

Human Microevolution in Outer Space

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Abstract

This article will argue that future outer space flight may cause micro-evolutionary changes to the human body, and will explain the nature of these changes from the point of view of evolutionary medicine. Initial adaptation will be protracted with considerable problems to long term outer space flight, especially inter-generational outer space travellers. The authors examine possible neuro-behavioural and psycho-social possibilities for long term outer space travellers due to separation from the biotic environment in which humans have evolved. The authors also develop novel ideas in reducing possible deleterious micro-evolutionary effects during long term outer space flight.

Keywords: Nature, neuro-behavioural, neuro-hormonal regulation, Heraclitean motion, symbolic cognition, future human population

Introduction: a systemic approach

The research conducted by space agencies (NASA, Russian) has now progressed to the stage at which we have a better understanding of physiological/anatomical and neuro-behavioural impacts on the human body when in outer space over short (16 weeks) (Schneider et al., 2003, 1998), to longer (438 days) (Manzey et al, 1998) time scales. Such research has provided scientists further insight into the possibility of longer term outer space flights. Were outer space flight possible for the entire human life, establishment of extraterrestrial colonies in space would become physically possible. The question arises whether maintenance of human

physical existence in space is sufficient to allow for multi-generational populations to thrive.

Humans are a part of Earth's ecological systems. They evolved from a richness of complex interactions with their habitat and its other inhabitants – plants, microbes and animals. They developed, to a larger extent than any other set of organisms, the ability to manage their life's resources through technological intervention. This ability, for the last few centuries has been based on scientific knowledge, that is, the knowledge that aims to be objective through systematic observation leading to formulation of hypotheses and their experimental testing. Such formulation of hypotheses, of intellectual necessity, must be based on parsimony – simplification proceeded by abstraction from less important phenomena and causes and focussing on the causes most important for a given outcome. This has been an effective approach in such fields as medicine and engineering, but is only based on empiricism. Therefore in studies of the entire web of systemic interactions with the totality of the environment, some relationships, judged unimportant for an investigation, are ignored. They have no immediate effects in experiments, but in real situations, especially those extending over longer times, they alter outcomes to the extent that becomes significant. A simple example is that of an internal combustion engine built of common steel. In the short run, of several years or decades, it will work very well if serviced adequately, but eventually it will wear out.

Space exploration is an exercise in engineering based on advanced scientific knowledge. Human bodies, so intricately linked to the Earth's ecosystem, cannot exist outside this ecosystem, unless parts of this ecosystem are constructed in outer space or on earth-like bodies. Following the approximative scientific approach, the engineered human habitat must ensure maintenance of basic vital functions – such as respiration and thermoregulation – for space sojourns of a few hours. This has been successfully achieved half a century ago. The sojourn of several days requires additional maintenance, that of metabolic functions – feeding, excretion – and interactions with other organisms in the human biome – microorganisms on the skin, in the respiratory tract and in the gastrointestinal tract – that in general may be termed “hygienic needs”. Some individuals have stayed in orbiting space stations for several months over the several decades since the first days of space flight.

When it comes to long-term residence on other than Earth celestial bodies, an increasing number of functions and needs of humans require engineered support. A greater web of interactions must be considered. In terms of classical scientific experiments, results of artificially engineered long-term human environments are difficult to assess due to obvious ethical limitations and a simple fact that experiments would have to last for the duration of human life. The Biosphere experiment has been limited to just under 30 years with periods of varying intensity of experimentation (Nelson & Dempster, 1996; Silverstone & Nelson, 1996; Walford et al., 2002).

Therefore, to be able to predict consequences of long-term biological existence of multi-individual human groups on other planets, we must rely on observational methods rather than on experimental ones and on those predictions that can be made quantitatively from existing theories. Abundant observations have been made by anthropologists on a wide variety of relationships of human biological, mental and social characteristics with variously structured environments. All of them were made on Earth. This is a limitation to their value, but careful consideration allows us to extrapolate results of those observations into outer space. Since sociological

and cultural aspects of out-of-Earth existence have been previously addressed (Pass, 2006) we will focus here on neurobehavioural and population genetics aspects of life in colonies on celestial bodies. Population genetics, including the theory of evolution, allows humans to formulate quantitative predictions regarding the state and changes of gene pools. These can be used in relation to humans forming a space population as well as to all kinds of organisms that will accompany them.

