Defining the Scope of Sensory Deprivation for Long Duration Space Missions

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Abstract

Sensory deprivation increasingly has been identified as a unique stressor for long-duration space missions (LDSMs) of one year or greater (for example, Mars). Sensory deprivation (SD) is reduction or removal of stimuli from one or more of the senses (Rasmussen, 1973). The prolonged stress consequences of SD lead to detrimental neurological changes in the human brain, which can manifest in maladaptive behaviors and disorders. Literature available regarding the effects of SD in space flight is limited due to the plurality of the problem of environmental factors in LDSM. It is difficult to separate the effects of the space flight environment between SD, behavioral issues, and social deprivation as well as individual variations in the isolated and confined space environment (Harrison, Clearwater, & McKay, 1991).

This literature review compiled and integrated the peer-reviewed, anecdotal and reference material available on the effects of SD on the five senses (visual, auditory, gustatory, olfactory and tactile senses) as well as cognitive and kinesthetic functions during both space flight and in analog and simulation studies. It presents the data currently available on SD in long-duration isolation and confinement studies, defines the scope of SD research and includes recommendations for future research.

Keywords: long-duration space missions, sensory deprivation, isolation, confinement, visual, olfactory, tactile, cognitive, auditory, stress, kinesthetic, sensory motor,

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Acronyms

BMED	Behavioral Medicine
CNS	Central Nervous System
CVP	Central Venous Pressure
DRA	Design Reference Architecture
EEG	Electroencephalography
ICE	Isolated Confined Environments/Extreme
ISS	International Space Station
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
POW	Prisoners of War
PTSD	Post Traumatic Stress Disorder

Introduction

As the goals for the NASA space program evolve and an increased focus is made on manned missions to deep space, mission duration increases. Currently, there is a lack of understanding of the detrimental impact that spaceflight missions of one-year and longer will have on behavioral health and performance for crewmembers (National Aeronautics and Space Administration, 2010). This literature review is meant to directly fulfill the knowledge requirement under the BMed 1 gap under the Risk of Adverse Behavioral Conditions and Psychiatric Disorders of the Behavioral Health and Performance section under the NASA Human Research Roadmap. Gap 1 (c) (i) asks, “What long term effect does sensory deprivation have on crewmembers?” (National Aeronautics and Space Administration, 2010).

Sensory deprivation (SD) is reduction or removal of stimuli from one or more of the senses (Rasmussen, 1973). Human evolutionary history and biology is one of rich sensory stimulation and the search for novel and interpretable information (Biederman & Vessel, Perceptual Pleasure and the Brain, 2006). However, a long duration mission in a capsule environment will drastically reduce stimuli for crewmembers. Anecdotal data suggests that a chronic stress state ensues which may have significant behavioral and cognitive effects (National Aeronautics and Space Administration, 2010). The prolonged stress consequences of SD lead to detrimental neurological changes in the human brain, which can manifest in maladaptive behaviors and disorders (Suedfeld & Steel, 2000) (Bluth & Helppie, 1986). However, the literature regarding the effects of SD in spaceflight is limited due to the plurality of the problem of environmental factors in LDSM. It is difficult to separate the effects of the spaceflight environment between SD, social isolation and monotony, and the confinement effects of the ICE environment (see Figure 1) (Sells, 1973).

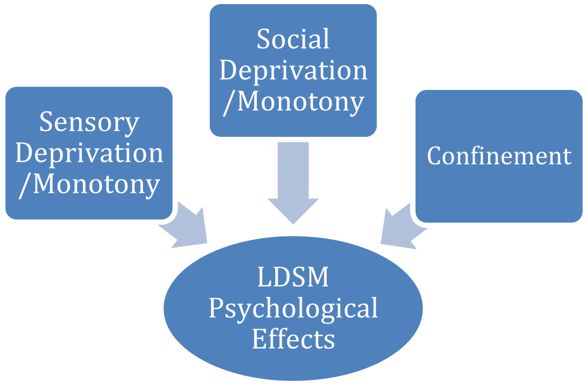

Figure 1. LDSM psychological effects

The goal of studying SD in the context of LDSM is to achieve an optimal behavioral state for the astronauts and cosmonauts before, during, and after a mission. This enables crewmembers to complete tasks with "minimal minor errors, no mission impact errors, and to interact with fellow crewmembers and ground support in a manner that maintains crew and crew-ground cohesion" (National Aeronautics and Space Administration, 2010).

Data is currently available for mid-term missions (6-months) due to the continued presence of astronauts and cosmonauts on the International Space Station (ISS). However, the relevance of current data to long duration space missions (LDSMs) longer than one year remains unproven. A case is made for a variety of analog studies as high fidelity analogs for long duration missions to study SD effects and the many shared characteristics between isolated and confined environments (ICE).

This report will define research requirements for future research related to the identification and development of methods and tools as a countermeasure for SD experienced in an isolated, confined, and extreme environment. The concluding chapter summarizes the highlights, difficulties, and new directions, which emerged in the literature.

Aim

The *AIMS* of this literature review is to

- Present the current status of knowledge on the psychological effects of sensory deprivation in long duration environments in the context of what we currently anticipate LDSMs to resemble

- Outline the sensory deprivation stress response
- Determine available biomarkers for stress
- Extrapolate conclusions can be drawn for LDSMs (Mars DRM, 12 month missions)
- Identify areas where further research is necessary

DEFENITIONS

Sensory deprivation is the deliberate reduction or removal of stimuli from one or more of the senses (Kubzansky, 1961). Kubzansky has provided an accepted differentiation between sensory deprivation (SD) and perceptual deprivation (PD). In the SD condition, "efforts are made to reduce sensory stimulation to as low a level as possible" (Rasmussen, 1973) (see Figure 2). In the PD condition, dubbed

Figure 2. Sensory deprived environment (courtesy of Courtnay-Smith, 2008)

the McGill procedure, the patterning and meaningful organization of sensory stimulations is reduced while maintaining its level near normal" (Rasmussen, 1973). A subject is placed in an isolated, confined environment subject to white noise devoid of meaningful organization. The LDSM environment could be considered a combination of both, the deprivation of the natural Earth environment and the monotony of the consistent stimuli and routine.

A Brief History of Sensory Deprivation

Anecdotal accounts of the physiological effects of SD and confinement have been reported for several centuries by philosophers, mystics, prisoners in solitary confinement, explorers, and shipwrecked sailors. These include the deterioration in ability to think and reason, perceptual distortions, gross disturbances in feeling states, and vivid imagery in the form of hallucinations and delusions (Heron, Cognitive and Physiological Effects of Perceptual Isolation, 1961).

As a subject of scientific concern, dedicated science research began in the early 1950's and 60s with D.O. Hebb's classified studies on the topic of brain malleability and susceptibility. This interest stemmed from the peculiar behavior elicited from prisoners during "confessions" during the Russian Communist Trials, followed by the emergence of "brainwashing" later applied to Chinese isolation procedures during the Vietnam War and Korean War (Heron, Cognitive and Physiological Effects of Perceptual Isolation, 1961). Hebb aimed to understand the function of the central nervous system (CNS) in light of psychological and physiological experimental results. He studied animal behaviors after being reared in sensory deprived environments from birth. The effects included atypical socialization patterns, perceptual and learning deficits, absence of startle and blink reflexes, increased anxiety and aggression (Heron, Cognitive and Physiological Effects of Perceptual Isolation, 1961). Yet at the time, the potential for reversibility of these effects was still unknown. Hebb proposed to extend his research to humans.

Hebb's Associates, Bexton, Heron and Scott ran SD experiments on volunteers resulting in a wide variety of behavioral changes. The effects included, inability to think or concentrate, deficits in task performance, anxiety, somatic complaints, temporal and spatial disorientation, and visual phenomena described as hallucinations (Heron, Cognitive and Physiological Effects of Perceptual Isolation, 1961).

Dedicated literature on the SD studies for space flight dates back to 1967 in anticipation of missions with the development of Skylab in 1973, concerns about the astronaut's well being was studied (Weinstein, Richlin, Weisinger, & Fischer, The Effects of Sensory Deprivation on Sensory, Perceptual, Motor, Cognitive, and Physiological Functions, 1967). The Soviets focused on SD studies upon recognizing cognitive, visual, and kinesthetic effects on the Salyut space station cosmonauts (Bluth & Helppie, 1986).

ICE Environment Description

Ideally, sensory deprivation would be studied directly in space, however, due to logistical, and resource constraints, SD effects must be studied in analogs in isolated and confined environments (ICE). While no analog is perfect, similar environmental comparisons are made with data from identified ground-based and space-based long duration ICE analogs.

Confinement is the extent to which group members are physically restricted to a fixed space or geographical area by either man-made or natural barriers, territorial boundaries, or hostile environment. *Isolation* is the extent to which group members are restricted, either by physically or socially prescribed limits, from communicating with others outside the immediate group or from receiving information (Rasmussen, 1973). This review will focus on the physical limits and briefly outline the social limits of isolation and confinement (see Social Monotony). There are several analogs that replicate the isolated, confined and extreme environment effects of SD over a prolonged length of time (Harrison, Clearwater, & McKay, 1991).

Shared LDSM and ICE environment characteristics influencing human performance and behavior include:

- Altered photoperiod
- UV deprivation
- Extreme cold
- Prolonged isolation
- Prolonged confinement
- Emotional deprivation
- Leadership
- Group function
- Work/rest scheduling
- Communication limitations
- Need for autonomous support

It is important to note that there are differences in conditions of confinement; astronauts are restricted in their movement compared to an Antarctic station with a hostile physical environment or a prisoner-of-war compound with a hostile social environment.

C*ommunication* capabilities vary across identified analogs. Future astronaut crews will expect a 44 minute round trip delay, whereas prisoners of war can receive letters but not send them (National Aeronautics and Space Administration, 2009). Military submarines can receive radio messages but not initiate them, and Antarctic winter-over participants' communications are determined by weather conditions, satellite connectivity and equipment failures (Rasmussen, 1973).

The constant *threat to life* from the harsh space environment (micrometeorites/ meteorites/ meteorite showers) and the potential for equipment failure must also be considered. Previous soviet studies identified the risk of micrometeorites indicating that one strikes each square centimeter of the space station surface once a month (Bluth & Helppie, 1986). This threat may increase with longer duration missions. Analogs that share the effects of prolonged threat to life include prisoners of war (POW), Antarctic stations, deep-sea habitats and space stations.

Variability in duration adds to the difficulty of making valid conclusions of analog data. It is not advisable to generalize across data collected from Mercury missions lasting a few hours, two week Shuttle missions, Mir space station missions of 6–12 months, and a possible 3-year voyage to Mars. Similarly, one or two months spent in the polar summer are different than an 8-month winter-over (Suedfeld & Steel, 2000).

Analogs

> "My worst fear is that an astronaut on the way to Mars will suffer a nervous breakdown that will be televised live around the world," Charles Stovitz, National Aeronautics and Space Administration consultant (Maugh, 1987).

It is important to understand the extremes of the effects of the ICE environments because studies suggest that increased duration increases the intensity and likelihood of maladaptive behaviors (Otto, South Pole Station: An Analogue for Human Performance During Long Duration Missions to Isolated and Confined Environments, 2007). Most of this information is anecdotal because a small number of incidents have happened, however, it is important recognize these to fully understand the risks in LDSMs.

Isolation Chamber Studies

The most literal attempt at SD is the water immersion technique, which places a subject in a large tank of water at 94 degrees and is instructed to inhibit all movement while wearing an opaque mask, earplugs, and gauntlet-type gloves. The first controlled studies in the 1950’s-1960 were of short duration, 4-14 days (Zuckerman & Cohen, Sources of Reports of Visual and Auditory Sensations in Perceptual Isolation

Experiments, 1964). The most comprehensive review of the literature on hallucinatory activity during SD and PD is Zuckerman and Cohen (1964) (Rasmussen, 1973).

Approximately 12% of the normal population has experienced hallucinations while awake. After SD studies, as many as one third and half of the SD population were experiencing symptoms. Hallucinations consisted of changes in shape and size of objects, exaggerated contrast, hyper-saturation and luminosity of colors, pronounced positive and negative after-images, accentuated or diminished depth of perception, and distortions of human faces as well as meaningless flashes of light, dots, or geometric forms to meaningful integrated scenes of a picture-like nature, such as people, scenery, and bizarre architecture (Doane, Mahatoo, Heron, & Scott, 1959). As studies increased in duration, the after effects were more profound and prolonged, some lasting 24 hours later after 6 days of PD (Heron, Doane, & Scott, 1956) The results of the McGill objective test data indicated impairments in cognitive and perceptual functioning, and progressive slowing of occipital alpha frequencies with an increasing duration of isolation.

