, descriptions and quantifications of the spontaneous behaviors in daily life activities, working tasks or experimental tests. Specific characteristics of the method are to collect exhaustive data within a wide repertoire of movements, postures, orientations, positions, actions, interactions and expressions while considering non-verbal behaviors, and to collect objective data limited to the field of observable manifestations. That is complementary to physiological data and psychological data. The collection of behavioral data in extreme conditions is made from video recordings. At the laboratory, we proceed to quantitative descriptions in terms of occurrence, frequency or duration of the observed acts, completed with statistic tests (Chi-Square on the absolute values; Standard Deviation about mean values). The human observer is supplied with a software-based solution, The Observer XT® 14.0, for encoding, organizing and processing the ethological information from synchronized video files (Tafforin, 2017). Details of the approach were provided with the published results from each paradigm.

In the presented studies, key findings are issued by correlations of independent variables, i.e. perceptive, experiential, temporal or multinational and the dependent variables, e.g. motor behavior, social behavior or cultural behavior.
The subjects participating in the studies provided their informed consents.

Findings and Discussion

Behavioral strategies emerging from the optimization of the relationship between humans and Space are adaptive responses through adapted referentials, adapted rhythms and adapted rituals.

Referentials

In parabolic flight, the Earthman frees himself from the terrestrial gravity. In a simple goal-directed orientation task while discovering weightlessness for the very first time, the neophytes were in incoherent referential cueing with inadequate body moving. They failed to reach all targets in the series during the first parabolas (Tafforin, 1996). We did not analyze the result of the behavior, i.e. the performances, but the motor patterns leading to it, the strategies. They had the possibilities to widen the range of body orientations but they spontaneously preferred to keep head-up orientations as they used to be on Earth about ceiling and floor configurations.

Figure 1(a) presents a Correspondence Factorial Analysis (CFA) combining the three groups of differently experienced subjects with the frequency of body orientations. The results showed that subjects were distinguished from each other by their use of space. The CFA distributes the groups around two axes (f1 and f2). The 76% contribution to the f1 axis

significantly represents the experience factor. The in-EXP group is linked to the fair-EXP group, by the head-up vertical orientation (r); the fair-EXP group is linked to the high-EXP group by a slight frontward orientation (s); the high-EXP group is linked to the in-EXP group by a strong frontward orientation, close to the horizontal (u). This illustrates that the subjects' experience helped in exercising more and more inclined body orientations, thus becoming independent of the cabin's orientations. They built a new referentials system adapted to the physical environment.

Once in short-term orbital flight, the astronaut has to perform domestic and professional tasks like those done under terrestrial gravity whereas a weightless body requires significant behavioral changes in these new conditions. Microgravity has the most obvious effect of diversifying movements, postures and predominantly orientations thus changing from a vestibular verticality to a visual verticality (Tafforin, 2018).

Figure 1(b) presents the percentage of head/body orientations in microgravity during a 7-day orbital flight. The results showed major levels of head-up orientations (between 95% and 100%) every day of the mission, with a minor level of head-down orientations (2%) the first day. Differences of percentage are significant. The last days from Day 5 to Day 7, the subject increases the levels between 6% and 3%. This describes how humans in space elaborate a new world of perceptions and actions through the changes of body orientations. After first trials on Day 1 to enlarge the repertoire that led to the three-day space sickness induced by sensorial mismatching, we observed the occurrence of head-down orientations as main changes in the motor behavior. The vestibular-ocular conflicts were accentuated by discordances of visual information on the subject's verticality. After several days of physiological adaptation, behavioral adaptation occurs by the fact that the vertical orientation is no longer the only possible. We defined orientation as the dynamics of spatial relationships between the subject's referentials (egocentric) and those available in his own space (exocentric and geocentric). The first set provides idiothetic information (vestibular, proprioceptive) on the location of the referentials. The second set provides allothetic information (visual, tactile). New concordances between them are indicators of adaptation. This means that for well-being and efficiency in living and working tasks, the astronaut has to invent new strategies by trying new possibilities of body orientations, thus moving comfortably and optimally within a tri-dimensional space.

From the training in parabolic flight to the experiencing in orbital flight, humans in Space move through spontaneous, preliminary and integrative stages of adaptation, emphasizing new relationships between the body's referentials and the environment's referentials. Such experiences lead the earthman to develop a new cognitive representation of space.