The nature of outer space travel removes humans from the terrestrial environment and places them in an artificial one where there is micro-gravity, confinement to small spaces, no diurnal/circadian patterns, disruption to circulation, vestibular and visual systems which may cause changes in function and neuro-hormonal activity in the human brain, especially centres such as the hippocampus. Moreover, assuming increased significance in the long term isolation, there is a limitation of social contacts to a very small group that is artificially structured and likely multicultural. With increasing distance from the Earth, immediate communication with friends and relatives becomes difficult and social separation increases. While astronaut engagement in exercise is important, this is insufficient. Physical activity levels (PAL) has been done since early homo evolution in conjunction with spatial locations, in which hunting was both exercise and worked concomitantly with the brain to learn, remember, and offered neuronal stimulation. PAL also created neurotrophic hormones which were probably exapted from thermoregulation.

In the first section, the authors examine possible neuro-behavioural and psycho-social possibilities for long term outer space travellers due to loss with the biotic environment in which humans have evolved. In this section the authors also recommend the use of 'Heraclitean motion' as a possible therapeutic method for reducing stress during long term outer space flight. In the second section the authors explore a novel idea in addressing possible deleterious micro-evolutionary effects during long term outer space flight.

Separation from the biotic environment and possible neuro-behavioural and psycho-social consequences during long term outer space flight

In this section we discuss possible future human micro-evolution due to separation from the biotic environment. Unfortunately, since *Homo sapiens* has not lived in outer space for sufficiently long periods of time it will be prone to evolutionary mismatch. Here, we provide an overview of several evolutionary possibilities due to evolutionary mismatch, in order to stimulate further theoretical attention in this area.

Neuro-hormonal implications for long term outer space flight

Recent studies in neuro-cognitive and neuro-behavioral performance show that during a long time spent in outer space astronauts' neuro-cognitive and motor performance deteriorate (DeLaTorre et al., 2012). While astronauts have been in outer space for up to 14 months, with no apparent severe psychosis, and with some psychosomatic adjustments (Kanas, 2011), this is a very small time scale in comparison to the extensive time scales which long term outer space travellers will face. Moreover, psychosocial research during outer space flights is in a nascent stage and has been limited to the near-Earth environment (Kanas, 2011).

Humans in outer space are disconnected from the biotic world, which poses

several short and long term neuro-cognitive and neuro-behavioural issues. Primate predecessors of humans started evolving over thirty million years ago. For 87,000 generations, hominins evolved in a “biocentric world” (Gulone, 2000). The evolutionary environments of adaptedness (EEAs) informed human genotypes and phenotypes, reinforcing the argument of human need to be in contact with other species (Suzuki, 1997).

The Biophilia Hypothesis proposes that humans have a ‘natural’ affiliation with nature, and this is biologically based (Wilson, 2003). This hypothesis also asserts that there is a correlation between human separation from nature and cognitive and affective deficits. Mentzer (1995) contends that current psycho-pathologies, including rising autism in industrial nations may already point to a disruption in developmental pathways as a consequence of ecocidal behaviour.

Ancestral humans would have possessed a strong affiliation with nature which conferred fitness. Knowledge of fauna/flora and weather patterns not only increased survival but regulated human neural and metabolic pathways. The current human proclivity to supplant natural environments with artificial environments undermines millions of years of evolutionary processes. For long term outer space travellers loss of contact with the biotic world may cause micro-evolutionary changes to human neuro-hormonal pathways.

This basic human need is recognised even in penal institutions. Prisons provide inmates regularly with opportunities to walk and exercise outdoors (usually in a prison yard). Regular prison cells have windows providing link to diurnal changes in natural light and, at the minimum, a glimpse of the sky.

Neuro-hormonal regulation was informed by a complex sensorial feedback system. Early primates developed stereoscopic, coloured vision which greatly assisted in depth accuracy in arboreal environments, increased ability in manipulating food varieties, and more efficient predation (Barton, 2004)

Probably from the Pliocene period onwards (3.5 Ma), Australopithecines used an arboreal-based visual sense to expand their life-worlds, increasing their time in terrestrial environments. Changes to neuro-hormonal regulation continued to *H. erectus*, whose morphology and social/technological behaviour was modern. Additionally, by the time of *H. erectus* there would have been significant changes to dopaminergic systems due to complex social environments and sophisticated hunting behaviours which increased meat/seafood intake (Previc, 2009). Considerable increase in physical activity level (PAL) of *H. erectus* onwards (Panter-Brick, 2002), necessitated more efficient dopaminergic metabolic pathways in order to optimise thermo-regulation, which may have been exapted for improving cognitive abilities in the pre-frontal cortex (Hoffmann, 2013). For example, various neurotrophic proteins such as brain derived neurotrophic factor (BDNF), vegetal endothelial factor (VEGF), and insulin growth factor (IGF) are dependent on exercise (Mattson, 2012) However, one theory notes that endurance exercise from *H. erectus* onwards augmented brain regions such as the pre-frontal cortex and hippocampus – key areas for spatial mapping and decision making which were important for tracking prey, foraging, and remembering geographical landscapes (Noakes & Spedding, 2012). In this way, exercise was linked to natural environments which had positive feedback to neuro-hormonal regulation. This indicates that while exercise regimes for extant astronauts are important for the creation of neurotrophic factors, there is no accompanying environmental stimulus for