Winter-Over Syndrome in Antarctica

"Research at Antarctic stations has provided a body of data relevant to many questions concerning the effects of confined living and individual and group behavior." (Rasmussen, 1973). With an elevation of 2,835 meters above sea level, South Pole Station is located on at the southernmost place on Earth the Geographic South pole. Implemented during the International Geophysical Year in 1957-58, the objective of the U.S. Antarctic Research Program is to conduct basic research, including meteorology,

Table 1. Analog environment correlations

	Isolation Chamber	NEEMO	Submarin e	ISS	Prisone r of War	Solitary Confinement	Antarctic Stations	Salyut / Mir	Mars 500	Biosphere 2	LDSM
Duration (months)	0.25	0.5	3	6	12	18	12	16	18	24	30
Threat to life	no	yes	yes	yes	yes	yes	yes	yes	no	no	yes
Isolation environmental	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Confinement physical (crowded space) social	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Emotional deprivation/ family/ friends	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Work/rest schedule	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Leadership	no	yes	yes	yes	no	no	yes	yes	yes	yes	yes
Group dynamics	no	yes	yes	yes	no	no	yes	yes	yes	yes	yes
Mission Control relations	no	yes	yes	yes	no	no	yes	yes	yes	yes	yes
Altered photoperiod	yes	yes	yes	yes	maybe	maybe	yes	yes	yes	no	yes
Communication limitations	no	yes	yes	yes	yes	yes	yes	yes	yes	maybe	yes
System and comm. failures	no	yes	yes	may be	no	no	yes	maybe	mayb e	no	yes
Food/lack of freshness	no	no	yes	yes	yes	yes	yes	yes	no	yes	yes
Reduced cognitive stimulation	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
UV Deprivation	no	yes	yes	yes	yes	yes	yes	yes	yes	no	yes
Extreme Cold	no	no	no	yes	no	no	yes	yes	no	no	yes
Elevated C02	no	yes	yes	yes	no	no	no	yes	no	yes	yes
Microgravity	no	no	no	yes	no	no	no	yes	no	no	yes
Volunteerism	yes	yes	maybe	yes	no	no	yes	yes	yes	yes	yes

oceanography and marine biology, with scientists as the key staff. Civilian and military crews cook, maintain the station and generally keep the bases running (Maugh, 1987). While there are 3 American year-long stations, South Pole Station has been identified as the highest fidelity analog to study SD in comparison to McMurdo and Palmer Station. Life at South Pole Station exposes crews to an altered circadian rhythm, extreme environmental monotony, communication barriers with family, friends and colleagues back home, as well as a constant threat to life. There is also a large body of data regarding the number of winter-over participants. For example, there have been close to 5000 winter-over person years over the past 54 year history of the United States Antarctic Program (Otto, Components of Habitability, 2011).

The harsh climate and continuous darkness of the winter period impose severe restrictions on work and recreational activities. Prolonged isolation from the outside world, together with the inevitable confinement experienced during the winter months, may adversely affect emotional equilibrium, motivation, and effectiveness" (Rasmussen, 1973). The extreme cold requires heavy clothing making outdoor work slow and difficult. Equipment breakdowns are frequent, with limited spare parts. Crowded living and working spaces make privacy difficult. Limited daily satellite connectivity (11.5 hour window), that processes around the 24 hour clock by 4 minutes per day, and an 8-11 hour time zone difference contribute to difficult communications with home.

Among the most drastic behaviors recorded include "a murderous attack over a chess game at a Russian Antarctic Station (Palinkas, 1990) and a 1996 assault with a hammer at McMurdo Station (New Zealand Herald, 1996) highlight the extremes of the potential behaviors. Fistfights are not uncommon and other anecdotes include the Australian cook who chased a diesel mechanic with a meat cleaver for three hours, though no casualties resulted. Another Australian crew built stocks outside, locked an unpopular mate in them for four hours and showered him with garbage (Maugh, 1987). These anecdotes are extreme representations of the irritability and frustration that build as a consequence of the persistent and unrelenting sensory and social deprivations.

Accidental deaths also occur, some as a result of ennui-bred adventurism. Three British scientists died in 1982 when they fell into a crevasse while exploring the forbidden sea ice. Other deaths and severe injuries have been recorded as the monotonous routine caused attention to wander (Maugh, 1987). Mullin, Connery, and Wouters (1958) found that 30 of their 85 subjects reported having experienced “absentmindedness” and “wandering of attention”. In a few cases the severity resembled a “fugue state.” Since the occurrence of fugue-like, or dissociative, trance states under conditions of restricted environmental stimulation (REST) is consistent with E.R. Hildegard (1991) (Hildegard, 1991) neodissociation theory. The dissociative state is believed to manifest as a means to escape the current environment which is perceived as unpleasant, under stimulating or threatening. This has serious implications for team dynamics and autonomy in LDSMs.

Biosphere 2

Biosphere 2 in Oracle, Arizona, was intended to demonstrate an artificial, closed-loop ecological system to explore the complex web of interactions within life systems in a structure that included five biomes and an agricultural area and human living/working space to study the possible use of closed biospheres in space colonization.

With a two-year duration, Biosphere 2 is the longest duration controlled isolated environment and serves as an important benchmark in isolation studies. While it was not the most confining area (3.14 acres), it did provide a high level of natural sensory stimulation (5 natural biomes with over 3000 species of flora and fauna). What is of great insight is the level of social monotony and isolation, despite the fact Biosphere 2 epitomized the environment that our brains are programmed to seek as stimulus. By happenstance, the experiment controlled for sensory deprivation which shined a spot-light on the consequences of social deprivation. Biosphere 2 provides the link between SD and social isolation considerations.

The Biospherian population was analogous to the astronaut selection process by selecting accomplished, healthy individuals with previous isolation experience and similar performance on psychological personality profiles (Poynter, 2006).

While not as drastic as other environments, peculiar behaviors were reported in Biosphere 2. Some were impulsive and creative, such as tearing off their clothes, painting their bodies with bright paint, and wandering naked in the rainforest (Poynter, 2006). While other behaviors negatively affected group morale and hinder larger mission goals. "When we entered the Biosphere, we had the idea that we would maintain, even create, a high level of civilization. But one's environment can have unexpected consequences… People's eating habits stood out, perhaps on account of cabin fever setting in. One biospherian insisted on eating with her mouth open while making disgusting noises that seemed to get louder with every passing day, though in reality I am sure that the decibel level remained unchanged. She grated on my nerves (Poynter, 2006). This reflects the stress of confined living and social monotony.

Exposure to the persistent stress of social monotony can exact a heavy toll on individual and team psychological functioning and performance and could compromise a Mars mission. "I could hardly pull myself out of bed. I felt numb from head to foot, heavy, so heavy. The weight of my own body was crushing me. I was in fact, clinically depressed." (Poynter, 2006) Finally, post-isolation behaviors reflect the negative effects of isolation. At least one of the biospherians experienced post traumatic stress disorder, and several developed clinical depression.

Salyut and Mir Space Stations

Space stations are the closest fidelity environments that can be used to study SD in an LDSM environment. In this environment all of the physiologic, confined, and social deprivation symptoms can be examined. There are still some differences that are not accounted for in Low Earth Orbit such as the lack of communication delay and the absence of seeing the Earth, or exposure to UV light. Previous space flight studies on SD were mostly available regarding Salyut 6 and 7, and Mir space stations.

Russian studies have shown that the likely consequences of isolation are:

- Emotional neurotic reactions to the absence of feedback

- Post-isolation hypomanic syndrome
- Phenomena of “catathymic negativism” (refusing an activity that does not conform with the emotional tone of effect)
- General drowsiness
- Sleep disorders
- Deterioration in work capacity
- Psychological stress (Bluth & Helppie, 1986)

Headaches were thought to be associated with inadequately expressed hostility. Evidence for this is found in the higher incidence of headache among officers and scientific personnel as compared to enlisted men, who presumably resort to more overt expressions of aggression” (World Health Organization, 1963).

In December, 1982, Soviet Salyut 6 space station cosmonauts Anatoli Berezevoi and Valentin Lebedev risked a hazardous night landing during a snowstorm rather than extend their 211-day mission another week. In a rare display of candor, Soviet authorities said the landing was prompted by the cosmonauts' growing irritability and inability to get along (Maugh, 1987).

Midway through an 84-day Skylab mission in 1974, the three resident astronauts shocked ground controllers by deciding to take a Sunday off from scheduled work (Maugh, 1987).

Supermax Prisons & Prisoners of War

A mission to Mars will be a historical and adventurous undertaking, but it will also represent the most extreme level of confinement and isolation ever encountered by a group of human beings. The supermax prison and prisoner of war environment provides insight on the extremes of the potential isolation and confinement effects with limited countermeasures. The supermax prison and prisoner of war environment provides insight on the extremes of the potential isolation and confinement effects with limited countermeasures. These effects are important in providing insight for LDSMs, since a 30-month mission is at the fringes of studies available on long duration ICE environments.

Section 3 subheading A, verse 2 of the Torture Victims Protection Act of 1991 U.S.C. § 9092 (1991) defines torture as "prolonged mental harm caused by or resulting from… procedures calculated to disrupt profoundly the senses or personality" The European Court also finds SD to have negative health consequences and to violate Article 3 of the European Convention for the Protection of Human Rights and Fundamental Freedoms prohibition on torture and/or cruel, inhuman and degrading treatment. The Court has said "complete sensory isolation, coupled with total social isolation can destroy the personality and constitutes a form of inhuman treatment which cannot be justified by the requirements of security or any other reason" (Physicians for Human Rights, 2005) In Iran, torture consisted in part of sleep deprivation, prolonged solitary confinement with sensory deprivation (Physicians for Human Rights, 2005).

In severe cases, solitary inmates "have developed florid delirium- a confusional psychosis with intense agitation, fearfulness, and disorganization" in even the most psychologically resilient inmates (Grassian, 1993). When the International Committee of the Red Cross (ICRC) visited the US detention facility at Guantánamo Bay in June 2004, it found a high incidence of mental illness produced by stress, caused by prolonged solitary confinement. It was observed that deprivation of sensory stimulation was causing spatial and temporal disorientation in detainees. The results were self-harm and suicide attempts (Physicians for Human Rights, 2005).

In solitary confinement studies, isolation sickness symptoms include, "massive free-floating anxiety, hypersensitivity to external stimulation, perceptual distortions or hallucinations, derealization experiences, difficulties with concentration or memory, acute confusional states, aggressive fantasies, paranoia, and motor excitement (that may include violent or self-destructive outbursts)" (Haney, 2003). In a study surveying inmates symptoms included, "suffering from heightened anxiety (91%), hyper-responsivity to external stimuli (86%), difficulty with concentration and memory (84%), confused thought processes (84%), wide mood and emotional swings (71%), aggressive fantasies (61%), perceptual distortions (44%), and hallucinations (41%). Moreover, fully 34% of the sample experienced all eight of these symptoms, and over half (56%) experienced at least five of them" (Haney, 2003) (Grassian, 1993).

Submarines

Despite its high fidelity as a LDSM analog, submarines have only recently been considered for studying the effects of isolation in relation to spaceflight. Submariners serving upwards of six months report Short Timer's Syndrome, a condition that sets in a couple of weeks before arriving at port. This time is characterized as more aggressive and candid with fights and cruel pranks (Poynter, 2006).

The men are volunteers, therefore socially motivated to help, and are there for educational opportunities – much like the astronauts, there is a psychiatric screening program, and the submarine medical officer monitors the crew. It has also shown that neurotic disorders such as anxiety and interpersonal problems were more prevalent in subjects that served for longer than three years (not all of this time was in a submarine), which indicate that these behavior disorders are a product of the duration of time in an ICE environment (Weybrew & Noddin, 1979).

Another study by Thomas et al. (2003) analyzed the rates of health events that occurred during submarine duty of officers and enlisted crew members. It extrapolated that in an a crew of seven officers, one medical event would be expected during a 6 month mission, and in a crew of seven crew members, two medical events would be expected during a 6 month mission, and would only cost 1 day of limited or no duty per medical event. However, this would need to be compared to ISS health event records to see if there is a similar correlation. Also, data is needed to understand if the risk increases with longer duration (Thomas, et al., 2003).

Mars 500

Housed at the Institute of Biomedical Problems (IBMP) in Moscow, Russia, the Mars 500 study is an isolation study that simulates a mission to Mars (520 days). It is comprised of an international crew (6 members) who underwent a rigorous selection process that closely correlates with astronaut/cosmonaut selection. While still in progress, current studies that may have implications for future SD studies include:

- *Effects of environmental factors on circadian rhythm and oxidative stress*
- *Medical skill maintenance during long duration spaceflight* (cognition will be highlighted here)

- *Effects of group dynamics and loneliness on cognitive and emotional adaptation to extreme, confined environments* (will highlight how stress affects cognition and emotion).
- *The evaluation of stress and immunity* (European Space Agency, 2011)

THE SENSES

To understand the negative *output* behavioral effects of living in an ICE environment for long durations, we must first understand the *input*. Input is received though the 5 senses, which are also closely linked to cognitive processes, as well as motor functioning. The replacement of our natural environment on Earth with an unchanging, monotonous environment of a spacecraft will deprive the sensory organs of normal levels of stimulation causing structural brain changes over a long duration. Though individual variability is a factor, Zuckerman (1971), there is an optimal level of stimulation of the senses. And the underlying mechanism that supports this is the fact that the brain is wired for pleasure.

Jeff Williams ISS Science Officer of Expedition 13 said that besides family and friends, he missed, “One of them is quiet…the smell of fresh air, and the smells we normally get in fresh air, the smell of trees and flowers and grass.” This speaks to a highly stimulating Auditory, olfactory, visual and tactile environment.