Rhythms

During medium-term travels on the Moon, behavioral changes would follow a temporal dynamic. The astronauts will have to adapt workload and daily life activities over time. Living and working in confinement is punctuated by social activities and individual tasks in peculiar environmental conditions comparatively to familiar contexts on Earth. We studied meals as periodic meetings in the collective area of the habitat and according to the mission day. Over a 4-month mission, the social behavior described by the mean duration of non-verbal interactions, followed variations from day 5 to day 132 (Tafforin, 2020).

Figure 2(a) presents the behavioral flow in acts per minute of the total behaviors (actions, interactions, expressions) during SIRIUS-19 experiment. The results showed significant differences as a function of time with low levels on day 34 (4 acts/minute) and day 118 (4,6 acts/minute) and the highest level on day 62 (8,1 acts/minute). We observed that the whole mission profile (Earth->Moon->Earth) drew ascending and descending curves around the Moon landing period like rhythmic variations in the behaviors' frequency. Before and after this specific period, when the crew was separated for spacewalks, 7-week periods appeared as we found in previous confinement and isolation studies (Tafforin, 2018). This supports findings on cycles and periods of collective daily life activities that described behavioral strategies built for extended time.

During a long-term travel to Mars, the temporal variable would have a major impact on the social behavior. On morning, day-to-day breakfast give the possibility to spend time together as a group. It is a relevant situation for observing, describing and quantifying personal actions and inter-personal actions in environmental conditions exacerbated with the mission duration.

Figure 2(b) presents the mean durations of personal actions as a function of time during Mars-500 experiment. The results showed different profiles of behavioral manifestations according to different rhythms of temporal variations from day 19 to day 513 and of temporal points between day 257 and day 271. In the phase 1, before Mars landing, we observed 35-day cycles of increasing personal actions' duration whereas in the phase 2, after Mars landing, it followed 70-day cycles. This

supports the first quarter phenomenon while considering the time factor in the adaptation process. The subjects avoided behavioral stereotypies such as performing the same actions, during the same task every day. We defined stereotypies as a continuum or lack of variation in patterns of actions. It is not the case in the observed cyclic variations thus emphasizing non-linear adaptive phases. Repetitive tasks made by the same crewmembers are nevertheless monotonous conditions. The crew broke up the rhythm of daily live activities by increasing and decreasing the actions' duration. Rhythms seem to act as behavioral strategies for group cohesion and against group monotony in extended periods of time.

Scenarios of Interplanetary missions will have to take into account the confined and isolated crew's organization upon phases, cycles, periods along with exacerbated time. That could be rhythms-based elements for self-organization of small groups as nominal effects with anticipative behavioral patterns until critical moments such as landing on the planet for a comprehensive salutogenic adaptation.

Rituals

Space colonization will be the challenge of multinational and mixed-gender crews. We found that the cultural variable had a positive impact on the group dynamics in what a micro-society evolves at a very-long term (Tafforin, 2020). Collective activities lead to crew's interactions like inter-personal actions and positions adapted to the environmental and temporal conditions.

Figure 3(a) presents the mean duration of visual interactions, body interactions and object interactions as a function of time during CELSS-180 experiment. As a whole, the results showed different levels of interactions from month 1 to month 6. The higher levels of occurrences were on visual interactions (mean durations = 2 seconds to 9 seconds) with increases every two months and a decrease afterward. The lower level was on body interactions that only occurred in month 2 (mean duration = 7 seconds). The stronger increasing level was on object interactions in month 6 (mean duration = 30 seconds). We observed that the physical environment, e.g. reduced volume of the modules generated by confinement, has few impacts on body contacts between the crewmembers. Whereas the social environment, e.g. reduced ritual context generated by isolation, has an impact on the subjects' visual interactions with behavioral changes upon a two-month rhythm. It could be an adaptive strategy for maintaining living habits on extended 6-month period. In the last month, the CELSS conditions contributed to enhance daily life activities as to bring variety to the meals. That strongly increased object interactions like sharing fresh food from life support production collectively served. The crew found again well-being and group spirit to what they used to do on Earth. Usual behaviors become exceptional behaviors in Space and the strategy could be to transform such events as rituals in a positive way.

Self-organization of small groups is governed by the heterogeneity of their elements. Particularly for human settlement on Mars, autonomy of crews with their own rules would be operated by the crewmembers' background despite the fact that isolation and confinement could modify effectiveness framework. The cultural background is a corollary to exercise one's typical social roles in daily life activities.