stimulating prefrontal cortical and hippocampal regions. What may also be important here is the relationship between PAL within natural environments and brain plasticity. As humans needed more brain power to track prey, increases in BDNF may have helped to build up the hippocampus and prefrontal cortex – key brain areas that are involved in spatial mapping, decision-making and control of context, fear and emotions, including violence (Neeper et al., 1996).

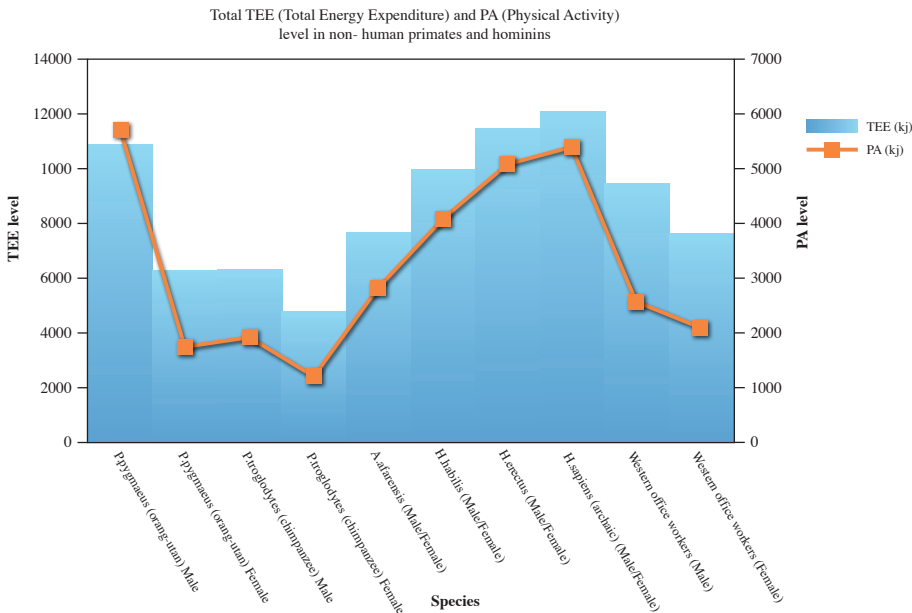


Figure 1. Total TEE (Total Energy Expenditure) and PA (Physical Activity) levels in non-human primates and hominins. Non-human primates (P.pygmaeus (orang-utan), P.troglodytes (chimpanzee))-Ancestral Hominins (A.afarensis, H.habilis, H.erectus, H.sapiens (archaic)- and Western office workers). Adapted from Cordain et al. (1998).

While benefits of short term exercise have been studied (Bue-Estes et al., 2008), more research needs to be done to investigate the link between exercise and sensorial stimulation and to what extent this aids in the innervation of cortical areas. In any event, the unique neuro-hormonal regulation of ancestral humans was contingent on their affiliation with the biotic world. This world is very difficult to imitate in a limited-size artificial constructions such as the Biosphere.

Nature and psycho-physical well-being: micro-evolutionary implications of long term outer space travellers

Unlike astronauts who spend short periods of time in outer space before returning to Earth, long term outer space travellers on inter-generational spacecraft will be permanently cut off from the biotic world with little prospect of ever returning to it. What will be the psychological effects of this perpetual separation from Earth? The psychological impact of separation from Earth has been reported in two studies which may exacerbate feelings of isolation, homesickness and possible psychosis (Kanas & Manzey, 2008). However, if experiencing Earth as a single, albeit, visually accessible dot in outer space may produce these mind states, what can we infer from this for outer long term outer space travellers?

Dozens of studies have examined whether natural environments promote human health and well-being. Several studies have shown that immersion in nature is psycho-physically restorative (Berto, 2005). The majority of studies suggest that human affiliation with the biotic world is significant for correct psycho-neuro-immunological function.