In addition to the need for a novel and stimulating environment, there is a need for the stimuli to bear meaningful information. This is the fundamental consideration in PD, where stimulation is provided, however it is unpatterned stimulation that does not convey any information interpreted by the brain. Automatic human tendency actively seeks novel stimuli, in particular natural Earth environments (Biederman & Vessel, Perceptual Pleasure and the Brain, 2006). Novel, interpretable stimuli cause significant neural activity in the temporal lobe producing greater endorphins, resulting in high visual preferenc**e** (Otto, South Pole Station: An Analogue for Human Performance During Long Duration Missions to Isolated and Confined Environments, 2007)**.**

Visual Deprivation and Monotony

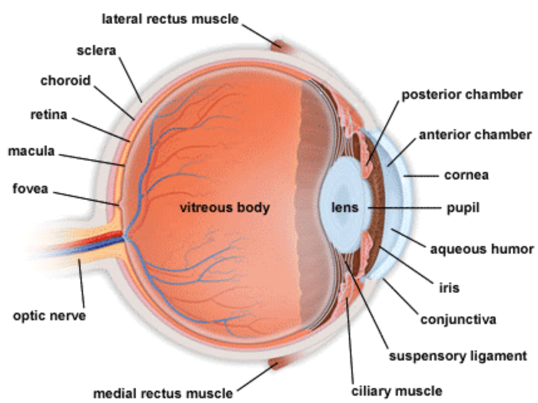

Figure 3. Anatomy of the eye (Larson Eye Center 2008)

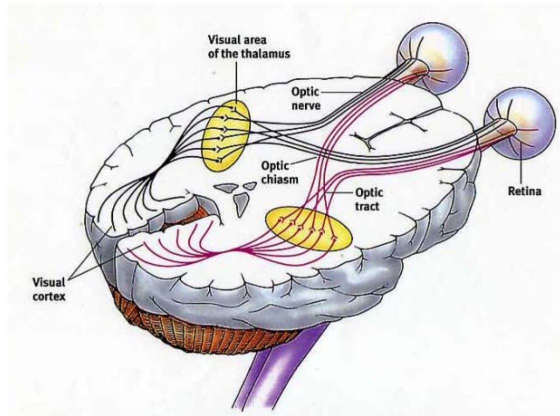

Figure 4. The human visual system (Mount Sinai School of Medicine 2010)

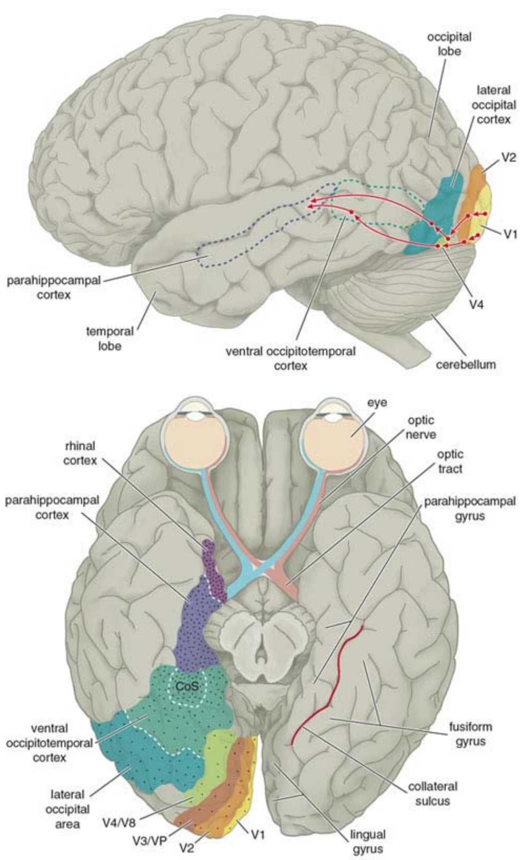

Figure 5. Ventral visual pathway (American Scientist 2006)

How the structures work

An object is perceived when reflected light (photons) bounces off an object and hits our eye. An image of what we see is passed through the several optical structures. There is a transduction of light energy to electrical energy that sets off nerve pulses that are directed towards the optic nerve and then the optic pathway before arriving at the occipital brain where the image is analyzed and recognized (see Figure 3 and Figure 4).

The visual stimuli present in the LDSM environment is a drastic change from the natural visual stimulation found on Earth. The visual environment is extremely monotonous, consisting of constant fluorescent lighting and computer screens, wires, clinical, cluttered surroundings and the same people. There is a lack of novel visual stimuli: nature, friends, family, new places, colors, art, open spaces.

Molecular receptors located on the surfaces of brain cells are activated when an opiate binds with it. One type of receptor called the mu-receptor is activated by endogenous morphine-like substance creating the experience of pleasure. The receptors are distributed over a gradient along the ventral visual pathway which is the area involved in the recognition of an object or a scene. The receptors are sparsest in the early stages of this pathway, where an image is processed as contour, color and texture. Intermediate stages such as the lateral occipital area and ventral occipito-temporal cortex, integrate information to detect surfaces, objects, faces and places, contain greater numbers of opioid receptors. The receptors are densest in the later stages of recognition, in the parahippocampal cortex and rhinal cortex, where visual information engage our memories (Biederman & Vessel, Perceptual Pleasure and the Brain, 2006).

The mu-opioid receptors (Figure 5 bottom; black dots), are involved in the of pain and pleasure mechanisms in other parts of the brain. Because they are sparse in the early stages and grow increasingly dense in the later stages, Biederman and Vessel postulate that visual stimuli that contain a great deal of interpretable information activate many opioid receptors in the later stages and so provide the greatest pleasure. These same areas in the visual pathway are associated with the CNS visual processing areas. Increasingly novel inputs result in greater interpretation and association thus maximizing endomorphin release.

Biederman and Vessel used functional Magnetic Resonance Imaging (fMRI) to observe the brain activity that results when subjects are exposed to different types of visual stimuli. Figure 6 shows the visual preference for highly interpretable stimuli versus blank walls or uninterpretable inputs because they result in little or no activity in the visual pathway. **“**Problems in visual cognition, visual memory, and visuospatial skills can likely be traced to the complete absence of visual novelty in the LDSM resulting in decreased opiate reward in the visual processing pathway.” (Otto, South Pole Station: An Analogue for Human Performance During Long Duration Missions to Isolated and Confined Environments, 2007)

In addition, more recently, astronauts have been suffering from farsightedness in space which is believed to have several causes some of which include the increase in intracranial pressure, potentially a side effect of fluid shift caused by microgravity as well as central venous pressure (CVP). It is unknown whether these effects could affect the quality of visual stimuli that is perceived.

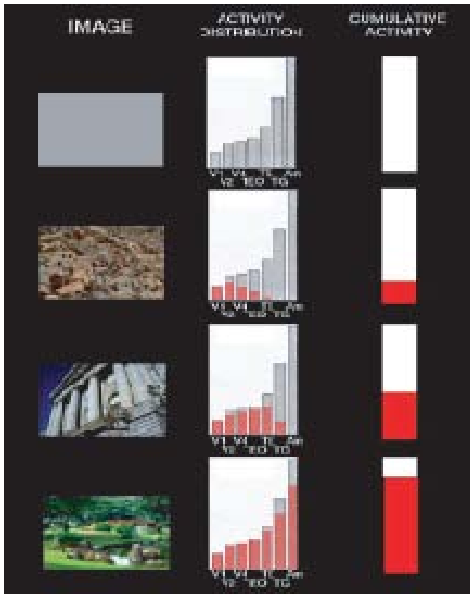

Figure 6. Human visual preference and activation of the visual reward system (Vessel & Biederman, 2002)

It is anticipated that the other senses have a similar mechanism, though perhaps to a different extent.

Previous Visual Studies

The earliest research on the reticular activation system showed that a state of alertness is achieved when there is exposure to a constantly changing visual input. (Rasmussen, 1973). A Soviet ground-based experiment indicated that any change in environment even a change for the worse, at least at the beginning is a positive stimulus. During this experiment, the level of illumination was sharply increased and the work productivity also increased and fatigue was mitigated. Then the illumination was sharply reduced, but the level of productivity increased again (Bluth & Helppie, 1986).

During Salyut 6 and 7 missions, color, light and music was studied for its psychophysiologic and aesthetic functions in regards to SD. Monotonous surroundings were found to lead to boredom, fatigue and reduction in job interest, physical anesthetization, as well as the emergence of psychic disorders and altered behavior. Colored light and music programs were employed to elicit temporal awareness to symbolize the seasons. Color was a major role in space station design. Small areas were paired with bold colors, and large areas with shades and tones. Colors varied according to tasks performed in the environment (sleeping, work, rest and recreation). A recommendation was made for changeable color panels for visual variety. These considerations improved operator activity (Bluth & Helppie, 1986). Lighting conditions were also found to impact work productivity. Natural light was found to be less tiring on the eyes than artificial light (Bluth & Helppie, 1986). Yet this will not be available on an LDSM having consequences such as fatigue or sleep. Efforts to reproduce natural light in the cabin environment would be beneficial.

During Valery Polyakov’s record-breaking 437-day mission, eye experiments showed changes in the threshold of color vision, depth of vision, eye capacity in various illumination conditions, tracking, eye-motor functions, and vestibular vision interaction (Bluth & Helppie, 1986) In terms of what is seen in the visual sphere, on a long duration mission, most objects will either be near or very far (view from windows) therefore, the depth perception at middle to long range will suffer (Bluth & Helppie, 1986). The effects were severe enough that this led to the development of psychological relief rooms which were brief 10 minute sessions with natural sounds and music, film and odors producing the effect of being surrounded by nature providing relief for visual fatigue and nervous emotional loads. In Soviet studies these rooms were shown to increase productivity by 17%. Ground-based studies stated that work production is increased 1.5 times and the number of errors is reduced by 25% (Bluth & Helppie, 1986).

Auditory Deprivation and Monotony

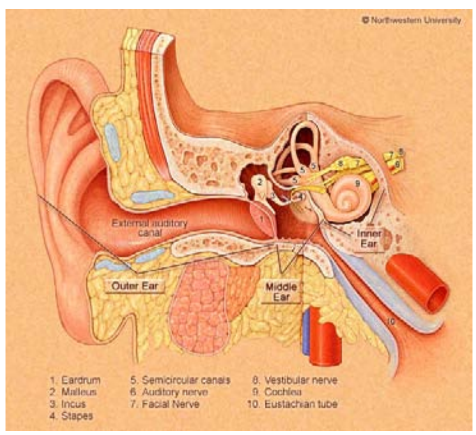

Figure 7. Auditory system structures

The confinement in a capsule environment on a long duration mission will severely limit the range of sounds to which a crewmember is exposed. The main stressor that has been identified is the background noise emitted from the machinery (fans blowing and pumps going continually) on board space stations.

How the structures work

Sound waves are directed through the auditory canal to the eardrum/ tympanic membrane. The mechanical energy of the sound causes the eardrum to vibrate along with the 3 middle ear bones that amplify the vibrations to other auditory structures. Hair cells on these structures bend in response to vibration. Neurons at their bases convey signals to the brain and are perceived as sound by the primary and secondary auditory cortex located on the temporal lobe.

Similar to the visual system described in the previous section, a mu-opioid receptor gradient has been found in the auditory system of the macaque monkey where receptors are sparse in the primary auditory cortex and more dense in the secondary auditory cortex indicating that the pleasures associated with sounds can be mediated by the mu-receptors in the auditory cortex (Goldstein, 1980). The secondary auditory cortex is also associated with processing harmonic, melodic and rhythmic patterns. This may explain why crewmembers often request rhythmic dynamic music during space missions (Abbott, 2002).

Previous Auditory Studies

Extensive research has been conducted regarding auditory stimulation under the Soviet space program during Salyut 6 and 7 missions. The idea came from the concept of music therapy. Music was considered both a form of relaxation and a stimulant. It offered a degree of control over noise, which adds to the ability to control one’s environment, was found to affect physical and psychological health, and stimulated work capacity. Cosmonauts would make frequent requests for the transmission of rhythmic-dynamic music as well as Earth sounds and noises starting with the second month of a mission. Music was used to increase concentration and sustain a high work capacity demonstrating that “cheerful” music is best. Energetic music was favored for simple jobs, whereas calm, neutral music was recommended for complex jobs (Bluth & Helppie, 1986).

Experimental data shows that music is a strong emotional and rhythmatic stimulus and has a great effect on the CNS heart activity and the muscle system. Most significant is the tempo, timbre, orchestration, and volume of the music. Dodecaphonic music was found to negatively affect the cardiovascular system, causing fatigue and irritation, but was found helpful as an emotional shock or jolt to awaken someone out of boredom, whereas classical music had a positive effect (Bluth & Helppie, 1986). Data also suggests that high intensity noise causes an alteration in the nerve cells that perceive sound and influences the functional and psychological state of the central nervous system.

In a ground-based simulation imitating long-term isolation, music that was unexpected in form and content turned out to be significantly greater in increasing work capacity than that of music selected according to request. Electronic music had the effect of an "emotional explosion," which helped to remove nervous tension of the test subjects better than ordinary music. It was recommended that programs should alternate between quiet, loud, fast and slow, major and minor keys (Bluth & Helppie, 1986).

For Russian selection, there was a recommendation for a 24-hour noise stress test. This test can permit an evaluation of the negative effect on the auditory analyzer, vegetative nervous system, work capacity, sleep, psychological functions (Bluth & Helppie, 1986).

There have been accounts of Otitis of the middle ear (Bluth & Helppie, 1986). No mention was made to the causes or remedies, but there are varying degrees of the severity of this condition, some of which can cause severe discomfort and could potentially affect crew productivity.

In a ground-based study exposing 3 subjects to continuous background noise in a hemochamber for one year, total adaptation to noise did not occur. At the end of the experiment, all three volunteers noticed a "wadded emptiness" noise and ringing in the ears and head that was the cause of restless sleep and insomnia. The subjects felt compelled to converse constantly in order to suppress the silence. Normal hearing resumed on the 7th and 25th days, but the 3rd volunteer's hearing did not resume (Bluth & Helppie, 1986).

Through auditory studies, noise level guidelines were established, differentiating between rest and living quarters. The recommendations included 25-30dB at night, 35-40 db during the day, and rest areas were restricted to 40 dB, any more would risk causing irritability, sleep disorders, headaches. In addition, the sound threshold was found to be lower in space than on Earth with no apparent explanation (Bluth & Helppie, 1986).

Cognitive Deprivation and Monotony

Cognition is defined as the mental action or process of acquiring knowledge and understanding through thought, experience and the senses. It includes the processes through which the sensory stimuli are interpreted. These processes affect the functions of memory, association, concept formation, pattern recognition, language, attention, perception, action, problem solving and mental imagery. In a sensory depriving environment, less cognitive stimulation causes fewer memory traces, less SWS activity, & decreased neurogenesis (Otto, Components of Habitability, 2011)

Merzenich et al (2004) reported that motor systems are tightly integrated with cognitive systems through pre-motor areas involved in movement planning, and indirectly provide feedback to sensory systems through proprioceptive and vestibular systems. Because sensory, cognitive, and motor systems are parts of a highly integrated information processing system, disruption in any one system would be expected to cause disruption in the others, and degrade the overall accuracy and speed of information processing (Schneider and Pichora-Fuller, 2000).

