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Plantar Biophotonic Stimulation improves Ocular-motor and Postural Control in Motor Vehicle Accident Patients.

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Introduction: Worldwide road accident related statistics reflect a consistent increase of motor vehicle accidents (MVA). Survivors of motor vehicle accidents experience a range of head injuries from whiplash, concussion, and mild to severe traumatic brain injuries, of which the most severe may result in incapacitation or death. Central sensory-motor controls (SMC), including ocular-visual, ocular-motor, vestibular, and cerebellar systems are primarily affected. **Methods:** Visual-ocular convergence (VOC) and postural balance (PB) tests are used among others to measure the degree of central sensory-motor controls dysfunction. This retrospective study (n=19) investigates the effect of passive biophotonic stimulation applied to plantar postural sensory afferents on VOC and PB tests conducted during a neurophysiological evaluation. Stabilogram diffusion analysis (SDA) of the centre of pressure trajectory from the PB test was used to determine the amount of stochastic activity and dynamic behavior of postural control (Collins and De Luca, Exp Brain Res 95:308-318, 1993). **Results:** Visual-ocular convergence was significantly closer ($p<0.001$) with stimulation (5.3±1.0 cm) than without (11±1.0 cm). Stabilogram diffusion analysis of the centre of pressure trajectory from the PB test showed trends to a reduction in the short term diffusion coefficient (0.2±0.03 to 0.15±0.03; $p=0.084$) and an increase in the long term diffusion coefficient (0.003±0.001 to 0.006±0.001; $p=0.079$) with stimulation. **Conclusions:** There was an increase in ocular-visual performance and quicker corrective postural response and reliance on a long term postural strategy with biophotonic stimulation. These data suggest that biophotonic stimulation may be a promising technology for treatment of post MVA trauma brain dysfunction.

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Space Flight Biomedical Deterioration Prevention & Correction Using Biophotonic Technology:
From Postural Deficiency Syndrome to Space Adaptation Syndrome

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ABSTRACT

This paper correlates ten years of selected clinical data, taken from patients suffering from PDS related acute and chronic post-traumatic medical conditions, to that of impacts on human neurophysiology found under typical Space mission constraints. Specifically, this paper focuses on the strong correlation between unmitigated symptoms associated with Space Adaptation Syndrome (SAS) and symptoms associated with Postural Deficiency Syndrome (PDS) that have been mitigated with biophotonic technology. This data provides strong evidence that biophotonic technology poses as a significant candidate for biomedical treatment and monitoring of astronauts in Space.

1.0 INTRODUCTION

With today's Space initiative focusing more towards human exploration, the search for viable biomedical performance restoration and monitoring devices has never been more important. These devices must be relatively small, lightweight, reliable and convenient for medical maintenance and sustenance in order to meet the rigid constraints of Space flight. A small biophotonic device, integrating and utilizing the principles of photonics and human dermal optical sensitivity (DOS), has, since 1988 in France and 1995 in Canada, clinically been shown to increase or recover performance, and provide biomedical benefits in medical traumatology by stimulating one's sensory-motor controls on Earth under the influence of Earth's gravity. It is recognized in fundamental Neurosciences and Space Operational Medicine that these sensory-motor controls underlie human factors that include, but are not limited to: postural balance, eye-hand coordination, fine tuned dexterity, body positioning in space, space projection and trajectory control, perception of environment/obstacles, orientation in space and time, sensory motor and cognitive aspects of decision making, sensory-motor/cognitive error proneness. All of these factors have high pertinence to astronauts' mission capabilities, and as will be shown, the sensory-motor controls are a key consideration for symptoms relating to Space Adaptation Syndrome and Post-flight Adaptation Syndrome. As a monitoring tool, biophotonic technology has been used terrestrially during clinical neurophysiological assessments over the last ten years in Canada to measure the level of dysfunction or damage occurring in an individual, and the probability of correcting that individual (1). Using this assessment along with biophotonic devices, the magnitude and susceptibility of symptoms relating to sensory-motor control dysfunctions can be objectively and accurately predicted.

The purpose of this paper is strictly to demonstrate a strong correlation between the symptoms of patients suffering from various conditions on Earth, including postural deficiency syndrome, that have been successfully treated at the NeuroKinetics™ Clinic in Vancouver, Canada, to that of the symptoms most often suffered by astronauts during adaptation periods for orbital flight and post orbital flight. It is not within the scope of this paper to explain to the reader specifically how the referenced biophotonic device and assessment procedures work, that information has been made available in previous papers (1, 2).

2.0 SPACE RELATED ADVERSE BIOMEDICAL PARADIGMS

In 1961, Soviet scientists were genuinely worried that any prolonged period of weightlessness might be fatal, therefore limiting Yuri Gagarin's first space flight to a 108 minute single orbit (3). Of the many health risks and problems facing astronauts during short and long duration missions, one of the biggest causes for concern is dealing with the harmful effects of weightlessness on the human body. Harmful effects include loss of bone density, muscle mass and red blood cells, lower to upper body fluid shifts, cardiovascular and sensory-motor deconditioning and changes within the immune system (4). During long duration inter-planetary missions to the Moon, Mars, and beyond, one of the most important effects to consider is sensory-motor control deconditioning. That includes deconditioning of posture and gait control.

The human sense of balance depends on an extremely sophisticated sensory system relying on Earth's gravity as a reference frame in order to provide a necessary data stream to the brain. Part of the key motion sensors is the subtle organs of the vestibular system inside the inner ear that function as super-sensitive accelerometers that feed the brain with a steady stream of signals that indicate motion and direction. There are also motion and pressure receptors (know as proprioception) in the skin, muscles and joints to assist in spatial awareness; the senses of sight and hearing complete this data stream. Without having to be consciously aware of it, humans typically know everything they need to about their body's posture and gait and therefore their state of balance at any given time.

Adaptation to microgravity requires the re-organization of central nervous system (CNS) processing of the three major sources of spatial information on Earth – visual, vestibular and somatosensory (proprioceptive) (5). Current experimental results support a hypothesis that the absence of gravity leads to adaptive changes in the neural strategies that are used for resolving ambiguous linear accelerations detected by the otolith system (6). In the absence of a gravitational vertical, normally ambiguous visual references here on Earth become vital for astronaut orientation during orbital flight. When gravitational down cues are absent in weightlessness, astronauts rely primarily on their vision and secondarily on proprioception for spatial orientation. Impairment of gaze and head stabilization reflexes can lead to disorientation and reduced performance in tasks relying on a high level of sensory-motor skill, such as piloting a spacecraft (6).

2.1 SPACE ADAPTATION SYNDROME (SAS) & SPACE MOTION SICKNESS (SMS)

In the absence of gravity, signals from the central vestibular system, peripheral pressure receptors, and visual sense become inappropriate and thus misleading, to such a point that immediate disorientation usually occurs, and many astronauts suddenly feel as if they are upside-down or may even have difficulty sensing the location of their own arms and legs. This disorientation is described as Space Adaptation Syndrome and is the main cause of Space Motion Sickness (SMS). Two thirds of all astronauts will suffer from symptoms of SAS during the first few days of orbital flight (3). Many astronauts maintain a local "subjective vertical" as shown by reports of inversion illusions and visual reorientation illusions. Instability in the "subjective vertical" direction in microgravity is thought to be a specific trigger for SMS (7). One classical example of SMS is that of the cosmonaut Titov (8). For a brief period immediately after transition into orbit, Titov felt that he was flying upside down, soon thereafter he described dizziness associated with head movements, and sometime between the 4th and 7th orbits (approximately six hours of flight) he exhibited motion sickness, the first recorded instance in space flight.

The most incapacitating effects of SAS have been recorded to typically last for the first 1-5 days of weightlessness, and even occurring in some astronauts just after they have returned to Earth (3). Known common symptoms include dizziness, vertigo, headaches, cold sweating, fatigue, nausea and vomiting (motion sickness) (3). Consequences may range from simple discomfort to incapacitation, creating potential problems during re-entry and emergency exits from a spacecraft. It is for this reason that no extra-vehicular activities (EVAs), or space-walks, are permitted during the first few days of NASA shuttle flights (9). An extensive list of most known symptoms, taken from various texts (3, 7, 11, 13, 19, 20) are shown in Table I on the following page:

TABLE I
Common SAS/PFAS Symptoms Found
(3, 7, 11, 13, 19, 20)

General Signs	SAS/PFAS	Symptoms
Pain	SAS	Headaches, vomiting, digestive spasms
Imbalance (Vestibular & Cerebellar)	SAS/PFAS	Motion sickness, nausea, dizziness, inexplicable falls, poor concentration postural equilibrium disturbance, faintness, illusions and alterations of motor performance such as feelings of heaviness, disorientation when making sudden head movements, inability to move about in the dark, illusions of floor motion during vertical body movements
Neuro-ophthalmologic Coordination	SAS/PFAS	Eye-hand, eye-body, eye-head coordination impairment, postural equilibrium disturbance, disorientation when making sudden head movements, inability to move about in the dark, illusions of floor motion during vertical body movements, illusory sense of surroundings
Proprioceptive	SAS/PFAS	Illusory sense of self, eye-head, eye-hand coordination impairment, postural equilibrium disturbance, dizziness, nausea, illusions and alterations of motor performance such as feelings of heaviness, disorientation when moving suddenly, inability to move about in the dark, illusions of floor motion during vertical body movements.
Articular	SAS/PFAS	Postural equilibrium disturbance, illusions and alterations of motor performance such as feelings of heaviness, limitation in extension amplitude
Neuromuscular	SAS/PFAS	Headaches, eye-head and eye-hand coordination impairment, postural equilibrium disturbance, nausea, illusions and alterations of motor performance such as feelings of heaviness, disorientation when making sudden movements
Neurovascular	SAS/PFAS	Headaches, postural equilibrium disturbance, faintness, dizziness, nausea
Autonomic Neuro-vegetative	SAS	Cold sweating, chills, paleness, dermal goose-bumps

Current evidence favors a sensory conflict theory as the primary cause of SAS observed in astronauts. (10). Conflicting sensory-motor control inputs from visual and tactile senses with inputs coming from the vestibular organs in the inner ear are likely. However, the precise mechanisms where the conflicts are occurring are not well understood and effective therapies or preventative measures for SAS have yet to be developed. Symptoms of SAS are not typically reduced on veteran astronauts during subsequent flights (3).

2.2 POST-FLIGHT ADAPTATION SYNDROME (PFAS)

Unfortunately, Space Motion Sickness is not the only potential health issue facing astronaut's sensory-motor adaptation. Re-adaptation during a return to the gravitational acceleration on Earth's surface is just as agonizing and occurs in almost all returning astronauts, much more so than symptoms of SMS. Following space-flight, crewmembers experience (often severe) gait and postural instabilities due to their in-flight adaptive alterations to sensory-motor control function. Post-flight astronauts display a variety of postural difficulties including the inability to maintain a stable posture, particularly with their eyes closed, using a wide stance to stand and walk, feeling sensations of lateral acceleration while walking, and an inability to detect small changes in head positions (11). Coupled with the effects of weightlessness on muscle tonus and bone degeneration, an astronaut may have difficulty standing or walking at all. In this paper, the authors refer to these post-flight symptoms and disturbances as Post-Flight Adaptation Syndrome (PFAS).

Much like symptoms of SAS/SMS, PFAS usually only lasts a few days, and it was concluded by NASA that Skylab astronauts took up to 10 days of recovery time before their preflight posture and gait abilities were fully restored (12). No long-term effects of this re-adaptation process have yet been observed. A major concern here is that on a manned-mission to another planet such as Mars, when the astronauts land on the surface, their bodies may likely be incapacitated for as long as a few days, particularly when we consider that the alien world in which they land on will likely be much more hostile and inhospitable than our Earth. Clearly this would be an unacceptable situation for crewmembers health and safety, as well as for the success of a mission that may perhaps prove to be the most momentous accomplishment in human exploration to date. Presently there exists no operational countermeasure to mitigate the symptoms of PFAS (13).

2.3 MEASURING-UP THE COUNTER MEASURES

2.3.1 Pharmaceuticals

Medications used for treating terrestrial motion sickness; typically scopolamine-dextroamphetamine sulphate (dexedrine) or promethazine-ephedrine combinations are currently the only method for preventing and treating SMS These pharmaceutical prescription drugs have many adverse side-effects, can be highly addictive and most importantly of all, are not consistently effective in treatment or prevention of SMS symptoms.

The following was taken from the *Public Health Agency of Canada's* "Statement on Motion Sickness" (14):

Common adverse effects of dexedrine include restlessness, talkativeness and over-stimulation. Other effects that have been observed include changes in sex drive, constipation, diarrhea, dizziness, dry mouth, exaggerated feeling of well-being or depression, headache, heart palpitations, high blood pressure, hives, impotence, loss of appetite, rapid heartbeat, sleeplessness, stomach and intestinal disturbances, tremors, uncontrollable twitching or jerking, unpleasant taste in the mouth, and weight loss. Chronic use may lead to hyperactivity, irritability, personality changes, schizophrenia-like thoughts and behaviour, severe insomnia and skin disease.

Scopolamine hydrochloride causes dry mouth, drowsiness and blurred vision, and there is concern that it may in fact decrease adaptation abilities to motion sickness. Visual problems may increase with continuous use, and can cause confusing states and/or visual hallucinations.

Common adverse effects of using promethazine are severe drowsiness, significant decreases in performance scores, psychomotor function, information processing and alertness. The manufacturer of promethazine describes it as possibly having less impairment than that attributable to the motion sickness itself.

Amphetamines (the anti-motion sickness drugs mentioned here) have a high likelihood of addiction and dependence with prolonged periods of use.

Aside from these undesirable side-effects of motion-sickness drugs, it was shown as early as the Skylab missions that these drugs are also rather ineffective in preventing or treating SMS.

Skylab 2 crew carried and took a scopolamine and d-amphetamine combination and was symptom free during the first couple of days of flight. However, the scientist pilot exhibited a slight increase in subjective body warmth on the twentieth day of flight, and cold sweats on day twenty-four. Also on day twenty-four of flight, the pilot reported epigastric awareness, increased body warmth, slight dizziness and cold sweating (8, 12).

Skylab 3 crewmembers carried the same drugs as the Skylab 2 crew; however, they did not take them before flight. The pilot experienced mild symptoms of motion sickness within one hour of insertion into orbit. He took some medication which alleviated his symptoms, although after a few hours his symptoms returned restricting his activities for the day. At eleven hours into the flight, the commander and scientist pilot also reported the onset of motion sickness, shortly afterwards the scientist pilot vomited. Recovery from SMS did not occur until the seventh day of flight (8, 12).

Skylab 4 crewmembers took medication before flight as a precaution, however the pilot experienced nausea and vomiting immediately after insertion into orbit and was not symptom free until after the third day. The commander reported epigastric awareness prior to meals, possibly indicating susceptibility to motion sickness. The scientist pilot remained symptom free. NASA concluded that the drug combinations "were not the ideal anti-motion sickness drugs" (8).