Table 1. *Cited benefits of natural environments for human health*

| Author | Noted benefits |
|-------------------------|---|
| Verlarde, 2007 | reduced blood pressure |
| Hartig et al., 2003 | reduced blood pressure |
| Heerwagen, 1990 | Reduced stress |
| Heerwagen, 2009 | restoring mental resources and inducing calmness |
| Herzog & Chernick, 2000 | increasing positive mood |
| Laumann et al., 2001 | restorative effect |
| Grahn et al., 1997 | fewer sick days |
| Park & Mattson 2009 | shorter post-operative hospital period |
| Kuo, 2001 | lower mental fatigue, lowering heart rate variability, blood pressure |
| Groeneweggen, 2006 | reducing anger and aggression |
| Morimoto et al., 2008 | improved natural killer immune activity |

In contrast, studies continue to indicate that decreasing levels of human contact with the biotic world are associated with loss of well-being and increasing disease. Louv has called the rising disconnect between humans and nature as the Nature Deficit Hypothesis which is creating various cognitive and affective deficits in children (Louv, 2008). While Louv's hypothesis has been theoretically challenged (Dickinson, 2013), it seems to be confirmed in various theoretical and empirical studies. A study examining mortality data revealed that death from all causes in income deprived individuals living in less green areas was higher than in individuals who lived in more verdant areas (Mitchell & Popham, 2007). Decreasing contact with nature among children living in modern urban societies also suggests disruption in developmental pathways. Another study conducted in Zurich revealed that 5 year old children who had declining outdoor play opportunities had less developed motor skills and "poorer social behaviours" than children who had better access to outdoor areas (Hüttenmoser, 1995). Empirical evidence also points to a correlation between ecological degradation and negative psycho-physical malaise in humans in modern societies (Roszak, 1995). The aforementioned evidence seems to concur with current psychological studies among astronauts who derive major positive well-being factor in being able to gaze at the Earth (Suzuki, 1997).

As suggested earlier, a possible reason for these cognitive/affective/motor deficits may be due to a critical reduction in contact with the biotic world which functions as an enriched environment (Kellert, 2002), for human proper neuro-hormonal regulation. Chronic stress leads to glucocorticoid dysregulation with consequential neurological and immunological deficits (Baatout et al., 2012).

In short, it seems likely that appropriate contact with biotic world is neuro-trophic and neuro-protective, as well as, informing neuro-genesis. This decline in contact with the biotic world and its subsequent neural/behavioural effects provide important lessons for future long term space travellers. Understanding the relationship between loss of connection with the biotic world and potential long-term psycho-physical disequilibrium for long term space travellers is necessary in order to implement counter measures for reducing this problem.

Less habitat exposure in outer space and possible micro-evolutionary reduction of sensory and cognitive acuity in long term outer space travellers

Evolution teaches us that environmental forces inform neuro-hormonal regulation and behaviour change. Habitat complexity is central to brain/behaviour processes. Lack of sensory stimulation may inhibit neuro-hormonal and metabolic processes which may eventually decrease both sensory and cognitive acuity with subsequent behavioural change. Studies point out that animals placed in less complex environments have subsequent neural effects such as loss of sensorial acuity and spatial memory. For example, thousands of years of domestication of the silk moth (*Bombyx mori*) have significantly reduced its olfactory perception of environmental odours (Bisch-Knaden et al., 2013). It also seems that domestication of dogs (*Canis familiaris*) has reduced their cognitive abilities (Udell, 2015).

Analysis of modern day dogs has shown reduced problem solving skills in comparison to wolves (*Canis lupus*) and Australian dingoes (*Canis dingo*) (Smith & Litchfield, 2010). One factor that may be contributing to this cognitive reduction is the change in habitat complexity (i.e. human/dog co-evolution) which altered dog neural pathways with subsequent behaviour change. In comparison, non-domesticated wolves and dingoes still operate in complex natural environments which hone sensory and cognitive acuity. In the same vein, it has been shown that African cichlids living in more complex environments have improved spatial memory and visual acuity (Shumway, 2008).

The point here is that long term outer space travellers will be exposed to even less habitat complexity, possibly leading to micro-evolution. The aforementioned animal studies provide important clues to possible micro-evolutionary scenarios. In relation to *Homo sapiens*, changes in habitat complexity and lifestyle have decreased brain size in the last 10ka by approximately 10% (Henneberg, 1988; Henneberg & Steyn, 1993). Reduction in brain volume was probably influenced by several factors, one being that it was an adaptation to nutritional constraints due to the transition to a agricultural based diet (Hawks, 2011).

Most likely microevolutionary changes in human subpopulations residing in outer space for several generations

Of course, all arguments concerning micro-evolutionary changes require that a time span of exposure to altered environments comprises a number of generations since a micro-evolutionary change occurs through a true Darwinian process of differential reproduction as well as the operation of non-directional forces of evolution (inbreeding, assortative mating, genetic drift etc.). Such time spans will occur during intergalactic outer space travels and during life on various planets. A new kind of people may emerge, especially when gene flow from Earth will be impossible to supplement the gene pool.