Figure 3(b) presents the percentage of subjects' position according to nationalities and the total number of women at the meal tables of Concordia station. During summer campaigns, the expeditioners came from various countries such as France and Italy in a majority, as well as English, Danish and Canada in a minority. The results showed a distribution of spatial positions upon culture. The two main tables (A and B) were shared between the French group (87.2%) and the Italian group (94.5%). We observed mixed gender grouping indifferently within the sub-groups but with place preferences in women (table A). We may relate the proxemies, i.e. inter-personal rapprochements, specifically in the Franco-Italian crew to different eating habits and food preferences. During the weekly day of observations, we checked the meaningful events. The most recurrent one was when the French sub-group gathered at the meal table near French food (e.g. cheese they are used to eating) and the Italian sub-group gathered near Italian food (e.g. pizza they customarily eat). Rules for life quality, working habits and specific customs in human groups allow us to understand the cultural behaviors with their rituals as salutogenic effects from an evolutionary perspective. Space colonization would be imprinted from such mosaic adaptation in the temporal process.

Referentials, Rhythms and Rituals (*3R*) are the adaptive strategies of humans in Space and answer to our second question.

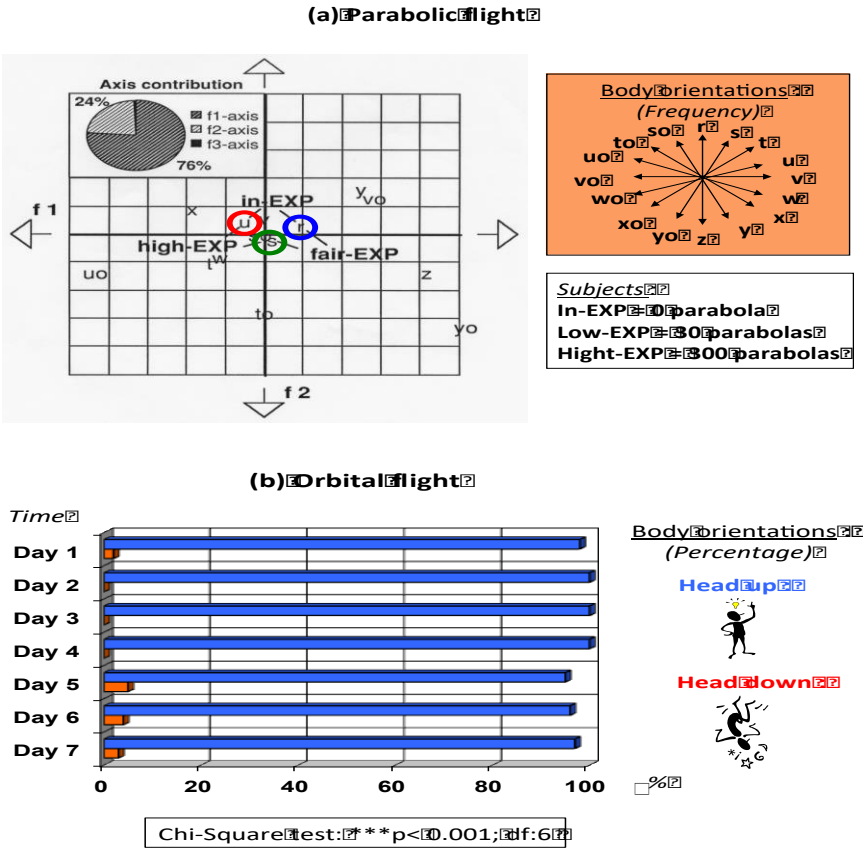
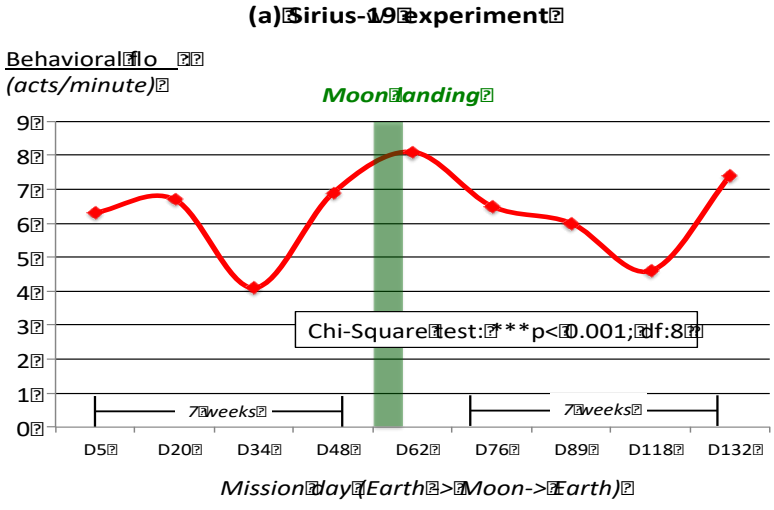