Previous Cognitive Studies

McGill studies, revealed a consistently poorer performance on measures of verbal fluency, anagrams, and various numerical tasks presented orally during several days of PD (Rasmussen, 1973).

After several months on the ice, about one-third of Antarctica winter–over subjects indicated that they experienced difficulty with memory or concentration in the form of absent-mindedness, wandering of attention, or inattentiveness. Two cases were extreme enough to resemble fugue states where the individual would recall leaving his quarters, but nothing afterwards, until he 'came to' moments later in some other part of the camp not knowing how he arrived there (Mullin & Connery, Psychological Study at an Antarctice IGY Station, 1959). Notice impairment of alertness, unrestful sleep, low motivation and productivity, "I laugh at myself and say that my attention span must be equivalent to that of a kindergartner. Both my recent and remote memory is lacking. I sometimes forget simple vocabulary words that I have known for perhaps twenty years. Or, I walk to get something and forget what it is two seconds later" (Harrison, Clearwater, & McKay, 1991).

The term "driftiness" emerged and is used to describe the mild fugue state that subjects experienced. Cognitive decrements affected well-learned tasks. Biospherian Jane Poynter recalled uncertainty in her ability to drive (Poynter, 2006). "After two years of nothing but a two-way radio and pruning shears on my belt, I could not keep track of things. I lost my sunglasses, my handbag, my car keys. All the sensory input overwhelmed me." (Poynter, 2006)

These instances were also recorded during Salyut 6 and 7 missions and were attributed to the monotony of the work schedule or from working on a particular project for a long length of time (Bluth & Helppie, 1986). Salyut 6 and 7 missions stressed reading, self-education, music, videocassettes as positive cognitive stimulation. Recreational tasks also stimulated cognition singing, reading, painting, creative writing, crafts, and cultural scenes. (Bluth & Helppie, 1986)

The cognitive and aesthetic needs are completely unresearched in isolated small group settings. While individuals do have interest in cognitive and aesthetic activities, they seem difficult to pursue in isolation. Anecdotal reports from Antarctic stations indicate that men frequently go to Antarctic duty with plans to complete correspondence courses or do nonfiction reading as part of their self-education. However, these plans, often fail to materialize. The low levels of activity, monotonous stimulus conditions, and/or relative lack of social reinforcement are not conducive to sustained cognitive activity (Harrison, Clearwater, & McKay, 1991).

Soviet investigators Agadzhanyan et al. (1963) reported a progressive increase in time required to trace a geometric pattern in subjects socially isolated for 60 days. While there was no change in quality, the task took twice as long to complete. The longest duration mission of

In a 175-day mission, Ryumin reported trouble articulating words upon return (Bluth & Helppie, 1986). Any task involving active reflection and manipulation of ideas rather than highly overlearned sets of operations would be most affected by sensory isolation (Rasmussen, 1973).

The Mir mission of Valeri Polyakov is the longest study recently conducted on grammar and cognitive abilities. The study reported a slowing of the memory-search response rate after the spaceflight. The results however did not report serious detriments to long-term cognitive abilities. The decrements were mainly found during the two adaptation phases: spaceflight and return to 1g. The response rate detriment only occurred post flight. Valeri Polyakov recovered his memory-search response rates 6 months after the mission and the return of performance and time-sharing efficiency to pre-flight baseline level at follow up assessments, provide strong evidence that long space missions do not lead to long-lasting impairments of higher mental functions (Manzey, Lorenz, & Poljakov, 1998). These results merit further validation and investigation.

Another Soviet experiment called the Balaton tested mental ability as well as changes in electrical conductivity of the skin and pulse. It demonstrated whether a task was performed easily or with effort (Bluth & Helppie, 1986).

Finally, studies on speech were common during the Salyut 6 and 7 missions. The hypothesis was that cognitive decrements could be studies by monitoring the tone, volume, rate and other characteristics of speech. (Bluth & Helppie, 1986)

Motor Sensory Deprivation and Monotony

Early motor sensory studies observed how the confinement in a spacecraft environment also affected the desire to exercise causing hypodynamia. Exercise became boring and monotonous requiring an increased effort for similar results (Bluth & Helppie, 1986). Under hypokinetic conditions, there is a restriction of muscular activity. A ground based study resulted in a severe reduction of interest in exercising. Four men, 30-42 years of age were placed in a 50-mA 2D pressure chamber for 37, 86, and 120 days. The average steps per day reduced from baseline 16,000 to 2-4,000 (Bluth & Helppie, 1986). A Cuban experiment aboard Salyut 6 tested the “Cuban Boot” shoe to see if changes in the arch might be responsible for motor disorders. It was intended to makes cosmonauts feel as if on the ground and reportedly reduced the severity of spatial illusions and motor disturbances (Bluth & Helppie, 1986).

As research on kinesthetics in space progressed, the organs behind posture, balance and motor control were further investigated. Apart from the 5 senses, there are there are other sensory receptors located in the muscles, spindles, tendons, joints, viscerae (somaesthetic receptors) and in the inner ear, which are used to detect position, sense and analyze motion. The vestibular organs (2) the first consist of the saccule and utricle send information to the brain on head translation in relation to gravity. The second detects angular acceleration (roll, pitch, yaw) (Clement, Reshcke, & Wood, 2005).

Vestibular organs as well as the kinesthetic, pressure and touch receptors may be altered by over- or underload in the microgravity environment. The response to stimulation may be outside the crewmember's physiological response range, or there may be a discrepancy between the perceived pressure/force, compared to visual input. This may result in spatial disorientation, postural and visual illusions, and a wide variety of symptoms called *space motion sickness*. The plasticity of the central nervous system (CNS) allows individuals to adapt to these altered sensory conditions, and the symptoms disappear after a few days. The consequence of this in-flight adaptation is a deconditioning of antigravity responses upon return to Earth (Clement, Reshcke, & Wood, 2005). Post-flight, astronauts' readaptation to Earth's gravity cause disturbances in "perception, balance, locomotion, gaze control, vestibular autonomic function spatial orientation, posture, gait, manual control and eye-hand coordination" (Reschke et al. 1998). The duration of these altered responses after spaceflight is proportional to the time spent in space.

Recovery takes an average of 2 weeks, similar to the observed recovery in postural equilibrium control (Mulavara et al. 2010). There are changes in the *otolith-spinal reflex* function essential to the motor response for posture and postural equilibrium during movement/locomotion (Reschke et al. 1984; Watt et al. 1986; Newman et al. 1997). Following a 211 day Russian mission, Berezevoy experienced muscle changes causing difficulty for walking and sitting, lying down is more comfortable and a swimming pool was helpful upon return. Following a 237-day Soviet mission, the crew experienced trouble walking caused by vestibular effects, but completely recovered from these motor disturbances eleven days after landing (Bluth & Helppie, 1986). Currently, the evidence suggests that the effects wear off, but after a 1 or 2 year mission, the issues may progress and the post-flight effects may last longer.

Motor skills are modified, leading to decrements in manual dexterity inhibiting tasks such as tracking, pointing and grasping (Bock et al. 2003; Bock and Bloomberg 2010). Depending on the situation this can affect movement speed, accuracy and/or the cognitive costs of performing the skill. The central reinterpretation of sensory inputs from the vestibular organs has adverse effects on gaze stabilization by the *vestibulo-ocular reflex,* and thus degrades eye-hand coordination and visual target acquisition.

Deficient gaze control experienced during adaptive periods (flight, postflight) during the first days of exposure to microgravity and re-exposure to a gravitational environment can cause blurred vision and decrements in dynamic visual acuity caused by a decreased ability to keep a visual target stabilized on the retina during head and body motion (Paloski et al. 2008). Decreased dynamic visual acuity coupled with changes in manual control poses a unique set of problems for astronauts especially during entry, approach, and landing on planetary surfaces.

However, in particular, it has been concluded that the neurovestibular system is able to adapt to microgravity fairly well, and detrimental effects are mostly upon return to Earth, While this does not have severe implications to long duration space travel in microgravity, it does have implications post flight in regards to performance of operational tasks that require movement immediately following landing on a planetary surface (e.g.,Mars) such as rapid emergency egress from a landing vehicle.

Current efforts to study a crewmember's motor movements in the Mars 500 study as well as ISS are using an Actiwatch - a device that measures motor function of the individual. The hypothesis is that the confinement of an enclosed spacecraft environment actively restricts the amount of movement the individual engages in. This isolation and confinement will severely limit the repertoire of motor movements that any one individual would normally perform over a one year period. This will have drastic consequences on the sensory motor areas of the brain likely in the form of brain atrophy.

Gustatory Deprivation and Monotony

On an LDSM, food freshness, and food variety will pose a major challenge which can result in psychological effects. Across all SD analogs, evidence suggests that there is an increase in interest of food in general. In a study on the subject of conversations of a winter –over crew in the Antarctic, food occupied 20% of all conversations (World Health Organization, 1963). In space, only particular types of food are considered “space ready” also lacking variety, and freshness. There are limited ways of preparing food, and the strict dietary limitations closely monitor food intake causing a restriction on the crewmember’s freedom to choose their meals.

How the structures work

Specialized cells found in our taste buds contain receptors capable of interacting with molecules found in food and drink, when receptors are stimulated, an electrical signal is produced by the sensory cell resulting in an impulse which is sent to the brain, and taste centers are in cortex and the thalamus of the brain.

Previous Gustatory Studies

A wealth of anecdotal data is available from Antarctic winter-over accounts. Drastic appetite increases and consumption are common and weight gains of up to 20 and 30 pounds are not unusual (Mullin & Connery, Psychological Study at an Antarctice IGY Station, 1959). During winter-overs food became so important that the cook’s role would be esteemed as highly as the station manager’s role. “Fortunately, the cook was competent, imaginative, and very anxious to please. His prestige was enormous” (Mullin & Connery, Psychological Study at an Antarctice IGY Station, 1959).

Biosphere 2 was a special case in which the quantity of food consumed did not reflect the food that the participants desired. “Seven of us were losing weight again, albeit slowly, but it heightened food anxieties. I fumed if another biospherian had put more food on his or her plate than I had managed to cram on mine …we had been hungry from the day we entered, even after meals” (Poynter, 2006). Food became an obsession, the banana storage room was such a temptation that it was kept under lock and key.

Food fantasies were considered a form of therapy. “We were all becoming so cranky from the change in diet that we called ourselves Grumposphere 2” (Poynter, 2006).

Soviet space flight studies noticed appetite decreases, and cosmonauts would become bored with foods. Dehydrated foods tasted better and there was a desire for spicy foods. Appearance and aroma became important, and taste changes due to weightlessness were observed. Nutritionists are studying to see if there are changes in taste as missions get longer and use sharp seasonings as appetite stimulators (Bluth & Helppie, 1986).

During a 150 day mission, the crew increasingly asked for more fresh fruit and vegetables and less meat. A taste experiment on Salyut 6 electrically stimulated taste buds to see how taste changes, anecdotes report that food that was originally considered delicious at first tasted like sawdust later (Bluth & Helppie, 1986). In particular, the lack of fresh food on a LDSM will be of great detriment to the crew. The plethora of anecdotal evidence regarding fresh food suggests that this may be the biggest hurdle to overcome.

Olfactory Deprivation and Monotony

Evidence suggests that there are significant changes in the olfactory system in space. In particular, the fluid shift that the body endures increases the fluid in the nasal cavities restricting the smell receptors. ICE environments usually maintain low temperatures which inhibit the odors to be sensed. In addition, the ventilators on the space stations quickly work to move the air, and any odor that is present quickly dissipates.

How the structures work

Smell and taste are closely related where receptors send signals to the somatosensory cortex. When the olfactory cortex is activated a signal is sent to odor memory bank allowing recall of the odors the next time they are present. 7 primary smells have been identified and must fulfill three characteristics to allow them to be sensed. They must be volatile to diffuse into air, water soluble to enter the membrane, and fat soluble to enter the circulatory system.

Previous Olfactory Studies

Antarctic winter symptoms have included anosmia (inability to perceive odors) due to low ambient working temperatures and a high degree of restriction of contact with the outside world (Harrison, Clearwater, & McKay, 1991).

Tactile Deprivation and Monotony

In space, there is a severe change in the contact with the environment. In space, the majority of touch interaction is clinical using the specific tools that have been prescribed. There is severe change in the variety of textures, temperatures and objects that are touched on a daily basis. This includes a large reduction in natural contact with the natural Earth environment (earth, water, nature) and an increase in contact with the clinical spacecraft environment (cables, wires, computers, control panels).

How the structures work

Sensory cortex in middle of brain responds to the stimulation of receptors in the skin. Receptors in the epidermis contain free nerve endings which respond to touch and pain. Merkel's disk responds to continuous touch. The dermis is below the epidermis where Misener's corpuscles send information to the brain about the texture of an object. Nerve endings at the base of hair follicles respond to pressure, by movement of the hair. Pacini's corpuscles respond to changes in pressure and vibration, and Ruffini corpuscles respond to changes in friction against an object, and the kinesthetic sense, and secondarily detect changes in temperature.

Previous Tactile Studies

Of all of the senses, studies on tactile data are the most limited. However the tactile sense makes up a particularly large area of the somatosensory cortex. Figure 8 shows the somatosensory cortex and the homunculus which shows how the human form would look if they were represented by the amount of brain volume that is attributed to each of the senses. A large emphasis can be seen on the hands and feet. A drastic change exists in the way that the human body adapts to microgravity and in the way the human body moves in space compared to Earth. Due to the lack of gravity, the main method of propulsion through space shifts from the feet to the hands, and the clinical environment of the spacecraft limit the variety of surfaces that the skin comes into contact with. This drastic change in environment and sensory stimulation is predicted to have an effect on the areas of the somatosensory cortex which are attributed to the tactile sense. In particular, the under stimulation of the tactile sense coupled with the increase in stress and effects of cortisol on the brain (see section) can lead to atrophy of the tactile regions of the somatosensory cortex. Further study is needed to fully understand the extent of the impact.