Limited opportunities for gene flow from outside, together with obviously restricted size of groups of outer space travellers, will facilitate significant effects of non-directional forces of evolution, primarily those of genetic drift and inbreeding. Although the direction of changes these forces could introduce cannot be predicted, it is certain that they will lower heterozygosity and promote homozygosity of offspring (Cavalli-Sforza & Bodmer, 1971). Any deleterious recessive genes will have a greater chance to be expressed in homozygous individuals. Drift will remove some alleles from the gene pool at random, thus interfering with possible orderly changes introduced by human-controlled selection or assortative mating. Directional forces of evolution – mutations and selection – may operate in artificial human populations at much faster rates. Exposure to alien environments, especially to significant rates of radiation, is likely to increase mutation rates (Horneck et al., 2010). It is thinkable to carry into space additional source of genetic variation in the form of frozen gametes. These, however, can be preserved for a limited time and will eventually run out. Such a device may delay the occurrence of problems, but will not solve them permanently.

In artificial environments and in the presence of the state-of-the-art medical care that will certainly be provided for outer space travellers, it will be difficult to expect much of the operation of natural selection. The artificial selection, however, will be likely to increase. In small human groups living in alien environments with artificially organised elements of biotic surroundings, reproduction will certainly need to be controlled. This may take various forms from gametic selection in a variety of IVF procedures through early tests of foetuses and selective abortions, to assortative mating and thorough genetic counselling. Since the knowledge of genetics and epigenetics is incomplete, the artificial selection will have only partially predictable effects, while unpredictable effects may be significant. Observations of recent microevolutionary trends on Earth indicate capacity of human populations to evolve at the rates many times faster than those occurring during human evolution in the Pleistocene.

Evolution is a generation-by-generation process facilitated by randomness of changes in DNA molecules, random events in their recombination and selective forces during the epigenesis of new individuals. Coupled with unpredictable changes in the artificial biomes and exposure to alien space environments, it is inevitable that extraterrestrial human groups will evolve away from the standard categorical human template considered normal on the Earth at the present time. No amount of technological manipulation and protection will be able to avoid this process even if basic parameters such as the force of gravity, atmospheric pressure and chemical composition of human surroundings are maintained at levels sufficient to preserve human physiological and structural integrity.

At this point the authors would like to provide two significant hypotheses which may reinforce their evolutionary argument. Firstly, the evidence on human health benefits in natural environments infers that longer term outer space travel may cause micro-evolutionary changes to neuro-hormonal function in future humans. Attention Restoration Theory contends that natural environments may provide a neuro-psychological respite from cognitive routines demanding high levels of concentration. In this way, temporary immersion in natural environments may assist in resting “depleted attentional resources” (Atchley et al., 2012). Restoration has been observed to occur in the pre-frontal cortex which performs executive functions (Winkelman, 2000a).

Possibly, for this reason such environments promote psycho-physical restorative effects. The authors contend that contact with the natural world (i.e. nature reserves, city parks, companion animals seem to play a vital role in modulating the hypothalamus-pituitary-adrenal axis, or HPA axis which regulates stress response. Consequently, there is a concern that permanent loss of contact with the natural may lead to changes in HPA axis regulation for long duration outer space.

Based on the premises of the Biophilia and Attention Restoration Hypotheses, the lack of natural stimuli and immersion in natural environments may lead to changes in cognitive and affective states in long duration outer space travellers. Such a lack of environmental stimulation has also been noted in relation to the proposed manned mission to Mars in 2035, which may make it difficult to implement appropriately familiar aesthetic positive based stimulations (Delatore et al., 2012).

Linked to attention restoration is the concept of 'Heraclitean motion', that refers to scenes that are perceived as changing and remaining the same; for example, the ocean, fire, fountains and moving animals (i.e. fish in an aquarium) (Katcher & Wilkins, 1993). Heraclitean motion seems to act on neural-hormonal regulation favouring parasympathetic bias, thereby leading to stress reduction. Consequently, Heraclitean motion seems to induce comfort and safety for the onlooker (Saniotis & Henneberg, 2011). What is interesting here is that the elicitation of self-hypnosis during Heraclitean motion, which may be an evolutionary legacy (Saniotis & Henneberg, 2009). Ability to enter hypnotized states may have been positively selected by natural selection as it conferred fitness benefits such as diminished stress response (McClenon, 1997). It is likely that Heraclitean motion may assist in attention restoration, and that current research demonstrates that higher order cognition improves with sustained exposure to the natural world. While more empirical studies are needed in testing the viability of Heraclitean motion in relation to astronauts, it seems likely that Heraclitean motion may improve individual resilience, especially in sensorially monotonous and enclosed environments such as spaceships.

