Oral Session 1: Neural Adaptation and Sensory Transduction

1–1 [#3019]

Experimental measurement of utricle dynamic response

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Introduction: The utricle of the red-eared turtle was subjected to forced sinusoidal oscillations across various frequencies (10–125 Hz) and amplitudes (5–15 \( \mu m \)) to determine utricle dynamic characteristics.

Experiment: After removing the utricle, the overlying utricle membrane was trimmed away to expose the otoconial crystals layer (CL) without disturbing this layer or the underlying neural epithelial layer (EL). The utricle was maintained under compatible solution, placed on a glass slide, and made parallel to the slide using glass chips. Three single strands of dental floss were used to rigidly attach the EL to the glass slide, while not impairing the natural CL displacement. A piezoelectric-actuated platform was fitted into the stage of the microscope and created controlled vibrations along the medial-lateral direction of the utricle. The CL surface crystal’s displacement was measured through the microscope with high-speed video (1500 fps, resolution = 144\text{nm/pixel}). A reference point outside macula was filmed under identical amplitude and frequency inputs to evaluate any small displacement relative to the glass slide motion. Cross correlation in a Matlab program determined CL and reference point displacements. Maximum displacement amplitudes of the CL and reference point relative to the piezoelectric actuator were used to determine the Amplitude ratio of the CL to reference point.

Results: Fitting a single degree of freedom model to measured values \((n = 9)\) of amplitude ratios determined the utricle’s natural frequency of 349 Hz \((\sigma = 95)\) with a damping ratio of 1.44 \((\sigma = 0.22)\). No amplitude or frequency dependence of damping or natural frequency was seen.

1–2 [#3039]

The effect of microgravity on mRNA expression in the vestibular endorgans: Comparison of the 90-day and 15-day space flight

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Significant decrease of vestibular inputs during the space flight is one of the major reasons for space motion sickness. In space, astronauts adapt normally to the microgravity environment within a few days. Indeed the central nervous system has a central role of adaptation, but the vestibular endorgans are believed to also show adaptation. Previous space flight study revealed the obvious change of synaptic arrangement in the rat vestibular endorgans [1]. Therefore, it is interesting and important to investigate the gene expression patterns in the vestibular endorgans during space flight. In this study, mRNAs from the mouse vestibular endorgans in two different space flight groups were analyzed.
90-day flight group: The samples were provided by Biospecimen Sharing Program (TSP) of Mice Drawer System (STS-128/129). Only three mice survived for 90 days in the mission to the International Space Station. The vestibular endorgans were dissected out from the temporal bones under RNA later solution and mRNAs were extracted.

15-day flight group: The samples were provided by BSP of STS-131. Tissues were extracted same as above.

Each extraction was quality checked and applied for DNA microarray. In each sample genes were selected from the gene profile that exhibited either an up (>2-fold) or down (<0.5) regulation. In 90-day flight group, 71 up-regulated and 43 down-regulated genes were detected. In contrast, the gene expression patterns were quite different in the 15-day flight group. These genes might be key molecules altered by microgravity and these analyses might shed light on the time course and underlying mechanisms driving vestibular adaptation during the space flight.

Reference


1–3 [#3004]

Neurovestibular adaptation in the utricular otolith following extended periods of hypergravity exposure and re-adaptation to 1G

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Space flight introduces a novel sensory environment and initiates adaptive mechanisms within the nervous system. Humans typically adapt to μG within 2–4 days and subsequently must re-adapt upon return to 1G. Here we ask: does the transfer from 1G to 3G impart the opposite effects on changes of gravitational sensitivity seen following μG exposure? Do the effects accompanying transfer from the 3G to the 1G conditions resemble in part (as an analog) the transfer from 1G to the μG? Adult toadfish were exposed to 3G for 1–32 days. Re-adaptation to 1G was studied after 3G exposure of 4- and 16-days followed by 1–8 days of recovery. Directional selectivity to translational and tilt stimuli were well characterized in typically > 60 afferents in each subject. Results show a biphasic response to 3G: an initial sensitivity increase (3- and 4-day), similar in magnitude to that observed in utricular afferents upon return to Earth, followed by a transition through normal sensitivity to a significant decrease at 16–32 day exposure. Return to control values following 3G exposure is ~4–8 days. As an internal control horizontal canal afferents respond normally to yaw rotation. On-Center Controls (228°/s rotation about Earth vertical) at 4- and 16-days respond normally for both utricular and canal afferents. Utricular sensitivity is strongly regulated by altered gravity signal, beginning within hours to days, and transition from hyper-G to normal gravity resembles the transfer from 1G to μG, and might be used as an analog ground-based model.

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1–4 [#3045]

Spaceflight-induced plasticity of utricular hair cell synapses

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Previous ultrastructural studies indicated that spaceflight resulted in upregulation of synapse density in utricular hair cells; however, it was not tested whether this could be generalized to hair cells distributed across the utricular topography. In the present study we addressed this issue using double-label immunohistochemistry and volumetric image analysis that facilitated broad topologic sampling, and report our findings from the medial extrastriola region. Specimens were obtained from C57BL/6J mice flown aboard Discovery during STS-131 (flight group), and from age-matched ground controls (control group). Temporal bones from flight specimens were harvested within R+5hrs and immersion-fixed (4% paraformaldehyde); control specimens were similarly obtained. Immunohistochemistry was performed on microdissected epithelia to label synaptic ribbons (anti-CtBP2) within hair cells, and
the postsynaptic complex (anti-Shank1A) within the afferent dendrite. A double-blind strategy was employed for synapse quantification in confocal image stacks from 6 regions (900 $\mu m^2$ each) of medial extrastriola in flight and control utricles ($n = 4$ each). The central regions of flight and control horizontal cristae ($n = 4$ each) served as internal controls insensitive to static gravitational loading. Only complexes exhibiting colocalization of pre- and post- synaptic markers were quantified. We found that synapse densities in medial extrastriola hair cells decreased in flight utricles compared to controls. Flight and control cristae exhibited similar synapse densities, supporting the conclusion that utricular synapse density modifications resulted from unloading concomitant with microgravity exposure. These data further demonstrate the capability of utricular hair cells for synaptic plasticity resulting from alterations of the ambient sensory environment, though the specific modifications may be topology-dependent.
Intuitive displays may help prevent spatial disorientation in degraded visual environments: Lessons from helicopters

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In the absence of visual orientation cues, the inadequacy of the vestibular sense often contributes to orienting illusions [1] during flight. Spatial disorientation (SD) plays a significant role in helicopter accidents [2, 3], often when outside visual references are lost during landings in dusty environments [4]. The lack of ambient visual cues, the close proximity to the ground, and the urgency of the situation (seconds from impact) often cause the helicopter pilot to act on the erroneous perceptions of motion generated by the vestibular system. Historic video clips of Apollo lunar landings show the potential for SD as the astronauts encountered similar situations during which clearly visible landing sites became totally obscured by blowing dust seconds before touchdown. This lack of time and altitude for reorientation and recovery has required the military to seek the development of displays that convey orienting information in more intuitive ways. The similarity between helicopter dust landings and extraterrestrial landings presents an opportunity for those designing future space vehicles and their instrumentation to gain from the lessons learned from military helicopters. Recent developments in visual/sensor (e.g., Brownout Symbology System, 3D Conformal Landing Symbology) and tactile (Tactile Situation Awareness System) technologies promise to provide helicopter pilots critical orienting information in more timely, intuitive representations of the flight and landing environments, thereby compensating for the unreliability of the vestibular system and reducing the possibility of SD due to vestibular illusions. This presentation will contrast current flight instruments with these evolving displays.

References
thresholds, we intend to fully integrate it into SDAT. In the mean time, we are adapting SDAT algorithms to include a full set of vector math functions.

2. Extend SDAT assessments to include typical space vehicle illusions. Validation will include assessment of Shuttle landing data, and Altair simulator data.

- Progress: We designed new illusion models for vertical landing vehicles (e.g., helicopters and lunar landers) and obtained actual helicopter flight data sets that include SD events. Shuttle data sets are unusable. Altair simulator data (e.g., from the NASA-Ames vertical motion simulator) are being analyzed. Furthermore, we are distributing an IRB-approved survey to Shuttle commanders and pilots to quantify their experiences with illusory sensations resulting from the transition from 1 g to 0 g and back.

3. Further extend SDAT by examining alternative visual reference frames. FORT is used to predict the cognitive cost of transitioning between reference frames.

- Progress: The FORT tool has been partially validated; further validation is ongoing. The FORT tool is a stand-alone tool and will not be integrated into SDAT.

4. To further enhance SDAT assessor performance, pilot multi-sensory workload is considered in countermeasure selection.

- Progress: We have added a representation of the N-SEEV attention model (noticing – salience, effort, expectancy, value) to SDAT to improve countermeasure triggering.

The presentation will emphasize the Shuttle survey and results to date.

