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Chapter

Human Missions Analysis for Intelligent Missions Improvement

Carole Tafforin

Abstract

The topic of this chapter is not manned vs. robotic missions but how to integrate them for successful missions. The point of view is from that of a human observer, an ethologist, with the goal to gain further knowledge on human behavior and high technology readiness levels in the field of exploration missions. On one hand, the concept is the adaptability of men/women to be trained and on the other hand, it is the reliability of artificial intelligence systems to be incremented. The content of the chapter is: (i) ethological analysis based on numerical methods; (ii) strategy, cooperation, and adaptation; (iii) artificial intelligence and emotional intelligence; and (iv) man-rated Mars exploration demands.

Keywords: methods, human factors, robotics, artificial intelligence, earth simulation, analog environments

1. Introduction

The challenge of the astronaut Jean-Loup Chrétien's Extra-Vehicular Activity (EVA) during the Aragatz orbital flight was to expand a deployable structure following operational procedures. Many hours of training were performed in a swimming pool to simulate each technical sequence and to test out the material in an optimal way. The operation did not run in orbit and the operator kicked in the structure to be deployed. We will not debate on manned vs. robotic missions but we will open discussions on how to integrate them for successful missions. The point of view is from a human observer, an ethologist, with the goal to gain further knowledge on human being and high technology readiness levels in the field of exploration missions.

From an evolutionary perspective, the naturalist Charles Darwin developed the idea that behavior is an important element of competition and natural selection in "The Origin of Species" [1]. His trip aboard the Beagle around the world for observing animals in their natural living conditions and the related geological environments is a fundamental event in human history. Over a long-term dynamics process, the motor behavior has progressed step by step in motion and motor patterns adapted to terrestrial gravity. Then, mankind developed elaborate technologies to fly further and further away and discovered how to move under reduced gravity on Moon and in low-earth orbits. EVA gave man the ability to indifferently operate in a three-dimensional space with head-up and head-down. Orientations, postures, and movements have to be coordinated under weightlessness according to new processes [2, 3]. Sensory-motor functions and cognitive functions are deeply demanded. Other physiological and psychological functions are necessary and become more

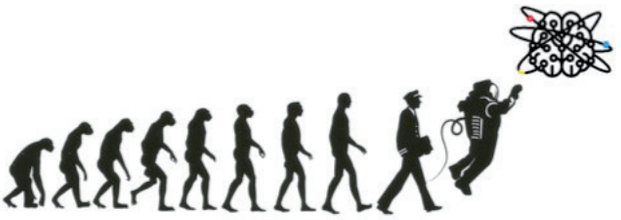


Figure 1.
Evolutionary steps from Earth to Space (extract from picture © Cité de l'Espace—Toulouse).

prominent over time. Thus, the next big step of human beings from earth to space (**Figure 1**) is to link up human individual intelligence with artificial intelligence (AI) for intelligent missions improvement.

2. Ethological analysis based on numerical methods

Since 30 years in the space domain [4, 5], ethology, defined as the science of behavior, has covered a wide panel of application fields on men and women living and working in real situations (orbital flights, parabolic flights), in simulated conditions (isolation and confinement campaigns), and in analog environments (south-polar stations, north-pole expeditions).

In its operational definition "behavior is the expression, the emergence, here and now, of a historical system constituted by the individual and his own universe" [6].

Behavior falls within the scope of phenomena and not physico-chemical objects. This phenomenon appears as a motor activity performed by a subject and represents a continuous manifestation. There is always an action or fact to describe even when the subject is at rest. Such a description leads to a large volume of discursive