While some studies indicate that visual representations of nature have been shown to reduce stress reduction and improving post-surgery healing rates (Ulrich, 1999), photographs are a dismal substitute for real nature. Extensive research needs to focus on developing models on how long duration outer space flight may affect the way in which humans cogitate in the absence of the natural world. Research conducted on Biophilia Hypothesis in relation to expediting healing rates in hospital patients (as aforementioned) is a good place to start.

The Attentional Restoration Hypothesis can be understood in relation to the ecological niches in which humans evolved in, such as savannahs and forests, which had water nearby (Ulrich, 1983). Possibly, for this reason such environments promote psycho-physical restorative effects. The authors contend that contact with nature (i.e. nature reserves, city parks, companion animals seem to play a vital role in modulating the hypothalamic-pituitary-adrenal axis, or HPA axis which regulates stress response. Consequently, there is a concern that loss or marked reduction of contact with nature may lead to increasing dysregulation of the HPA axis for astronauts and future space (DeLaTorre et al., 2012).

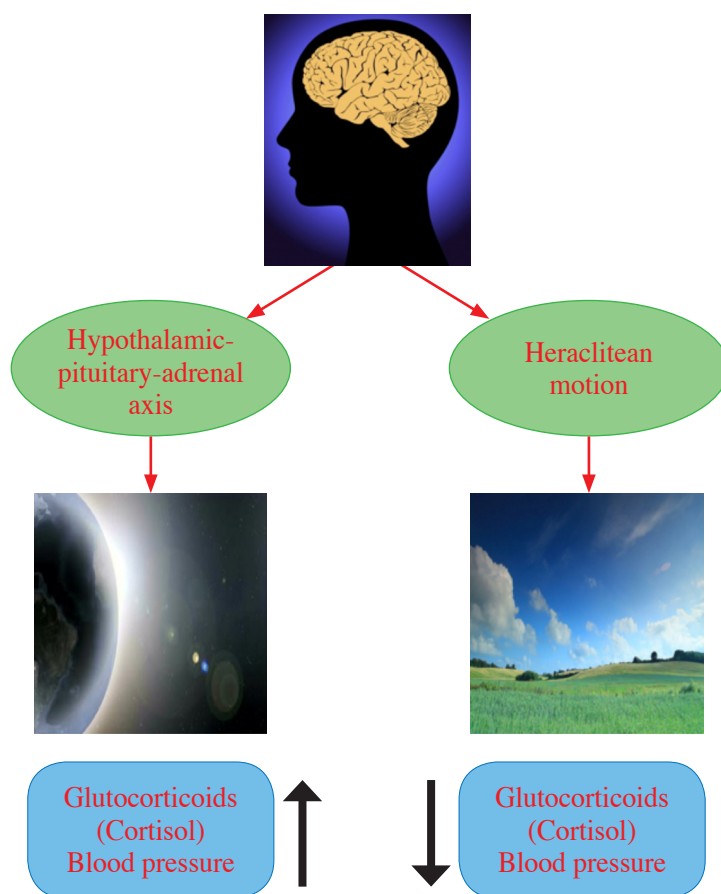


Figure 2. Correlation between space and natural environments and their effect on GC levels

One possible way of providing exposure to the biotic world in outer space is a Biosphere-like exercise. This is a complex task requiring substantial resources to transform a sizeable section of alien space into a close imitation of Earth with its soils, waters (including sea), atmosphere, flora and fauna (Charlton, 2008). It is a materially closed system open to the flow of energy. Despite the assumed complete cycling of the matter within a Biosphere-like system, a leakage occurs at a few percentage points per year even in terrestrial conditions of gravity, atmospheric pressure and external temperatures as shown by the Biosphere 2 project. The energy for this system comes from solar radiation. This radiation would be providing less energy on planets more distant from the sun, such as Mars or, theoretically, more energy on some planets in other solar systems. In the Mars-like situation, energy supplementation would be required to bring the total energy flowing into the Biosphere-like closed system close to that required by Earth-based ecosystem. This could come from a variety of sources, each one, however, will introduce another source of complexity and of possible failures. With gravity and atmosphere different from those on Earth, the expected biosphere leakage may be greater than that measured on Earth, but even if it were the same, or somewhat smaller, a few percentage points per year would amount to the loss of over 50% per generation or over 95% over 100 years (assuming leakage rate of about 3% and 30 years

long generation time). With random fluctuations in living elements of the system, the reliability of Biosphere-like solution is too low to base on it sustainable life of a human population in outer space. The only other solution available now is continuous supplementation of the Biosphere from Earth. This requires regular shipments of plants, animals, chemicals and gases. Some of these can be obtained from local resources, but at a cost of energy and labour that may be difficult to obtain.