2–3 [#3049]

Pseudo-coriolis effect: A 3D angular velocity storage phenomenon described by a left-hand rule

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When stationary, gravitationally upright human subjects undergoing optokinetic stimulation experience yaw circularvection and then make a pitch or rolling head movement, they describe strong paradoxical tumbling and tilt sensations resembling vestibular Coriolis Effect (CE). Brandt and Dichgans [1,2] referred to this as a “Pseudo-Coriolis Effect [PCE], noting that “a model that would explain the pseudo-Coriolis effects entirely, including the surprising conformity of direction of the illusory tilt in CE (Coriolis Effect) and PCE (Pseudo-Coriolis Effect) cannot yet be proposed.” These and several subsequent studies [3,4] compared the nauseogenic properties of PCE as compared to CE, and noted that CE and PCE effects appeared qualitatively similar. We recently applied Merfeld’s et al’s “Observer” model for vestibular cue integration [5,6] to predict CE when subjects make head movements during prolonged physical rotation in darkness. We confirmed that vestibular CE follows a positive vector cross product (“right hand”) rule, e.g. during clockwise rotation, a clockwise head roll produces a pitch backward sensation [7]. We then [8,9] extended the Observer model to include optokinetic angular velocity and visual “down” cues, and ran PCE simulations. The extended model incorporates a 3D visual-vestibular angular velocity storage-like mechanism. It predicts that – as proposed by Guedry [10] and Bles [3] – vection perception initially moves with the head, producing tumbling and tilt sensations analogous to “Purkinje” (aka Dumping) vestibular illusions. However, we emphasize that, unlike vestibular CE, optokinetic PCE sensations actually follow a “left-hand-rule,” e.g. during clockwise vection, a clockwise roll produces a pitch forward illusion. Also, unlike CE and Purkinje illusion, vection continues, but paradoxical PCE tumbling and tilt components disappear as the vection axis gradually realigns with visual and gravitational stimuli. We experimentally confirmed the CE/PCE direction difference in a group of human subjects.

Acknowledgement: Supported by the National Space Biomedical Research Institute through NASA NCC 9–58.

References

2–4 [#3010]

Relationships between observer and Kalman filter models for human dynamic spatial orientation

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How does the central nervous system (CNS) combine sensory information from semicircular canal, otolith, and visual systems into perceptions of rotation, translation and tilt? Over the past four decades, a variety of input-output (“black box”) mathematical models have been proposed to predict human dynamic spatial orientation perception and eye movements. The models have proved useful in vestibular diagnosis, aircraft accident investigation, and flight simulator design. Experimental refinement continues. We review the history of these models, distinguishing two widely known model families, the linear “Kalman Filter” and the nonlinear “Observer”. We derive simple 1-D and 3-D examples of each model for vestibular inputs, and show why – despite apparently different structure and assumptions – the models predictions are dynamically equivalent when model free parameters are adjusted to fit the same empirical data, and perceived head orientation remains near upright. We introduce the idea that the motion disturbance and sensor noise spectra employed in the 1-D Kalman Filter formulation may reflect human perceptual thresholds and prior motion exposure history, and thus justify the interpretation that the CNS cue blending scheme minimizes perceptual errors.

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Sensory weighting in space: The Bodies in the Space Environment (BISE) experiment

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On Earth the perceived direction of “up” can be predicted from a weighted sum of visual, gravity and body orientation cues. The relative weightings of these cues vary from person to person and depend on the task, for example when aligning a line with gravity or when identifying the optimal orientation for object recognition. How are the weightings affected when one cue becomes uninformative? During short periods of microgravity (during parabolic flight) the relative weighting of vision decreased (Dyde et al., 2009, Exp. Brain Res., 196: 647). What is the effect of longer term exposure to microgravity?

We measured perceived orientation in seven astronauts before, during and after long-duration space flight. Pre- and post-flight we used the oriented character recognition test (OCHART, Dyde et al., 2006, Exp. Brain Res., 173: 612), shape-from-shading and luminous line probes in upright and right-side-down body orientations. On station, subjects performed OCHART early and late in flight. A parallel study used ground-based controls tested at similar intervals.

A trend for a reduction in visual influence was observed in flight with lower-than-baseline levels maintained throughout six months in orbit. Visual influence was still lower than baseline levels several months after returning to Earth.

We conclude that sensory weightings are altered by long-term exposure to microgravity and do not recover within six months of return to normal gravity. These findings will be discussed in terms of sensory adaptation and in comparison to the ground-based control data.

LASOIS: Enhancing the spatial orientation capabilities of astronauts on the lunar surface

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The environment experienced by astronauts on the lunar surface can seriously limit the perception of spatial orientation. Lack of atmospheric cues and familiar objects of reference can cause a lunar explorer to miscalculate distance, spatial relationships, and shapes of terrain objects [1,2]. The microgravity environment causes the vestibular system to provide the brain with an incorrect understanding of position and motion. During Apollo 14, astronauts successfully completed a traverse of about 2 KMs, but they suffered from disorientation due to several lunar environmental factors such as influence of reduced gravity, different reflection properties, and lack of familiar references, so that they did not reach the science target of Cone Crater that was very close while resources were running out [3].

To overcome challenges to spatial orientation experienced on the lunar surface, we are developing a Lunar Astronaut Spatial and Orientation Information System (LASOIS) composed of on-suit, foot-mounted, and off-suit sensors [4]. Data from the on-suit stereo cameras and foot-mounted IMU, integrated by an Extended Kalman Filter, continuously track the astronauts and provide spatial information in real time. What to display (and how) of the derived spatial information (on a wrist-mounted device) is determined using a psychological-effectiveness algorithm developed to best represent the perceptions of position, distance, and spatial orientation. LASOIS has been tested successfully in lunar-like environments at Moses Lake, WA and Black Point, AZ, where LASOIS was able to achieve a 2.67% accuracy over a 1700 m traverse.

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References
Oral Session 3: Vestibular Function

3–1 [#3040]

**Complementarities of utricular and semicircular canal tests**

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The human vestibular system comprises five motion detectors, being the three semicircular canals for rotation detection and two otolith organs for linear acceleration detection. Whereas Unilateral Centrifugation (UC) [1] is used for over a decade to evaluate the utricle, the ocular vestibular evoked myogenic potential (oVEMP) test is a very recent test, claiming to be also a utricular test. The current study investigates to which extent there is a similarity between the asymmetry for utricular and horizontal canal function, using ENG, UC and oVEMP.

We tested 257 patients with vestibular problems, visiting the department of otolaryngology in the Antwerp University Hospital. After the clinical investigation, the patients were referred to AUREA where either ENG and oVEMP was performed (*N* = 177), either ENG and UC (*N* = 80). For the ENG data, we used caloric asymmetry (%) as the outcome variable, based on the Jongkees formula for the slow component velocity at maximum. For UC testing we used utricular asymmetry, based on the ocular counter rolling, and for oVEMP we used the asymmetry between right and left amplitude of the EMG signal of the inferior oblique muscle upon bone vibration with a Bruel and Kjaer minishaker at the forehead.

Results: None of the correlations (ENG – UC) or (ENG – oVEMP) was statistically significant, with *R*² values below 10%. These results indicate that evaluation of the function of horizontal semicircular canal and the otoliths is very independent, and conclusions on asymmetry in one system due to a lesion are not valid for the other system.

**Reference**


3–2 [#3059]

**Vestibular prosthesis tested in non-human primates: Oculomotor, perceptual, and postural effects**

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Vestibular dysfunction causes prominent perceptual, postural, and oculomotor (e.g. visual) symptoms. To alleviate these vestibular-mediated symptoms, we have been developing and testing a semicircular canal prosthesis that senses head rotation in three dimensions and provides this information to the brain by modulating activity in all six canal ampullary nerves through direct electrical stimulation.

We are testing the efficacy of this prosthesis in rhesus monkeys by characterizing percepts of head orientation (using a method derived from the subjective visual vertical), postural control (by measuring sway during quiet stance, during voluntary head turns, and during tilt of the support surface), and the angular vestibulo-ocular reflex (VOR) in three dimensions in normal monkeys, monkeys with marked bilateral vestibular hypofunction (BVH), and BVH monkeys with chronic prosthetic stimulation.

Our results to date demonstrate that the prosthesis can produce a compensatory VOR that reduces motion...
of images on the retina during head motion, shows evidence of adaptation (gain, axis, symmetry) and normal spatial orientation properties. Preliminary results indicate that perceptual and postural responses are impaired by bilateral vestibular damage and that these deficits can be reversed in part with chronic prosthetic stimulation.

These findings suggest that providing vestibular information to the brain with a prosthetic device can improve vestibular-mediated behaviors when these are abnormal. While we have focused to date on canal (rotational) information, otolith (gravito-inertial) information could also be provided to the brain with a prosthesis, although the challenges are greater given the complexity of the otolith maculae compared to the relative simplicity of the canal cristae.

3–3 [3037]

Computerized posturography incorporating static and dynamic head tilts

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Head position or movement can increase sway in healthy persons during balance tests, which has led to the development of more sensitive balance tests for astronauts returning to terrestrial gravity after returning from space. This study evaluated measures of computerized dynamic posturography during static and dynamic pitch head tilts using a large sample of 113 healthy student military aviators. Postural equilibrium was measured with the NeuroCom EquiTest® Sensory Organization Tests (SOTs). Each subjects performed SOTs with his/her head upright (control), during static 30° posterior head tilt, and during ±30° dynamic head pitch movements. SOT5 (eyes closed, unstable support), which is considered the most vestibular-dependent SOT, proved to be the most useful test for distinguishing head upright from head tilt or movement conditions. SOT5 equilibrium scores were significantly worse in the head tilt/movement conditions (versus head upright). Moreover, falls during SOT5 occurred in only 0.3% of head erect trials, but were observed in 1.5% of static head tilt trials, and 4.1% of dynamic head pitch trials. Although there were more falls with dynamic (versus static) head tilts, the equilibrium scores were similar for static and dynamic tilts. This study supports other experiments suggesting that head tilt or movement while balancing with eyes closed on a moving platform is a difficult variant of the balance test which may prove useful for postural testing of aviation personnel and astronauts. Static head tilts should be especially useful for assessing astronauts following spaceflight, since they are not as provocative as dynamic tilts nor as likely to cause readaptation during testing.