In order for astronauts to be effectively cured of these ailments it is clearly desirable to find alternatives to counter these unacceptable kinds of adverse effects during Space missions.

2.3.2 Other Countermeasures

It has been shown previously on two cosmonauts, during a 196 day MIR mission that tactile information such as pressure on the soles of the feet can continue to promote a vertical sense. The results of this particular study indicated that the application of foot pressure throughout the course of a long duration spaceflight effectively increases neuromuscular activation, suggesting that it may prove useful to explore more sophisticated forms of delivering foot pressure during spaceflight as a countermeasure to SAS/SMS (15). However, this alone would not be enough as pressure stimulation strictly stimulates the proprioceptive sensory system, and does nothing for the other physiological and cognitive factors being faced by astronauts.

According to Heiko Hecht and Laurence R. Young (16), other traditional countermeasures against the adverse effects of weightlessness such as exercise, resistive garments and low-body negative pressure (LBNP) appear to be insufficient in practice and are often too inconvenient for astronauts. Artificial gravity induced by centrifugation has also been widely studied on Earth as a viable countermeasure. Much of this work, pioneered by Dr. Young, has shown strong evidence for positive effects in regards to muscle tonus, cardiovascular deconditioning and bone degeneration. However, while it has been shown that proper centrifugation has little to no adverse effect on vestibular functions, there is little evidence to suggest that it would permanently correct vestibular and proprioceptive disturbances during Space flight since artificial gravity experimentation in Space has yet to take place. It is also unclear as to what effects an astronaut may incur when being subjected to only short, multiple periods of this kind of centrifugation during Space flight.

2.4 EXAMPLES OF TYPICAL ASTRONAUT SYMPTOMATOLOGY

Prior to Skylab missions where the human physiology in Space first began to be seriously studied, four USSR crewmembers and nine out of the twenty-five Apollo astronauts experienced Space motion-sickness. None of the twelve Apollo lunar astronauts experienced motion sickness, nor did astronauts from the Mercury and Gemini programs reported occurrences of motion sickness. However, other sensory-motor control dysfunctions were reported far more frequently than motion sickness, and postural illusions were experienced immediately after transition into orbit by nearly all astro/cosmonauts (8). In fact, some cosmonauts continued to experience illusions until the g-load that was associated with re-entry appeared. Such illusions induced by rotary motions of the head and/or body movement (sensations of turning and dizziness) were experienced not only in early flight but also recorded over prolonged periods of time (8). One should note that Mercury and Gemini astronauts were severely restricted in body and head movement due to the small size of the capsules they flew in, and by the helmets that they wore.

Pre-flight and post-flight testing from Apollo 16 crewmen indicated some decrement in postural equilibrium three days following recovery when they were tested with their eyes closed (8).

Crewmen of the eighteen-day Soyuz 9 mission manifested difficulty in maintaining a stable vertical posture which did not normalize until 10 days after flight (8).

In order to investigate this further, the Skylab missions' crewmen were tested for balance and basic vestibular function six months pre-flight.

The Skylab 2 mission, which lasted for twenty-eight days, had tests limited only to balancing with eyes open and closed while standing on the floor. The crewmembers were tested during the 1st and 2nd day following splashdown, and indicated that they all experienced considerable difficulty when standing on the floor with their eyes closed, however no problems were recorded when visual cues were given. These tests were performed on a moving ship (8, 12).

The Skylab 3 mission, which lasted for 59 days, had the scientist pilot and pilot tested on the 2nd, 9th, and 29th day following splashdown. The tests showed a decrement in performance under both the eyes open and closed conditions, although a much more pronounced decrement was observed during the eyes closed condition. On the 2nd day, with visual aid, the pilot experienced considerable difficulty even when attempting to stand on the floor, despite his excellent pre-flight scores. The rate of recovery of the pilot was much slower than the scientist pilot, showing poor performance even on the 9th day of recovery. The Skylab 3 commander reported feeling that he was moving sideways while stepping forward, and several other crewmembers reported this sensation of 'forced lateral movement' (8, 12).

The Skylab 4 mission, lasting for 84 days, had all crewmembers tested on the 2nd, 4th, 11th and 31st day post-flight. The commander and pilot showed no decrease in post-fight abilities when tested with their eyes open, however they did show a very large deficit in ability to balance with their eyes closed. On the first day of post-flight testing, the commander was barely able to maintain the required vertical posture while standing on the floor with his eyes closed; his pre-flight abilities were not gained back until the 11th day of post-flight recovery (8, 12).

Although Skylab crewmen were able to walk immediately after exiting the command module, they did so with noticeable difficulty, tending to use a wide-stance shuffling gait with the upper torso bent slightly forward (12). During the first several days following post-flight recovery, crew reported the simple act of walking required a conscious effort.

All crewmen reported that rapid head movements post-flight produced a sensation of mild vertigo and any slight head movement while their eyes were closed would induce vertigo and cause loss of balance. NASA Skylab flight surgeons and scientists concluded that Skylab crewmen required about ten days to regain normal postural stability (12).

The most overt change affecting astronauts in space flight, according to Charles Oman, is the immediate response of the neurovestibular area of the sensory-motor control system to changes in gravity level (17). MIR crewmembers have been recorded as saying that 3D relationships between modules, particularly those with different visual verticals, are difficult to visualize. While crewmembers are able to learn routes, their noticeable lack of direction and surveying abilities is a major concern should fire, power-loss, or depressurization limit their visibility in any way. As the International Space Station, future interplanetary missions, and particularly private industry space travel grow in duration the likelihood of such a situation will continue to grow exponentially.

3.0 POSTURAL DEFICIENCY SYNDROME & BIOPHOTONIC STIMULATION PARADIGMS

This section explores a more in-depth look at the sensory-motor control system, with particular focus on vestibular functions. This is done in respect to the neurophysiological adaptation of astronauts in microgravity, and terrestrial patients suffering from post-traumatic conditions.

3.1 BALANCING ACT – ADAPTATION OF THE SENSORY-MOTOR CONTROL SYSTEM

Correct transduction and integration of signals from all areas of the sensory-motor system is essential for maintenance of stable vision, spatial orientation, eye-head and hand coordination and postural and locomotion control on Earth. Perception of location and positions are a result of the brain's ability to integrate visual and auditory signals with vestibular input (gravity and motion detecting organs in the inner ear) and proprioceptive information (motion, pressure and temperature sensors in the tendons, muscles, joints and skin). The input the brain receives from sensors, modified by gravity changes, prompts the CNS to develop a new interpretation, hence a different (compensatory) adjustment strategy. The plasticity of the CNS allows individuals to adapt and compensate under altered sensory stimulus conditions such as those experienced in Space flight. The suppression in microgravity of sensory stimulus rearranges the relationship between signals from vestibular, visual, skin, muscle and joint receptors. If this new interpretation does not match fundamental specific calibrated functional patterns in the brain, symptoms of SAS are likely incurred, significantly reducing an astronaut's operational efficiency (18). Astronauts therefore experience symptoms related to SAS.

3.1.1 The Vestibular System is Key

The peripheral vestibular apparatus in the inner ear consists of two sensory receptors, the semi-circular canals and the otolith organs. The semicircular canals signal rotary movements of the head. These liquid filled tubular loops act as angular accelerometers arranged in three orthogonal planes. The change in volume of each loop translates movement to neural signals to the brain. The otolith organs sense linear forces such as gravity acting on the head. These calcium carbonate concretions embedded in gelatinous material act as linear accelerometers for the brain. Neural signals produced under acceleration are integrated in the CNS with signals from proprioceptors reporting the position relationships of the limbs, trunk and neck. Signals from skin pressure receptors, vision and stored cognitive perceptual memory data, are integrated to coordinate movements of the limbs, head and eyes.

Postural reflexes under otolithic control appear to be depressed in flight and return to normal only after several days of recovery post-flight. These symptoms occur even after missions of relatively short duration, where changes in bone and muscle strength are minimal (19). One possible reason for reaction to weightlessness is described in the Otolith Tilt Translation Reinterpretation (OTTR) hypothesis (3). It states that the brain learns to reinterpret signals coming from the vestibular system to represent only linear acceleration rather than pitch or roll of the head (20). Another explanation of these observations is that a gain on otolith signals may be reduced, consequently leading to a decrease in the ability to sense linear acceleration (19). Therefore, confusing signals from the inner ear become largely ignored and vision returns as the primary source of posture and gait information (3).

3.1.2 The Fine Postural System

An important function in postural control is the coordination of various muscular activities to maintain proper orientation of the body with respect to gravity. It is provided by a complex regulatory system, the Fine Postural System (FPS). The FPS models the core neurophysiological system which provides balance control to the human body during static and dynamic performance. Known components of the FPS include ocular motricity and vision, vestibular system, proprioception of the lower limbs as well as of the paravertebral muscles and of the eye movements.

The sensory-motor controls system underlies the FPS. Located in the brain, it handles through the CNS hierarchy sensory input and directs integrated motor adjustment and movement throughout the body. It governs adjustments of postural neuromuscular tonus, visual-ocular motor controls, and vestibular controls. Hence, the FPS regulates postural tone and precisely adjusts posture and gait under all circumstances, whether static or dynamic. Its functional core structure includes synergistic and antagonistic sensory motor and cognitive structures which are part of a network diffusely located in various areas of the brain (2).

The structure of the FPS consists of exosensors and endosensors (2). These components only control small postural disturbances which move the body's axis up to four degrees from the balance reference in a given position, hence the name the Fine Postural System. Research has shown that postural balance depends on whether the amplitude of spontaneous movements to or from the balance position (not necessarily vertical) is greater or less than four degrees (36).

3.1.3 The Primary Factors Involved

1. Factors Involved in Spatial Orientation

In orbital flight and in the free-fall phase of parabolic flight, feelings of inversion of self and spacecraft, or aircraft, are often experienced. The absence of falling sensations during weightlessness points to the importance of visual and cognitive factors in eliciting such sensations (35). Human spatial orientation and ocular-motor control are under multimodal influence. Many patterns of behaviour and response that have been attributed solely to vestibular function are actually dependent wholly or in part on touch, kinesthetic, and proprioceptive stimulation (32).

2. Spatial Representation and Localization

Gabriel Gauthier, et al demonstrated the capacity of the vestibular apparatus for coding spatial information through a better use of vestibular signal for further motor purposes than for plurimodal cognitive matching (37). Posture dependent performance relates to position in space, and space perception, complex motor skills and gait (38).

3. Factors Involved in Perceptual Abilities
The perceptual localization of sound often is thought to depend solely on the pattern of auditory cues at the ears. Evidence has been presented to show the computation of auditory direction also involves non auditory information from visual, vestibular, tactile, and proprioceptive sources concerning the spatial configuration of the entire body (33). The biasing of auditory localization indicates that identical patterns of arrival time and intensity cues at the ears can give rise to the perception of sounds in widely disparate spatial positions in relation to the head and body, depending on the proprioceptive representation of the direction of the sound source (34).

4. Factors Involved in Detection of Relative Motions
Detection of relative motions between the subject and the objects in space relies on the perception of peripheral visual field stability. It results from the integration of the four signals: visual, ocular-muscular proprioceptive, vestibular and ocular-cephalic movement (efferent copy). Incoherence in activation patterns of these various signals results in illusory motion perception such as that experienced during two to three days of exposure to magnifying lenses. Previous experiments have demonstrated the involvement of the cerebellum in the mechanisms responsible for the adaptive changes resulting from the alteration of the normal visual-vestibular relationship (37).

3.2 POSTURAL DEFICIENCY SYNDROME – A MEDICAL DEFINITION

Postural Deficiency Syndrome (PDS) is medically described as a condition that includes a composite of symptoms in relationship with variations of the upright position. PDS labeled patients always acknowledge, among other signs, instability, sensory and cognitive overloads, dizziness, pains radiating from their body axis, circulatory disorders. As defined, PDS does not correspond to any macroscopic lesion of an anatomically defined system. The severity of PDS symptoms has no relationship to that of the cause (1, 21).

Tables II and III show the "cardinal" neuromuscular and neurovascular functional signs and other characteristics of symptoms of patients suffering from PDS as defined by H. Martins Da Cunha in 1987(22).

TABLE II
Cardinal Signs (22)

Signs	Clinical manifestations - symptoms
Pain	**Headache**, retro-eye, thoracic or abdominal pain, arthralgies, rachialgies
Imbalance	**Sickness**, **nausea**, **dizziness**, **inexplicable falls**
Ophthalmological	Asthenopia, dim vision, diplopia, directional scotoma, metatopsia
Proprioceptive	Dysmetria, somatoagnosia, **errors of appreciation of the body image**

TABLE III
Associated Signs (22)

Signs	Clinical manifestations - symptoms
Articular	TMJ Syndrome, stiff neck, lumbago, periarthrities, sprains
Neuromuscular	Paresia, **defect of driving control of the extremities**
Neurovascular	Paresthesia of the extremities, Raynaud's phenomenon
Cardio-circulatory	Tachycardia, lipothymia
Respiratory	Dyspnoea, **fatigue**
ORL	Hummings, deafness
Psychic	Dyslexia, dysgraphia, agoraphobia, **defect of orientation**, **defect of spatial localization right and left,** **defect of concentration**, loss of memory, asthenia, anxiety, and depression

The symptoms commonly reported in cases of SAS and PFAS are shown in bold type. For convenience, the reader may find the definition for many of the medical terms shown in the above tables in the Definitions, Abbreviations and Acronyms section at the end of this paper (29).

According to Da Cunha, PDS is a medical situation always accompanied by an alteration of the ocular and postural equilibrium and by a defect of proprioceptive and visual information (23). Clinical evidence for this definition will be shown in the next section, followed by a section outlining some recent astronaut biomedical discoveries that correlate well with the above definition of PDS.

3.3 A PROVEN COUNTERMEASURE USING BIOPHOTONICS

3.3.1 A Biophotonic Technology

It is not within the scope of this paper to explain how the biophotonic technology works, that information has been made available in previous papers (1, 2). However, a brief introduction is displayed in the following couple of paragraphs.

Dermal optical sensitivity (DOS) is the physical sensory part of defining perceptual awareness which relates to the cognitive integration.

Photonics includes the science of physics in respect to emission, transmission, absorption, transformation and processing of rays, light, particles and electromagnetic energy. DOS belongs to the field of biophotonics which refer to the biological applications of photonics and the interactions with the physiology of living beings.

This technology was originally designed to enhance performance, and was later on proven to be a very effective therapeutic tool. This dermal optical photonic stimulation technology provides a non-invasive stimulation and is able to counteract effects of stressors. Physical and clinical trials in France demonstrated that these stimulators have a lasting corrective effect on postural, visual, vestibular and proprioceptive disturbances such as those observed in PDS and SAS (30, 31).