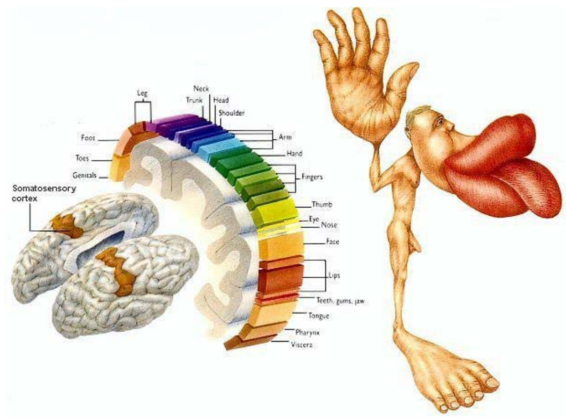

Figure 8: Somatosensory cortex and homunculus

Stress

The human need for stimulating environments is presented in the context of our species' need for novelty and sensory stimulation. More specifically, there is a need for connection to the living world inherent to planet Earth and our species evolution. The consequences of its absence are perceived as stress. The end organ effects occur mainly in the central nervous system (CNS) by activating the stress response and the hypothalamic-pituitary-adrenal (HPA) axis and chronically elevate cortisol levels. The biochemical impact of this chronic stress. This provides the fundamental rationale for the behavioral and cognitive changes that occur during prolonged exposure to isolated and confined operational environments. The data details the chronic extrinsic stress factors that result in physiologic change, and ultimately physiologic decline.

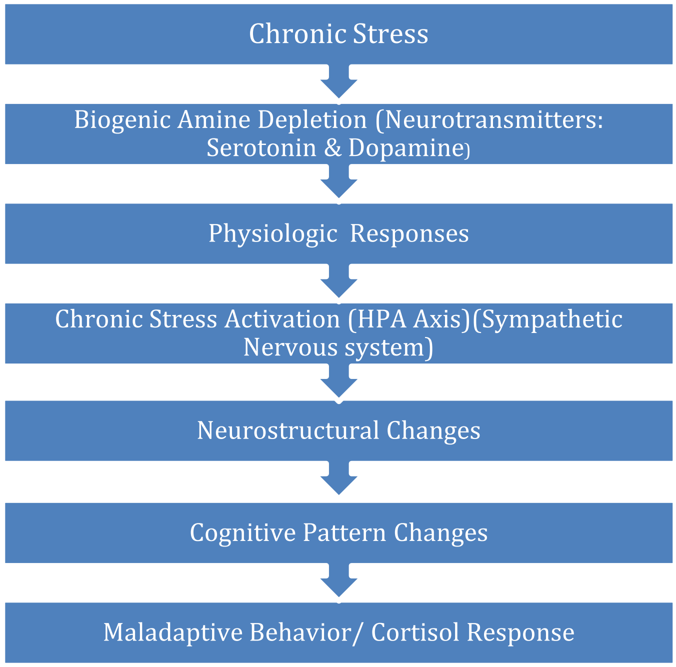

Figure 9. Process of prolonged stress resulting in maladaptive behaviors

Chronic and Acute Stressors

ICE environments are not just a static source of stress, but rather, a dynamic environment in which a large number of *acute* (short term) and *chronic* (consistent, long-term) stressors impinge upon the individual resulting in detrimental effects. Acute stressors include an injury to a crewmember or a breakdown in life-sustaining equipment. They interact with ICE environment and amplify the psychological and physiological responses to the chronic stress of the setting (Fleming, Baum, Davidson, Rectanus, & McArdle, 1987). Stimulus reduction was found to cause stress in isolated lab groups. In SD experiments, Smith, Myers and Murphy (1967) found that a stimulus enriched confinement environment produced far fewer requests for release (aborts) and stimulus-seeking behavior than did a stimulus reduced confinement environment (Myers, Smith, & Murphy, 1967).

There are differing conditions regarding the intensity and duration of the sensory deprivation. Increased risk of adverse psychiatric consequences has been associated with increased sensory stimulation, and longer duration of deprivation. This is indicated in the "Stress response curve" (see Figure 10). Stress builds as coping mechanisms deteriorate and neurobiology and neurostructural changes occur. These characteristics must be taken into account in personnel selection and countermeasures. (Otto, South Pole

Station: An Analogue for Human Performance During Long Duration Missions to Isolated and Confined Environments, 2007)

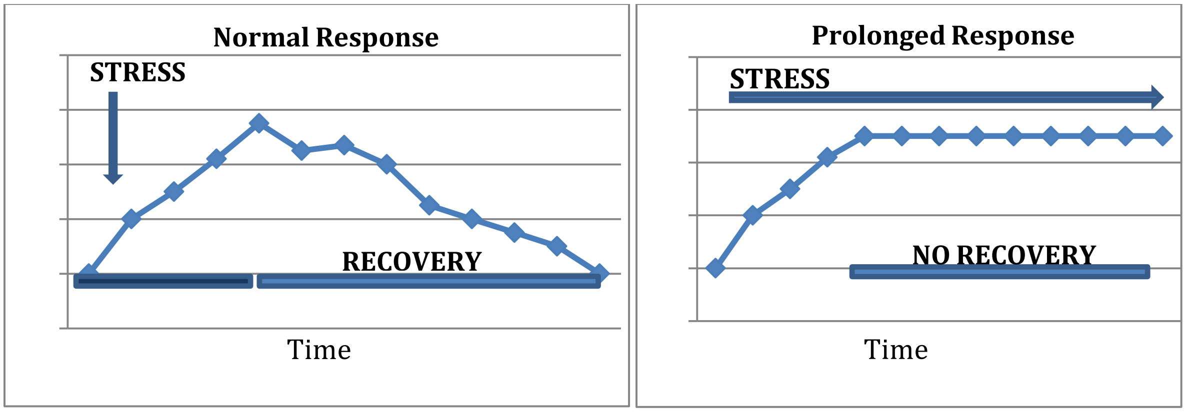

Figure 10. Normal and prolonged stress response (Adapted from Otto, 2011)

Human nature shows a preference for both novel and pleasurable experiences. Basic human biological drive maximizes the rate at which we acquire new but interpretable information (Biederman & Vessel, Perceptual Pleasure and the Brain, 2006)to maximize the rate at which we acquire knowledge. Endogenous or exogenous opiates bind to opioid receptors on a neuronal cell surface modulating the activity of the neuron thereby altering the brain's activity. The receptors are located in the cerebral cortex where visual information is processed. Conversely, the prolonged lack of sensory stimuli provides opposite effects. SD is perceived as stress to the brain (see Figure 11).

Figure 12 extrapolates the potential long-term effects of prolonged stress on a 30-month Mars mission. These stresses have manifested in significant symptoms for the five senses and other processes across multiple SD studies. It is important to note that the strongest data is available for the first 6 to 8 months due to the availability of ISS and Antarctic data, however the longer duration information has been extrapolated from predicted effects. For example, the third quarter system that has been present in many isolation studies regardless of mission duration has been included. During this time, it is predicted that stress increases due to the realization that the mission is only half way complete, and monotony and routine is the most severe.

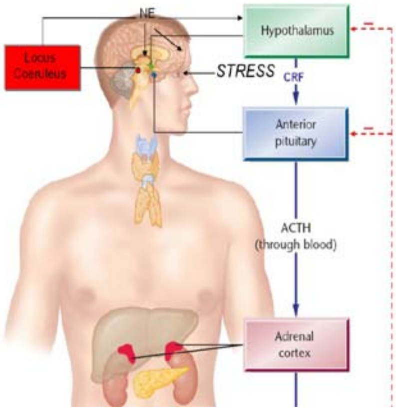

Figure 11. HPA Axis (Otto, 2007)

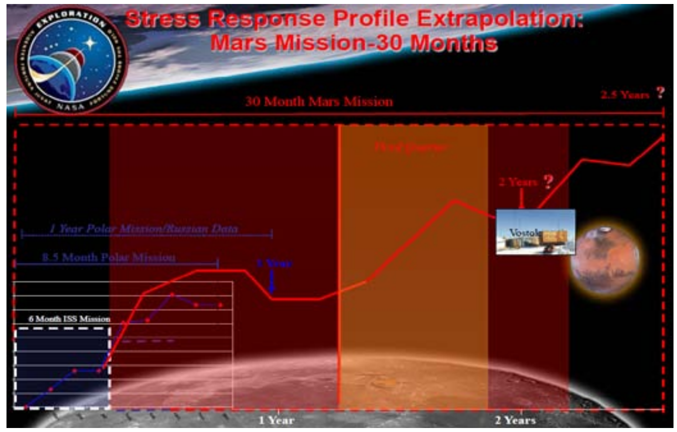

Figure 12. Stress Response profile extrapolation Mars mission 30 months (Otto, 2007)

Effects of Cortisol on Limbic Structures of the Brain

Only humans can keep HPA axis going indefinitely. The faculties of perception, thought and emotion are connected to the stress response resulting in chronic stress. The hippocampus processes declarative and episodic memories which keep track of episodes, events in daily life sequential memory, and names of people, places and things encountered in daily life.

Under chronic stress, spatial and verbal memory and cognitive processes suffer. Excessive levels of cortisol interfere with memory formation and retrieval and can lead to difficulty in word finding (aphasia). Behavioral effects include an increase in anxiety, paranoia, withdrawal and territorial behavior. On a neuronal level, the reduction in synaptic connections caused by increase in cortisol cause a reduction in dendritic branching and this forms an abnormal neuron. This reduces the number of synaptic nerve terminals.

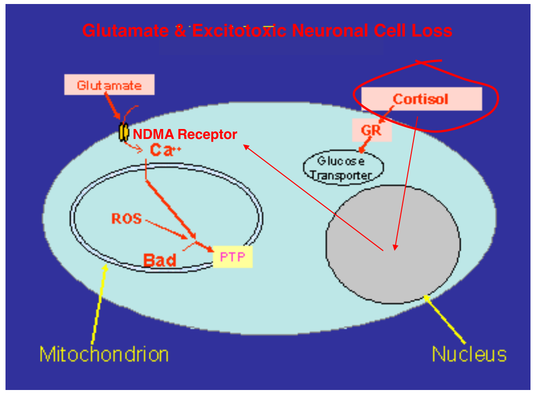

Figure 13. Neurotoxic effects of chronic cortisol elevation (Otto, 2011)

The uptake and retention of cortisol in the hippocampus due to high concentration of cortisol receptors develop a vulnerability to maintain chronically elevated levels of cortisol (see Figure 11). This causes a reduction in hippocampal volume. The reduction in volume over prolonged stress duration in turn is considered atrophy of the hippocampus and manifests in behavioral changes in the subject. The behavioral changes elicit behaviors that are very similar to post traumatic stress disorder (PTSD). Prolonged exposure to extreme threat may result in long term changes in behavior and neurobiological systems.

In studies examining Cushing's disease, which is an over-production of cortisol, hippocampal volume is smaller than normal. Studies have shown that the degree of shrinkage and extent memory loss is proportional to elevated cortisol levels. In addition, amygdalar hypertrophy has fear response increases due to chronic isolation, confinement and social stress.

Human and animal models revealing sensory stimulation enhances slow brain wave activity which influences neuronal plasticity. Neuronal replay in sleep of wake active neurons thought to induce synaptic modifications at target neurons. Significant correlations between hippocampal events during neuronal replay and slow wave sleep. Sleep deprivation inhibits Hippocampal LTP (Otto, Components of Habitability, 2011).

During Salyut 6 and 7 missions, cosmonauts were monitored for stress through television monitors, voice analysis self assessment, questionnaires, answering questions about Eating and sleeping habits, leisure time activities, vision, hearing, smell, posture, and the need for medication (Bluth & Helppie, 1986).

Individual differences in tolerance for stressors greatly complicate the task of predicting who will be able to tolerate any specific isolation and confinement situation. In order to help clarify the picture, we can begin by identifying the various sources of stress and the reactions associated with each (Rasmussen, 1973).

In self accounts of winter-overs in Antarctic stations, there is an increase in self-reports of anxiety over time. High winds were associated with higher depression rates along with significant decreases in epinephrine, and norepinephrine and systolic blood pressure (Harrison, Clearwater, & McKay, 1991).

In manitoba laboratory (Zubek et al.) three or four subjects who were exposed to a week of isolation twice, a year apart, reported that the second period was far less stressful, and were able to get back to serious work sooner than after their first experience. Furthermore, when their performance during isolation was compared with that of four matched (on pretests) non repeaters; it was found that they performed better on 9 of 12 cognitive tests. Similar results, Ruff, Levy, Thaler (1961) reported that most subjects who participated in two or three consecutive experiments indicated that each period seemed easier than the last (Ruff, Levy, & Thaler, 1961).

Neuroplasticity and Neurogenesis

Neuroplasticity is the ability of the brain and nervous system to change structurally and functionally as a result of environmental input (Shaw & McEachern, 2001). The cognitively depleting environment of LDSMs reduces brain activity and weakens neuromodulatory control. This results in negative brain plasticity processes, which “create a self-reinforcing downward spiral of degraded brain function” (Otto, South Pole Station: An Analogue for Human Performance During Long Duration Missions to Isolated and Confined Environments, 2007). The lack of environmental input perceived through our senses degrades sensory systems. At the same time, neuroplasticity provides the means through which countermeasures can act effectively to preserve and restore the brain.