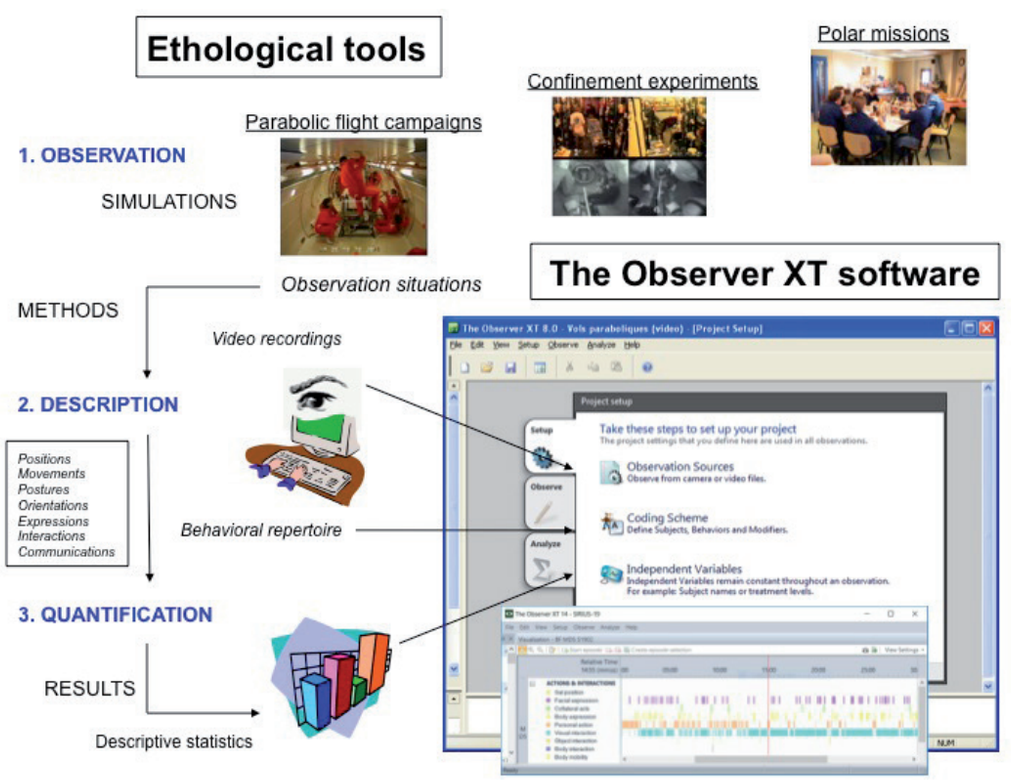


Figure 2.
Ethological tools related to The Observer XT software.

data whose subsequent analysis must be sequenced. The specificity of the ethological method is the transition from qualitative observation to quantitative description that reflects continuity in its analogical aspects as a mathematical function. The analysis is carried out in three steps: observation, description, and quantification (**Figure 2**).

2.1 Observation

In human ethology, the method is to observe the subject's behavior in usual activities. It can be not only acts of daily life, leisure, execution of work tasks but also in experimental situations or the performance of tests. A special feature of this approach is to exploit the field of observable events. Everything is observable to the extent that the relationship between the individual and his environment emerges, that is, is objectively visible. The observer's eye remains irreplaceable for describing behavior in all its complexity (positions, orientations, motions, expressions, interactions, and communications).

2.2 Description

Since behavior is a continuous process, it is necessary to build a system of units that breaks down this continuity and digitizes it. This amounts to dividing the observed behavioral flow into motor acts, the various possibilities of which are described over time.

The behavioral reading instrument consists of establishing a repertoire, in terms of action verbs, according to a vocal-mimo-posturo-gestural vocabulary (e.g., "raise the arm," "lower the head," "turn the body to the right," "darken the eyebrows," "smile," "speak to," "give an object to," etc.). The ethologist builds a digitization instrument corresponding to different levels of description (microscopic vision, macroscopic vision).

The description tool is the direct input in the field or the delayed input of video recordings collected in a situation.

2.3 Quantification

The numerical tool measures the probability of occurrence of each act in the repertoire, by counting these manifestations in terms of frequency, duration, or sequential order, replacing each behavioral unit in its functional framework and in its own space. It allows this complexity to be represented by multivariable processing. The quantification of the observed behavior is then translated into occurrence frequencies (absolute or relative), transition frequencies, and association frequencies. The duration of the items is also measured in the behavioral sequence. A spatial mapping into digitized units is performed in the same way. We obtain a scheme of use of space combining space, time, and activity.

2.4 Computer support

A software-based solution for research in space ethology is called The Observer XT® software [7]. It is a professional system that can be used for the collection, analysis, and presentation of observational data. It allows annotation of behavioral descriptors through a traditional encoding process. Its technical specificity is the synchronization of video files with the collection of ethological data as state events or point events, and any other source of information such as psycho-physiological measurements and environmental parameters.