Figure 1: Referentials. (a) Correspondence Factorial Analysis between the body orientations frequency and the subjects' experience level (in-experienced, fair-experienced and high-experienced) to microgravity generated in parabolic flight. Image extracted from Tafforin (1996). (b) Percentage of the up/down body orientations as a function time during a short-term orbital flight. Image extracted from Tafforin (2018).



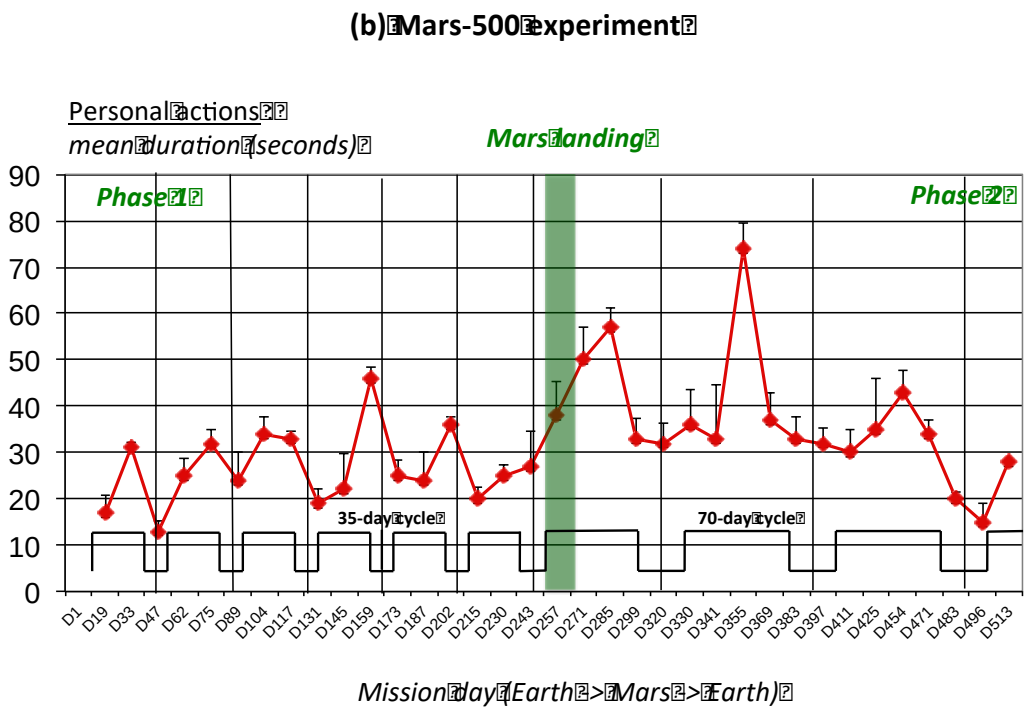
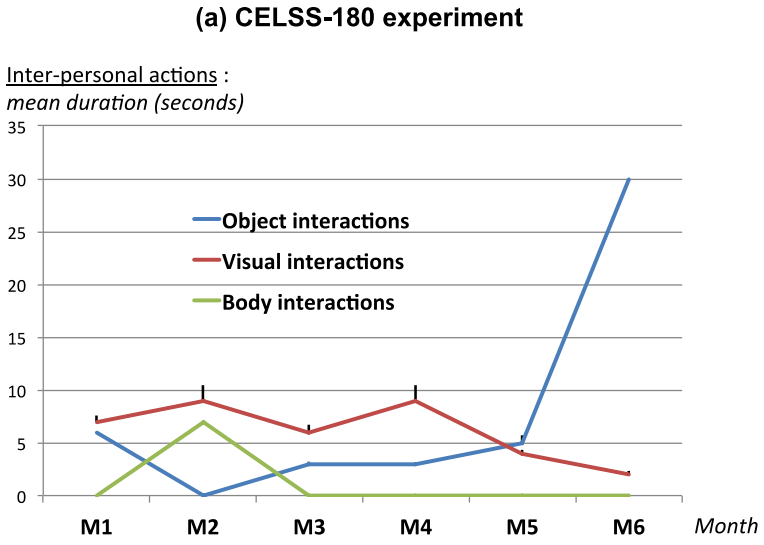