However, there are limits to the ability of the brain to recover from such prolonged periods of stress as would be encountered on a Mars mission. Evidence has shown that prolonged stress exposure places the subject at a significant risk for future psychiatric deterioration, possibly including the development of irreversible psychiatric symptoms (Physicians for Human Rights, 2005). Further understanding of brain plasticity is essential in understanding the severity of the risks of long term mental

The opposite of monotonous life in a capsule environment and its effects could be assimilated to licensed London taxi drivers which show a remarkable capacity to acquire and use knowledge of a large complex city to navigate. This is associated with greater gray matter volume in the hippocampus relative to controls. In particular, greater experience shows an increase in right posterior gray matter volume and a decrease in anterior volume which suggests that spatial knowledge, and not stress, driving, or self-motion, is associated with the pattern of hippocampal gray matter volume in taxi drivers (Maguire, Wollett, & Spiers, 2006). In the sensory aspect, drivers are constantly visually stimulated. While the space remains the same, each trip is different with different cars, people, passengers, and the driver must remain engaged and alert, but not necessarily stressed. There is a social aspect regarding the interaction with passengers, conversations, variation of location, dark to light cycles, seasons and the drivers have the chance to rest from this environment.

These types of studies provide evidence that sensory stimulation increase the number of synapses and increases neural growth in the form of dendritic branching and increased nerve terminals. This is the basis behind the process of neurogenesis. In turn, understumulation causes neural atrophy. This natural process is at the crux of the detrimental effects and could provide insight into the development of countermeasures to mitigate the negative effects of cortisol.

PTSD

Across all of the analog ICE environments examined, post-isolation effects were recorded. While they each vary in intensity and duration, the symptomatology resembles post traumatic stress disorder (PTSD). For example, in solitary confinement inmates, symptoms include long-term psychological harm, anxiety, nervousness, frequent nightmares, depression, difficulty sleeping, inability to work, and difficulty trusting people, as well as difficulties adapting to the world outside of confinement. These effects demonstrate that mental scars can be more detrimental and long lasting than physical ones (Physicians for Human Rights, 2005).

Craig Haney, an expert on the psychological effects of incarceration, has stated that “the negative effects of solitary confinement are analogous to the acute reactions suffered by torture and trauma victims, including post-traumatic stress disorder or PTSD and the kind of psychiatric sequelae that plague victims of what are called ‘deprivation and constraint’ torture techniques (Physicians for Human Rights, 2005).

Biospherian Jane Poynter mentioned untriggered crying fits which took years to subside. There is mention of the anxiety of life after the isolation experience, as well as others who have adapted to their ICE environment find it difficult to re-adapt to civilization as a kind of “post-partum depression” (Poynter, 2006).

Winter-over group members also experience difficulty adjusting to home. “Marital difficulties, financial problems, sleep disturbances, or the activities of a complicated culture seemed to overwhelm them.” (Harrison, Clearwater, & McKay, 1991) “Oliver’s (1979) interviews with former winter-over residents indicate that the adjustment back to the high-stimulus environment of the United States may be more difficult than the adjustment to the Antarctic” (Harrison, Clearwater, & McKay, 1991) The prevalence of winter-over syndrome and post winter adjustment symptoms prompted the development of the Scientific Committee on Antarctic Research (SCAR) of the Working Group on Human Biology and Medicine. They focus on understanding the effects of cold, darkness, isolation and pathogens on the health and welfare of scientists and support staff in the Antarctic.

The theories of the cognitive processes surrounding trauma maintain that PTSD is brought on as a reaction to the violation of previously held assumptions concerning invulnerability and personal safety. Techniques that are highly unpredictable or involve a high degree of uncontrollability are associated with higher degrees of distress than those techniques in which the victim feels that he or she has some degree of control over the level of pain and suffering that is inflicted (Physicians for Human Rights, 2005)

One study of former prisoners of war found that even forty years after their release, some soldiers still suffered symptoms of anxiety, confusion, depression, suspiciousness and detachment from social interactions (Physicians for Human Rights, 2005). Moazzam Begg and Feroz Abbasi, who were subjected to strict isolation at Guantánamo for 18 months beginning in February 2003, suffered from post-traumatic stress and had attempted suicide (Physicians for Human Rights, 2005)

BIOMARKERS

Partly because some of the stressors are not dramatic and their impact is cumulative over time, the crew may not become aware of them until their effects are serious. For this reason, it is important to monitor the symptoms of accumulating stress and to apply appropriate countermeasures (Suedfeld & Steel, 2000). Tools to measure psychological, physiological and psychophysiological biomarkers of stress would be advantageous in maintaining high levels of performance.

Psychological tests

Much of the information that has been presented was collected through the use of psychological measures that monitor the performance and or mood of the subject. The following is a non-exhaustive list of some of the measures that have been found in the literature.

Standardized instruments:

- Stanford, Hypnotic Susceptibility Scales
- Barber suggestibility scale (BSS) of Barber and Glass

- Myers Briggs Type indicator (MBTI)
- Personal Orientation Inventory (POI)
- Minnesota Multiphasic Personality Inventory (MMPI)
- Rorschach test
- Wechsler memory battery
- Intelligence tests
- Associative learning
- Digit span tests
- Analogies test

In the Rorschach test, successful endurers of SD isolation chamber studies possessed a high Index of Control, while quitters fell in the low Index of Control group (Rasmussen, 1973).

An important obstacle must be overcome before considering the reliability of these measures. Psychological assessments generally rely on symptoms that subjects must be aware of in order to report. Subjects must be consciously in distress over a symptom to complain about it; the greater their awareness, the higher the frequency and extent of measured negative effects. Subjects may undergo forms of psychological deterioration of which they are unaware and, consequently, incapable of reporting, however, in the course of adjusting and adapting to painful and distressing conditions, inmates, may believe that what they are experiencing is normal or develop coping mechanisms to make their misery seem more manageable (Physicians for Human Rights, 2005). As long as the deterioration is not obvious or disabling, it is likely to escape the attention of mental health staff that, in most cases, rarely performs careful routine psychiatric assessments for prisoners who appear to be otherwise minimally functioning. The problem of diagnosing these measures is important in studying the onset of stressful states (Haney, 2003).

ESA is testing the automatic mental health assistant (AMHA) strategic multi-player games to alleviate stress, and as an unintrusive tool to monitor the mental capacity of astronauts as well as the development of different social interaction patterns within the crew (Voynarovskaya, Gorbunov, Barakova, & Rauterberg, 2010)

Physiological Biomarkers for Stress

Evidence for chronic stress in the Antarctic was found through increasing levels of psychological stress during 11-year South Pole winter-over clinical database. Two studies of winter-over personnel showing increased plasma cortisol after one-year deployment and after 14 month deployment (Quanfu, Guangjin, & Xiangyin, 1994). There were also increases in urinary adrenaline and noradrenaline (Harinath et al., Sawhney et al.). Elevated sympathetic outflow was measured by heart-rate-variability analysis (Harinath et al.).

Currently, biomarkers for the Mars 500 Environmental factors study are electroencephalograph (EEG) to monitor sleep/awake patterns (alpha waves), body temperature, heart/respiration rate, saliva/urine hormones to electrolytes, plasma proteins and blood cell genes (European Space Agency, 2011).

Alpha Waves/Frequencies:

Early SD Studies showed the potential of monitoring the alpha frequencies of the brain. Two subjects who complained about being "hemmed in" showed the largest posttest decreases in alpha frequency (-1.00 and -1.18). 7 day confinement with rich audiovisual stimulation and availability of social communication produced a slowing of the alpha rhythm. The magnitude of this cortical slowing appeared to be related to the size of the chamber (Rasmussen, 1973).

EEG Activity of 6 subjects enduring 4 days of PD show slow alpha waves of high voltage and marked delta wave activity. The activity revealed a progressive slowing in mean alpha frequency with increasing duration of isolation indicating a relaxed or idling brain (Rasmussen, 1973). In a longer SD study, a progressive decrease in frequencies in the alpha range was observed during 14-day exposure to unpatterned light and white noise. The EEG records were still abnormal 1 week later, and long-lasting motivational losses were observed (Zubek, Welch, & Saunders, 1963).

A group of Russian investigators Lebedinsky, Levinsky, & Nefedov, (1964), using much longer periods of social isolation showed a change in EEG activity was always greatest toward the end of an experimental period, whether it was 10, 30, 60, or 120 days. Post-experiment, indications of EEG abnormality were still evident up to 10 days after release from isolation. Lebedinsky observed indications of EEG abnormalities months after the termination of a 2-month period of social isolation certain physiological aftereffects may persist for periods equal to the initial isolation duration. Post isolation motivational losses, A correlation of +.67 was found to exist between the magnitude of the EEG decreases and the duration of the motivational losses (Rasmussen, 1973).

Zubek & Welch (1963) studied 40 subjects, 10 in each of four conditions: SD, PD, recumbent control, and ambulatory control. For a 1 week duration, EEG records were taken before and after each condition. The results indicated that all 20 subjects in the two experimental groups showed a post isolation decrease in alpha frequency. The mean decrease was significantly greater under the PD (1.21 cps) than under the SD condition (0.85 cps) (Zubek & Welch, 1963)

Another variable that can affect the magnitude of EEG changes is the severity of the deprivation condition, Zubek, (1963) compared between exercising and non exercising SD subjects, while both groups showed a decrease in mean alpha frequency, the decrease in the exercising-group was approximately one-half that observed in the non exercising group. This can explain the greater perceptual, motor and cognitive impairments under PD than under SD (Rasmussen, 1973).

Between 1973 and 1982, inmates at Kingston Maximum Security Penitentiary, Kingston, Ontario were subject to one week of solitary confinement of prison inmates produced significant changes in their EEG frequency and visual evoked potentials (VEP) that parallel those reported in laboratory studies of sensory deprivation. EEG frequency declined in

a nonlinear manner over the period with most of the decrement (77%) occurring in the first four days. VEP latency, which decreased with continued solitary confinement, was shorter for these 5s than for control 5s whose VEP latency did not change over the same period. Experimental 5s who had been in prison longer had shorter VEP latencies than relative newcomers to the prison (Gendreau, Freedman, Wilde, & Scott, 1972).

Heart Rate/BP

Heart rate changes were demonstrated by a group of Soviet investigators (Agadzhanian, Bizin, Doronin, Ilin, Kuznetsov, & Ezepchuk, 1965) in three socially isolated subjects for a period of 60 days. Both respiratory rate and blood pressure began to decrease after this period. Since these results were based on a small sample, they must be regarded as suggestive.” (Rasmussen, 1973). During a 150-day mission, bioelectrical activity of the heart was recorded while the cosmonaut rested (Bluth & Helppie, 1986)

Heart Rate Variability

HRV is a physiological phenomenon where the time interval between heart beats varies. It is measured by the variation in the beat to beat interval. Methods used to detect these include ECG and blood pressure. Few studies have been conducted relating to LDSMs. In a Russian study, mean heart rate and heart rate variability in low- and high-frequency bands did not change during spaceflight. The most pronounced changes in HRV occurred after landing (Baevsky & al., 2007). Studies show that long-term endurance training increases heart rate variability. HRV can also indicate sympathetic and parasympathetic tone of the individual.

Body Weight

Weight assessment has been proposed as a biomarker for successful adaptation to a stressful environment. Previous studies have monitored weight, though “length of confinement is not indicative of how much you will eat” (Rasmussen, 1973). However, in the spaceflight environment, weight may be difficult to monitor due to the individual variability arising from fluid shift and the loss of mass in the bones and muscles in the microgravity environment.

Pain Endurance

Dolorimeter testing for SD studies show inconclusive results (both inverse and direct relationships) that were likely to be affected from the use of different measures (Rasmussen, 1973).

Endocrine Responses

Adrenaline Level: Several dedicated biomedical studies were conducted in the 50s and 60s in which the trend showed that quitters of SD and PD experiments generally had a lower adrenaline baseline level during pre and post isolation time periods, and months later as well compared to the successful endurers.

While further study on this is needed, because this adrenaline baseline difference seems to be a stable characteristic

Uric Acid: Haythorn (1967) reported that subjects who were unable to endure a week of SD possessed a relatively high level of serum uric acid prior to the experiment. However cross-validation by preselecting volunteers on the basis of high or low adrenaline and uric acid levels for future studies are necessary (Rasmussen, 1973).

Anti Diuretic Hormone of the Pituitary Gland: An analysis of the 24-hour urine volume of the successful solitary confinement endurers revealed a progressive decrease in excretion during the week of isolation, a decrease significantly greater than that shown by the recumbent controls. No significant difference in total fluid intake of the two groups occurred during the 1-week period. A similar progressive decline in urine volume, independent of fluid intake, has also been reported by Winters (1963) in monkeys placed in SD for 2 weeks. Since water consumption was not reduced in either experiment, this decreased urinary volume may be a primary response possibly “triggered” by a greater production of the anti diuretic hormone (vasopressin) of the pituitary gland. It regulates the water, glucose, and salt in the blood. This suggestion is further supported in a study from Zuckerman’s laboratory in which an increased production of the pituitary thyroid-stimulating hormone occurred after 8 hours of SD (Zuckerman et al., 1996). It is derived from a hormone precursor in the hypothalamus which is linked to the nervous system and can be affected by stress.

Ketosteroids: Ketosteroids are formed when the body breaks down male steroid sex hormones (andogens) and other hormones released by the adrenal gland. The adrenal glands are a component of the HPA axis, and SD environments have shown to affect Ketosteroid levels. In a Soviet study, Gorbov, Miasnikov, and Yazdovsky (1963) reported an increase in 17-ketosteroids in subjects individually confined for 15 days in an altitude chamber under a condition of no-communication. However, in experiments where some degree of two-way communication between the subject and experimenter was permitted, no changes in 17-ketosteroid output were observed (Rasmussen, 1973).