Right now, the interface between the human observer and *The Observer XT®* software is not computerized. Because of the complexity of the behavior to be analyzed, the ethologist's eye remains an essential tool. We can use techniques like the newly developed Facial Action Coding System [8] first adopted by psychologists [9]. It is a common standard to systematically categorize the physical expression of emotions, but it does not integrate the behavioral activity from the human repertoire as a whole, that is, in egocentric references (with regard to the subject), allocentric references (with regard to the other subjects), and geocentric references (with regard to the three-dimensional environment).

3. Strategy, adaptation, and cooperation

Such an approach is not only concerned with the result of the behavior, that is, performances, but also with the motor patterns leading to it, that is, behavioral strategies. They are a synergy of abilities that could be a high-level plan to achieve goals under extreme conditions involving both strategic planning and strategic thinking [10]. As a cognitive activity, it produces decision-making and thus a motor activity follows to perform the task for the success of the mission goal.

During the Aragatz mission, the astronaut in EVA carried out procedures according to a checklist consistent with the operation called ERA. The final technical condition was a deployed structure (**Figure 3**). The final human action was a kick in the compact package (**Figure 4**).

During simulations in water immersion, the operator followed motor sequences as we analyzed them with numerical methods. Strain arms followed by grasp hands followed by release hands followed by keep still, then manipulate followed by release hand followed by flex arms, are motor patterns in neutral buoyancy. The task automation

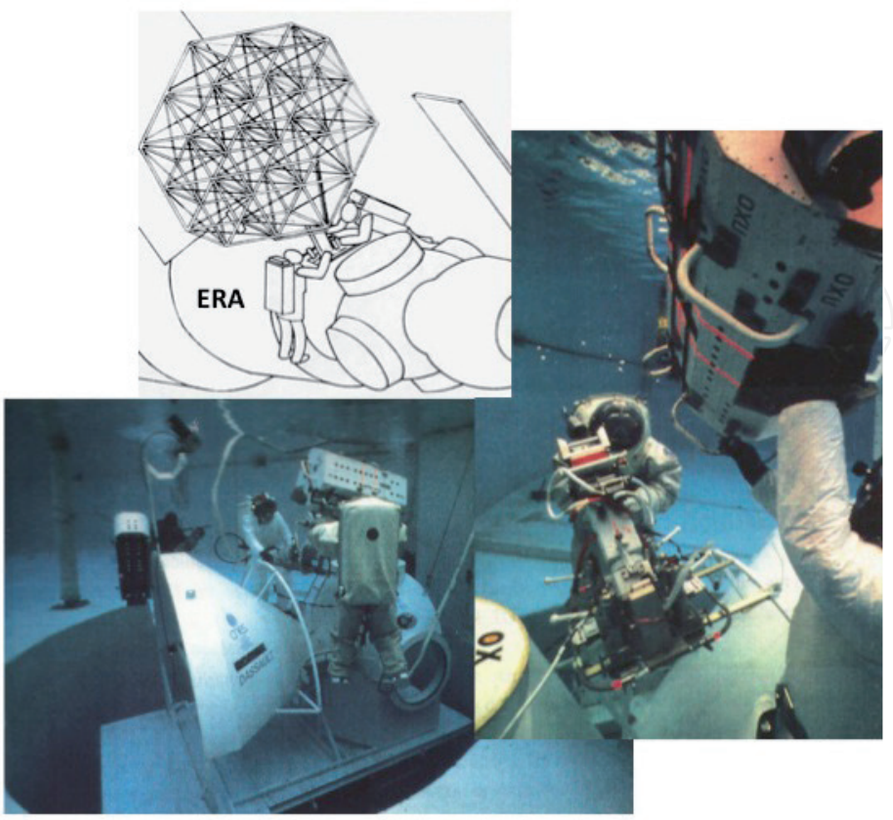


Figure 3.
EVA in water immersion during the ERA operation.