3–4 [3025]

Behavioral and kinematic measures in simple screening tests of vestibular function


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Few simple but well validated screening tests of the vestibular system are available for use at remote landing sites and other situations where limited test facilities are available. The goal of this study is to develop a valid and reliable screening battery that will a) indicate the presence or absence of a vestibular impairment, b) take no more than 15 minutes, and c) be performed and interpreted with minimal equipment by staff without significant technical expertise in the vestibular system. The new battery includes tests of dynamic visual acuity for indirect testing of the vestibulo-ocular reflex [1], standing balance test on compliant foam with eyes closed [2], tandem gait with eyes closed [3], and clinically well accepted head thrusts and Dix-Hallpike maneuvers. Kinematic measures were obtained from inertial measurement unit (IMU) sensors attached to the head and torso during the performance of these tests. Subjects included 50 normals, aged 21 to 79, and 50 patients with unilateral caloric weakness or post-acoustic
or vestibular impairments are significantly impaired on performance of these tests. These data support previous work showing that performance of some balance tests is sensitive to vestibular disorders. Therefore this test battery should be useful for screening post-flight crewmembers at landing.

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**Reference**


3–5 [#3016]

**Metrics of balance control for use in screening tests of vestibular function**

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Decrement in balance control have been documented in astronauts after space flight. Reliable measures of balance control are needed for use in post flight field tests at remote landing sites. Diffusion analysis (DA) is a statistical mechanical tool that shows the average difference of the dependent variable on varying time scales. DA techniques have been shown to measure differences in open-loop and closed-loop postural control in astronauts and elderly subjects. The goal of this study was to investigate the reliability of DA measures of balance control. Eleven subjects were tested using the Clinical Test of Sensory Interaction on Balance: the subject stood with feet together and arms crossed on a stable or compliant surface, with eyes open or closed and with or without head movements in the pitch or yaw plane. Subjects were instrumented with inertial motion sensors attached to their trunk segment. The DA curves for linear acceleration measures were characterized by linear fits measuring open-loop (DS) and closed-loop (DL) control, and their intersection point (X-int, Y-int). DS and Y-int showed significant differences between the test conditions. Additionally, Ds was correlated with the root mean square (RMS) of the signal, indicating that RMS was dominated by open-loop events (< 0.5 seconds). The Y-int was found to be correlated with the average linear velocity of trunk movements. Thus DA measures could be applied to derive reliable metrics of balance stability during field tests.

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4–1 [#3031]

Cross-coupled stimulus during artificial gravity: Asymmetric tumbling sensation response

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Artificial gravity (AG) through centrifugation is a promising countermeasure for long-duration spaceflight physiological deconditioning. Vestibular adaptation to AG is necessary in order to mitigate the negative side effects associated with the cross-coupled stimulus (CCS) that results from performing head turns out of the plane of centrifuge rotation. Previous research has investigated many of the factors that contribute to the CCS such as head turn velocity, centrifuge velocity, and magnitude of head turn rotation, among others. Most of these can be understood by an analysis of the physics of the CCS. However, we have consistently noted an asymmetry between clockwise (CW) and counter-clockwise (CCW) yaw-axis head turns. This asymmetric response is not readily explained by the physics of the CCS, and it has also not been adequately explained by any of the existing models of the vestibular system. We have characterized the asymmetry of the CCS through three experiments in which we provide yaw head turns during AG with: 1) CW supine, 2) CCW supine, and 3) CW prone centrifugation. The data indicate that head turns resulting in a subjective tumbling sensation of rotating away from the horizontal centrifuge bed always produce a more intense tumbling sensation than head turns that lead to a sensation of rotating into the bed. We propose that the perceived danger of the CCS-induced tumbling sensation movement modulates the subjective tumbling intensity responses.

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4–2 [#3035]

Effects of labyrinthectomy on rat soleus muscles properties and lumbar motoneurons

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The aims of this study were to determine whether the suppression of the vestibular inputs 1) could have effects on the soleus muscle properties similar to the modifications observed after an episode of artificial microgravity and 2) could affect the morphology and the excitability of the motoneuron pool which innervate the soleus.

The inner ear lesion was obtained by surgical labyrinthectomy. Male Wistar rats were used and divided in 2 groups: control (CONT, \(n = 21\)) and bilateral labyrinthectomised (BL, \(n = 14\)). Mechanical, histochemical, electrophoretic, electrophysiological parameters and soleus electromyographic (EMG) activity were measured 17 days after the surgical operation.

Our results showed that rat soleus of the BL group were not atrophied when compared to CONT group. The ratio of peak titanic tension relative to the muscle wet weight was not changed. However, the kinetic parameters and the phenotypical profile determined following MHC isoforms revealed that the BL soleus muscle evolved from a slow towards a slower type. This has been correlated to a more tonic EMG activity pattern. The soma sizes of the soleus motoneuron pool of the BL group were shifted towards smaller size classes. A decrease in the monosynaptic reflex thresh-
old and an increase in the monosynaptic reflex latency were observed in the BL group. Therefore, our data demonstrated that the soleus muscle transformations observed after simulated microgravity cannot be the result of a vestibular silence. However the loss of vestibular information led to modifications of the motoneuron properties.

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4–3 [#3048]

Denoising of impedance cardiography data from returning astronauts using the Ensemble Empirical Mode Decomposition method: Preliminary results from the ESA SPIN experiment

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Impedance cardiography is a robust and well documented non-invasive method for measuring heart stroke volume. This technique is combined with the recording of impedance in 4 body segments to measure the fluid shifts during a standardized-tilt test protocol performed on 4 astronauts returning from long duration missions (~6 months) to the ISS. This protocol is part of the ESA SPIN study on otolith and autonomic deconditioning after spaceflight and is performed after rotation of the subjects on the VVIS centrifuge.

In returning astronauts the data acquisition is often altered by noise from physical as well as physiological origin. The Ensemble Empirical Mode Decomposition (EEMD) is a novel technique ideal for non-linear and non-stationary signals [1] which adaptively decomposes a signal into Intrinsic Mode Functions (IMFs) [2].

The performance of the EEMD denoising algorithm is compared with a Wavelet coefficient thresholding algorithm. Artificial model wave shapes were constructed and white noise was added to test both algorithms. In most cases the EEMD technique outperformed the Wavelet thresholding method.

EEMD was applied to the recordings (3 pre-flight BDC & 3 post-flight (R+1, R+4, R+9)) of the SPIN study. Our results show that EEMD allowed a denoising method tailored to our problem. Moreover the IMF that showed to be consistently correlated with the respiratory signal was extracted as a surrogate respiratory signal. Impedance in the 4 segments of the body (thorax, abdomen, thigh and calf) were calibrated and show that after space flight the fluid shift is more pronounced compared to the pre-flight baseline.

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References


4–4 [#3027]

Adaptation to coriolis-inducing head movements in a sustained-G high performance flight simulator

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The goal of the present experiment is to investigate and quantify cognitive and physiological adaptation to head movements made in a sustained G high performance flight simulator. Sustained G simulators combine long arm centrifugation with high fidelity, gimbaled, flyable cockpit modules to mimic the physiological stresses and G forces experienced during actual tactical flight. In order to properly reproduce these forces,
Astronaut spatial orientation perceptions during simulated lunar landing


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Lunar landing requires the identification and selection of a suitable landing zone and a safe and precise descent to the surface. In crewed landings, astronauts are expected to interact with automated systems to accomplish those objectives through supervisory and possibly manual control. Astronauts must maintain accurate perceptions of vehicle orientation and velocity while maintaining terrain and situational awareness. A simulation was run on a physiologically-based, numerical model of visual-vestibular interaction using vehicle motions during landing trajectories to predict the astronaut’s perceptions of vehicle orientation. An experiment was performed in which subjects reported their perceptions of vehicle attitude and horizontal velocity during motions typical of lunar landing simulated on the NASA Ames Research Center Vertical Motion Simulator (VMS). During those motions, we studied subjects’ perceptions resulting from three different sets of orientation cues: Vestibular only (VO), visual-out-the-window view (VOTW), and instrument display panel (IDP). Both the numerical simulation and experimental results found a somatogravic illusion in the VO (blindfolded) case: subjects reported upright vehicle orientation even when the vehicle model imposed a significant tilt. The model predicts that having a view of the lunar terrain will improve the perception of vehicle orientation, but the experimental results did not show that predicted improvement. The somatogravic illusion was suppressed when the subjects had access to the IDP. Finally, the experiment found misperceptions of horizontal velocity in the VO and VOTW cases. These misperceptions of vehicle attitude and velocity are likely to degrade astronaut control and may impact landing performance and safety.

Acknowledgement: This work was supported by the National Space Biomedical Research Institute through NASA NCC9-58-11 Projects SA01604 and SA01302.
effect of dynamic otolith stimulation ($OTO_{dyn}$) on the VS can explain both, the rVOR and self-motion perception behavior. rVOR was recorded with dual-search coils during per- (‘natural’ $OTO_{dyn}$) and post-rotatory (altered $OTO_{dyn}$) constant-velocity pitch EHR. Pitch-tilt perception was assessed by asking hS, which of two consecutive motion stimuli was perceived as larger tilt. One stimulus (reference-stimulus) consisted of a constant-velocity pitch-tilt, the other of either: (1) a smaller/larger pitch-tilt (‘natural’ $OTO_{dyn}$), (2) a smaller/larger pitch-tilt combined with a surge translation providing $OTO_{dyn}$ equal to the reference-stimulus (altered $OTO_{dyn}$). Per-rotatory slow-phase eye-velocity ($7.8 \pm 2.1s$) decayed significantly slower than post-rotatory slow-phase eye-velocity ($3.6 \pm 0.7s$) [2]. During pitch-tilts, hS recognized larger tilts in $83.5 \pm 15.8\%$ of trials in paradigm (1) compared to $70.3 \pm 21.7\%$ in paradigm (2) ($p < 0.001$). This demonstrates that the proper activation of VS by ‘natural’ gravity-dependent $OTO_{dyn}$ has a striking role in both, the rVOR and self-motion perception. We speculate that in altered-gravity environment, $OTO_{dyn}$ that differs from the one expected on Earth may cause incorrect VS processing of low-frequency components of rotational stimuli, possibly affecting pitch-tilt assessment.