Thyroid Stimulating Hormone (TSH): TSH is a hormone synthesized and secreted by the cells in the anterior pituitary gland which is a major organ of the endocrine system relating to stress. SD studies showed an increase in the Thyroid stimulating hormone (TSH) (Rasmussen, 1973)

Biomarker Measurements

Psychophysiological Biomarkers

As new technology is developed that allow us to more precisely measure the processes of the human body, they can prove invaluable in measuring the deterioration of our senses, as well as to validate potential countermeasures for such effects.

While PET and MEG are methods of measuring brain activity, they will not be described newer technology has been introduced that improve on spatial resolution, expense, and resources. The following are descriptions of the identified psychophysiological instruments that can be used to measure the long-term deterioration of the brain caused of SD stress.

Electroencephalogram (EEG)

An EEG measures and records the electrical activity of the brain. Certain conditions, such as seizures can be seen by the changes in the normal pattern of the brain's electrical activity. It is used to study and detect sleep disorders, physical problems (problems in the brain, spinal cord, or nervous system) or a mental health issues. EEGs record 4 types of brain waves:

- Alpha waves have a frequency of 8 to 12 cycles per second and are present only in the waking state when your eyes are closed but you are mentally alert.
- Beta waves (13 to 30 cycles per second) are present during states of alertness or under high doses of certain medicines.
- Delta waves (3 cycles per second) and theta waves (4 to 7 cycles per second) are registered during sleep.

Normal EEGs show both sides of the brain with similar activity and steady brain waves. Abnormal results show Delta and Theta waves, variability in the amplitude of waves, spurts and slowing down of wave pattern (Fischbach & Dunning III, 2009).

MRI and fMRI Imaging

MRI and fMRI imaging provides a non invasive, which show high resolution anatomic structural changes as well as changes in blood flow and blood oxygenation in the brain as well as specific changes in neuronal activity, without the need for ionizing radiation making it more suitable to test subjects multiple times. Short duration structural MRI images have been collected for Space Shuttle crews, and there is potential for using functional MRI images, which can detect the mechanisms of cognition in the brain. Although there is a lack of mobility allowed, this is a drawback with other imaging systems, and new developments are being made to overcome this obstacle (National Aeronautics and Space Administration, 2001).

Optical Imaging

Optical imaging of cerebral oximetry (oxygen saturation of hemoglobin in the brain) though less sensitive than PET, it can be used to assess the state of the user (National Aeronautics and Space Administration, 2001).

Near Infrared Neuroimaging (NIN)

NIN is a relatively new neuroimaging modality that enables continuous, noninvasive, and portable monitoring of changes in blood oxygenation and blood volume related to human brain function. The main benefit of this technology is the portability in a wearable minimally intrusive device; this could be the main technology that would be beneficial to use to monitor changes in the brain (Izzetoglu, 2005). This may be one of the most promising technologies for in-flight neurological testing.

Conclusion: To understand the full breadth of changes in the human body as a result of prolonged SD stress across all SD analogs as well as for redundancy and to account for variability, a combination of psychological measures, physiological and psychophysiological biomarker measurements is necessary to offer a complete evaluation of an ideal candidate for an LDSM.

Social Monotony

> "Social deprivation should not be considered any more normal than, water or food deprivation" (deWaal, 1991).

Social monotony and sensory deprivation are separate conditions that are closely interrelated which contribute to the overall effects and experiences of crewmembers in LDSM environments. Evidence shows that sensory deprivation exacerbates the social problems that emerge in LDSMs. However, social monotony deserves a dedicated in-depth discussion that is beyond the scope of this report. But a brief discussion outlining the social considerations is attempted. Disruptive effects on the group have been noted in Antarctica (Smith 1969), in submarines (Sandal, Vaernes, & Ursin, 1995), and in the Soviet space program (Bluth & Helppie, 1986), (Suedfeld & Steel, 2000). Table 2 briefly lists the commonly identified social stressors.

Table 2. Social stressors for conflict

Stressor for conflict	Source
Enforced togetherness/crew composition	(Kubis, 1972)
Social monotony	(Kubis, 1972)
Inadequate leadership	(Smith, 1969)
Others' behavior	(Smith, 1969)
Crew structure	
Group split	(Mullin & Connery, Psychological Study at an Antarctice IGY Station, 1959)
Lack of private quarters	(World Health Organization, 1963)
Mission control issues	
Skill mix	(National Aeronautics and Space Administration, 2009)
Mission goals	(National Aeronautics and Space Administration, 2009)
Autonomy-personal control	(Smith & Jones 1962, Stuster 1996)
Goal-oriented action – as motivation	(Bluth & Helppie, 1986)
Territoriality	(Rasmussen, 1973)

The experience of the Biosphere 2 participants is an example of the detrimental effects of social isolation on a crew exposed to a highly sensory enriched environment, and the detrimental effects that the social isolation had on the experience, and final outcomes of the mission. There were no distractions. "I dealt face to face with only seven other people…I had to find my entertainment, my satisfaction from within the confines of the 3.15 acres of Biosphere 2 and from within the thirteen hundred cubic centimeters of my brain" (Poynter, 2006). "In spite of the controversies and turmoil, my brain was not bombarded with the millions of stimuli we all experience in modern life." (Poynter, 2006). Poynter described the world outside Biosphere 2 as a "sensory orgy" (Poynter, 2006).

Sex Deprivation

> "It is axiomatic that no area of human functioning is more subject to distorted reporting, exaggeration, suppression, and repression than the area of sex." (Mullin & Connery, Psychological Study at an Antarctice IGY Station, 1959)

The lack of privacy, social stresses and mission responsibilities, along with the potential for bad publicity and implications of sex as a taboo topic prohibit long term sex deprivation from being properly investigated. For these reasons, only anecdotal evidence is available regarding sex deprivation in analog studies. Accounts vary widely. Biosphere 2 did not report any incidents related to sex. "The two couples who entered remained coupled, and the other four people remained celibate for the entire two years" (Poynter, 2006). In Antarctica however, early accounts of all-male crews mention that pin-up pictures were described to have existed in larger amounts compared to stateside stations. Sex dreams, nocturnal emissions, and masturbation generally increased in particular during periods of inactivity and personal emotional stress and toward the end of the tour (Mullin & Connery, Psychological Study at an Antarctice IGY Station, 1959). However, physiological and social benefits have been identified such as an improved immune system, better prostate health in men, stress relief, among others which would benefit the LDSM environment.

Physiological Mechanisms behind Social Monotony

As primates, humans share nature's adaptive mechanism of the social brain to meet the challenge of survival as part of a group. Our yearning for connection is a primal human need (Goleman, 2006). This connection will be severely blunted on long duration space missions due to a fixed number of crew members.

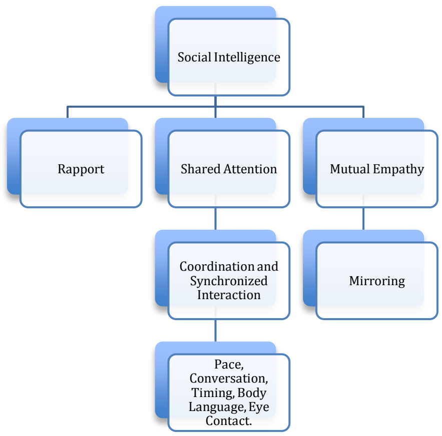

Figure 14. Social Intelligence

Mirror neurons pick up what we observe in others, allowing us to sense and feel what they are feeling (Goleman, 2006). The human mirror system includes Broca's Area, a fundamental language center. As we have seen, the detrimental effects of long-term sensory deprivation have the ability to change the brain structurally. There has been evidence which show how speech and language are negatively affected in long term isolation. Therefore, Broca's area is at risk for change, thus affecting the human mirror system which is related to social intelligence (see Figure 14). This could be the basis for social strife in a team setting.

In addition, there is the chemical basis for social interaction in which the hormone oxytocin is a natural anxiolytic acting on GABA receptors much like valium, which is released following connection with loved ones as in an embrace, or a meaningful conversation. This will be lacking in the LDSM environment.

Selection

Sensory Deprivation raises questions about astronaut selection. Volunteers for isolated environments tend to attract adventurous people, however they soon discover that they have committed themselves to monotonous routine, boring tasks in a confining environment, with the same unvarying group, and they cannot get out (Suedfeld & Steel, 2000). Astronaut selection will need to take the effects of sensory deprivation into account when selecting crews for LDSMs. In particular, the resilience and tolerance of the ICE environment as well as an endurance mitigation of stress will be as crucial as the ability to perform mission tasks (Bluth & Helppie, 1986)

The voluntary nature of participation in most such programs provides reasonably good assurance of motivated individuals who are not likely to be easily alarmed or frightened by the inherent dangers. And research suggests that prior experience in ICE environments results in less stress, and an increased tolerance to the negative ICE effects. "Those who have done the best under the endless deluge of stressors are those who can bend with, and rebound from, lapses into despair and anger, month after month. Instead of resistant, the new astronaut needed to be resilient."

Analysis/Conclusion

> "When Byrd went to the Antarctic in the twenties he is said to have taken along, in addition to two coffins, an even a dozen strait jackets. While this precaution turned out to be unnecessary, it demonstrates the respect experienced explorers have for the psychological vicissitudes of isolated polar living" (Rasmussen, 1973).

It has been determined that there is a general lack of information and reliable evidence making it difficult to extrapolate conclusions on the effects of SD for LDSMs. Gaps in the research must be filled before the effects of SD can be considered a mitigated risk. The following are recommendations to further the field of SD research:

1. Dedicated studies on SD are necessary to isolate its effects from those of social isolation. Long-duration studies (1-2 years), with astronaut-like participants in high-fidelity ground-based ICE environments (analogs)

Until recently, SD considerations for LDSMs have been passively mentioned as a stressor, and the collaborative nature of behavioral studies typically combines SD studies with social monotony studies. This literature review has examined sensory effects that have already been studied and bridges the relationship between sensory inputs and the stress response that is elicited. SD should be considered a stressor in its own right requiring dedicated studies to study the impact of SD to the development of behavioral and physiological symptoms.

To accomplish this goal, analog studies of longer duration (1-2 years) are necessary to constitute a reliable analog for LDSMs. While there is a strong data set for the Antarctic group, a spread of the same length of time to other analogs would be helpful in identifying the similar effects of ICE environments in general. Consequently, a database of similar symptoms can be assessed, and greater conclusions about these could be mitigated.

2. In-depth assessments of the adequacy of different analogs for SD studies as they pertain to long-duration space flight (e.g., BHP Analog Assessment Tool)

As SD discriminates itself as an independent field of research, there is a need to evaluate the validity of the analogs directly related to SD. This review established a qualitative argument for the relevance of a number of analog environments for SD, but a quantitative analysis is necessary. The BHP Analog Assessment Tool developed by the Behavioral Health Program (BHP) at NASA has been identified as an ideal instrument for this task. This tool is directly intended to quantitatively evaluate the validity of different analog environments to study specific behavioral effects of LDSMs (National Aeronautics and Space Administration, 2011). Future studies in SD should utilize this tool to extrapolate the relevance of current analogs, and can be used as a measure to validate future proposals for new analog environments.

3. Analog studies on the ISS or lunar missions of up to one year

Valeri Poliakov's mission on Mir for the length of a theoretical trip to Mars gives us hope that humans can survive the trip, but much more research is necessary. A "thorough ground-based research program coupled with flight research on the ISS and the lunar surface must be conducted to provide an understanding of the physiological basis for human responses, develop appropriate treatments and countermeasures, and decide how best to support crew members" (National Aeronautics and Space Administration, 2009). This research can establish the baseline for the 6-month transit from Earth to Mars and help develop extrapolations and inferences necessary to plan for the 18-month Mars surface habitation and the 6-month return transit to Earth. Research on the moon is essential to help provide a stepping stone approach to a reliable Mars mission (National Aeronautics and Space Administration, 2009). Human adaptation to long-term exposure to partial-gravity conditions is a critical component of future long-duration surface operations on Mars and may need to consider SD effects.

4. Development of international standards of psychological assessments for LDSMs

More universal international psychological assessment standards need to be developed to monitor and diagnose prolonged SD effects. This faces several challenges, as a mission to Mars will be such a formidable undertaking, it will most likely be composed of an international crew. This implies greater variability in measures, language barriers, as well as fundamental physiological variability across groups. This will have major implications for astronaut selection.

5. Develop effective, scalable countermeasures for sensory and social deprivation effects

Significant studies have been conducted which propose countermeasures to the detrimental effects of sensory deprivation. These countermeasures need to be quantitatively validated as measures to effectively combat the negative effects of LDSMs.

The types of countermeasures provided heavily depend on the duration and complexity or missions. The composition of the crew member’s schedule has a major impact on their sensory environment. We currently are not certain about the work that crew members will be expected to complete on their mission, “higher-order details of the scenarios have not been fully developed” (National Aeronautics and Space Administration, 2009). As of now, no mission architecture is available for a Near Earth Asteroid Mission, and only a high-level description of the crew tasks for the Mars mission has been identified by the Mars Architecture Working Group (MAWG) in the Mars Design Reference Architecture (DRA) 5.0. The goals would include Mars Planetary Science, Preparation for Sustained Human Presence and Ancilliary Science (National Aeronautics and Space Administration, 2009).

6. Studies on individual variations in response to LDSMs and analog environments

Variability among individuals may offer insight on the individual mechanisms of resilience in ICE environments. This research is necessary to understand and validate results from analog studies.

Differences in the ability of man to withstand the conditions vary widely. Some people have noticed effects of SD within one-and a half hours, whereas others have endured up to 36 hours. Also, under prison isolation, some prisoners endure months of isolation where others have succumbed within days. Lack of sleep affects the performance of some people more than others.

It is speculated that genetic characteristics may be responsible for this variability in resilience to ICE environments. Another argument describes the importance of a personality of the man, and his view towards the experience, affect his ability to withstand it. Confident people fare better than helpless People with vivid imagination and intellectual activity do better than people who depend on interaction with people (Bidderman & Zimmer, 1961).