Contingency Table Analysis

DF:	15
Total Chi-square:	474.522 p< 0.0001
G Statistic:	.
Contingency Coefficient	.443
Cramer's V:	.495

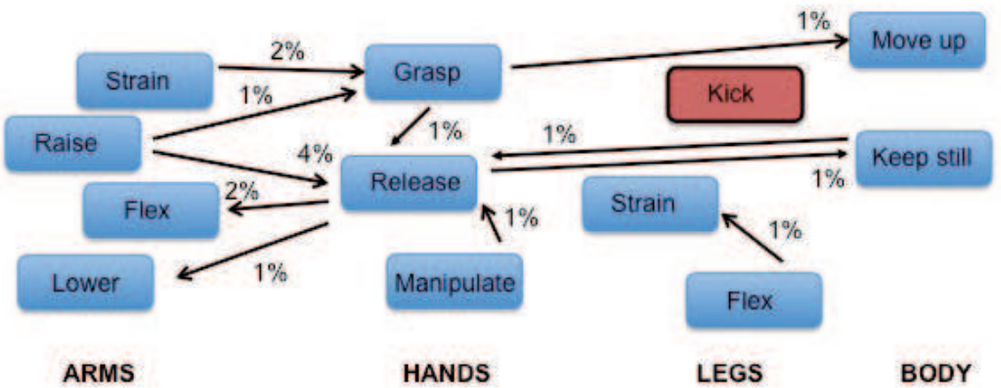


Figure 4.
Motor sequences of the astronaut during the ERA operation in orbital flight (red) and in swimming pool (blue).

could be performed by a robot as by the astronaut in nominal situation. Because of off-nominal conditions with the negative goal of failure, Jean-Loup Chretien's strategy was to add a new action that was not learned and not repeated before but efficient for a positive final goal. On one hand, there is the reliability of robots and on the other hand, there is the adaptability of man to his environmental conditions. In ethology, the behavioral manifestations are optimized relationships between the individual and the environment. Such adaptive strategies can be built as an action pattern occurs in an environment [11] with unexpected events or untrained conditions.

Adaptation capacities could be factors of human intelligence. In psychology, the intelligence quotient is a total score derived from standardized tests obtained by dividing a person's mental age score [12] but not necessary from measurements of coping skills. In biology, humans face basically the same adaptive challenges as all organisms on earth but they are complex in having most of their adaptation transmitted culturally upon experience.

Quantitative descriptions of the sensory-motor adaptation from the early seconds in parabolic flights to the first days and last days in orbital flights, then on the social adaptation over long-duration analog missions for future Mars exploration, offer an overview of human intelligence.

We found spontaneous [13], preliminary, and integrative stages of behavioral adaptation, emphasizing new relationships between the body references and those of the surrounding world [14]. Such experiences lead the subject to develop a new mental representation of space [15]. The adaptive model refers to the sensory-motor sphere and neuro-physiological sphere like a "hard" system that acts to recover its main equilibrium in terms of conservative regulation with respect to a mismatching physical environment. At the highest levels, human brain is one of the most amazing systems as biological organ, functional machine or supercomputer [16]. Connections are done through a "soft" system with new adaptive strategies. For instance, stage by stage, the astronaut's motor actions are to manipulate floating objects and to move upside down, which show he is exploiting new possibilities of the weightlessness conditions. Human intelligence is incremented with motor experience just as advanced machine learning.

In this regard, the issues currently being raised are on one side, to what extend human adaptability is required for Mars exploration and on the other side, to what extend machine learning capability is involved for Mars exploration?

Cooperation should be emphasized. We need to take carefully into account the Human Factors (HFs) in regard to their diversity and the quality of relations between heterogeneous partners: human-human; man-robot or AI; machine-machine [17]. When the astronaut Jean-Loup Chretien makes a decision and finds a solution to anomalies in the equipment, thus HF are positive. But operational error detection has to be improved for preventing negative HFs. For instance, automated techniques for routine monitoring during space operations may be appropriate in future missions [18]. Nevertheless, an ethological monitoring performed during routine operations at a Networks Operation Center (NOC) on ground showed increasing human-human verbal interactions as optimizing behavior in the task progress [5]. Cooperative systems could be implemented.

One improvement facilitator is while a crew has to cope with monotony, robot or AI can implement automatic tasks. During long-duration isolation and confinement periods, human behavior is cyclic over time for breaking up monotonous tasks [19] whereas a robot or AI is constant over time and can supplement. Another example, Rover curiosity helps in enriching the curiosity of earthmen and updates their knowledge of planet Mars [20]. It becomes the eyes of human observer in that cooperation.