References

4–8 [#3006]

Reduction in Dynamic Visual Acuity reveals gaze control changes following spaceflight

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Introduction: Exposure to microgravity causes adaptive changes in eye-head coordination that can lead to altered gaze control. This could affect postflight visual acuity during head and body motion. The goal of this study was to characterize changes in dynamic visual acuity after long-duration spaceflight.

Methods: Dynamic Visual Acuity (DVA) data from 14 astro/cosmonauts were collected after long-duration (∼6 months) spaceflight. The difference in acuity between seated and walking conditions provided a metric of change in the subjects’ ability to maintain gaze fixation during self-motion. In each condition, a psychophysical threshold detection algorithm was used to display Landolt ring optotypes at a size that was near
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each subject’s acuity threshold. Verbal responses regarding the orientation of the gap were recorded as the optotypes appeared sequentially on a computer display 4 meters away. During the walking trials, subjects walked at 6.4 km/h on a motorized treadmill.

Results: A decrement in mean postflight DVA was found, with mean values returning to baseline within 1 week. The population mean showed a consistent improvement in DVA performance, but it was accompanied by high variability. A closer examination of the individual subject’s recovery curves revealed that many did not follow a pattern of continuous improvement with each passing day. When adjusted on the basis of previous long-duration flight experience, the population mean shows a “bounce” in the re-adaptation curve.

Conclusion: Gaze control during self-motion is altered following long-duration spaceflight and changes in postflight DVA performance indicate that vestibular re-adaptation may be more complex than a gradual return to normal.

4–9 [#3012]

Lateral tilt illusion caused by idiopathic utricular dysfunction. Is it detectable by ocular VEMP?

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The vestibular labyrinth is composed of two otolith organs and 3 semicircular canals. The otolith organs, utricle and saccule, work as sensors of linear acceleration. From the viewpoint of polarity, the utricular macula seems to be sensitive to lateral tilts. Therefore, its dysfunction could lead to lateral tilt illusion. Vestibular evoked myogenic potentials around the eye (ocular VEMP, oVEMP) have been recognized as a clinical test of utricular function. Herein, in order to confirm validity of oVEMP as a test of utricular function, we studied oVEMP in patients presented with idiopathic lateral tilt illusion. Patients presented with episodes with idiopathic lateral tilt illusion were enrolled. It was the inclusion criterion for subjects to have episodic lateral tilt sensation including sensations pushed or pulled laterally. Subjects with the following signs or symptoms were excluded. 1. Episodic rotatory vertigo, or canal dysfunction detected by caloric tests (canal paresis > 20% or bilateral canal dysfunction, maximum slow phase eye velocity < 10 deg/sec bilaterally). 2. Episodes of loss of consciousness or black out sensation). 3. Any symptoms or signs of central nervous system dysfunctions or proprioceptive dysfunctions. 4. Definite diagnoses of known diseases which cause disequilibrium (e.g. Meniere’s disease). For patients who passed the above-mentioned inclusion and exclusion criteria, oVEMP and cVEMP were recorded using 500Hz air-conducted tone bursts.

Majority of subjects showed unilateral or bilateral absence of oVEMP but preserved cVEMP. These findings suggested that lateral tilt illusion could be caused by idiopathic utricular dysfunction and such dysfunction is detectable using oVEMP.

4–10 [#3018]

Novel tool development to assess vestibular health

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Ocular responses to head perturbations consist of intermingled segments termed “slow” (nystagmus) or “fast” (saccade), according to their average speed characteristics. Currently, valuable information that may be contained in saccade data is ignored due to a lack of suitable methodology available to analyze it, and vestibulo-ocular reflex (VOR) health is assessed using inaccurate ad hoc linear methodology or a clinician’s ability to judge abnormal eye movements. Here, we develop an a posteriori non-linear tool to quantify VOR health. This goal is accomplished by constructing a diagonal block-oriented data matrix and exploiting its natural sparseness, allowing this novel modeling and analysis technique to achieve these goals concurrently. Our VOR modeling and estimation tool allows for the objective assessment of VOR health by rendering it feasible to analyze both nystagmus and saccade phases simultaneously and efficiently from a single experimental record. This tool provides robust information to the clinician or a trained flight crew enabling an accurate evaluation vestibular health.

A good sense of balance is vital for a pilot/astronaut to safely operate advanced research aircraft or civilian
passenger aircraft, heavy equipment operators and persons who drive cars or motorcycles etc. This tool may lead to a more timely and comprehensive evaluation for VOR disease quantification and progression possibly providing insights for innovative therapeutic treatment modalities. In addition, the development of a tool for VOR health assessment has important implications not only for public safety, but also for exploratory class missions requiring optimal crew performance.

4–11 [#3028]

Gaze control with and without additional retinal optokinetic stimulation on cosmonauts after prolonged spaceflight

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In the ground experiment “SENSORY ADAPTATION” which is a part of the ISS Russian Science Program, we have investigated characteristics of the gaze control (smooth pursuit, saccades, gaze holding) with and without additional retinal optokinetic stimulation (ROKS). The study involved 26 Russian ISS-crewmembers before and after a prolonged exposure to weightlessness (126–195 days). Examinations were carried out on L-45 and L-30 preflight and R+1-2, R+4-5, R+8-9, and R+14-19 postflight. Cosmonauts were required to acquire the foveal stimulus (a small white square with angular displacement less than 1°) against the clear background or against the ROKS (a variety of blurred ellipses with angular displacement ∼2–4°) moving horizontally or vertically. All visual tracking tests were performed using a videooculography recording with a head fixed by a head holder. To evaluate additional spontaneous eye movements we have used a special test with both EOG (eyes closed) and VOG (eyes opened) recording in central and eccentric positions of the eyes. Oculomotor reactions were analyzed using parametric and nonparametric methods of multiple comparisons (ANOVA), correlation and cluster analysis. We have found that visual tracking on a clear background was accompanied by a statistically significant decrease of all characteristics being evaluated (latency, amplitudes, peak velocities, gain, precision etc.) until R+8-9 for all cosmonauts and, for some cosmonauts, until R+14-19. However, in the same tests with an additional ROKS even on R+4-5 several cosmonauts had a significant improvement of the gaze control while its characteristics were similar to the preflight, baseline values.

4–12 [#3043]

Enhancements of vection in depth from viewpoint oscillation: Effects of field of view, amplitude, focal distance and body posture

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Incorporating jitter or oscillation of the vantage point in visual displays produces more compelling illusions of self-motion (vection), despite generating greater sensory conflicts [1]. We are working with the Canadian Space Agency to develop an experiment to study this phenomenon on the International Space Station. Pragmatic issues favour small, near displays rather than typical immersive displays. This paper studies impact of display characteristics on the jitter/oscillation enhancement on vection.

Methods: Visual displays simulated constant velocity forward motion at 1.33 m/s through a virtual world, or the same motion with simulated viewpoint oscillation, on a laptop monitor viewed through an aperture. Various experiments examined the effect of oscillation amplitude, direction, field of view (with a different monitor), focal distance and body posture on vection responses.

Results: Adding simulated horizontal or vertical viewpoint oscillation to radial flow increased vection a similar amount. Vection strength was increased more for oscillation peak velocities of 0.28 m/s compared to 0.09 m/s. Increasing focal distance by the use of +2D ophthalmic lenses did not measurably impact reported strength of vection. While field of view had no effect, closer viewing distances reduced vection but had no significant effect on the oscillation enhancement.

Discussion: Motion sickness and spatial disorientation continue to impact the availability and effectiveness of astronauts. The current results will guide the development of ISS studies to improve our understanding of how vestibular and visual signals are recalibrated in altered gravity.
Reference


4–13 [#3054]

Otolith-ocular responses during counter-rotation in mice

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Introduction: In the 5th symposium in this series, Benson and Barnes (1970) described the modulation of horizontal eye movements in human subjects exposed to a rotating linear acceleration vector without angular acceleration (counter-rotation). This linear acceleration stimulus is similar to Off-Vertical Axis Rotation (OVAR), except that during OVAR the semicircular canals are stimulated during the establishment of the acceleration vector. The purpose of this study was to establish baseline ocular responses in mice using a similar counter-rotation paradigm as a test of otolith-ocular function.

Methods: Seven C57BL6 mice between ages 4 to 6 months were restrained onto a counter-rotation platform inside a light-tight drum. Two dimensional eye movements were measured using video-oculography. Mice were tested in both clockwise and counterclockwise directions from 30–180°/s (corresponding to 0.08–0.5 Hz).

Results and conclusions: Similar to other otolith-ocular studies, a frequency dependent horizontal nystagmus was observed that continued throughout rotation in either direction. The largest nystagmus response occurred during rotation 90°/s to 150°/s (0.25 to 0.4 Hz). We conclude that counter-rotation is a viable test of otolith-ocular function in mice. This paradigm will be useful to examine human ortholog genes and proteins necessary for development and maintenance of balance that have been identified and can be easily manipulated in mice.