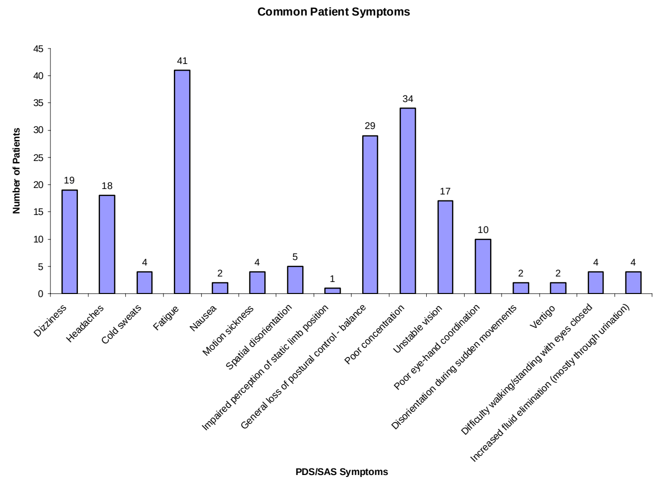
3.3.2 Clinical Results with PDS

The following data and results were taken from the medical files of fifty-nine consenting patients. The data correlates symptoms exhibited in patients suffering from a PDS relating form of acute and chronic post-traumatic medical conditions to that of symptoms commonly exhibited by astronauts suffering from SAS and PFAS.

The patients sampled in this report range in age from ten years to eighty-four years, with a mean age of forty-eight years old. Thirty-nine percent of the patients are male and sixty-one percent female. It has been observed that gender and age have negligible bearing on the effectiveness of biophotonic stimulation. Patients, prior to coming to NeuroKinetics™, had been clinically diagnosed with a variety of neuro-psycho-physiological conditions including major head traumas, varying magnitudes of concussion, post concussion syndrome, whiplash, fibromyalgia, tinnitus, manic depression, and various other kinds of chronic fatigue and pain syndromes. These patients had received severe physical, emotional, intellectual and/or cognitive traumas, many of them suffering from ten or more symptoms as described in Tables I and II shown on the previous page. They received a comprehensive neurophysiological treatment program that comprised of neural stimulation through the use of biophotonics complemented with combinations of stimulation via semi-permanent needles (SPN), traditional Chinese acupuncture, homeopathic remedies, infrared stimulation, subliminal electric stimulation (diascope), and a cranial neural stimulation applied to the external lateral pterygoidian area (ELPS). However, photonic stimulation is by far the predominant treatment modality used as all other treatments act to be complementary to photonic stimulation. Treatment programs for patients typically last from three to six months depending on the severity of their symptoms, reflecting the complexity of their CNS dysfunction.

3.3.2.1 Patient-Symptom Chart

This graph (Fig. 1) shows seventeen common symptoms observed in astronaut's neurophysiological adaptation to orbital flight and by the patients used for this report. The graph shows how many patients suffered from each symptom.

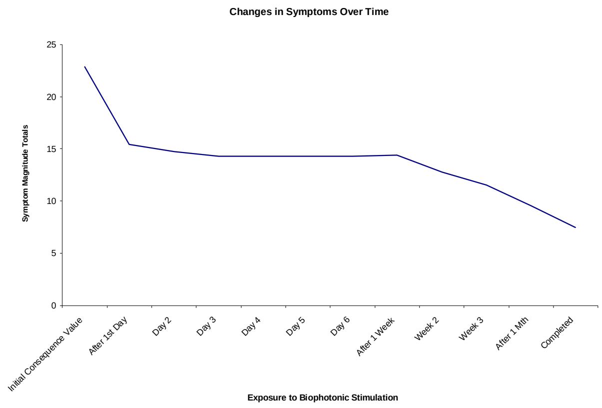


From this graph, it can be seen clearly that most patients suffered from at least four to five of these SAS/PFAS like symptoms. The sixteen symptoms shown here are: dizziness, headaches, cold sweating, fatigue, nausea, motion sickness, spatial disorientation, impaired static limb position, general loss of postural control/balance, poor concentration, unstable vision, poor eye-hand coordination, disorientation during sudden movements, vertigo, difficulty walking/standing with eyes closed, and increased fluid elimination through frequent urination.

3.3.2.2 Symptom Magnitude Drop over Time Chart

This graph (Fig. 2) shows the average decrease in symptoms for the patients as a function of time from the beginning of a given treatment program to its completion. A similar scale to the Neurological Function Rating Scale that NASA uses for short duration space shuttle flights was used (25). The scale goes from 0 (negligible symptoms) to 3 (persistent or severe symptoms). The scores of all the patients symptoms were summed and then graphed for the following time-frames: after 1 day, 2 days, 3 days, 4 days, 5 days, and 6 days of treatment, after 1 week, 2 weeks, 3 weeks of treatment, after 1 month of treatment and after the treatment program was completed.

The graph below displays the average symptom total scores and magnitude drops of all the patients sampled. The total scores of all patients were summed then divided by the total number of patients, to give an average symptom magnitude drop over time; selected individual patient results are graphed and shown in APPENDIX A for comparison.

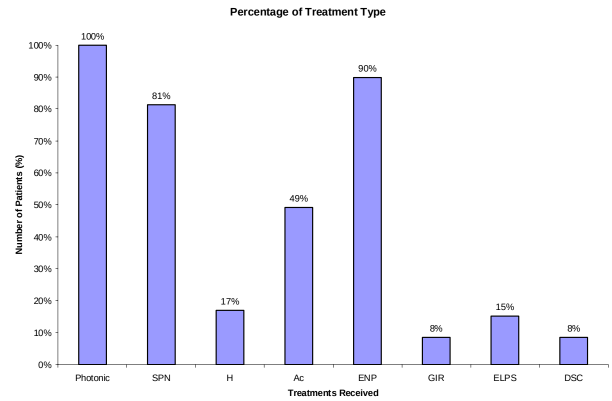


What should be most notable to the reader here is that the largest decrease in symptoms is typically observed within the first week, and typically a significant drop is seen in the first day or two of treatment. This is very important as we have seen that SAS and PFAS symptoms tend to appear and dissipate in the first few days or weeks both in-flight and post-flight. It has also been observed that patients will immediately (often within less than one minute) have a noticeable improvement in their subjective 'feel' and objectively measured sensory-motor control performance after a single application of biophotonic stimulation, without any other stimulation applied (1, 2)

As a reminder to the reader these patients suffered from severe traumas. It is therefore necessary to treat them for several months in order to stabilize their condition and ensure the complete and permanent dissipation of their symptoms, some of which may have persisted for several decades or longer. This point is illustrated by the slight increase in magnitude seen in figure 2 around the one week point, followed by a steady decline and then stabilization.

3.3.2.3 Percentage of Treatment Type Chart

Patients are usually clinically treated with up to four different treatment (neural stimulation) modalities. This chart (Fig. 3) shows that 100% of the patients sampled were treated with biophotonic stimulation, while 81% of the patients were stimulated via semi-permanent needles (SPN), 17% were treated with homeopathic remedies (H), 49% were stimulated with traditional Chinese acupuncture (Ac.), 90% with probes (ENP), 8% with infrared (GIR), 15% with base-of-the-skull cranial neural stimulation (ELPS), 8% with subliminal electric stimulation (DSC).

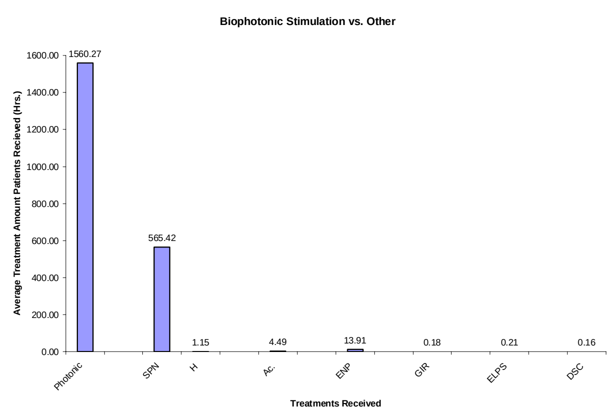


Photonic stimulation is the most widely and often used treatment modality for our patients suffering from PDS. While other treatments are chosen depending on the specific condition and medical history of the patient, nearly all patients receive biophotonic simulation.

3.3.2.4 Treatment Use Chart

The following figure, figure 4 shows the total average hours of treatment that the patients received from each treatment modality during the total length of a treatment program. The total hours of treatment received for each treatment modality was summed for all the patients and then divided by the number of patients, to arrive at an average treatment, in hours, received by each modality.

It is clearly displayed in the below graph that biophotonic stimulation, on average, provides the largest exposure of treatment being received by a given patient



The following sub-section ties together some recent studies done in respect to the neurophysiological adaptation of astronauts in microgravity, with the terrestrial patients suffering from PDS we have just seen.

3.4 RECENT ASTRONAUT BIOMEDICAL DISCOVERIES

Microgravity has offered a unique opportunity to study the role of these vestibular organs as well as the adaptive mechanisms the brain uses to adjust for altered forces and motion environments. This opportunity was grasped during the 1998 Neurolab (STS-90), where the study of the human vestibular system in Space was a major focus (4).

In the late 1990's, Rosemarry Speers, William Paloski and Arthur Kuo took data from ten astronauts (nine male, one female, mean age of thirty-eight years) who were selected and subjected to a 'Sensory Organization Test' (SOT) (19). They found that changes in postural control following spaceflight are multivariate in nature indicating not only a change in the amount of sway, but change in astronaut coordination as well. Because the coordinative changes varied with sensory conditions, it was shown that they are at least partially explained by changes in sensory processing, which may affect astronaut's perception of spatial orientation. Post-flight testing showed noticeably increased sway, and performance was observed to be much worse when the astronauts were tested with their eyes closed. Their results implied that the contributions of a multivariate combination of somatosensory, visual, and vestibular information for postural control are altered following spaceflight. The multivariate nature of postural control requires a treatment that addresses vestibular function in combination with somatosensory (proprioception), and visual function. To further reinforce the multivariate conclusions of Speers, Paloski and Kuo, Bernard Cohen et al. recorded data from four astronauts who were exposed to interaural and head vertical (dorsoventral) linear accelerations on a centrifuge on Earth and in-flight on Neurolab. Their results suggest that a combination of other non-vestibular inputs, including an internal estimate of the body vertical and somatic sensation, were utilized in generating tilt perception (24).

It can therefore be stated that astronauts suffer from a syndrome that alters a multivariate combination of ocular-visual and postural equilibrium along with proprioceptive information. This supports our clinical observations of the patients presented here, which correlates the symptoms of SAS and PFAS directly with the definition and observations of PDS.

4.0 CONCLUSION

This paper displays ten years of selected clinical data, taken from patients suffering from acute and chronic post-traumatic medical conditions. The data presents a strong correlation between the symptoms associated with Space Adaptation Syndrome (SAS) and Post-flight Adaptation Syndrome (PFDS) to that of symptoms associated with Postural Deficiency Syndrome (PDS). With this correlation apparent, existing biophotonic devices should be considered for application to biomedical prevention and correction for astronauts in and post flight. The correlation shows a high probability that these biophotonic devices shall be able match their terrestrial success in Space, which would prove to be a vast leap forward in sustaining prolonged human Space exploration.

ACKNOWLEDGEMENTS

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Asthenopia – Weakness or speedy tiring of the visual organs, attended by pain in the eyes, headaches, dimness of vision, etc.

Diplopia – The perception of two images of a single object.

Scotoma – An area of depressed vision within the visual field, surrounded by an area of less-depressed or of normal vision.

Lumbago – Pain in the lumbar region

Periarthritis – Inflammation of the tissues around a joint.

Paresthesia – Abnormal sensation, as burning, prickling, formication.

Raynaud's phenomenon – intermittent attacks of pallor or cyanosis of the extremities, especially of the fingers or toes and sometimes of the ears and nose, brought on by cold or emotion.

Tachycardia – Excessive rapidity in the action of the heart.

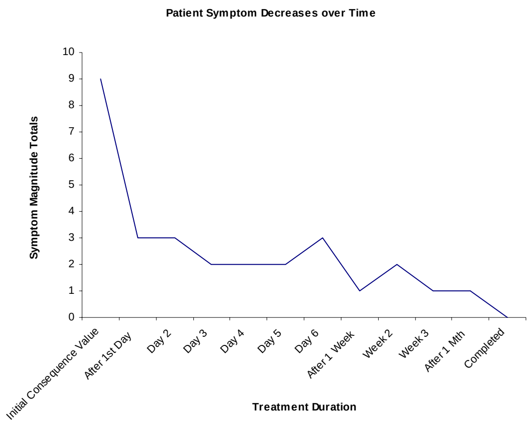
Lipothymia – Faintness or swooning; a swoon or faint

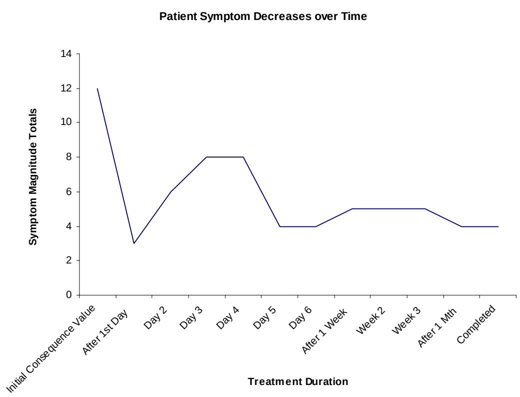
Dyspnea – Difficult or laboured breathing.

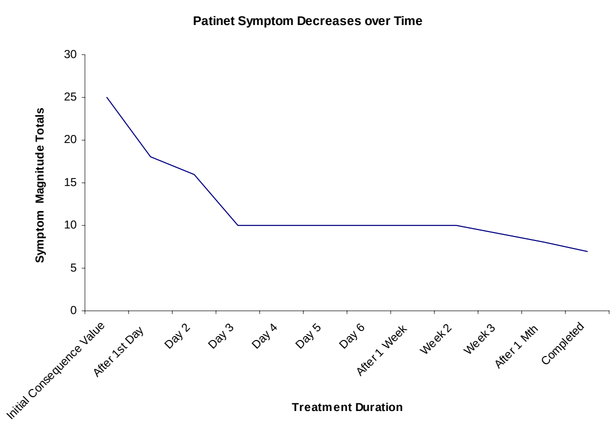
Dysgraphia – Inability to write properly because of ataxia, tremor or motor neurosis.