4. Artificial intelligence (AI) and emotional intelligence (EI)

Intelligent automation and trusted autonomy are being introduced in aerospace cyber-physical systems to support diverse tasks including decision-making, data processing, information sharing, and mission execution with the technological developments of sensor networks [21]. This leads to the field of AI in manned space missions. Men and women are endowed with sensation, feeling, and perception that are altered due to stress, mental and physical workload during living and working simulations of Mars conditions [22]. This leads to the field of EI within the space crewmembers

AI is a virtual concept or rather a set of concepts and technologies [23] more than an independent discipline. It is data integration-dependent in computer sciences vs. a real concept with human decision-making in neurosciences and sciences of behavior. Notions of neural networks are common between human mechanisms and intelligent machines. When the first ones reach limits of physical capacities, the last ones can supplement them to improve long-term operational performance. Significant development in technical innovation has succeeded in transforming manual and repetitive tasks. AI reduces the quantity and improves the quality in many application fields. They could be industrial, intellectual, social [24] and also medical as required by telecommunications between ground control teams and space crews. Security and safety are improved as a result. Benefits of expert systems were aboard the International Space Station (ISS). They make excellent monitoring tools since they never get bored or tired, are always alert, and react faster than astronauts [25]. The status of a trained machine is immediate whereas the human adaptive state is dynamic as it gains in experience during simulations on Earth. For instance, a review of studies about women who lived and worked on remote and isolated Antarctic stations for up to 15 months showed mitigated feelings from positive experiences in the natural physical environment and negative experiences in the social male-dominant context [26]. Such human missions analyses help in drawing scenarios of Mars via Moon missions for intelligent missions (**Figure 5**).

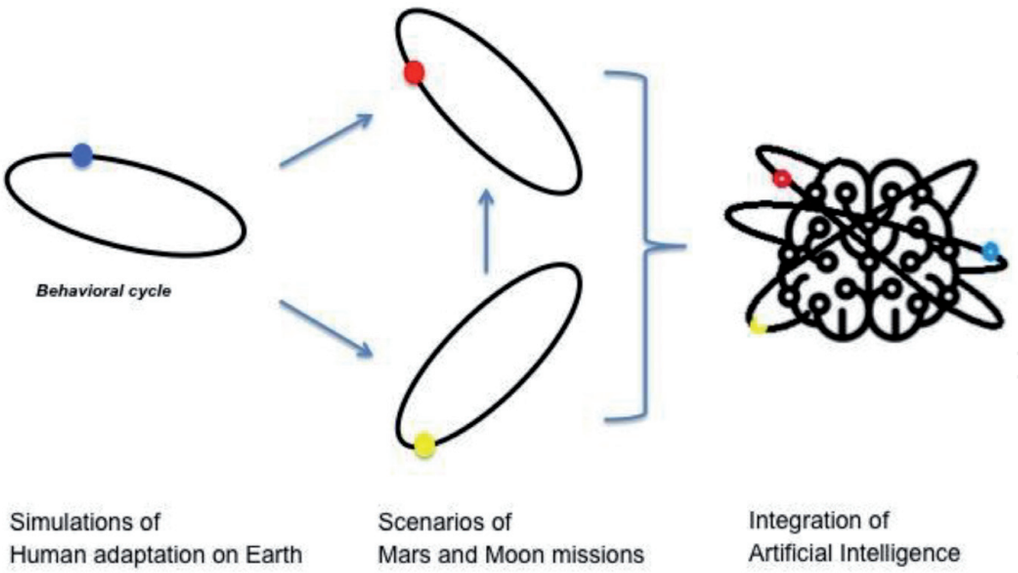


Figure 5.
Artificial intelligence integrated into space missions based on human Earth experiences.