Sensory re-weighting with changes in vestibular and cutaneous sensitivity following short duration space flight (HYPERSOLE)

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Information from the vestibular system is coupled with somatosensory input from the feet and lower limbs to facilitate orientation of the body in the environment [1]. Anecdotal evidence suggests that the skin on the foot sole may become hypersensitive during and following spaceflight. The extent of skin hypersensitivity and its impact on postural disequilibrium observed following space flight have not been documented to date.

To assess skin contributions, four vibration frequencies (3, 25, 60, and 250 Hz) were used to assess the vibration sensitivity of the four classes of mechanoreceptors at three sites on the foot sole (great toe, 5th metatarsal head, heel). Nylon monofilaments (0.026 to 110g of force) applied normal to the surface of the skin assessed static sensitivity thresholds. These data were coupled with functional balance tests (computerized dynamic posturography, CDP) to relate skin hypersensitivity with vestibular changes and balance function.

We hypothesize that skin sensitivity will increase Post-Flight and will correlate to changes in balance control. Preliminary data analyses from three subjects suggest that skin sensitivity is selectively increased at different sites, with greater incidence of hypersensitivity at the 5th metatarsal head. Increased sensation from skin may be due to sensory re-weighting with an altered gravito-inertial environment [1]. Specifically, as vestibular inputs are reduced information from the skin is increased. Insight into balance challenges as a result of heightened skin input will enhance current theories on skin contribution to postural control, and may be applied to long duration spaceflight in the future.
Reference


4–15 [#3058]

New method for quantifying human high-frequency linear and rotational VOR during launch-relevant conditions

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The human vestibular system stabilizes one’s conjugate gaze point in 3D in the face of self-motion disturbances with a 6 degrees-of-freedom Vestibulo-Ocular Reflex (VOR). We have constructed a video-based system that can track the stabilizing binocular smooth eye movement response to the linear and rotational vestibular perturbations that would typically occur during launch (chest-to-spine vibration during into-the-chest sustained G loads of 1g or higher). Our new method enables the precise measurement (4ms and 0.01° or better resolution) of a gaze-stabilization response dominated by the combined pitch (rotation) and heave (linear) VORs at frequencies in the 5 to 25Hz range and for vibration levels of up to \( \pm 1g \). To validate this method, for self-generated rotational pitch motion of about \( \pm 5° \) at about 0.7Hz, 1) we measured the gaze angle \( \Delta \) (solid gray line) by tracking the image of the pupils and subtracting out head motion, 2) we measured the head position by tracking the image of a fiducial triangle, and 3) we computed the head-induced demand \( \Delta \) (dashed black line) for oculomotor compensation by adding the arctangent of heave over viewing distance (linear demand) with the pitch angle change (rotational demand). The power density curves (B) for oculomotor demand and gaze angle nearly superimpose as expected for near perfect VOR compensation. Our plan is to use this new approach to document the trade-space between VOR gain and G-load-plus-vibration condition to determine when gaze stabilization becomes inadequate to support effective human performance in spaceflight-relevant tasks (i.e., reaching, dynamic visual acuity, pursuit, visual target acquisition). The data will guide future spacecraft interface design and operational concepts, independent of the specific launch conditions.

4–16 [#3002]

Motion sickness etiology: A cholinomimetic agent hypothesis

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Motion sickness has been defined as a set of physiological signs and symptoms produced as a result of prolonged sensory conflict in central nervous system vestibular centers. It has long been noted that the particular pattern of motion sickness signs and symptoms does not fit the conventional “fight or flight vs. rest and digest” autonomic synergy. We argue that most of the progression of symptoms is consistent with a new etiologic hypothesis: that an as-yet-unidentified ganglionic cholinomimetic agent is slowly released in proportion to sensory conflict. The agent accumulates systemically and stimulates the peripheral sympathetic and parasympathetic ganglia, the adrenal medulla, and potentiates the response of central cholinergic emetic pathways to the same conflict stimulus. The adrenergic response may eventually also counter the central emetic drive. The hypothesis could be experimentally pursued via human and animal experiments employing a nonselective cholinergic antagonist that has both central and peripheral ganglionic actions such as mecamylamine.
Acknowledgement: C. Oman was supported by the National Space Biomedical Research Institute through NASA NCC9-58. S. Sheehan was supported by the department of Diagnostic Radiology at the Brigham and Women’s Hospital, Boston, MA, USA.

4–17 [#3009]

Visual bias predicts gait adaptability in novel sensory discordant conditions

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We designed a gait training study that presented combinations of visual flow and support-surface manipulations to investigate the response of healthy adults to novel discordant sensorimotor conditions. We aimed to determine whether a relationship existed between subjects’ visual dependence and their postural stability and cognitive performance in a new discordant environment presented at the conclusion of training (Transfer Test). Our training system comprised a treadmill placed on a motion base facing a virtual visual scene that provided a variety of sensory challenges. Ten healthy adults completed 3 training sessions during which they walked on a treadmill at 1.1 m/s while receiving discordant support-surface and visual manipulations. At the first visit, in an analysis of normalized torso translation measured in a scene-movement-only condition, 3 of 10 subjects were classified as visually dependent. During the Transfer Test, all participants received a 2-minute novel exposure. In a combined measure of stride frequency and reaction time, the non-visually dependent subjects showed improved adaptation on the Transfer Test compared to their visually dependent counterparts. This finding suggests that individual differences in the ability to adapt to new sensorimotor conditions may be explained by individuals’ innate sensory biases. An accurate preflight assessment of crewmembers’ biases for visual dependence could be used to predict their propensities to adapt to novel sensory conditions. It may also facilitate the development of customized training regimens that could expedite adaptation to alternate gravitational environments.

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Oral Session 5: Motion Sickness and Pharmacology

5–1 [#3036]

Validation of a Specific drug against G-Level transition induced spatial disorientation and orthostatic intolerance: The ESA SPIN-D study

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Spaceflight is known to induce vestibular and cardiovascular deconditioning. Consequently, astronauts suffer from orthostatic intolerance and spatial disorientation upon return to a gravitational environment. The aim of the current ESA SPIN-D study was to identify the most appropriate pharmacological countermeasure against the aforementioned symptoms.

This double blind placebo controlled study was conducted on 20 healthy, male volunteers. Tested medications were: baclofen (10 mg), meclizine (50 mg), dimenhydrinate (40 mg) in combination with cinnarizine (20 mg), promethazine (25 mg) combined with dextroamphetamine (5 mg). The effects of the drugs were investigated by a series of specific vestibular tests: electronystagmography, cervical vestibular evoked myogenic potentials and unilateral centrifugation for canal, saccular and utricular function evaluation respectively. A head up tilt-test (HUT) was conducted in order to evaluate the cardiovascular response of the subjects during orthostatic stress.

Baclofen significantly increased the phase of the vestibulo-ocular reflex (VOR). This observation confirms the known inhibitory effect of baclofen on the velocity storage mechanism. Promethazine and dextroamphetamine caused a significant increase of the diastolic blood pressure (DBP) only during the supine part of the HUT, suggesting an influence of the combination on the activation of the vestibulo-sympathetic reflex when standing up. Based on the preliminary analysis of our data, we can conclude that the different medications seem to be acting on different, specific parts of the vestibular system.

5–2 [#3046]

Pharmacokinetics of Scopolamine Intranasal gel Formulation (INSCOP) during antiorthostatic bedrest

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Space Motion Sickness (SMS) is experienced during early flight days of space missions and on reduced gravity simulation flights which requires treatment with medications. Oral administration of scopolamine tablets is still a common practice to prevent SMS symptoms. Bioavailability of medications taken by mouth for SMS is often low and variable. Intranasal (IN) administration of medications has been reported to achieve higher and more reliable bioavailability than from an equivalent oral dose. In this FDA reviewed phase II clinical trial, we evaluated pharmacokinetics of an investigative new drug formulation, INSCOP during ambulatory (AMB) and antiorthostatic bedrest.
(ABR), a ground-based microgravity analog. Twelve subjects including 6 males and 6 females received 0.2 and 0.4 mg doses of INSCOP on separate days during AMB and ABR in a randomized, double blind cross over experimental design.

Blood samples were collected at regular time intervals for 24 h post dose and analyzed for free scopolamine concentrations by an LC-MS-MS method. Pharmacokinetic parameters were calculated using concentration versus time data and compared between AMB and ABR conditions. Results indicated that maximum concentration and relative bioavailability increased marginally during ABR compared to AMB; differences in PK parameters between AMB and ABR were greater with 0.2 mg than with 0.4 mg dose. Gender specific differences in PK parameters was observed both during AMB and ABR with differences higher in females between the two conditions than in males. A significant observation is that while gender differences in PK appear to exist, the differences in primary PK parameters between AMB and ABR after IN administration, unlike oral administration, are minimal and may not be clinically significant for both genders.