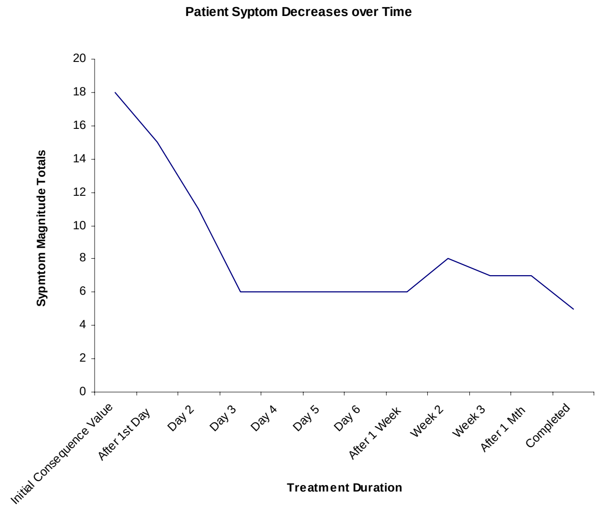
APPENDIX

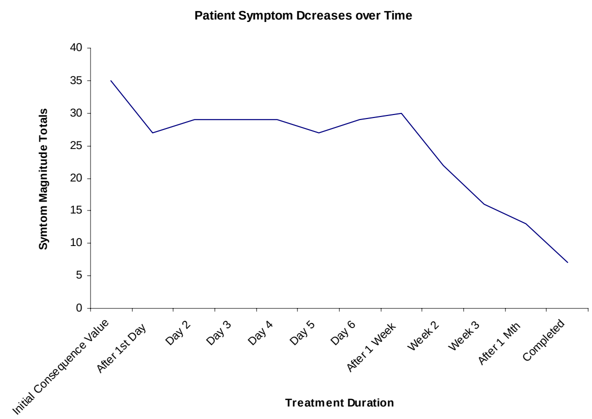
APPENDIX A – SELECTED INDIVIDUAL PATIENT SYMPTOM DECREASES OVER TIME

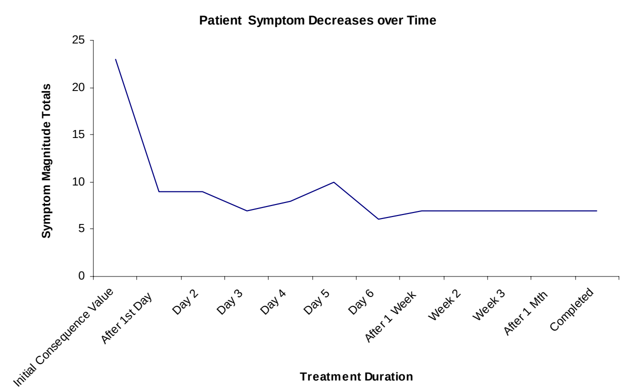












2006-01-2298

Static Postural Analysis: A Methodology to Assess Gravity Related Sensory-Motor Controls' Status for Astronauts

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ABSTRACT

Static postural analysis not only provides classic musculoskeletal and spinal symptoms along with clinical data, but also specific neurophysiological markers that identify the occurrence of Postural Deficiency Syndrome (PDS). The symptoms of PDS have been shown recently to correlate with astronaut's Space Adaptation Syndrome (SAS) and Post-Flight Adaptation Syndrome (PFAS) related symptoms. This correlation is briefly reviewed and expanded upon with respect to the importance of static postural data in understanding these symptoms. A neurophysiological assessment methodology is discussed to illustrate how specific postural data combined with vestibular and ocular-visual data can explain PDS symptoms as they relate to the sensory-motor controls. A selection of research objectives is suggested in terms of future considerations on better understanding SAS and PFAS as applied to astronaut operations.

INTRODUCTION

Static postural abnormalities are known in medicine as either consequences, or causes of underlying mechanisms, functional disorders, and diseases. In respect to human performance, the first publications on the interest of such postural parameters in Medicine date from as early as 1865 (7). Since then, the technologies developed to study static posture have not seen significant advances, being left to the wayside in preference of dynamic postural movement analysis or motion analysis. Since the early stages of experimental research in medical neurophysiology and clinical observation with Vierordt in the 1840s (7) it has been demonstrated and validated that static postural analysis can yield a wealth of information. This is not only in respect to the biomechanical and physiological status of the spine, muscles, and joints, but also to one's overall neurophysiological central nervous system (CNS) functional status (28).

Included in the CNS is the sensory-motor controls (SMC) and related cognition responsible for gravity related sensory, motor, and postural control, perception of space, coordination, trajectory control, as well as the ability for physical, perceptual, and mental adaptation to changes in gravity. Exposure to space flight environment, including microgravity, increases the stress on astronaut's sensory-motor controls regulatory system located in the brain due to the fact that human beings are calibrated to operate under Earth-based gravity, i.e. G=1. For instance even on a 4 to 9 day mission (28), the CNS adjusts to a change in calibration resulting due to the transition from G1 to microgravity, causing postural ataxia and making sensory-motor, cognitive, and postural re-adjustment necessary once returning to Earth.

The authors briefly review the historic development and the specifics of the static postural analysis and discuss methods for the assessment of the sensory-motor controls regulatory system. Appropriately applied static postural analysis provides neurophysiological markers that assist to identify the occurrence of Postural Deficiency Syndrome (PDS). This neurophysiological approach has been successfully applied clinically in a medical setting since the mid-1980's to evaluate pathological conditions of chronic trauma PDS patients and monitor their recovery status (35, 36, 37). A brief introduction to the interpretation of these particular parameters underlying these symptomatic and functional deficiencies includes how they relate to astronauts' dysfunctions that adversely impact performance and safety. PDS has recently been correlated (35, 36) with two common SMC related conditions astronauts suffer from: Space Adaptation Syndrome (SAS) and Post-flight Adaptation Syndrome (PFAS).

1. A BRIEF HISTORY OF POSTURE ANALYSIS

The fundamental question, "How does man stand erect?" was posed by Charles Bell in 1837 (2), but responses offered by physiologists at the time were perplexing. According to the topographical logic of the time regarding the sensory organs - one organ for one sense – previous efforts had concentrated on searching for the sense of equilibrium and it was found that the eye (6), the vestibule (6), cervical muscles (24), the foot (5) and even the ocular-motor muscles (5) all contributed to this "sense" of equilibrium or postural control, rather than only one.

Claude Bernard's Introduction à l'Étude de la Médecine Expérimentale (3) published in 1865, marked perhaps the first truly scientific study of posture. Around this time a group of neurologists from the Salpêtrière Hospital in Paris under the leadership of Professor Charcot, were trying to describe new diseases of the central nervous system for which no anatomical lesions were observed. A Société de Neurologie meeting held in 1916, during the First World War, dealt with a problem field physicians had encountered with soldiers with head traumas. Wounded soldiers complained of subjective symptoms such as vertiginous sensations, visual disorders, instability, headaches, etc., for which no anatomical clinical explanation at the time could be found. This marked one of the first attempts to describe a posture related affliction (7).

This unspecified condition, which did not fit into the neurological anatomical clinical categories of the time, was only seriously studied further much later on in the early 1980's; it actually became one of the major avenues of clinical research that led to develop further into the studies of medical postural studies.

In the 1970's, Dr Nashner, PhD in Neurosciences from Massachusetts Institute of Technology, completed a groundbreaking doctoral thesis regarding the neuro-sensory functional patterns contributing to the human postural control (27). To open feedback loops for vision and podal proprioception, technology was constructed that had the ability to be subjected to movements at the center of gravity of the individual being examined, the movements of the cabin, and/or the platform on which he was standing. The posture of a human standing erect and at rest, was found to be controlled by a particular system that integrates information from a series of entries from the postural system within a feedback loop intended to correct any straying of the body from its equilibrium, thus stabilizing it. Neuroscientists have collected and analyzed these physical signals from the postural system. These dynamic analyses of this stabilometric signal have been confirmed to show that the dynamics of the postural system are in fact non-linear (8). This has lead to the ability to model the postural system and make predictions of outcomes utilizing the postural static equation for which the normal ranges were defined by the French Society of Posturology (11).

From more recent physical studies (9), spectral and stochastic analyses of the signals (10, 4), and simultaneous recordings of the center of pressure and center of gravity (31, 33), it is known now how the center of pressure behaves with respect to the center of gravity. The constant movements of the center of pressure stabilize the center of gravity. Ninety-five percent of the observed stabilization phenomena of a 'normal' person standing at rest would correspond to these center-of-pressure strategies (43). This shows that postural control plays a role with balance control, and therefore is related to the vestibular system and its functions, or conversely its dysfunctions when they occur.

These discoveries lead to another important development in understanding the function, particularly that of gravity, in postural control. Coordination of various muscular activities is required to maintain proper balance and orientation of the body with respect to gravity. This coordination is provided by a complex regulatory system called the fine postural system (FPS) defined in the 1980s (9). The FPS models the core neurophysiological system through the CNS to provide balance control to the human body during static and dynamic performance. The FPS's functional core structure includes synergistic and antagonistic sensory-motor and cognitive structures that are part of a network diffusely located in various areas of the brain (37). Another aspect of the multi-modal structure of the FPS includes exosensors and endosensors (37, 38). These components only control small postural disturbances that move the body's axis up to four degrees from the balance reference in a given position.

Neural postural control is a key area in the study of the nervous system, as normal posture and movement results from interaction between large numbers of neural structures arranged according to a characteristic functional hierarchy (1). Postural analysis is critical to understanding sensory-motor control related disorders, and should be appropriately applied in such cases as astronauts suffering from SAS or PFAS symptoms (35).

2. POSTURAL SYSTEM & SENSORY-MOTOR CONTROLS REGULATION

The correct transfer and integration of signals within the CNS from all areas of the sensory-motor system is essential for maintenance of stable vision, spatial orientation, eye-head and hand coordination and postural and locomotion control on Earth. CNS plasticity allows individuals to optimally adapt and compensate when exposed to long lasting and/or increasingly deteriorating environmental conditions. Gravity changes towards microgravity adversely influences the functional status, and hence, the relationship between signals within the ocular-visual, vestibular and other postural control systems. This contributes to rearrange the sensory-motor controls (39) causing on set dysfunctions such as SAS or PFAS symptoms (24, 28). This rearrangement or modification of signals can be seen in the change in strategy applied and exhibited within the SMC (32).

The perception of location and position are a result of the brain's ability to integrate signals from the SMC into useful information. The input the brain receives from sensors which are modified by gravity changes, prompts the CNS to develop a new interpretation, hence a different and therefore compensatory adjustment strategy. For instance, during space flight, when this new interpretation does not match specifically calibrated functional patterns in the brain, symptoms of SAS or PFAS are likely incurred, significantly reducing an astronaut's operational efficiency. The following sections outline how each system, with particular emphasis on the vestibular and postural systems, are related to each other and thus effect each other while dysfunctioning.

2.1. THE VESTIBULAR SYSTEM

The peripheral vestibular apparatus in the inner ear consists of two sensory receptors: semicircular canals and otolith organs. The semicircular canals signal rotary movements of the head. These liquid filled tubular loops act as angular accelerometers arranged in three orthogonal planes. The change in volume of each loop translates body movement to signals interpreted by the brain. The otolith organs sense linear forces such as gravity acting on the head. The calcium carbonate concretions embedded in gelatinous material act as linear accelerometers for the brain. Neural signals produced under acceleration are integrated in the CNS along with signals from proprioceptors reporting the position relationships of the limbs, trunk and neck. Signals from skin pressure receptors, vision and stored cognitive perceptual memory data, are integrated to coordinate movements of the limbs, head and eyes.

Postural reflexes under otolithic control appear to be the key major physiological mechanisms depressed early during space flight as these symptoms occur even after missions of relatively short duration, where changes in bone and muscle strength are still minimal (32). A major difficulty facing aerospace physiologists is the identification and monitoring of how the vestibular system becomes depressed (24) and which specific areas are depressed and at what times. Understanding the postural system by studying postural changes pre-, in- and post-flight with standardized neurophysiological assessments may yield more clues.

For example, one possible reason for reaction to weightlessness is described in the Otolith Tilt Translation Reinterpretation (OTTR) hypothesis (24). It states that the brain learns to reinterpret signals coming from the vestibular system to represent only linear acceleration rather than pitch or roll of the head (27). Another explanation of these observations is that a gain on otolith signals may be reduced, consequently leading to a decrease in the ability to sense linear acceleration (40). Therefore, confusing signals from the inner ear become largely ignored and vision returns as the primary source of posture and gait information (24). However, it is difficult to see this hypothesis being proven or disproved without a thorough understanding of the postural inputs and outputs being generated in such environments as Microgravity.

2.2. THE POSTURAL SYSTEM

Known components of the postural system can be best examined by looking specifically at the fine postural system (FPS) (45, 46). For this reason, the FPS model provides a concise relationship between an individual's posture and the ocular-visual and vestibular systems. Research has shown that one's postural balance depends on whether the amplitude of spontaneous movements to or from the balance position (not necessarily vertical) is greater or less than four degrees after a shift in strategy (22).

When investigated and measured, the FPS problematic areas within the sensory-motor controls system and its associated subsystems, such as the vestibular system, can then be identified, assessed and monitored. An appropriate measurement system should calibrate measurements of the SMC as a function of the FPS in terms of overall performance, connecting the major systems within the SMC. A system designed to incorporate the FPS for sensory-motor based assessment measurements has been shown previously by the authors (36).

2.3. ADDITIONAL FACTORS RELATING TO THE SMC

Considering the static posture, an inclusive literature review is briefly discussed here to point out other additional factors that need to be included when studying the SMC. A detailed discussion of these factors, however, is not within the scope of this paper.

1. Spatial Orientation
In orbital flight and in the free-fall phase of parabolic flight, feelings of inversion of self and spacecraft or aircraft are often experienced. The absence of falling sensations during weightlessness points to the importance of visual and cognitive factors in eliciting such sensations (21). Human spatial orientation and ocular-motor control are therefore under multimodal influence. Many patterns of behaviour and response that have been attributed solely to vestibular function are actually also dependent at least in part to touch, kinesthetic, and proprioceptive stimulation (22).

2. Spatial Representation and Localization
Gauthier, et al demonstrated the capacity of the vestibular apparatus for coding spatial information through a better use of vestibular signal for further motor purposes other than for cognitive matching (12). Posture dependent performance therefore relates to position in space, spatial perception, complex motor skills and gait (15).

3. Auditory Perceptual Abilities
The perceptual localization of sound is often thought to depend solely on the pattern of auditory cues directed at the ears. Evidence has been presented that the computation of auditory direction also involves non-

auditory information from the SMC concerning the spatial configuration of the entire body (19). The biasing of auditory localization indicates that identical patterns of arrival time and intensity cues in the ears can give rise to the perception of sounds in widely disparate spatial positions in relation to the head and body, depending on the proprioceptive representation of the direction of the sound source (20).

4. Factors Involved in Detection of Relative Motions
Detection of relative motions between oneself and the objects in Space relies on the perception of peripheral visual field stability. It results from the integration of the primary signals within the SMC: visual, ocular-muscular proprioceptive, vestibular, and dynamic ocular-cephalic movement. Incoherence in activation patterns of these various signals results in illusory motion perception such as that experienced during two to three days of exposure to magnifying lenses. Previous experiments have demonstrated the involvement of the cerebellum in the mechanisms responsible for the adaptive changes resulting from the alteration of the normal visual-vestibular relationship (12).

5. Trajectory Control
Trajectory control includes gait, locomotion, and coordination, such as eye-hand, ear-hand, eye-foot, eye-head coordination etc (37).