EI has been defined as a wide array of individual variables based on emotional awareness, an ability that has usually been conceptualized along with the cognitive functions [27] and abilities [28]. Personality traits convey the adaptability of intelligence and the subjective experiences based on emotions. Mental health-related outcomes such as well-being or good group spirit are attributed to humans. They impact space missions positively. The key factor is the quality—not necessarily the quantity—of the relationships between the crewmembers and their mental representations within the social context and environmental conditions (**Figure 6**) that activate cognitive functions. AI can benefit from this higher level of integration. Nevertheless, it cannot integrate the uniqueness of an individual as living being. In that process, the human brain works at the highest operational level. In ethology, we also explain behavioral universals by their functions, like smiling observed in

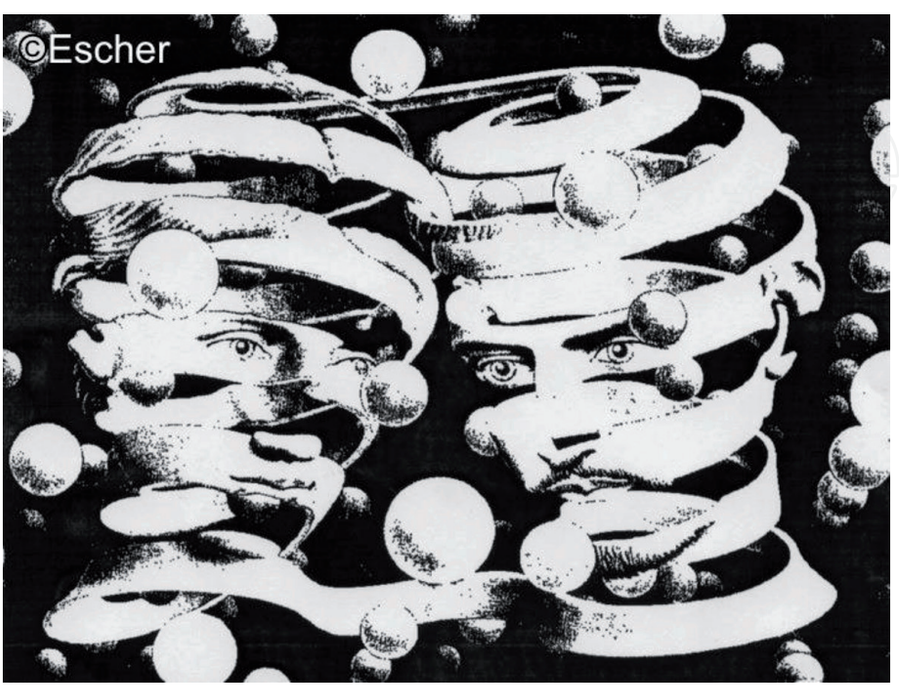


Figure 6.
Cognitive schema of the relationship between crewmembers during interplanetary missions.

autistic persons with communication disorders as well in ethnic groups with their own languages [29]. They can be expressions of emotion and are built by imitation in the human-human relationship. Such associative communication could be a computerized process in human-machine learning and thus create connections between EI and AI. Cultural variable with terrestrial life imprint is another issue to live in space.

5. Man-rated Mars exploration demands

> *"Everything we love about civilization is a product of intelligence, so amplifying our human intelligence with artificial intelligence has the potential of helping civilization flourish like never before – as long as we manage to keep the technology beneficial [30]."*

During a Mars exploration, the crew will be isolated from any civilization. It will be extracted from the ongoing relationships it has experienced on earth, and will be associated to a new micro-society with its own spatial restriction, social deprivation and cultural organization [31]. All of these variables are exacerbated with time. In anthropology, the qualitative description of living rules, working habits, specific customs, and values of remote tribes allow to understand how they behave differently than other self-sufficient groups [32] and how they survive.

Autonomy of the crew [33, 34] is one demand for Mars exploration in technology for life-Support systems [35], and on humanity for a controlled environmental system and an ecological evolution. This advances the field of collective intelligence for survivability from earth to space.

Heterogeneity of the crew [36] is a second demand. Future crews of three to six members, mixed-gender and multi-cultural compositions would be core features of terrestrials gathered for deep space exploration [37]. The operating rules of an isolated and confined crew could thus be compared to the laws governing self-organizing systems. These laws are based on the heterogeneity of their own elements like a thermodynamic model. AI could serve such a group model. It is a dynamic organization where all the forces are in equilibrium and regulated to obtain optimal efficiency structure [38] with multi-function integration [39].