5–3 [#3003]

Postural prediction of motion sickness

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Predicting motion sickness incidence is an inexact science. Existing methods rely on subjective data, such as motion history questionnaires, or on mathematical models that estimate sensory conflict. I offer a novel method that relies on a qualitatively different type of data. The subjective symptoms of visually induced motion sickness are preceded by changes in postural activity. This effect has been demonstrated in a wide range of settings including laboratory devices, fixed base flight simulators, virtual environments, head-mounted displays, and console video games. Effects occur during both standing and seated posture, and whether the observer has or does not have control of the visual motion stimuli. The robustness and generality of these effects suggest the possibility that motion sickness susceptibility might be predicted from data on postural activity. We [1] exposed standing subjects to oscillating optical flow in a moving room. We measured head movement prior to and during exposure. Using discriminant analysis, we developed equations that predicted motion sickness incidence (subjects’ yes/no forced choice reports of whether they were motion sick) from specific parameters of head movement. These equations account for a higher percentage of the variance in subjective reports of motion sickness (up to 60%) than is typically found with more traditional methods of prediction. Importantly, motion sickness incidence was predicted by body sway before subjects were exposed to the nauseogenic visual motion stimulus. This approach might be extended to predict motion sickness across different situations, including weightlessness.

Reference


5–4 [#3056]

Cerebral blood flow decreases prior to nausea during off-vertical axis rotation

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Nausea and motion sickness are important operational concerns for aviators and astronauts. Understanding underlying mechanisms associated with motion sickness may lead to new treatments. The goal of this work was to determine if changes in cerebral blood flow precede the development of nausea in motion sick susceptible subjects. Cerebral flow velocity in the middle cerebral artery (transcranial Doppler), blood pressure (Portapres) and end-tidal CO2 were measured while subjects experienced a 20° off vertical axis rotation (OVAR) for 15 min at 0.1 Hz (36°/sec) followed by 15 min of 0.2 Hz (72°/sec) rotation. Rotation was terminated when subjects reported persistent moderate nausea. Rotation while upright did not significantly change cerebral blood flow or blood pressure. Prior to nausea, subjects had significant increases in blood pressure (+7.3 ± 2.4 mmHg, \(P < 0.02\)) and cerebrovascular-
lar resistance (\( +17 \pm 2\% \), \( P < 0.001 \)) and decreases in cerebral flow velocity both in the second (\(-5.2 \pm 2.1\%\)) and last minute (\(-4.9 \pm 1.8\%\)) before termination (\( P < 0.001 \)). In comparison, motion sick resistant subjects demonstrated no change in blood pressure, cerebrovascular resistance or cerebral flow velocity. These data indicate that cerebral hypoperfusion precedes the development of nausea. Further work is necessary to determine what role cerebral hypoperfusion plays in motion sickness. This work was supported by NASA grant NNJ04HI13G (Serrador) and NIH grant R21DC009900 (Serrador).

5–5

Are evolutionary hypotheses for motion sickness “Just So” stories?

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The survival advantage conferred in most vertebrates by powerful and easily conditionable nausea and vomiting reflexes as a third line of defense against ingested neurotoxins is relatively self-evident. In 1977 Triesman [1] proposed that ingestion of neurotoxins creates inconsistent vestibular, visual, and proprioceptive spatial referents, so linkages from sensory to emetic centers evolved as an additional defense mechanism. That certain motions also cause nausea and vomiting was considered an unfortunate epiphenomenon. Triesman’s hypothesis (aka the “Poison Theory”) is certainly plausible, and is often cited as a scientific explanation for motion sickness. However after three decades it is fair to ask: how compelling is the evidence for it? Darwin [2,3] repeatedly cautioned that plausible evolutionary explanations are not always correct, since not every characteristic is adaptive. The notion that evolution shapes all phenotypic traits for survival advantage is referred to as “adaptationism” [4]. Kipling penned “Just So Stories” (e.g. “how the leopard got his spots”) partly as parody. In evolutionary science, the term is now used to describe a plausible, but unverifiable/unfalsifiable evolutionary explanation for a specific phenotype. Certainly the generation of alternative plausible evolutionary hypotheses is an essential part of science – provided the hypotheses are testable. Thirty five years after Triesman proposed it, how compelling is the evidence for the “Poison Theory” [5]? Do ingested toxins typically cause vertigo? Vestibular sensory conflict neurons [6,7] exist whose primary role is arguably in body movement control, rather than vomiting. What about other plausible evolutionary explanations [8]? Alternatively, since vertebrate balance and emetic system neuroarchitectures are dictated by many potent phylogenetic and ontogenic factors, could coupling between them in motion sickness simply be a maladaptive pleiotropic trait, recently manifested on an evolutionary timescale? Supported by the National Space Biomedical Research Institute through NASA NCC9-58.

Reference


5–6

The evidence based etiology of Space Motion Sickness

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Space Motion Sickness (SMS) was reported on the second orbit of the second manned flight. Almost five decades later there is no satisfactory etiology [1]. Virtually all approaches to the problem to date are based on the concept of motions which produce conflicting responses from different sensory modalities [1,2]. Characteristic symptoms are triggered by such sensory conflicts through vestibular inputs to the chemo-receptor trigger zone Both symptoms and courses of motion sickness (MS) and SMS differ. SMS symptoms are consistent with demonstrated otolith organ function [3] and observed and recorded inflight effects [4]. The crux
of vestibular effects of weightlessness is inherent in the graviceptor sensors of the otolith organs. Functionally they are weighted single axis pendulum accelerometers, spring loaded to a neutral position in the absence of displacing force. Thousands of these transducers are arranged geometrically to sense any orientation of the head to gravity. In weightlessness the variously oriented sensors all indicate a gravity vector normal to their mounting axis. This produces an intrinsic single modality sensory conflict which causes a paresis of the gastro-intestinal tract and produces the episodic vomiting and other symptoms characteristic of primary SMS [5]. Also, in weightlessness the otolithic sensors cannot produce their usual signals in response to angular head motion. This produces a bimodal sensory conflict with semi-circular canal signals, even with normal head motions and probably accounts for the characteristic of MS sometimes seen in SMS [2]. Thus weightlessness causes anomalous otolithic signals with both an intrinsic conflict and a bimodal motion dependent conflict. These produce differing symptoms apparently through different connections to the gastrointestinal system [4].

Reference

Oral Session 6: Sensorimotor Integration

6–1 [#3020]

Fear of falling: Posture control as influenced by perceived fall height

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Human control of posture, developed to permit standing and locomotion in Earth’s gravity, can be adapted to meet a variety of environmental challenges. Whether posture is associated with an EVA looking at the Earth from orbit, locomotion on the moon, or simply standing on a moving surface on the ground, the strategy for maintaining balance is influenced by the perception of the consequence of falling. We examined the posture mechanisms for three groups of subjects who attempted to maintain balance on a moving platform, first at ground level and then elevated. The subjects were young normals, elderly normals, or patients recovering from hemi-labyrinthectomy. We observed an alteration of strategy, especially among the elderly and the patients, when we either increased the task difficulty, by eye closure, or when we increased the consequence of falling by raising the platform. Subjects with a fear of falling reverted to a “rigidification” strategy which caused the head to be stabilized over the moving platform, as opposed to an inertial compensation strategy in which the feet and hips oscillated under an inertially fixed head.

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6–2 [#3021]

Effects of mechanostimulation of the foot sole cutaneous receptors on characteristics of leg muscles stretch reflexes under conditions of “Dry Immersion”

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Effects of the mechanostimulation of deep cutaneous receptors of the sole on the recruitment and the recovery curves of m.soleus (S) and m.gastrocnemius lateralis (GL) stretch reflexes have been studied under conditions of dry immersion (DI).

18 volunteers 22–30 years of age that signed the informational content to participate in the study have been exposed to 7-day DI, being divided in 2 groups – control (C) and experimental (E) ones. Subjects of E group when being in immersion received every day the mechanical stimulation of the support zones of the soles, that mimicks all the parameters of slow and fast pacing. The overall duration of the stimulation, produced by Compensator of Support Unloading (KOR), was 2 hours per day. The recruitment and the recovery curves of muscles under study have been recorded pre-, during (on the days 3 and 7) and postimmersion (also on the days 3 and 7). To obtain the recovery curve the paired stimulation procedure has been used with interval durations between conditioning and testing stimuli from 10 to 3000 ms and with the reflex amplitudes of both equal to 40–60% of the maximal one.

The results of studies of the H-reflexes recovery curves revealed a pronounced facilitation effect of the cutaneous foot sole afferentation that was manifested by a significant decline of the curves amplitude under conditions of support unloading in the C group and its enhancement in E group in which the mechanostimulation of the foot sole support zones during DI has been
used. The changes of characteristics of the recruitment curves, on the opposite, pointed out to inhibitory effects of the foot sole stimulation on the excitability of the leg muscles stretch reflexes: the absolute and relative values of reflexes maximal amplitudes in this case have increased in DI in “no stimulation” control group and didn’t change in the E group.

Thus, the results of studies have shown that cutaneous afferents of the soles interact strongly with spinal interneuronal circuits and that the effects of this interaction could be both excitatory or inhibitory depending on testing protocol.
Oral Session 7: Suborbital and Parabolic Flight

7–1 [#3033]

Tactile cueing as a gravitational substitute for spatial navigation during parabolic flight

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Introduction: Spatial navigation requires an accurate awareness of orientation in your environment. The purpose of this experiment was to examine how spatial awareness was impaired with changing gravitational cues during parabolic flight, and the extent to which vibrotactile feedback of orientation could be used to help improve performance.

Methods: Six subjects were restrained in a chair tilted relative to the plane floor, and placed at random positions during the start of the microgravity phase. Subjects reported their orientation using verbal reports, and used a hand-held controller to point to a desired target location presented using a virtual reality video mask. This task was repeated with and without constant tactile cueing of “down” direction using a belt of 8 tactors placed around the mid-torso. Control measures were obtained during ground testing using both upright and tilted conditions.

Results: Perceptual estimates of orientation and pointing accuracy were impaired during microgravity or during rotation about an upright axis in 1g. The amount of error was proportional to the amount of chair displacement. Perceptual errors were reduced during movement about a tilted axis on earth.