2.4. THE POSTURAL DEFICIENCY SYNDROME

Postural Deficiency Syndrome (PDS) is medically described as a condition that includes a composite of symptoms in relationship with variations of the upright position (47). PDS labeled patients always acknowledge, among other signs, instability, sensory and cognitive overloads, dizziness, pains radiating from their body axis, circulatory disorders. As defined, PDS does not correspond to any macroscopic lesion of an anatomically defined system. The severity of PDS symptoms has no relationship to that of the cause (38, 46). Tables I and II show the neuromuscular and neurovascular functional signs and other characteristics of symptoms of patients suffering from PDS as defined by H. Martins Da Cunha in 1987 (47). Such signs are conventionally used in medicine to diagnose PDS in clinical posture-related practices.

3. STATIC POSTURE ANALYSIS FOR THE ASSESSMENT OF THE SENSORY-MOTOR CONTROLS REGULATORY SYSTEM

Postural analysis has become more commonly used across a breadth of medical disciplines such as rehabilitation medicine, physiatry, and orthopaedic medicine, as well as paramedical disciplines such as kinesiology, physiotherapy, and chiropractics. More specifically, static postural analysis should be applied when appropriate in order to successfully capture data that is of interest for the analysis of the sensory-motor controls' regulatory status. As is shown in Section 3.1, our review shows that these disciplines apply postural analysis that capture some but not all relevant parameters necessary for SMC study.

The current assessments used in the field of medical neurophysiology have combined and refined the measurements of various medical and paramedical disciplines while upgrading them with progress made in neuroscience focused on postural study. The outcome has shown to be an effective method to quantify data specifically concerning sensory motor controls' interactions and further identify their respective functional patterns. This is illustrated in Section 3.2.

3.1. STATIC POSTURAL ANALYSIS IN HEALTH CARE

3.1.1. Chiropractics

Static posture assessments are used in chiropractic care primarily for assessing the status of a patient's spine without the use of x-rays. The number of widely available devices and systems to perform static posture analysis developed for chiropractors attests to its importance in chiropractic care. However, these technologies concentrate measurements and analysis on determining the biomechanical shape of the spine, which is of little use for sensory-motor or neurological analysis.

3.1.2. Kinesiology, Physical Therapy & Rehabilitation

In disciplines such as kinesiology it has been shown how moments of force in gait can be interpreted as CNS signals that reveal balance control strategies in standing and in gait. Winter (25) concluded that without knowing information on the centre of pressure and centre of gravity in the subject it is impossible to identify many balance related issues. This is important to note in analysis of the SMC, as it further shows the connection between the postural and vestibular systems in the control of balance. Clearly any balance disorder must necessarily be both a vestibular and postural disorder (28, 11).

3.1.3. Neurology

In Neurology, static postural analysis is used to help identify the cause of neurological ailments, syndromes, and diseases that are relevant to the muscular-skeletal system. It can also be part of a comprehensive clinical examination of the neural-motor system. However, it is not adequately used to address neural functional performance such as coordination and dexterity, trajectory control, space perception, and collision avoidance. A comprehensive and more integrated approach to sensory-motor and cognitive performance is required to actually differentiate syndromes that could be confused with actual disease defined by degenerative and destructive evolution.

For example, a patient with Parkinson's disease is known to stand in a characteristically flexed posture. There are other afflictions involving the extra-pyramidal system that may similarly affect one's posture (26). However, examination measurements of this type have not been quantified with respect to posture, and are performed by visual inspection by the physician. Therefore, it can occur that a patient may be held in such a bizarre posture that a mistaken diagnosis of a psychiatric disorder is made rather than a neurological disease (26). Neurological postural examinations yield little in information relating to the sensory-motor controls. However, it can be seen that even in Neurology's routine examinations of the motor system, posture is considered a major element in the diagnosis of disease.

3.2. STATIC POSTURAL ANALYSIS IN MEDICAL NEUROPHYSIOLOGY

Over two decades of medical research and practice have lead to a focus on the study of the sensory-motor controls regulatory system (SMC-RS) (37) which appears to be the core control system governing the FPS mechanisms underlying posture and gait. For example, clinical observation has shown that SMC-RS governs postural neuromuscular tonus, as well as visual ocular motor, vestibular, and cerebellar controls, through the FPS (37, 39). These areas coordinate to handle and naturally optimize balance control during both static and dynamic activities.

The SMC-RS is known to underlie coordination and motion, postural control, trajectory control, time awareness, body perception, spatial laterality, as well as cognitive functions and emotional stability. For this reason, sensory-motor overloads may "shut-down" functional "circuits", reducing the ability to cope with future overload and result in "invisible disabilities" which equate to incident-accident proneness (37, 38, 39). It is known that exposure to weightlessness in microgravity and subsequent adjustment of SMCs result in postural ataxia in astronaut's (28). Re-adjustment to G=1 becomes necessary and often transitorily difficult upon returning to Earth (28) or possibly an Earth-like gravitational field (35). As found in the literature symptoms such as dizziness and postural ataxia, which suggest a loss of the normal relations between a subject and the environment may be an indication of dysfunction within the fine-postural system (11).

3.2.1. Neurophysiological Methodology Objectives

Traumas may affect or induce disorders in one or more of the physical, cognitive, intellectual, and emotional and behavioural origins, and it is important to identify which of these areas are affected. An example of trauma includes the increased stress during astronaut's insertion and return from orbit in Space. These overloads are often observed to cascade into the rest of the healthy subsystems.

Sensory-motor dysfunction induces three possible mechanisms of error proneness occurrence as seen in PDS. 1) Physical origin, which includes alteration of fine postural control, coordination and fine-tuned dexterity, strength, reaction time, fatigue, space perception and orientation, balance and stiffness. 2) Cognitive origin, which includes perceptually, deterioration of position and trajectory control, attention and vigilance, time awareness, decision-making, concentration, and memory. Decision-making is based on information available from the sensory-motor system, and when this information is distorted, judgment can be severely affected. Memory related dysfunction also impacts decision making skills. 3) Intellectual origin, which includes the ability to reason, plan, solve problems, think abstractly, comprehend ideas and language, and learn. 4) Emotional and behavioral origin, which includes loss of motivation, self-control, irritability, fear and anxiety, as well as excess or loss of aggressiveness.

In confined and extreme environments, overloaded sensory-motor controls have been observed to induce physical, cognitive/perceptual, intellectual, emotional, and behavioral changes (13, 35) such as those described in the clinical definition of postural deficiency syndrome (PDS), discussed in the next section.

The assessments in neurophysiology focus on the FPS. This is done by assessing the visual-ocular-vestibular-postural strategy connections, interrelations, and strategy status. While this paper focuses on the postural components only, the following steps summarize this approach more clearly:

- Detecting SMCs disorders that underlie condition, symptoms, disabilities, accident proneness and defects by exploring postural, visual, vestibular and related cognitive functional status. This allows identification of Postural Deficiency Syndrome (PDS) which is defined as the underlying neurophysiological medical condition.
- Identifying SMC related symptoms.
- Monitoring functional loss and gain potential while under stimulation, treatment (pharmaceuticals, visual cues etc.).
- Monitoring levels of recovery.

By identifying areas of risk these techniques can also be applied to proactively reduce proneness of human-error (accident proneness) (39). This is achieved through four steps: 1) forecasting accurately a subject's vulnerability to error and accident proneness; 2) determining areas of a subject's impairment which would increase risk; determining a subject's aptitude to perform a given task; 3) orienting a subject towards resolving the actual underlying cause of impairment; defining the proper therapeutic sequence of action and strategy for a subject; 4) monitoring a subject's error and accident proneness status.

These techniques and steps are combined with the basic outline of a postural examination appropriate for analysis of the SMC. Why and how this should be further studied for application with astronauts is discussed in the following section.

3.2.2. Postural Parameters Measured

There are a number of requirements in order to obtain relevant data. Subjects should stand comfortably facing forward, looking straight ahead at a target (36), with arms at their sides. Angles are measured in respect to vertical and horizontal planes. In the frontal plane, asymmetries in scapular and pelvic girdles, head tilt, shoulder slope, and upper limbs. In the horizontal plane, scapular and pelvic girdle rotation are noted. In the sagittal plane, head-neck-spine rapport, and head-neck-upper limb-lower limb rapport. The postural static equation (11) includes the scapular and pelvic girdles position in respect to each other.

An examination of head-neck motion is also appropriate here. These tests address the dynamic head-neck-scapular girdle equation, which includes the four directions of motion in space. Head-neck flexibility and motion amplitude are measured from side to side, forward/backward, and turning left to right. There are two levels of comparison - range and symmetry - between right and left. Norms for head-neck-scapular girdle dynamics relate to the physiology of the locomotor system.

According to our clinical experience, for optimal results, thirteen parameters ought to be measured in a static postural assessment focused on the analysis of the SMC-RS status (38). The normal ranges for each parameter are defined in the Norms established by the French Society of Posturology in the 1980s (34). Taking measurements of these parameters will yield information and towards specific postural (and therefore SMC) strategies that have been developed in a given individual. These strategies can be modeled via the postural static equation (11) to yield information regarding the FPS which in turn yields clues about the interactions of the visual and vestibular systems.

3.2.3. Example: A Routine Static Postural Assessment Used for Postural Deficiency Syndrome

The following describes how a postural analysis may be applied by example of clinical results and conclusions (36). The case described how these symptoms can be successfully diagnosed and mitigated in PDS patients as seen in aviation, sports, motor-vehicle accident related traumatic contexts.

In order to stay within the scope of this paper, we present here only the static postural component of this case study. It demonstrates how measurements of the FPS can be used as a gateway to identify specific dysfunctions within and between the subsystems integrated within SMC. The full case study was presented at the International Astronautical Association's Symposium on Human's in Space, in May 2005 Graz, Austria (36).

A 23-year-old professional NHL hockey player had experienced three severe concussions, along with other traumas on the ice over five year period. He suffered from a number of severe classic post-concussive PDS related symptoms, including lack of coordination, back pain, headaches, poor sense of balance and space and increased anger and fear emotions.

Fig. 1 shows some of the static postural measurements before treatment occurred. The vertical axis of the chart displays the deviation in degrees measured from the normal or ideal, which is calibrated to be the zero line. The horizontal axis displays the postural parameters being measured: head tilt (HT), shoulder girdle (SGL), hip girdle (HG), and hand line (HL), and multi-plane hand line (MPHL). Each parameter is displayed distinguishing between the right and left laterality, and front and back (delta R (red), delta L (green), delta F (blue), and delta B (yellow) respectively).

Here six areas of compensation can be identified (three green bars, two yellow bars and one red bar all rising upwards), one area unable to be compensated for (red bar declining downwards), and seven areas near the zero line (ideal). Overall this should be interpreted as 50% of the static postural test "failing" on a magnitude of the degrees shown. This relates to and confirms the severity of the symptomatology and error proneness the player was experiencing. Equally as important is distinguishing what are the most problematic - dysfunctional - areas in the postural system in order to further connect the relationships within the SMC.

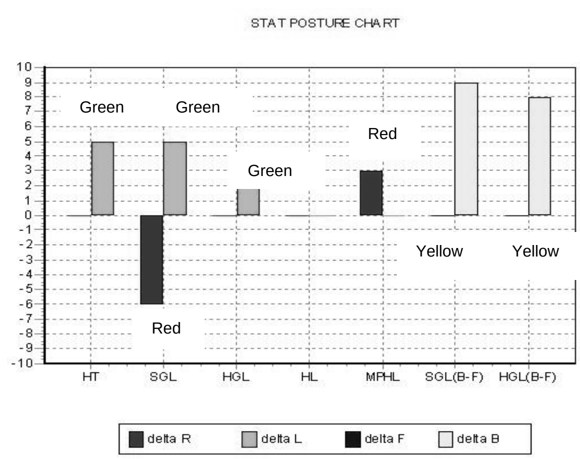


Fig. 1: Static Posture before Treatment

Analysis of this postural data, along with visual-ocular motor and balance test (vestibular) data, indicated disturbances involving the III, IV, V, VI, VII, XI, and X cranial nerves (35, 36). These functional neural networks also involve upper structures located higher within the CNS functional hierarchy, such as the central grey nuclei, vestibular, ocular-motor and limbic systems and others also relating to the autonomic nervous system. These are all systems found within the SMC. The testing objectively confirmed that the cause of this condition was from a central dysfunctional origin within the CNS. It meant for this individual that all related areas of physical performance outcome, such as balance, proprioception, movement, hand-eye and foot-eye coordination would be impacted as well as intellectual, emotional, and decision making abilities.

4. FUTURE RESEARCH FOR APPLICATION WITH ASTRONAUTS

The following sections delineate considerations and steps for future research objectives, which in our view would lead to a greater understanding of SAS and PFAS along with related applications to astronaut operations. Such applications include prognosis, selection, risk prevention, diagnosis, accident proneness and performance optimization, effective treatment, and return to work. This is taken as indicated from the literature reviewed in this paper.

4.1. SAS & PFAS CORRELATE WITH PDS

Tables I and II show the neuromuscular and neurovascular functional signs and other characteristics of symptoms of patients suffering from PDS as defined by H. Martins Da Cunha in 1987 (47). Such signs are used to diagnose PDS in clinical posture-related practices. This section reviews and further illustrates how these compare with SAS and PFAS symptoms

The most incapacitating effects of SAS have been recorded to last for the first 1-5 days of weightlessness, and even occurring in some astronauts just after they have returned to Earth (24). Consequences may range from simple discomfort to incapacitation, creating potential problems during re-entry and emergency exits from a spacecraft. It is for this reason that no extra-vehicular activities (EVAs) are permitted during the first few days of NASA shuttle flights (51). An extensive list of known symptoms, taken from various texts (24, 48, 49, 50, 33, 29) are shown in Table III.

SAS is not the only potential health issue facing astronaut's sensory-motor adaptation. Re-adaptation during a return to the gravitational acceleration on Earth's surface occurs in all returning astronauts. Following space-flight, crewmembers experience (often severe) gait and postural instabilities due to their in-flight adaptive alterations to sensory-motor control function. Post-flight astronauts display a variety of postural difficulties including the inability to maintain a stable posture, particularly with their eyes closed, using a wide stance to stand and walk, feeling sensations of lateral acceleration while walking, and an inability to detect small changes in head positions (49). Coupled with the effects of weightlessness on muscle tonus and bone degeneration, an astronaut may have difficulty standing or walking at all.

PFAS usually only lasts a few days, and it was concluded by NASA that Skylab astronauts took an average of 10 days of recovery time before their preflight posture and gait abilities were fully restored (17). A major concern is that on a manned-mission to another gravitational body such as Mars, astronauts may be incapacitated for as long as a few days. Clearly this would be an unacceptable situation for crewmembers health and safety, as well as for the success of the mission.