The quantitative description of behavioral expressions of groups who differ according to gender variable, nationality variable, and time variable shows to what extent the value of diversity is a key element along with mission duration (**Figure 7**). We found differences in positive facial expressions ("smile," "laugh") and collateral acts ("scratch the head" "rub the nose") from comparative analysis in three settings during three periods of time. Firstly, the Mars Desert Research Station (MDRS-14d) was a 14-day campaign located in Utah, USA. Secondly, the Controlled Ecological Life Support system experiment (CELSS-180d) was a 180-day confinement that took place in Shenzhen, China. Thirdly, the Mars-500 experiment (MARS-520d) was a 520-day confinement that took place in Moscow, Russia, with the objective to simulate a round trip to Mars.

We observed that the rate/min of facial expressions vs. collateral acts is not significant in the international groups (MDRS-14d and MARS-520d) compared to the mono-national group (CELSS-180d) regardless the simulation time. Well-being expressed by facial expressions highly occurs in the mixed-gender group (MDRS-14d) whereas perceived stress expressed by negative collateral acts occurs in the men's group. This underscores the importance and complexity of personal, social, and cultural factors in behavioral occurrences and the related emotional feelings.

The question then arises about AI as a complex entity like a crew?

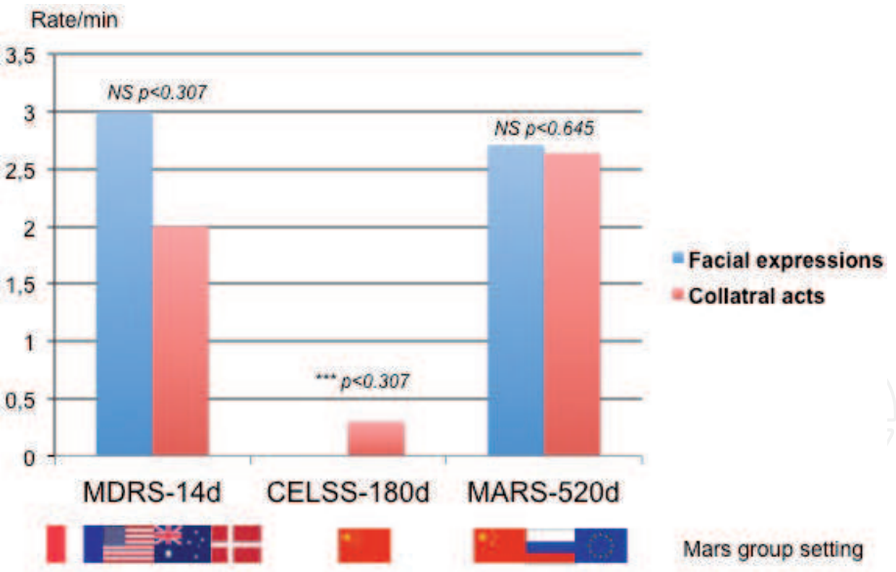


Figure 7.
Behavioral expressions according to three group settings of Mars trip simulations (MDRS-14d: 3♀ & 3♀; FR,US,AU,DK; CELSS-180d: 5♀ & 1♀; CH; MARS-520d: 6♀; RU, EU,CH).