Conclusions: Reduced perceptual errors during tilts in 1g indicate the importance of otolith and somatosensory cues for maintaining spatial awareness. Tactile cueing may improve navigation in operational environments or clinical populations, providing a non-visual non-auditory feedback of orientation or desired direction heading.

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7–2 [#3034]

Gravity dependence of the pitch vestibulo-ocular reflex

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Head movements in the pitch plane are especially relevant to sensorimotor function following spaceflight, as many astronauts have reported hypersensitivity to pitching movements during re-adaptation to a 1g environment. This study focuses on changes in the pitch vestibulo-ocular reflex (pVOR) in different gravity levels. While the pVOR is primarily driven by the vertical semicircular canals, considerable evidence from clinical and spaceflight studies has demonstrated that it is modulated by otolith input. Here, we present the results of several parabolic flight studies in which we measured the pVOR, either directly via simultaneous measurements of head and eye movements, or via a new technique that we have entitled vestibulo-ocular nulling (VON). In VON, a rate sensor measures head
movement and feeds it to a computer, which displays a visual target. As the head moves, the device measures head motion and uses it to control target position. The subject controls the gain of the target motion (relative to head motion) in order to reduce the apparent motion of the target to zero. Because the motion-gain value set by the subject is inversely proportional to the desired VOR gain, the motion-gain value set by the subject provides a surrogate measure of vestibulo-ocular function. In general, during parabolic flights, subjects showed differences in VOR gain in different g-levels, as predicted based on otolith stimulation. These differences decreased with experience, so that gains were similar in the various g-levels after adaptation, suggesting a context-specific otolith contribution.

7–3 [#3030]

An agenda for sensorimotor research in sub-orbital flight

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The excitement of space travel will be open to thousands of people by new commercial sub-orbital operations. Experience with changing g levels during space flight and parabolic flight suggests that sensorimotor disruptions are likely in these travelers, including postural stability, eye movements and motor coordination. We believe overcoming these sensorimotor disruptions will require a framework that delineates how approaches should differ from those applied to orbital flight and between sub-orbital passengers and pilots. For example, while most passengers are interested in maximizing enjoyment and flying only once, pilots are interested in maximizing precision and safety, and fly often. Strategies for overcoming disruptions include sensorimotor adaptation, re-adaptation, pre-adaptation, pharmaceuticals and cognitive training.

Sensorimotor adaptation is one strategy for overcoming disruptions. However, its application to sub-orbital flight, with periods of reduced and enhanced gravity lasting less than four minutes, is an open question. We have performed experiments on sensorimotor adaptation during parabolic flight, in which we tested subjects over four consecutive days of flying. The reflex we tested, the pitch vestibulo-ocular reflex, took a few days during to overcome an initial disruption. This suggests that sensorimotor adaptation will be important for sub-orbital pilots, and that sub-orbital passengers may benefit from previous exposure to parabolic flight.

To improve comfort and safety during sub-orbital operations, we recommend using parabolic flight to pre-adapt sub-orbital passengers, and we recommend continued research to understand the best timing for these flights, and tasks for passengers to conduct. We recommend emphasizing recency of experience for sub-orbital pilots.

7–4 [#3061]

Pre-flight adaptation protocols for suborbital flight

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Commercial suborbital flights will present a challenging sensorimotor experience, with 4–5 minutes of 0g between hyper-g launch and landing phases. Based on experience with parabolic flight, and the likely wide range of fitness and experience levels of suborbital passengers, sensorimotor disturbances are very likely to be a problem (motion sickness, disorientation, discomfort and anxiety). Pre-flight adaptation protocols might alleviate some of these issues. We are developing a set of sensorimotor assessment tests for use after long-duration space flight. A subset of these tests can be applied to passengers before and after suborbital flight. The tests include rotational and translational vestibulo-ocular assessment, ocular skew and disconjugate torsion, and roll vection. Performance on these tests can be examined for correlations with in-flight experience (motion sickness, etc.) based on questionnaires and cabin video recordings. Through an understanding of adaptation to parabolic and orbital flight, obtained from many previous studies, we can then suggest appropriate pre-flight adaptation procedures. Available pre-flight adaptation protocols include parabolic flight and centrifugation, and related concepts include context-specific adaptation and adaptive generalization. Coupling each of these to the appropriate passenger, based on pre-flight testing, is the challenge. As one example, if incorrect canal-otolith integration is identified, based
on pitch and roll VOR testing, then pre-flight training of the pitch and roll VOR in parabolic flight might be of use. The premise is that the appropriate 0g-specific sensorimotor program would be learned ahead of time, and called into play once in 0g suborbital flight. Such a research program would not only provide information on human adaptation to flight, but could also improve the flight experience for passengers, and involve them as part of the scientific enterprise rather than simply as thrill seekers. Testing of suborbital passengers should begin as soon as possible after flights begin, to quickly establish the required database to enable this work.

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Oral Session 8: Gaze, Posture and Locomotion

8–1 [#3029]

Perceptual roll tilt thresholds demonstrate visual-vestibular fusion

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Sensory fusion, the process of combining noisy and sometimes ambiguous signals, is disrupted in spaceflight. This study examined visual-vestibular fusion during roll tilt using three conditions:

1. VESTIBULAR ONLY: subjects rotated in the dark.
2. VISUAL ONLY: subjects at rest while observing a rotating scene.
3. VESTIBULAR+VISUAL: subjects rotated with the lights on.

Subjects (3 F, 4 M) were screened for normal vestibular function. We measured thresholds using an adaptive staircase (3-down 1-up) in which subjects tilted left or right and indicated perceived tilt direction. A range of frequencies (0.05, 0.1, 0.2, 0.5, 1, 2, 5 Hz) allowed us to use differing dynamic properties to separate the contribution of different sensory cues. Motions consisted of a single-cycle of sinusoidal angular acceleration yielding a sigmoid-like displacement.

With VESTIBULAR ONLY, gravitational tilt measured by the otoliths dominated at low frequencies while the SCC contribution increased at higher frequencies. Threshold at 0.05 Hz was 1.32°. As frequency increased, threshold was reached with smaller tilt angles, dropping to 0.05° at 5 Hz. VISUAL ONLY thresholds were lower than VESTIBULAR ONLY between 0.1 and 2 Hz, greater at 5 Hz, and the same at 0.05 Hz. VESTIBULAR+VISUAL thresholds between 0.1–1 Hz were reduced versus VESTIBULAR ONLY (ANOVA; p < 0.005) and similar to VISUAL ONLY, while at 5 Hz VESTIBULAR+VISUAL was similar to VESTIBULAR ONLY thresholds. We conclude that the predominance of vestibular and visual cues varies with frequency, and roll-tilt motion thresholds are smaller when vestibular and visual cues are combined, consistent with maximum-likelihood estimation.

8–2 [#3050]

Is postural stability controlled through punctuated equilibrium?

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Postural stability deficits following spaceflight are a well established phenomenon typically quantified...
through forceplate sway analytics; yet current measures may have limited resolution if test subjects fail to reach a fall or near fall. Furthermore, current control models fail to account for both individual variations in stability and the feedback control necessary for stability during movement generation. We propose a control model of punctuated equilibrium where the region of equilibrium can be redefined by a dynamic “escape” trajectory. This model uses Hidden Markov Model (HMM) techniques to classify our two states: 1) related COM trajectories identifying a series of stable equilibria and 2) dynamic “escape” trajectories.

In this study we test the theoretical HMM framework by identifying local stability equilibria and postural control failures during quiescent standing in astronauts pre- and postflight by quantifying the dwell time, size, and shape of the equilibria, the dynamic trajectories, and the equilibria region as a whole. The COM trajectories observed consistently demonstrated punctuated equilibrium, characterized by alternating patterns of temporary equilibrium followed by transient escape. Immediately after spaceflight, equilibrium periods were shorter in duration and more diffuse in area. The same algorithm was also able to distinguish quiescent standing from dynamic activities, such as squatting or arm-lifting. This capability to identify intentional perturbations further facilitates the classification of intentional, controlled COM shifts from unintentional, destabilizing shifts in COM. Thus, we suggest our punctuated equilibrium model can offer detection of postural instability in a greater range of testing or operational scenarios.

8–3 [#3017]

Changes in vestibular-ocular interaction in long-term space flights

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Introduction: The aim of the study was to examine effects of long-duration exposure to weightlessness on characteristics of horizontal and vertical gaze fixation reaction.

Methods: Nine cosmonauts – members of 186–198 days mission on “Mir” station – participated in the study. The subjects were to perform the target acquisition task on targets that appeared at a distance of 16 angular degrees in a random order right- left, up- and down from the center. Test sessions were performed 4 times before launch, once a month during flight, and twice after landing.

Results: In BDC sessions time of gaze fixation reaction in all the cosmonauts didn’t exceed 650 ms. During space flight (SF) it extended up to 900–1000 ms and more. The velocities of head movement in space decreased, the velocities of eye counterrotation decreased also but to a less degree. This difference resulted in increase of VOR gain up to 2.3 values, that was especially pronounced during the 1st month of flight; further it decreased reaching the values of 0.5–0.7 on the 5th month of SF. After landing VOR gain increased greatly again, and the time of reaction up to the 5th post-flight session remained high. The described dynamic of changes had the same direction for both horizontal and vertical reactions, being more expressed in vertical ones.