TABLE I
Cardinal Signs (47)

Signs	Clinical manifestations - symptoms
Pain	Headache, retro-eye, thoracic or abdominal pain, arthralgies, rachialgies
Imbalance	Sickness, nausea, dizziness, inexplicable falls
Ophthalmological	Asthenopia, dim vision, diplopia, directional scotoma, metatopsia
Proprioceptive	Dysmetria, somatoagnosia, errors of appreciation of the body image

TABLE II
Associated Signs (47)

Signs	Clinical manifestations - symptoms
Articular	TMJ Syndrome, stiff neck, lumbago, periarthrities, sprains
Neuromuscular	Paresia, defect of driving control of the extremities
Neurovascular	Paresthesia of the extremities, Raynaud's phenomenon
Cardio-circulatory	Tachycardia, lipothymia
Respiratory	Dyspnoea, fatigue
ORL	Hummings, deafness
Psychic	Dyslexia, dysgraphia, agoraphobia, defect of orientation, defect of spatial localization right and left, defect of concentration, loss of memory, asthenia, anxiety, and depression

Seen together, as shown in Table IV, these tables yield a clear correlation between symptoms of SAS and PFAS with the criteria for PDS diagnosis. This was first presented at the 35th International Conference on Environmental Systems and 8th European Symposium on Space Environmental Control Systems

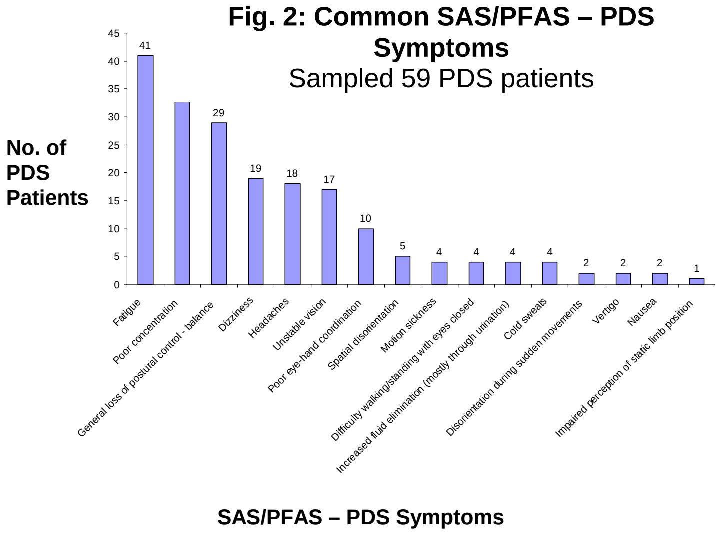
TABLE III
Common SAS/PFAS Symptoms Found (24, 29, 33, 48, 49, 50)

General Signs	SAS/PFAS	Symptoms
Pain	SAS	Headaches, vomiting, digestive spasms
Imbalance	SAS/PFAS	Motion sickness, nausea, dizziness, inexplicable falls, poor concentration postural equilibrium disturbance, faintness, illusions and alterations of motor performance such as feelings of heaviness, disorientation when making sudden head movements, inability to move about in the dark, illusions of floor motion during vertical body movements
Ophthalmological	SAS/PFAS	Eye-hand, eye-body, eye-head coordination impairment, postural equilibrium disturbance, disorientation when making sudden head movements, inability to move about in the dark, illusions of floor motion during vertical body movements, illusory sense of surroundings
Proprioceptive	SAS/PFAS	Illusory sense of self, eye-head, eye-hand coordination impairment, postural equilibrium disturbance, dizziness, nausea, illusions and alterations of motor performance such as feelings of heaviness, disorientation when moving suddenly, inability to move about in the dark, illusions of floor motion during vertical body movements.
Articular	SAS/PFAS	Postural equilibrium disturbance, illusions and alterations of motor performance such as feelings of heaviness, limitation in extension amplitude
Neuromuscular	SAS/PFAS	Headaches, eye-head and eye-hand coordination impairment, postural equilibrium disturbance, nausea, illusions and alterations of motor performance such as feelings of heaviness, disorientation when making sudden movements
Neurovascular	SAS/PFAS	Headaches, postural equilibrium disturbance, faintness, dizziness, nausea
Autononmic Neuro-Vegetative	SAS	Cold sweating, chills, paleness, dermal goose-bumps

TABLE IV
PDS Criteria Applied to SAS/PFAS Symptoms

PDS Criteria	SAS/PFAS	SAS/PFAS Symptoms
Pain	SAS	Headaches, vomiting, digestive spasms
Imbalance: Vestibular - Cerebellar	SAS/PFAS	Motion sickness, nausea dizziness, inexplicable falls, poor concentration postural equilibrium disturbance, faintness, illusions and alterations of motor performance such as feelings of heaviness, disorientation when making sudden head movements, inability to move about in the dark, illusions of floor motion during vertical body movements
Neuro-Ophthalmologic Coordination	SAS/PFAS	Eye-hand, eye-body, eye-head coordination impairment, postural equilibrium disturbance, disorientation when making sudden head movements, inability to move about in the dark, illusions of floor motion during vertical body movements, illusory sense of surroundings
Proprioceptive	SAS/PFAS	Illusory sense of self, eye-head, eye-hand coordination impairment, postural equilibrium disturbance, dizziness, nausea, illusions and alterations of motor performance such as feelings of heaviness, disorientation when moving suddenly, inability to move about in the dark, illusions of floor motion during vertical body movements.
Articular	SAS/PFAS	Postural equilibrium disturbance, illusions and alterations of motor performance such as feelings of heaviness, limitation in extension amplitude
Neuromuscular	SAS/PFAS	Headaches, eye-head and eye-hand coordination impairment, postural equilibrium disturbance, nausea, illusions and alterations of motor performance such as feelings of heaviness, disorientation when making sudden movements
Neurovascular	SAS/PFAS	Headaches, postural equilibrium disturbance, faintness, dizziness, nausea
Autonomic Nervous System	SAS	Cold sweating, chills, paleness, dermal goose-bumps

The above chart resulted from the study of fifty-nine consenting PDS patients. The data correlates symptoms exhibited in patients suffering from PDS to



that of symptoms commonly exhibited by astronauts suffering from SAS and PFAS (35). This graph (Fig. 2) shows sixteen common symptoms observed in astronaut's neurophysiological adaptation to orbital flight and by the patients used for this report. The SAS symptoms are pooled in terms most symptoms experienced by PDS patients sampled. The graph shows how many patients suffered from each symptom. From this graph, it can be seen clearly that most patients suffered from at least four to five of these SAS/PFAS like symptoms. The sixteen symptoms shown here are: dizziness, headaches, cold sweating, fatigue, nausea, motion sickness, spatial disorientation, impaired static limb position, general loss of postural control/balance, poor concentration, unstable vision, poor eye-hand coordination, disorientation during sudden movements, vertigo, difficulty walking/standing with eyes closed, and increased fluid elimination through frequent urination.

A similar distribution pattern in SAS and PFAS symptoms in astronauts should be investigated and more research should be dedicated towards specific historical astronaut/cosmonaut medical data for comparison with this plot. This could be the first real test of this correlation.

4.2. STATIC POSTURAL ANALYSIS METHODOLOGY APPLIED TO ASTRONAUTS

This section illustrates how static postural analysis in medical neurophysiology may be used to study more effectively astronaut SMC related disorders.

Current experimental results support hypotheses that the absence of gravity leads to adaptive changes in the neural strategies that are used for resolving ambiguous linear accelerations detected by the otolith system (32). In the absence of a gravitationally defined vertical, normally ambiguous visual references here on Earth become vital for astronaut orientation during orbital flight. When gravitational down cues are absent in weightlessness, astronauts rely primarily on their vision and secondarily on proprioception for spatial orientation. Impairment of gaze and head stabilization reflexes can lead to disorientation and reduced performance in tasks relying on a high level of sensory-motor skill, such as piloting a spacecraft. This is believed to be the lead cause of SAS and PFAS (32). Clearly it is a combination of the visual, vestibular and postural systems contributing to cause the central neural functional disorder and related symptoms.

Examples of the above can be seen in the well-documented Skylab missions. Also it can be seen that postural analysis was and is not well represented physiological examinations of the astronauts.

The Skylab 2 mission lasted for twenty-eight days, limited to simple tests of balancing with eyes open and closed while standing on the floor. The crewmembers were tested during the 1st and 2nd day following splashdown, and indicated that they all experienced considerable difficulty when standing on the floor with their eyes closed, however no problems were recorded when visual cues were given. These tests were performed on a moving ship (14).

The Skylab 3 mission, which lasted for 59 days, had the scientist pilot and pilot tested on the 2nd, 9th, and 29th day following splashdown. The tests showed a decrement in performance under both the eyes open and closed conditions, although a much more pronounced decrement was observed during the eyes closed condition. On the 2nd day, with visual aid, the pilot experienced considerable difficulty even when attempting to stand on the floor, despite his excellent pre-flight scores. The rate of recovery of the pilot was much slower than the scientist pilot, showing poor performance even on the 9th day of recovery. The Skylab 3 commander reported feeling that he was moving sideways while stepping forward, and several other crewmembers reported this sensation of 'forced lateral movement' (14).

Skylab 4, lasting for 84 days, had all crewmembers tested on the 2nd, 4th, 11th and 31st day post-flight. The commander and pilot showed no decrease in post-fight abilities when tested with their eyes open, however they did show a very large deficit in ability to balance with their eyes closed. On the first day of post-flight testing, the commander was unable to maintain the required vertical posture while standing on the floor with his eyes closed; his pre-flight abilities were not gained back until the 11th day of post-flight recovery (14).

Although Skylab crewmen were able to walk immediately after exiting the command module, they did so with noticeable difficulty, tending to use a wide-stance shuffling gait with the upper torso bent slightly forward (17). During the first several days following post-flight recovery, crew reported the simple act of walking required a conscious effort. All crewmen reported post-flight that rapid head movements produced a sensation of mild vertigo and any slight head movement while their eyes were closed would induce vertigo and cause loss of balance. NASA Skylab flight surgeons and scientists concluded that Skylab crewmen required ten days to regain normal postural stability (17).

Presently there exists no operational countermeasure to mitigate the symptoms of PFAS (50) such as those experienced by the Skylab astronauts. Studying measurements of postural parameters and combining that information with ocular-visual and vestibular data, such as done in the diagnosis of PDS patients, may yield information towards specific SMC strategies that have been developed in a given astronauts.

These strategies may be modeled via the postural static equation (11) to yield information regarding the FPS which in turn yields clues about the interactions of the visual and vestibular systems. This could then possibly lead to effective treatment strategies for PFAS such as those that have been developed for PDS (35, 39). Such a research study could be collaboratively done in a similar approach to the example given in Section 3.2.3.

CONCLUSION

The history of Medicine shows that the study of human posture has been found to be a necessary part in the comprehensive and integral understanding of any functional disorder within the sensory-motor controls located in the CNS. Postural Deficiency Syndrome closely correlates with Space Adaptation Syndrome and Post-Flight Adaptation Syndrome symptoms in astronauts (36) and this correlation should be investigated further.

Static postural analysis is simple, reliable, and easy to apply, incorporates standardized norms, and is allows for the objective quantification of postural data. Given these facts, it is recommended that neurophysiological postural analysis, as described within the scope of this paper, ought to be studied further for pre-flight, in-flight and post-flight assessments of astronauts along with currently applied balance and visual tests.

Such investigation appears necessary if sensory-motor control disorders, as found in Space Adaptation Syndrome and Post-Flight Adaptation Syndrome, are to be better understood and ultimately adequately addressed. This understanding could eventually be applied towards selection, accident proneness, risk prevention, and performance optimization for long duration space missions in the near future.

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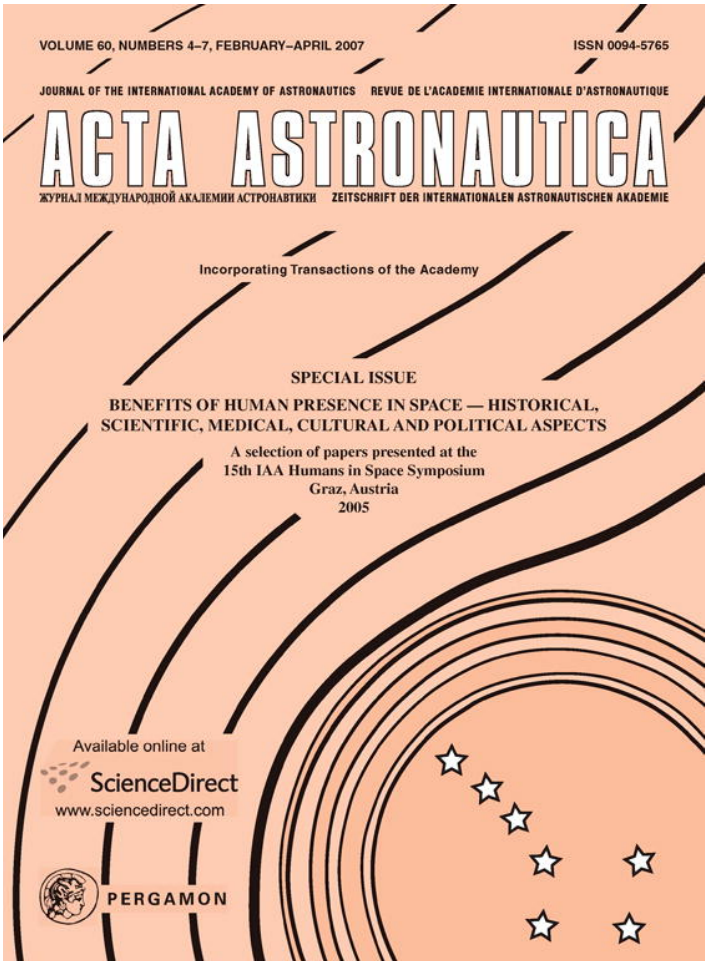
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Biomedical performance monitoring and assessment of astronauts by means of an ocular–vestibular monitoring system

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Abstract

The paper focuses on the strong correlation between unmitigated symptoms exhibited by post Space flight astronauts, and symptoms associated with postural deficiency syndrome (PDS) that can be correctly assessed, identified, and monitored via a neurophysiological ocular–vestibular monitoring system (OVMS). From examining clinical data taken over a 10-year period from patients experiencing PDS related acute and chronic post-traumatic medical conditions, the authors show the potential for current assessment and monitoring techniques to examine better the impacts on astronaut neurophysiology. The data presented provide strong evidence that this biomedical monitoring and assessment methodology along with appropriate technology can lead to a better understanding of astronaut post-flight neurophysiology, which is necessary if human exploration in Space is to continue on a successful path.

Keywords: Biomedical; Neurovestibular; Monitoring; Astronaut; Post-flight; Ocular–visual

1. Introduction

The sensory-motor controls (SMC) located in the brain encompass various components and sub-systems influencing the full central neural hierarchy that handles sensory input and directs integrated motor adjustment and movement throughout the body. This integration links postural neuromuscular tonus, visual–ocular-motor controls, neurovestibular controls and the fine postural system (FPS). It is recognized in fundamental neuroscience and Space operational medicine that these SMC underlie human factors that include, but are not limited to eye–hand coordination, fine tuned dexterity, body positioning in Space, Space projection and trajectory control, perception of environment/obstacles, orientation in Space and time, sensory-motor and cognitive aspects of decision making, sensory-motor/cognitive error proneness. All of these factors are necessary for the astronaut's mission capabilities, both while carrying out operations in Space and performing the tasks required during and after re-entry.