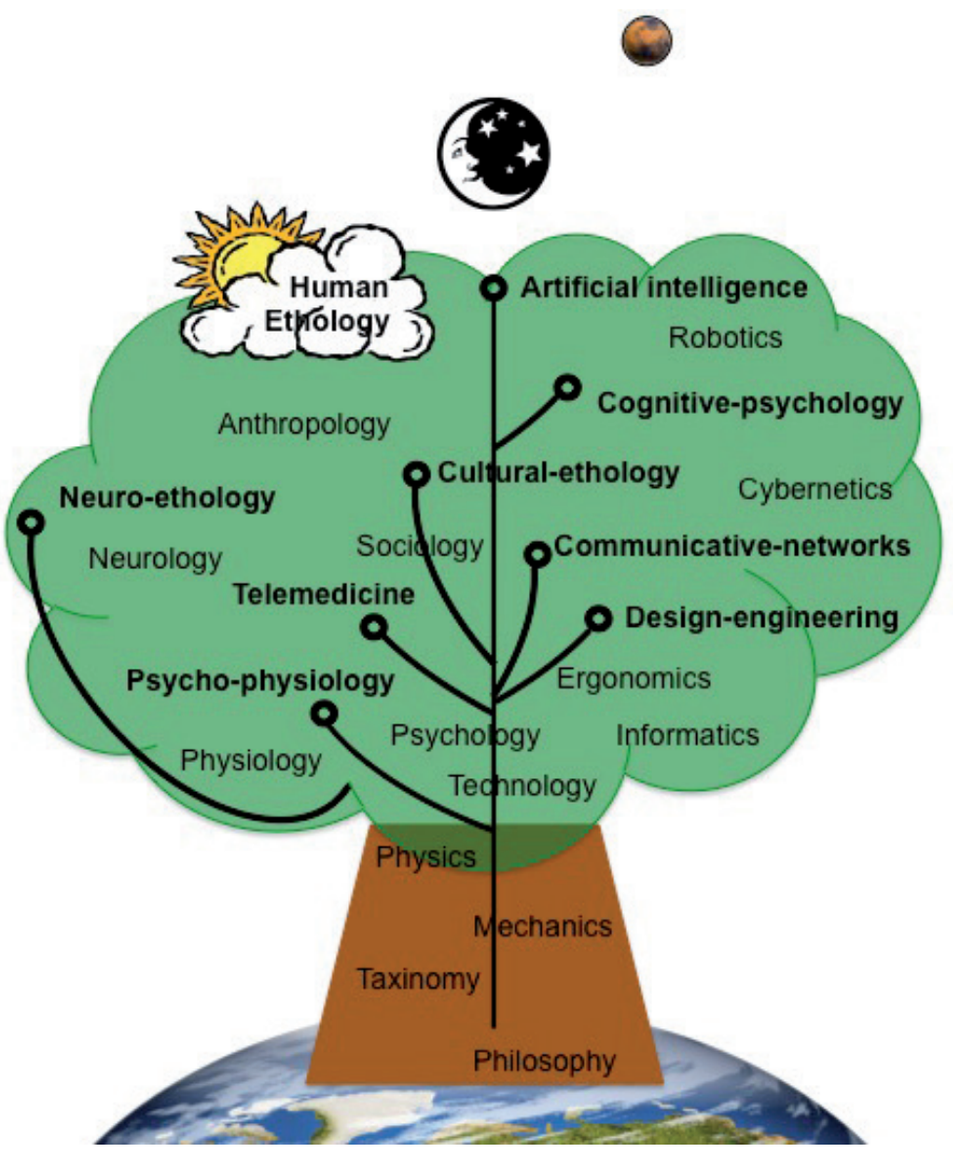


Figure 8.
Epistemological points of multidisciplinary approaches in human ethology.

Man-rated Mars exploration demands are to consider the personal value [40], the mixed-gender [41], and the cultural value [42] of a human mission and to take into account this diversity value as inputs of AI like variations of outputs generated by the machine. An intelligent mission becomes a multi-variable system with strategic processes, adapted processes, and cooperative processes that are running in synergy and that inject multi-sensorial inputs in the crew's EI. We hypothesize that such multiplicity improves over time. Monotony is prevented by robotic-automation tasks and autonomy is ensured by human-dependent actions.

The global demand is multidisciplinary in order to make human-machine interaction evolve. The evolutionary model of the human species is punctuated by so many disciplines that are points of organization from philosophical roots, to the naturalist current, to human ethology (**Figure 8**). Aristotle described behavioral traits from the perspective of a classification, that is, species taxonomy, to complete the anatomical and morphological image. From these epistemological nodes, integrated approaches such as psycho-physiology, neuro-ethology, communicative-networks, telemedicine, cognitive-psychology, and AI as the very last point of integration and evolution of the human species on other planets flourish. The whole approach is systemic [43] and is both behavioral and computational.

6. Conclusion

Numerical methods developed in ethology of humans in space have contributed to give insight into adaptive behaviors that underlie human intelligence as multiple processes of optimization of the individual-environment relationship. Human being's activity is the heart of the system, be it natural or artificial. AI can perform additional functions by processes of imitation, cooperation, and automation that include the diversity of the crewmembers, cyclicity of their behavior, and autonomy of the confined and isolated crew from Earth.

From the individual to the cultural crews' behavior that expresses individual intelligence to collective human intelligence, space missions will improve as intelligent missions by associating AI as follows:

$$\text{Artificial intelligence} + \sum \text{Human intelligences} * = \text{Intelligent missions}$$
$$(* \text{ Individual intelligence} + \text{Emotional intelligence} + \text{Collective intelligence})$$

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