Figure 2: Rhythms. (a) Behavioral flow of 6 crewmembers (Σ) according to time, at breakfast, during SIrius-19 experiment Original study results. (b) Mean duration of personal actions of 6 crewmembers (Σ) according to time, at breakfast, during Mars-500 experiment. Image extracted from Tafforin (2013).



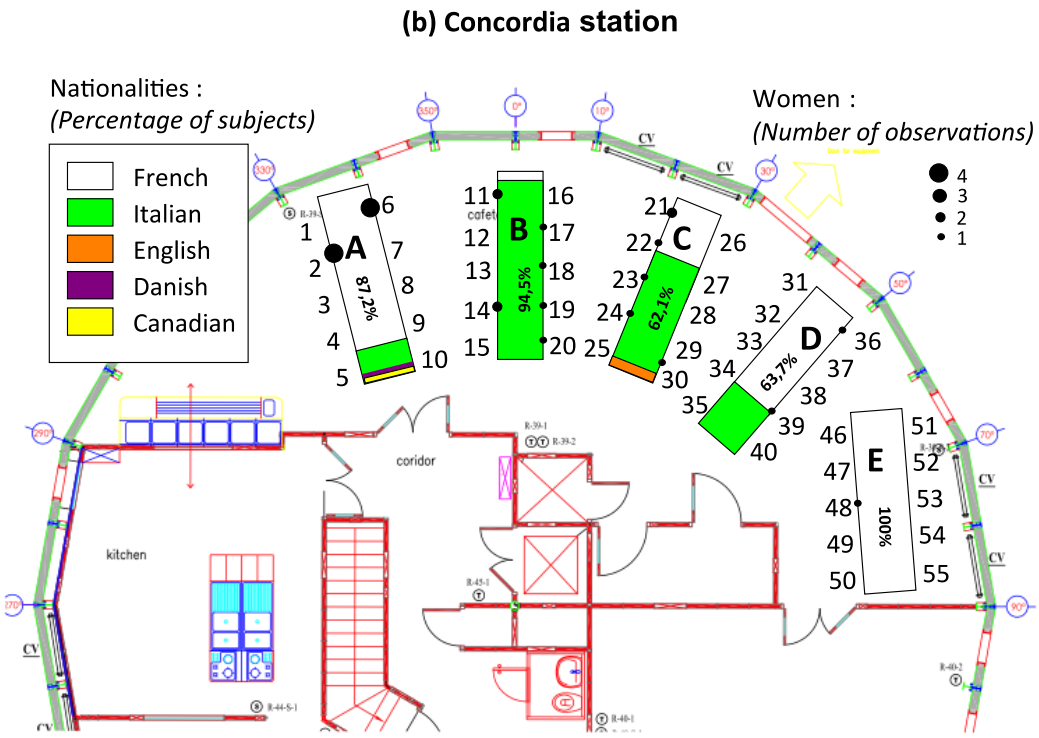


Figure 3: Rituals. (a). Mean duration of inter-personal actions the 4 crewmembers (Σ) according to time, at lunch, during CELSS-180 experiment. Image extracted from Tafforin & al. (2019). (b) Percentage of subjects' positions around the tables, at dinner, according to nationalities and gender at the Concordia station. Image extracted from Tafforin (2009).

Conclusion

The 3*R*-adaptation could be applied to humanities on Earth during unprecedented situations. The 2020 springer pandemic is a relevant example. The resulting lockdown could be a unique opportunity to do further daily live activities and best working tasks (Yousoupova, 2020). The goal is to strike a new balance for mitigating physiological and psychological stress imposed by the physical and social environment. The presented ethological findings emphasized optimization of relationships between the individual and the environment through adapted motor, social and cultural behaviors. Inter-individual distancing used new tools to keep referentials, rhythms and rituals. Keeping an own area for teleworking, changing in unusual meal menus against boring time and interacting in virtual networks like in real gatherings with imaginary actions are answers to our third question.

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