It has recently been shown that there exists a strong correlation between the symptoms of patients suffering from postural deficiency syndrome (PDS) [30] on Earth that have been successfully assessed, diagnosed and treated, to that of the symptoms most often suffered by astronauts during adaptation periods for orbital flight and post-orbital flight [1]. In this paper, the authors focus on how PDS related medical conditions are currently assessed, identified and monitored, and how these procedures and technology translate into a potential for

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better understanding of the sensory-motor adaptations of astronauts.

With today's Space initiative focused towards exploration, the need for viable biomedical and performance monitoring and restoration technology has never been greater. An ocular–vestibular monitoring system (OVMS), utilizing neurophysiological principles with respect to sensory-motor and cognitive controls, and state of the art technology, has clinically shown to effectively assess and monitor performance in individual's SMC system and sub-systems such as the neurovestibular system [2,3]. This methodology and technology allow for a better understanding of a higher order of functional interconnection of the neurovestibular, visual-ocular, and postural control systems, what we will refer to as the "Big 3", and its affects within the human body at large. The OVMS does this by providing accurate, objective measurements and correlations of one's SMC allowing precise evaluation of the fine postural system status. This has led to more physiologically specific diagnoses and therefore effective treatment strategies and protocols.

The assessment approach and technology presented here have been successfully applied in evolving forms over the last two decades on a large number of patients and subjects including test/fighter pilots and flight crews, Olympic gold medalists, and professional athletes. One of these patients, a National Hockey League (NHL) player, is included here to illustrate the full scope and benefits of this neurophysiological approach.

While this paper focuses on the potential for studying the symptoms exhibited by all astronauts after landing, there is also a brief discussion on Space adaptation syndrome. It is important to understand the adaptive processes astronauts go through when they are exposed to microgravity before the symptoms exhibited by them when returning to Earth can be fully understood and further discussed.

2. Astronaut health and performance paradigms

Of the many health risks and problems facing astronauts during short and long duration missions, one of the biggest causes for concern is dealing with the negative effects of weightlessness on the human body. Such effects include loss of bone density, muscle mass, and red blood cells; lower to upper body fluid shifts; cardiovascular and sensory-motor deconditioning, and changes within the immune system [4]. During long duration inter-planetary missions to the Moon, Mars, and beyond, one of the most important effects to consider is the deconditioning of the SMC and the subsequent impacts that has on all human-related operations during and after re-entry to a planetary object.

The human sense of balance depends on an extremely sophisticated sensory system calibrated to Earth's gravity as a reference frame providing an appropriate data stream to the brain. Part of the key motion sensors is the subtle organs of the vestibular system inside the inner ear that function as super-sensitive accelerometers that feed signals to the brain that indicate motion and direction. There are also motion, tension and pressure receptors in the skin muscles, and joints to assist in spatial awareness (proprioception); the senses of sight and hearing complete this data stream. Without having to be consciously aware of it, one typically knows everything they need to about their body's posture and gait, and therefore their state of balance, at any given time.

Adaptation to microgravity requires the functional re-organization at a higher order of integration of the central nervous system's (CNS) processing of these three major sources of spatial information, the "Big 3"—visual, vestibular, and postural controls [5]. Current experimental results support a hypothesis that the absence of gravity leads to adaptive changes in the neural strategies that are used for resolving ambiguous linear accelerations detected by the otolith system. In the absence of a gravitational vertical, normally ambiguous visual references here on Earth become vital for astronaut orientation during orbital flight. Impairment of gaze and head stabilization reflexes can lead to disorientation and reduced performance in tasks relying on a high level of sensory-motor skills, such as when piloting a Spacecraft [6].

The exact nature of this re-organization and adaptation has not been well defined or understood, and therefore no substantiated techniques to mitigate these problems have yet been developed.

2.1. Space adaptation syndrome

Conflicting SMC inputs from the "Big 3" are most likely the cause. In the absence of gravity, some signals from within the "Big 3" become inappropriate and thus conflict with the normal function processing patterns to such a point that immediate disorientation usually occurs. This causes many astronauts to suddenly feel as if they are upside-down or spinning and may even have difficulty sensing the location of their own arms and legs. This disorientation is described as part of Space adaptation syndrome (SAS) and is the main cause of Space motion sickness (SMS). Two-thirds of all astronauts will suffer from symptoms of SAS during the first few days of orbital flight [7].

The most incapacitating effects of SAS have been recorded to typically last for the first one to five days of weightlessness [7]. Known common symptoms include dizziness, vertigo, headaches, cold sweating, fatigue, nausea, and vomiting/motion sickness [7]. Consequences may range from simple discomfort to incapacitation, creating potential problems during re-entry and emergency exits from a Spacecraft. It is for this reason that no extra-vehicular activities (EVAs) are permitted during the first few days of NASA shuttle flights [8].

Current evidence favors a "sensory conflict theory" as the primary cause of SAS observed in astronauts, as shown by animal studies performed in Space [9]. Symptoms of SAS are not typically reduced on veteran astronauts during subsequent flights and the precise mechanisms where the conflicts are occurring are not well-understood and thus effective therapies and preventative measures for SAS have not yet been adequately developed [7].

2.2. Post-flight adaptation syndrome

Unfortunately, SMS is not the only health issue facing astronaut's SMC. Re-adaptation during a return to the gravitational acceleration on Earth's surface is just as challenging and will affect all returning astronauts to some degree. Following Space flight, crewmembers experience (often severe) postural and gait instabilities due to their in-flight adaptive alterations to SMC function. Post-flight astronauts display a variety of postural difficulties including the inability to maintain a stable posture, particularly with their eyes closed, requiring a wide stance to stand and walk, sensations of lateral acceleration while walking, and an inability to detect small changes in head positions [10]. Coupled with the effects of weightlessness on muscle tonus and bone degeneration, an astronaut may have difficulty standing or walking at all. The authors refer to these post-flight symptoms and disturbances as post-flight adaptation syndrome (PFAS) [1]. Symptoms of PFAS have been previously well-documented and tabulated [7,11,10,12–14,1].

Like symptoms of SAS, this disorientation usually lasts a several days. It was determined by NASA researchers that Skylab astronauts took, on average, 10 days of recovery time before their pre-flight abilities were fully restored [15,24]. While no long-term effects of this re-adaptation process have yet been observed, the major concern here is on a manned mission to other planetary objects such as Mars. As the astronauts land on the surface, their bodies may likely be incapacitated for up to several days. We must consider that the alien world in which they land on will likely be hostile and inhospitable and there will be no ground crew there for on-site support. A rescue operation, such as the one launched for the crew of ISS Expedition 6 when their re-entry module landed off course in 2003, would be improbable if not impossible. An unsafe and unfit crew landing on Mars would be an unacceptable situation for the success of a mission that may be the most momentous accomplishment in human exploration to date. Like SAS, PFAS has also been poorly understood and there presently exists no operational countermeasure to mitigate its symptoms [12].

3. The ocular–vestibular monitoring system

The OVMS is a combination of neurophysiological methodology and high technology merged to allow for consistent and accurate measurements of human neurophysiological parameters. The system requires a sensory-deprived environment, and utilizes a unique and patented binocular monitoring device, shown in Fig. 1, a large calibrated target directly opposite of where the patient stands, and a semi-automated computerized data acquisition system. Here, sets of elegant non-invasive sensory–motor tests are conducted for which a patient's response is measured and then recorded [2]. Each test brings fundamental data and clues, which can be used in subsequent tests.

The suite of tests in this assessment procedure includes postural, visual–ocular–postural, writing–throwing–catching strategies, visual–postural–manual aiming perception of Space, extra-ocular-motor status, postural balance and perception of self in Space, static and dynamic balance tests, head–neck motion, along with monitoring the laterality of each of these neurophysiological parameters during the tests.

The system is designed such that each subsequent test validates results from each prior test. This reinforcement suggests consistency and can be interpreted by itself as confirmation of a subject's given sensory-motor and cognitive status.

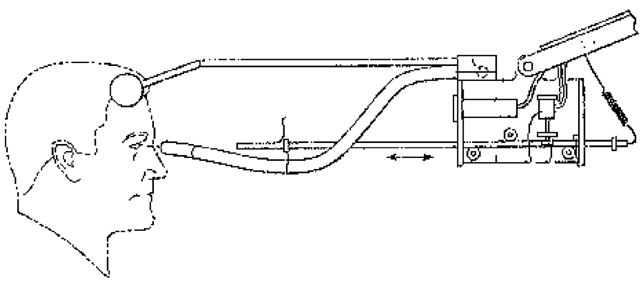

Fig. 1. Binocular monitoring device.

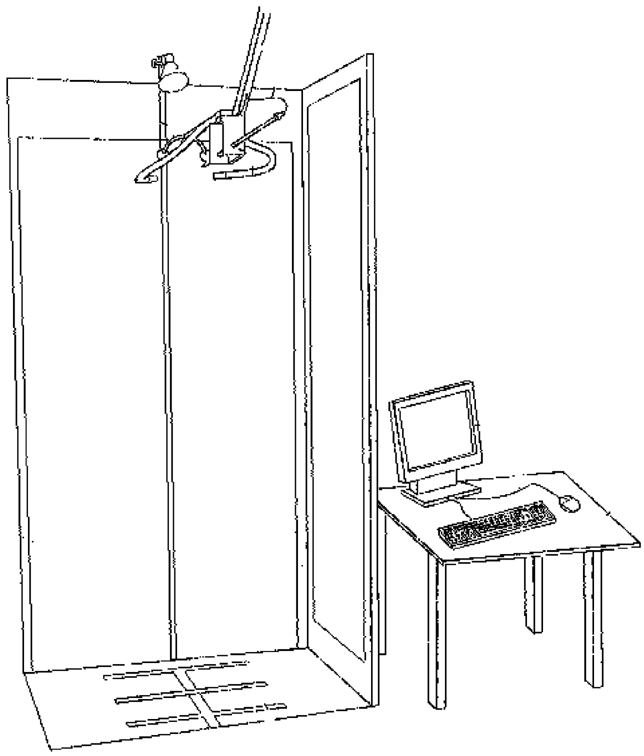

Fig. 2. Patient area of OVMS.

Assessing visual–ocular–vestibular–postural ("Big 3") strategy connections, interrelations, and strategy status is of primary importance to be able to provide realistic, effective solutions to the patient. Five objectives characterize the OVMS approach presented here as applied in a clinical setting:

1. Detecting sensory-motor disorders.
2. Identifying sensory-motor related symptoms.
3. Evaluate functional loss and gain potential.
4. Monitor the condition recovery.
5. Evaluate Error/Accident Proneness.

To explain this composite system, shown in Fig. 2, a brief introduction to SMC and some of the related sub-systems, which are examined and measured by this system, is explained. This is followed by a case study that illustrates the principles the OVMS is based on and the data that it is capable of producing from these tests.

3.1. Balancing act–OVMS parameters explained

The correct transfer and integration of signals within the brain and central nervous system (CNS) from all areas of the sensory-motor system is essential for the maintenance of stable vision, spatial orientation, eye–head and hand coordination and postural and locomotion control on Earth. The plasticity of the CNS allows individuals to adapt and compensate under altered sensory stimulus conditions. The change in conditions to microgravity rearranges the relationship between signals from the "Big 3" causing SAS or PFAS symptoms.

The perception of location and position are a result of the brain's ability to integrate signals from "Big 3" into useful information. The input the brain receives from sensors, modified by gravity changes, prompts the CNS to develop a new interpretation, hence a different and therefore compensatory adjustment strategy. If this new interpretation does not match specifically calibrated functional patterns in the brain, symptoms of SAS or PFAS are likely incurred, significantly reducing an astronaut's operational efficiency [16].

3.1.1. The neurovestibular system is the key

The peripheral vestibular apparatus in the inner ear consists of two sensory receptors. The semicircular canals signal rotary movements of the head. These liquid filled tubular loops act has angular accelerometers arranged in three orthogonal planes. The change in volume of each loop translates body movement to signals interpreted by the brain. The otolith organs sense linear forces such as gravity acting on the head. These calcium carbonate concretions embedded in gelatinous material act as linear accelerometers for the brain. Neural signals produced under acceleration are integrated in the CNS with signals from proprioceptors reporting the position relationships of the limbs, trunk and neck. Signals from skin pressure receptors, vision and stored cognitive perceptual memory data, are integrated to coordinate movements of the limbs, head and eyes.

Postural reflexes under otolithic control appear to be the key major physiological mechanisms depressed in flight as these symptoms occur even after missions of relatively short duration, where changes in bone and muscle strength are minimal [13]. A major difficulty facing aerospace physiologists is the identification and monitoring how (or even if) the vestibular system becomes depressed and which specific areas are depressed and at what times.

3.1.2. The fine postural system

An important function in postural control is the coordination of various muscular activities to maintain proper balance and orientation of the body with respect to gravity. This coordination is provided by a complex regulatory system called the fine postural system (FPS) [2,29]. The FPS models the core neurophysiological system through the CNS to provide balance control to the human body during static and dynamic performance.

Known components of the FPS [29] include the "Big 3" and the SMC system. Its functional core structure includes synergistic and antagonistic sensory-motor and cognitive structures that are part of a network diffusely located in various areas of the brain [3].

Another aspect of the multi-modal structure of the FPS consists of exosensors and endosensors [2,3]. These components only control small postural disturbances that move the body's axis up to 4° from the balance reference in a given position. Research has shown that one's postural balance depends on whether the amplitude of spontaneous movements to or from the balance position (not necessarily vertical) is greater or less than 4° [17].

The FPS provides a concise relationship between an individual's posture and the ocular–visual and vestibular systems. Therefore, when one investigates and measures the FPS, problematic areas within the SMC system and its associated sub-systems such as the neurovestibular system can then be identified, assessed and monitored. The OVMS calibrates measurements of the "Big 3" as a function of the FPS in terms of overall performance, neatly connecting each of the "Big 3" to the other.

3.1.3. Factors relating the "Big 3"

3.1.3.1. Factors involved in spatial orientation. In orbital flight and in the free-fall phase of parabolic flight, feelings of inversion of self and Spacecraft or aircraft are often experienced. The absence of falling sensations during weightlessness points to the importance of visual and cognitive factors in eliciting such sensations [18]. Human spatial orientation and ocular–motor control are therefore under multimodal influence. Many patterns of behavior and response that have been attributed solely to vestibular function are actually also dependent at least in part to touch, kinesthetic, and proprioceptive stimulation [19].

3.1.3.2. Spatial representation and localization. Gabriel Gauthier et al. demonstrated the capacity of the vestibular apparatus for coding spatial information through a better use of vestibular signal for further motor purposes than for cognitive matching [20]. Posture dependent performance relates to position in Space, and Space perception, complex motor skills and gait [21].