A long-term solution would be organisation of an entirely artificial ecosystem adapted to local conditions. Such system, however, may require profound changes in physiology and anatomy of its living elements, including humans. The profound change in human biology may result in such alterations in the neurohormonal regulation that mentality of evolved individuals will not be compatible with that of humans living on Earth.

As humans venture into outer space the loss of the natural environment will have an indelible effect on human cognitive and metabolic functions which will impact on every aspect of sociality. Based on the premises of the Biophilia and Attention Restoration Hypotheses, the lack of natural stimuli and immersion in natural environments may contribute in increasing psychological and neurological pathologies in long term outer space travellers. While some studies indicate that visual representations of nature have been shown to reduce stress reduction and improving post-surgery healing rates (Parsons et al., 1998), photographs are a poor substitute for real nature. Based on considerable scientific evidence it seems that human neurological and metabolic systems are dependent on consistent affiliation with the biotic world in some form.

Micro-evolution altered states of consciousness for long term outer space travellers

A peculiar feature of the human brain/mind is its ability to enter altered states of consciousness with relative ease. Altered states of consciousness have evolved in the hominin lineage for millions of years and are central to cultural evolution. Early tool use during the Oldowan and Acheulian period indicate imaginative and aesthetic elements. In other words, the ability to make tools necessitates having a mind image of how the tool will be used augmented by an aesthetic impulse.

Ancestral shamans may have used altered states of consciousness in order to understand the natural world. In this way, early shamanic attempts to access domains of nature via mind technologies may have contributed to extant human ability to access multiple states of awareness which in turn can trigger parasympathetic response (McClenon, 1997). Upper Palaeolithic shamanism which was based on an intimate knowledge and experience of fauna/flora, may have informed human brain evolution (Winkelman, 2000a; Winkelman, 2000b; Winkelman, 2004). Possibly, for this reason human contact with the biotic world elicits restoration and stress recovery.

Micro-evolution of symbolic cognition and aesthetics for long term outer space travellers

The biotic world is a prime source of human symbolic thinking and is central in human communication and aesthetics. Nature does not merely surround *Homo* but is assimilated in *Homo* – shaping and mediating human biological, as well as, cultural

evolution (Charlton, 2008). The human psyche is embedded within the biotic psyche – the *anima mundi* (Roszak, 1995). Human corporeality is embedded in sensuous reciprocity with the biotic world, the latter acting as the underlying template for human social and biological rhythms (Abram, 2010). In many cultures, human language is inseparably linked to the natural environment. For example, human metaphors often mediate or synthesise between the human body and nature (Jackson, 1998). Bodily activities are referenced and understood in relation to natural geography and biotic processes. Especially among indigenous people, language is sustained by maintaining communication between the social and natural domains. This correspondence is vital for gaining insight into the world, and is a source of aesthetic sensibilities (Turner, 1967).

Various authors reveal that there is a correspondence between loss of biodiversity and linguistic diversity, and that this may be due to loss of habitat in which languages developed (Gorenflo et al., 2012). This correlation may offer a glimpse of how human language may evolve in long term outer space travellers. Some thinkers have stressed that the loss of linguistic diversity may lead to decreasing adaptational strength in humans since it diminishes the knowledge pool which humans can access (Maffi, 1998).

Outer space and the internal space ship environment may become the referential source for human linguistic and aesthetic experience. This change in linguistic and aesthetic development may lead to new kinds of cognition. In any case, outer space will provide new kinds of linguistic and aesthetic challenges due to human conceptual dependence on the biotic world, as well as, physical isolation which may inform unique languages and dialects to evolve. These languages will probably also be informed by changes in cognitive and motor functions.

It will be interesting how the roles of natural selection and mutation operate in outer space in relation to neuro-hormonal function. However, increasing isolation from Earth's biosphere, with the concomitant loss of habitat complexity, may have unforeseen consequences to human neuro-behavioural patterns.

Large size – a possible solution

Theoretically, effects of inbreeding and of genetic drift are small when the effective population size (the number of unrelated adults) exceeds 200. To achieve this effective population size the total number of individuals in the population must be of the order of 500 – this includes children and elderly. Gene pool of such population, though still subject to all forces of evolution, will be relatively stable during the time span of several generations without requirement of significant artificial control.