7. Develop tools to measure biomarkers for stress of the five senses, cognition, kinesthetics and SD

Neurological deterioration caused by SD, stress has on this as well. Absolutely must reduce stress in any way shape or form.

We do not know the exact **limits of neuroplasticity**. Neuroplasticity is a growing field, which is at the crux of sensory deprivation and the way in which it manifests during long-term isolation. The limits of neuroplasticity have yet to be tested on a wide scale. Is there a limit at which the neurological changes are irreversible? Future studies on subjects enduring long durations in ICE environments are necessary to determine the ideal neurological characteristics of future crewmembers.

8. Utilize stress biomarkers to monitor the effectiveness of countermeasures and to up or down regulate as required

9. Formulation of a pre-flight, in-flight, and post-flight regimen to mitigate SD effects

It is important to note that long-term SD results in long term post flight effects. Therefore, all opportunities for pre-flight, in-flight, and post-flight prevention must be considered in future long term studies.

Bibliography

Abbott, A. (2002). Neurobiology: Music, maestro, please! *Nature , 416*, 12-14.

Agadzhanian, N., Bizin, I., Doronin, G., Ilin, E., Kuznetsov, A., & Ezepchuk, N. (1965). Effect of prolonged Isolation in a small closed cabin on the human organism. . *Problemi Kosmicheskoi Biologii* , 31-43.

American Academy of Neurology. (2011). *Neurology*. Retrieved July 25, 2011, from Magnetoencephalography: http://www.neurology.org/cgi/content-nw/full/67/3/522/F241

Baevsky, R., & al., e. (2007). Autonomic cardiovasular and respiratory control during prolonged spaceflights abord the International Space Station . *Journal of Applied Physiology* , 156-161.

Beard, M. (2000, December 9). *The Independent*. Retrieved July 8, 2011, from 'Planet in a bottle' ended in acrimony, controversy and high drama: http://www.independent.co.uk/environment/planet-in-a-bottle-ended-in-acrimony-controversy-and-high-drama-626441.html

Bidderman, A., & Zimmer, H. (1961). *The Manipulation of Human Behavior.* New York: Wiley & Sons, Inc.

Biederman, I., & Vessel, E. A. (2006). Perceptual Pleasure and the brain. *American Scientist* , 249-255.

Biederman, I., & Vessel, E. (2006). Perceptual Pleasure and the Brain. *American Scientist , 94*, 249-255.

Bluth, B. J., & Helppie, M. (1986). *Soviet Space Stations as Analogs* (Vol. I & II). Washington D.C.

Centro interdipartimentale Mente/Cervello dell'Università di Trento a Rovereto. (2011, July 22). *Center for Mind/Brain Sciences CIMeC*. Retrieved July 25, 2011, from Magnetoencephalography Lab: http://www.unitn.it/en/cimec/10906/magnetoencephalography-lab

Clement, G., Reshcke, M., & Wood, S. (2005). Neurovestibular and Sensorimotor Studies in Space and Earth Benefits. *Current Pharmaceutical Biotechnology* , 267-283.

Courtnay-Smith, N. (2008, January 22). *Loosing Your Mind: What happens during 48 hours in a pitchblack bunker*. Retrieved July 10, 2011, from Mail Online: http://www.dailymail.co.uk/sciencetech/article-509648/Losing-mind-What-happens-48-hours-pitch-black-bunker.html

Doane, B. K., Mahatoo, W., Heron, W., & Scott, T. (1959). Changes in perceptual function after isolation. *Canadian Journal of Psychology/Revue canadienne de psychologie , 13* (3), 210-219.

European Space Agency. (2011, May 21). *ESA's Participation in Mars 500: Scientific Protocols*. Retrieved July 30, 2011, from European Space Agency: http://www.esa.eu/SPECIALS/Mars500/SEM12PBDNRF_0.html

Fischbach, F., & Dunning III, M. B. (2009). *Manual of Laboratory and Diagnostic Tests.* Philadelphia: Lippincott Williams and Wilkins.

Fleming, I., Baum, A., Davidson, L., Rectanus, E., & McArdle, S. (1987). Chronic Stress as a factor in physiologic reactivity to challenge. *Health Psychology* , 221-237.

Gendreau, P., Freedman, N. L., Wilde, G. S., & Scott, G. D. (1972). Changes in EEG alpha frequency and evoked response latency during solitary confinement. *Journal of Abnormal Psychology* , 54-59.

Goldstein, A. (1980). Thrills in response to music and other stimuli. *Physiological Psychology , 8* (1), 126-129.

Goleman, D. (2006). *Emotional Intelligence: Why it can matter more than IQ.* New York: Bantam.

Gor'koy, V., & Kon'kov, N. (1983). *Memoirs on 211-Day Spaceflight.* USSR.

Grassian, S. (1993, September). *Psychiatric Effects of Solitary Confinement*. Retrieved July 20, 2011, from Declaration Submitted in the case of Madrid v. Gomez, 889F.Supp.1146.: http://www.prisoncommission.org/statements/grassian_stuart_long.pdf

Hall, H., & Poirier, J. (2001). *Detecting Malingering and Deception: Forensic Distorion Analysis.* Boca Raton: CRC Press LLC.

Haney, C. (2003). Mental Health Issues in Long Term Solitary and "Supermax" Confinement. *Crime & Delinquency , 49*, 124-156.

Harrison, A. A., Clearwater, Y. A., & McKay, C. P. (1991). *From Antarctica to Outer Space.* New York: Springer-Verlag.

Heron, W. (1961). Cognitive and Physiological Effects of Perceptual Isolation. In P. Solomon, P. Kubzansky, P. H. Leiderman, J. H. Mendelson, R. Trumbull, & D. Wexler, *Sensory Deprivation* (pp. 6-40). Cambridge: Harvard University Press.

Heron, W., Doane, B., & Scott, T. H. (1956). Visual disturbances after prolonged perceptual isolation. *Canadian Journal of Psychology/Revue canadienne de psychologie , 10* (1), 13-18.

Hildegard, E. (1991). Dissociation: Clinical and theoretical perspectives. In S. J. Lynn, & J. W. Rhue (Eds.), *Theories of Hypnosis.* New York: Guilford Press.

Izzetoglu, M. (2005). FUnctional Near-Infrared NeuroImaging. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* , 153-159.

Lebedinsky, A., Levinskiy, S., & Nefedov, Y. G. (1964). *General principles concerning the reaction of the organism to the complex environmental factors existing in spacecraft cabins.* Washington, D.C.: National Aeronautics and Space Administration.

Maguire, E. A., Wollett, K., & Spiers, H. J. (2006). London taxi drivers and bus drivers: a structural MRI and neuropsychological analysis. *Hippocampus* , 1091-1101.

Manzey, D., Lorenz, B., & Poljakov, V. (1998). Mental performance in extreme environments: results from a performance monitoring study during a 438-day spaceflight. *Ergonomics* , 537-559.

Maugh, T. (1987, September 28). *Los Angeles Times*. Retrieved July 7, 2011, from Science/Medicine: Cooped Up: Scientists are growing concerned that the confinement, monotony and prolonged close contact in space can diminish productivity and even lead to psychotic behavior endangering others : http://articles.latimes.com/1987-09-28/local/me-6881_1_space-station

Mullin, C. (1960, October). Some psychological aspects of isolated antarctic living. *American Journal of Psychology* , 323-325.

Mullin, C., & Connery, H. M. (1959). Psychological Study at an Antarctic IGY Station. *U.S. Armed Forces Medical Journal* , 290-296.

Mullin, C., & Connery, H. (1959). Psychological Study at an Antarctice IGY Station. *US Armed forces Medical Journal* , 290-296.

Myers, T., Smith, S., & Murphy, D. B. (1967). Personological correlates of volunteering for and endurance of prolonged sensory deprivation. *Unpublished Manuscript* .

National Aeronautics and Space Administration. (2011). *BHP Analog Assessment Tool.* Houston: National Aronautics and Space Administration.

National Aeronautics and Space Administration. (2011). *Different Perspectives on Asthenia in Astronauts and Cosmonauts: International Research Literature Review.* Houston: National Aeronautics and Space Administration.

National Aeronautics and Space Administration. (2009). *Human Exploration of Mars Design Reference Architechture 5.0.* Washington D.C.: National Aeronautics and Space Administration.

National Aeronautics and Space Administration. (2010, January 10). *NASA Human Research Roadmap*. Retrieved June 22, 2011, from Human Research Roadmap: http://humanresearchroadmap.nasa.gov/gaps/?i=393

National Aeronautics and Space Administration. (2009, April 2). NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT. Cambridge, Massachusetts, United States.

National Aeronautics and Space Administration. (2001). *The Efficacy of Psychophysiological Measures of Implementing Adaptive Technology.* Hampton: National Aeronautics and Space Administration.

Netherlands Institute of Human Rights. (2004, August 7). *Netherlands Institute of Human Rights*. Retrieved July 30, 2011, from Ilascu and others v. Moldova and Russia:

http://sim.law.uu.nl/sim/caselaw/Hof.nsf/d0cd2c2c444d8d94c12567c2002de990/83f9f9b2dfed15a3c1256ec9004d882d?OpenDocument

Otto, C. (2011, March 10). Components of Habitability. Houston, Texas, USA.

Otto, C. (2007). *South Pole Station: An Analogue for Human Performance During Long Duration Missions to Isolated and Confined Environments.* Houston: NASA.

Palinkas, L. A. (1990). Psychosocial effects of adjustment in Antarctica: lessons for long-duration spaceflight. *Journal of Spacecraft Rockets* , 471-477.

Physicians for Human Rights. (2005). *Break them Down: Systematic Use of Psychological Torture by US Forces.* Cambridge: Physicians for Human Rights.

Poynter, J. (2006). *The Human Experiment: Two years and twenty minutes inside Biosphere 2.* New York: Thunder's Mouth Press.

Quanfu, X., Guangjin, Z., & Xiangyin, C. (1994). A survey on changes of multiple humoral factors in Antarctic expedition members. *Antarctic Research* , 21-26.

Rasmussen, J. (1973). *Man in Isolation & Confinement.* Chicago: Transaction Publishers.

Ruff, G., Levy, E., & Thaler, V. (1961). Factors influencing the reaction to reduced sensory input. In P. Solomon, *Sensory Deprivation: A symposium held at Harvard Medical School.* Cambridge: Harvard University Press.

Sandal, G., Vaernes, R., & Ursin, H. (1995). Interpersonal relations during simulated space missions. *Aviation, Space and Environmental Medicine* , 617-624.

Schwetje, F. K. (n.d.). Justice in the Antarctic, space and the military.

Sells, S. (1973). The Taxonomy of Man in an Enclosed Space. In J. Rasmussen, *Man in Isolation and Confinement* (pp. 280-303). Chicago: Transaction Publishers.

Shaw, C. A., & McEachern, J. C. (2001). *Toward a theory of Neuroplasticity.* Psychology Press.

Siple, P. (1959). *90 Degrees South - The Story of the American South Pole Conquest.* New York: G.P. Putnam's Sons.

Stawicki, S. (2008). Short timer's syndrome among medical trainees: Beyond burnout. *OPUS 12 Scientist* , 30-32.

Suedfeld, P., & Steel, G. D. (2000). The Environment Psychology of Capsule Habitats. *Annual Review of Psychology* , 227-253.

Suedfeld, P., & Steel, G. D. (2000). The Environmental Psychology of Capsule Habitats. *Annual Review of Psychology* , 227-253.

The New York Times. (1994, April 4). *The New York Times*. Retrieved July 6, 2011, from Two Former Biosphere Workers are Accused of Sabotaging Dome: http://www.nytimes.com/1994/04/05/us/two-former-biosphere-workers-are-accused-of-sabotaging-dome.html

Thomas, T. L., Garland, F. C., Mole, D., Cohen, B. A., Gudewicz, T. M., Spiro, R. T., et al. (2003). Health of U.S. Navy submarine crew during periods of isolation. *Aviation Space Environmental Medicine , 74* (3), 260-265.

Voynarovskaya, N., Gorbunov, R., Barakova, E., & Rauterberg, M. (2010). Automatic Mental Health Assistant: Monitoring and Measuring Nonverbal Behavior of the Crew During Long-Term Missions. *Proceedings of Measuring Behavior 2010* (pp. 77-81). Eindhoven: Noldus Information Technology.

Weinstein, S., Richlin, M., Weisinger, M., & Fischer, L. (1967). *The Effects of Sensory Deprivation on Sensory, Perceptual, Motor, Cognitive, and Physiological Functions.* Washington D.C.: National Aeronautics and Space Administration.

Weybrew, B., & Noddin, E. (1979). Psychiatric Aspects of Adaptation to Long Submarine Missions. *AD A077080*. Groton: Naval Submarine Medical Research Laboratory.

World Health Organization. (1963). *Medicine and Public Health in the Arctic and Antarctic: Selected papers from a conference.* Geneva: World Health Organization.

World Health Organization. (1963). *Medicine and Public Health in the Arctic and the Antarctic: Selected Papers from a Conference.* Geneva: World Health Organization.

Zubek, J. P., Welch, G., & Saunders, M. G. (1963). Electroencephalographic Changes during and after 14 Days of Perceptual Deprivation. *Science* , 490-492.

Zubek, J., & Welch, G. (1963). Electroencephalographic changes after prolonged sensory and perceptual deprivation. *Science* , 1209-1210.

Zuckerman, M. (1971). Dimensions of sensation seeking. *Journal of Consulting and Clinical Psychology , 36* (1), 45-52.

Zuckerman, M., & Cohen, N. (1964). Sources of Reports of Visual and Auditory Sensations in Perceptual Isolation Experiments. *Psychological Bulletin* , 1-20.