3.1.3.3. Auditory perceptual abilities. The perceptual localization of sound often is thought to depend solely on the pattern of auditory cues directed at the ears. Evidence has been presented that the computation of auditory direction also involves non-auditory information from the "Big 3" concerning the spatial configuration of the entire body [22]. The biasing of auditory localization indicates that identical patterns of arrival time and intensity cues in the ears can give rise to the perception of sounds in widely disparate spatial positions in relation to the head and body, depending on the proprioceptive representation of the direction of the sound source [23].

3.1.3.4. Factors involved in detection of relative motions. Detection of relative motions between oneself and the objects in Space relies on the perception of peripheral visual field stability. It results from the integration of the primary signals within the "Big 3": visual, ocular–muscular proprioceptive, vestibular, and dynamic ocular–cephalic movement. Incoherence in activation patterns of these various signals results in illusory motion perception such as that experienced during two to three days of exposure to magnifying lenses. Previous experiments have demonstrated the involvement of the cerebellum in the mechanisms responsible for the adaptive changes resulting from the alteration of the normal visual–vestibular relationship [20].

3.2. Clinical case study

The factors and parameters linked to the symptoms of PFAS are likely the same as those that are exhibited in PDS suffers. The following describes how these symptoms have already been successfully diagnosed and mitigated in PDS patients.

The case study presented here illustrates several of the OVMS parameters that are being measured and the degree of accuracy for the measurements. It demonstrates how measurements of the FPS are used as a gateway to identify specific dysfunctions within and between any of the subsystems of the integrated within the "Big 3."

A 23-year-old professional hockey player had experienced three severe concussions, two of which induced significant loss of consciousness, along with other traumas on the ice within a period of 5 years. He suffered from a number of severe classic post-concussive symptoms, including lack of coordination, back pain, headaches, poor sense of balance and Space and unbearable anger and fear. He was able to perform only intermittently and so spent most of his time sitting on the bench.

The following figures show the measurements that the OVMS is designed to obtain, and the order in which those measurements are taken so that a relationship between the "Big 3" can be established.

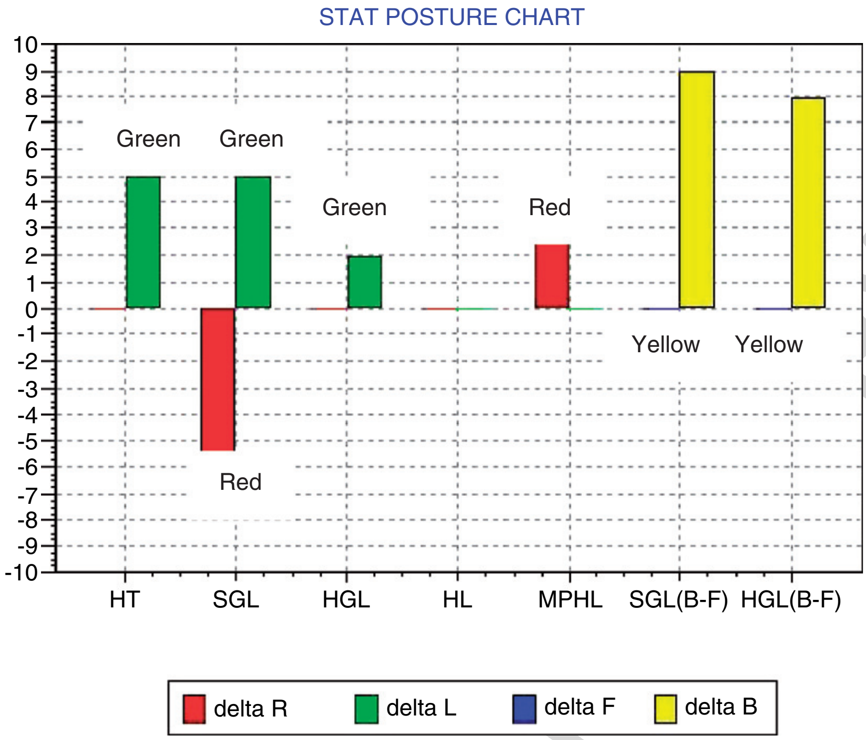

Fig. 3. Static posture before treatment.

Fig. 3 shows static posture measurements of this individual before treatment occurred. The vertical axis displays the deviation in degrees measured from the normal or ideal, which is calibrated to be the zero line. The horizontal axis displays the postural parameters being measured: head tilt (HT), shoulder girdle (SGL), hip girdle (HG), and hand line (HL), and multi-plane hand line (MPHL). Each parameter is displayed distinguishing between the lateral of right and left, and front and back (delta R (red), delta L (green), delta F (blue), and delta B (yellow), respectively). Here six areas of compensation can be identified (three green bars, two yellow bars and one red bar all rising upwards), one area unable to be compensated for (red bar declining downwards), and seven areas near the zero line (ideal). This should be interpreted as 50% of the static postural test "failing" on a magnitude of the degrees shown. This relates to and confirms the severity of the symptomatology and error proneness the player was experiencing. Equally important is distinguishing what are the most problematic—dysfunctional—areas in the postural system in order to further connect the relationships within the "Big 3."

Fig. 4 shows the same static postural measurements taken 3 weeks after treatment, displaying the dramatic progress of this individual. Treatment of these dysfunctions was only possible through proper identification and assessment allowing for treatments [3,1] specifically targeted for these dysfunctions.

The following binocular eye tracking charts reflect the ocular–visual strategies and related SMC activities. Fig. 5 shows the significant inadequate and asymmetric eye tracking strategies of this individual prior to receiving any treatment. The vertical axis shows the deviation of the right or left eye from the norm or ideal, which is calibrated to be the zero-line. The red line (Delta X) shows the deviation (in millimeters) in the x-direction (horizontal) of the line-of-sight of an individual. The green line (Delta Y) shows this deviation of the eye in the y-direction (vertical). The horizontal axis of each graph represents the time-lapse span of 10 s.

This display of poor ocular–visual performance noted in Fig. 5 is related to vestibular, postural, as well as cognitive impairments through the previously measured deviations found in the static postural tests. Analysis of these data indicated disturbances involving the III, IV, V, VI, VII, IX, and X cranial nerves. These functional networks also involve upper structures within the CNS relating to the central grey nuclei, vestibular, ocular–motor and limbic systems and to the autonomic nervous system, all systems found within the "Big 3." The testing objectively confirmed that the cause of this chronic "plateaued" condition was from a

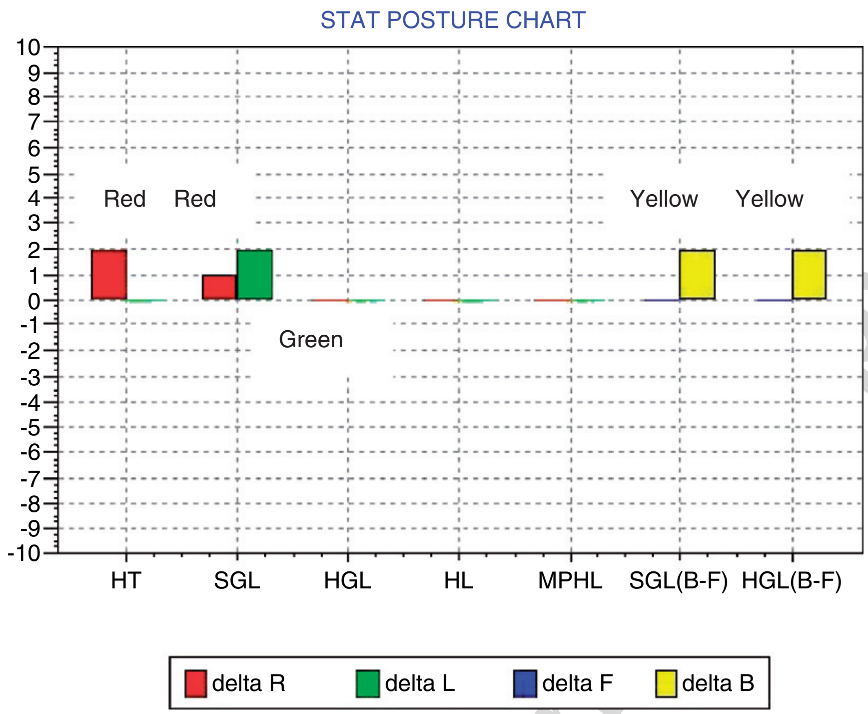

Fig. 4. Static posture after 3 weeks of treatment.

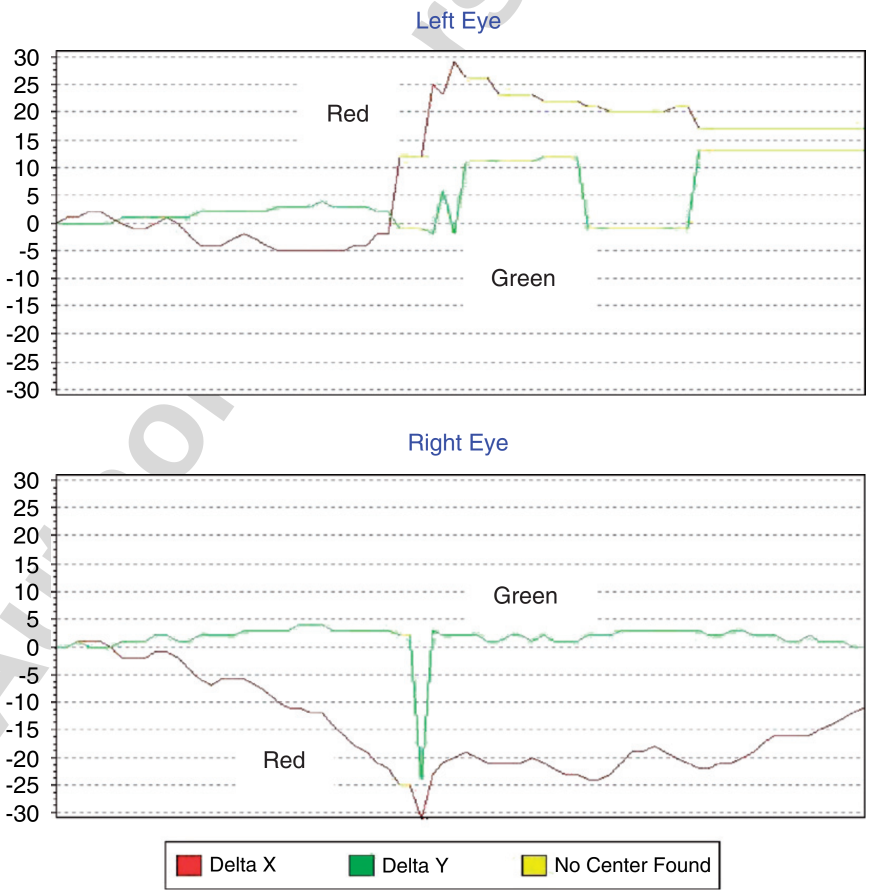

Fig. 5. Binocular eye tracking before treatment.

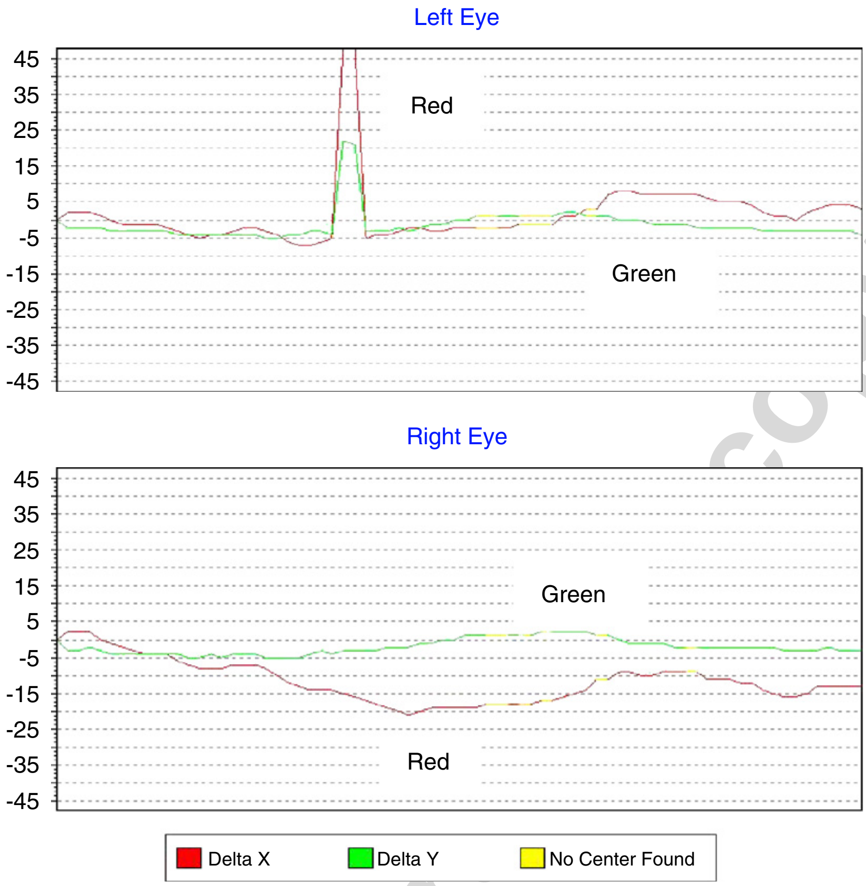

Fig. 6. Binocular eye tracking after 3 weeks of treatment.

central dysfunctional origin within the CNS. It meant for this individual that all related areas of physical performance outcome, such as balance, proprioception, movement, hand–eye, and foot–eye coordination, would be impacted as well as intellectual, emotional, and decision making abilities. Fig. 6 illustrates the benefits shown here in terms of the ocular–visual strategies, of correct identification of the dysfunctional areas and providing the appropriate treatment protocols and strategies.

3.3. Clinical results to date

The results presented here are averaged from the data compiled from all medical patients assessed, between 1995 and 2005, to the OVMS protocol. Data from 116 patients were used for these statistics, with a mean age of 41 years, and a 36% to 64% male/female split. Of these patients, 85% showed a significant decrease in all of their symptoms, as predicted accurately in the preliminary OVMS assessment before starting treatment. This number, very conservatively, reflects the accuracy of the OVMS capabilities in correctly diagnosing the postural deficiency syndrome related condition, as well as the accurate prognosis of performance recovery. This number can be considered a conservative estimate as all of these patients displayed significant decreases in at least some of their symptoms predicted by the OVMS.

4. Conclusion

The correlation between unmitigated symptoms exhibited by post Space-flight astronauts, and symptoms associated with PDS are certainly undeniable. This knowledge introduces a high likelihood that assessing post-flight astronauts with the OVMS, which achieves successful diagnosis and monitoring of PDS patients, will yield a higher level of understanding of the neurophysiological mechanisms affected by Space flight. This higher level of understanding is necessary in order to reach the next stage of success for humans living and working in Space.

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