In terms of social relations and psychological needs of individual populations of this size (~500 persons) were found to be functional as separate “nations”. Transport of a population of this size through outer space and its maintenance pose enormous technical problems. These, however, can be overcome given enough energy and resources. It is impossible in a relatively short article to provide detailed estimates of the size and functioning of the artificial biosphere adequate to support life of a 500 strong human population, but the way to obtain such estimates can be based on a simple rule of adaptation (Henneberg & Wolanski, 2009).

If a human group is to survive in a particular set of conditions, those conditions must provide an amount of matter and energy that is equal to the amount required to

satisfy the vital needs of the entire group. In short this may be represented in figure 3 as follows:

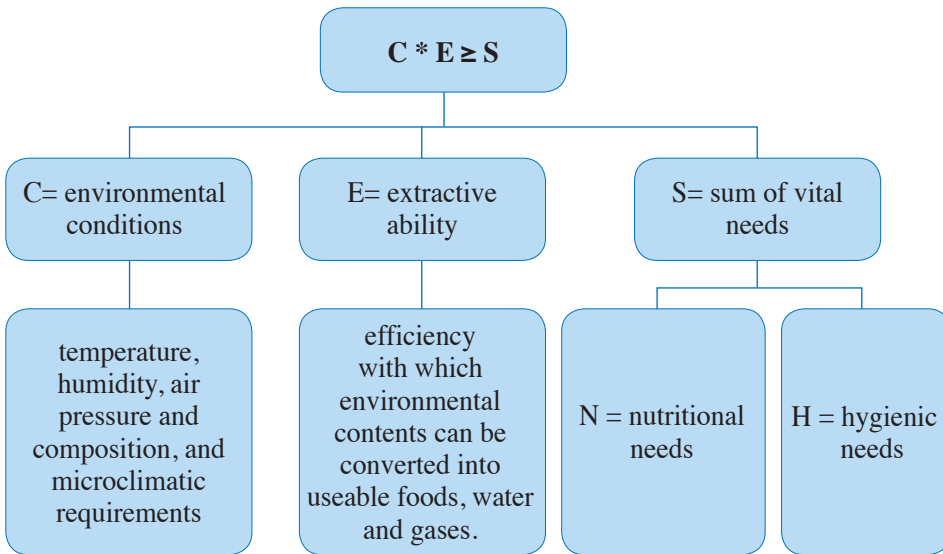


Figure 3. Formula for calculating sum of vital needs for human groups living in outer space

As a simple example we may use the calculation of nutritional needs. Food and Agriculture Organisation of the United Nations provides a number of standards for human energy needs by sex and age (FAO/WHO 1979), as well as energy content of various foods (FAO corporate Document Repository, 1998). Assuming that the age structure of the human group in outer space, following several generations, will be that of a stationary population with low premature mortality and the net reproductive rate of about 1.0, it can be calculated that an average daily energy need per person would be approximately 10 MJ assuming moderate body size (adult males 65 kg, females 55 kg) and moderate physical effort. This translates into 1,825,000 MJ per year. To satisfy this need 132,009 tons of wheat would need to be produced, or their equivalent in various food products. Cereal yield per hectare in most advanced agricultures reaches about 8 tonnes (Worldbank.org, 2015), that translates to 16.5 hectares of agricultural land to be cultivated in the Biosphere-like space colony. Using the actual experience of the Biosphere 2 crews of 7 and 8 adults who were sustained by 0.22 ha of agricultural land produces similar result – 14.7 ha.

This example illustrates the scale of the sustainable human outer space colony. Assuming the same division of the land area among agriculture, forest, sea etc. as in Biosphere 2, the total size of the artificial environment would have to be about 100 hectares (1.25 ha x 16.5/0.22), that is 1 km². Though seemingly large, it is not technically impossible to construct artificial Earth-like environment of this extent. The real problem is the leakage that during the outer space travel cannot be controlled by supply of new gases fluids and materials from the extra-terrestrial substrate and thus will require the outer space vehicle to carry stores of necessary supplies. In the case of a colony on a heavenly body, the replacement of losses sustained through leakage would be possible by using locally available materials and

energy that will convert them to necessary substances. The energy will have to either be captured from outer space, or produced by nuclear reactions.

Conclusion

Extra-terrestrial existence of humanity, though technically very difficult to imagine at the moment, is possible when the biology of human populations is considered. This paper has postulated various neuro-behavioural and psycho-social challenges for long term outer space travellers, as well as, possibilities for reducing potential deleterious micro-evolution. Current knowledge of astronauts living in micro-gravity in outer space reveals various undesirable neuro-physiological effects. Given the relatively short amount of time in which the bodies of astronauts undergo neuro-physiological deterioration, space medicine needs to construe new ways of thinking for mid to long term outer space flight. This paper has proposed novel ideas which the authors hope will promote further investigation.

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