Conclusions: These results are in agreement with the data of I. Kozlovskaya, M. Sirota et al., which showed in the experiments with monkeys that VOR gain increased together with redundant inadequate responses of vestibular nucleus on vestibular stimulation and that in the course of adaptation to these conditions central nervous system inhibited vestibular input from the motor control systems (“vestibular neglect”, Kozlovskaya et al., 1985–1987).

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8–4 [#3014]

Effect of passive horizontal totations and vertical oscillations on dynamic visual acuity


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Astronauts experience sensorimotor disturbances after long-duration spaceflight. These crewmembers may need to egress the vehicle within a few minutes for safety and operational reasons in various sea state condi-
tions following a water landing. Exposure to even low frequency motions induced by sea conditions surrounding a vessel can cause significant fine and gross motor control problems affecting critical functions. The objective of this study was to document human motor and visual performance during simulated wave motion in the 0.1 to 2.0 Hz range. We examined, in 12 healthy subjects, the changes in accuracy when performing a seated visual target acquisition task in which the location of target was offset vertically during horizontal full-body rotation at an oscillating frequency of 0.8 Hz (peak velocity of 160 deg/s). The main finding was that the accuracy of performance degraded in 7 of 12 subjects when acquiring vertical targets at perturbing frequencies of 0.8 Hz in the horizontal plane by one step size. We also examined, in a separate study on 12 healthy subjects, seated dynamic visual acuity (DVA) task performance during vertical full-body oscillations at perturbing frequencies of 2 Hz (peak-to-peak motion of 5 cm). The main finding was that DVA was significantly reduced when acquiring targets at perturbing oscillations at frequencies of 2 Hz in the vertical plane by approximately 1 chart line. Thus, low frequency perturbations in the horizontal and vertical planes can cause decrements in visual performance.

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8–5#3005

Eye movements and motion perception during off-vertical axis rotation after spaceflight

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Constant velocity off-vertical axis rotation (OVAR) provides dynamic linear acceleration stimuli that can be used to assess otolith function. Eight astronauts were rotated in darkness about their longitudinal axis 20° off vertical at low (0.125 Hz) and high (0.5 Hz) frequencies, and their responses were compared before and after 10–14 days spaceflight on board the Space Shuttle. Eye movements were recorded using infrared videography and perceived motion was evaluated using a joystick with four degrees of freedom – pitch and roll tilt, front-back and lateral translation. Low-frequency OVAR generates tilt otolith-induced responses – modulation of ocular counter-roll and counter-pitch with perceived conical motion path – whereas high-frequency OVAR generates translational otolith-induced responses – modulation of horizontal slow phase velocity and vergence with perceived cylindrical motion path. No major changes were seen in the eye movements after adaptation to weightlessness. However, there was an increase in sensitivity to motion perception after spaceflight. The experiment also indicated that sensitivity to motion sickness was reduced during OVAR immediately after spaceflight. These results confirm that some otolith reflexes may not be altered by short-duration spaceflight – or may readapt very quickly – and that the resolution of sensory conflict associated with postflight recovery involves higher-order neural processes.

8–6 [#3051]

Walk on Floor Eyes Closed Test as a measure of postflight ataxia


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tion: Astronauts returning from space flight universally exhibit impaired posture and locomotion. Measurement of this impairment is an evolving process. The walk on the floor line test with the eyes closed (WOFEC) provides a unique procedure for quantifying postflight ataxia. Data from a modified WOFEC were obtained as part of an ongoing NASA interdisciplinary pre- and postflight study (Functional Task Test, FTT) designed to evaluate astronaut postflight functional performance.

Methods: Seven astronauts (5 short duration with flights of 12-16 days; two long duration crewmembers with flights of 6 mo) were tested twice before flight, on landing day (short duration only), and 1, 6, and 30 days after flight. The WOFEC consisted of walking for 10 steps (repeated twice) with the feet heel to toe in tandem, arms folded across the chest and the eyes closed. The performance metric (scored by three examiners from video) was the percentage of correct steps
completed over the three trials. A step was not counted as correct if the crewmember sidestepped, opened their eyes, or paused for more than three seconds between steps.

**Results/conclusions:** There was a significant decrease in percentage of correct steps on landing day (short duration crew) and on first day following landing (long duration) with partial recovery the following day, and full recovery beginning on day sixth after flight. Both short and long duration fliers appeared to be unaware of foot position relative to their bodies or the floor. Postflight, deviation from a straight path was common, and the test for two crewmembers elicited motion sickness symptoms. These data clearly demonstrate the sensorimotor challenges facing crewmembers after returning from spaceflight. The WOFEC test has value providing the investigator or crew surgeon with a simple method to quantify vestibular ataxia, as well as providing instant feedback of postural ataxia without the use of complex test equipment.
Oral Session 9: Adaptation and Rehabilitation

9–1 [#3023]

Training to facilitate adaptation to novel sensory environments

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After spaceflight, the process of readapting to Earth’s gravity causes locomotor dysfunction. We are developing a gait training countermeasure to facilitate adaptive responses in locomotor function. Our training system is comprised of a treadmill placed on a motion-base facing a virtual visual scene that provides an unstable walking surface combined with incongruent visual flow designed to train subjects to rapidly adapt their gait patterns to changes in the sensory environment. The goal of our present study was to determine if training improved both the locomotor and dual-tasking ability responses to a novel sensory environment and to quantify the retention of training. Subjects completed three, 30-minute training sessions during which they walked on the treadmill while receiving discordant support surface and visual input. Control subjects walked on the treadmill without any support surface or visual alterations. To determine the efficacy of training all subjects were then tested using a novel visual flow and support surface movement, not previously experienced during training. This test was performed 20 minutes, 1 week, 3 and 6 months after the final training session. Stride frequency and auditory reaction time were collected as measures of postural stability and cognitive effort, respectively. Subjects who received training showed less alteration in stride frequency and auditory reaction time compared to controls. Trained subjects maintained their level of performance over six months. We conclude that, with training, individuals become more proficient at walking in novel discordant sensorimotor conditions and are able to devote more attention to competing tasks.

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9–2 [#3022]

Different profiles of vestibular habituation in pilots and common people

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Objective: The different profiles of vestibular habituation in pilots and common people were explored after their Coriolis test selection.

Methods: 12 healthy men and 14 pilot students passed the Coriolis test selection and participated in this experiment. They were exposed to five-day continuous or intermittent Coriolis adaptation training. The vestibular autonomic responses such as motion sickness symptom, ECG, EGG, EOG, facial skin infrared images and blood biochemistry indexes elicited by Coriolis test were monitored at 1st day, 1st week, 2nd week, 4th week, 5th week, 9th week and 14th week after training.

Results: It was found that subjects all passed the 10min continuous or 15min intermittent Coriolis adap-
tation training. For common healthy men, after Coriolis training the low motion sickness symptom scores can maintain 1 or 2 weeks, the habituation of autonomic responses was about 1 week, the endocrine system response held for 2 weeks, the habituation of facial skin was about 2 weeks and the slow phase speed of EOG can maintain for 3 months. For pilot students, the low motion sickness symptom scores lasted for 5 weeks, the EGG habituation was about 2 weeks, the slow phase speed of EOG can maintain for 9 weeks, but the autonomic responses had no habituation effects.

Conclusion: It was suggested that pilots were a special group of people, and the profile of vestibular habituation presented a dynamic changes expression in respective aspects of vestibular autonomic responses.

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References

9–3 [#3052]

Enhancing vestibular function by imperceptible electrical stimulation

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Loss of vestibular function occurs with both disease and aging, but currently there are limited options to treat this loss. Stochastic resonance (SR) is a counterintuitive phenomenon in which the addition of a suitable noise level can enhance the detection of weak signals. SR has been shown to improve sensory function in a number of systems. Since loss of vestibular function is likely due to loss of hair cells, and thus a reduced sensory input, we hypothesized that SR noise would enhance this response and thus improve vestibular function in elderly subjects. To test this we applied SR noise at sub threshold levels to electrodes located over the mastoid process during sinusoidal roll tilt of ± 25 degrees in 8 elderly subjects and 7 younger subjects. We examined ocular counter-roll (OCR) during tilt, a reflexive eye rotation in the opposite direction mediated through the vestibular system. We found that all elderly subjects increased OCR (Mean 23%, Range 4–60%) in contrast to younger subjects (Mean +1%, Range −16–27%).

The increase was linearly related to baseline OCR ($R = 0.67, P = 0.007$), indicating that subjects with impaired vestibular function showed the greatest benefit, regardless of age. These findings demonstrate that galvanic stimulation with SR noise is able to restore vestibular function in those with impaired function. Since stimulation was sub threshold, these data suggest that application of SR galvanic stimulation may provide a new treatment alternative to restore vestibular function.

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9–4 [#3015]

Vestibular-somatosensory convergence in head movement control during locomotion after long-duration space flight

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d Exposure to the microgravity conditions of space flight induces adaptive modification in the control of vestibular-mediated reflexive head movement during locomotion after space flight. Space flight causes astronauts to be exposed to adaptation in both the vestibular and body load-sensing (BLS) somatosensory systems. The goal of these studies was to examine the contributions of vestibular and BLS somatosensory influences on head movement control during locomotion after long-duration space flight. Subjects were asked to
walk on a treadmill driven at 1.8 m/s while performing a visual acuity task. Data were collected using the same testing protocol from three independent subject groups; 1) normal subjects before and after exposure to 30 minutes of 40% bodyweight unloaded treadmill walking, 2) bilateral labyrinthine deficient (LD) patients and 3) astronauts who performed the protocol before and after long duration space flight. Motion data from head and trunk segmental motion data were obtained to calculate the angular head pitch (HP) movements during walking trials while subjects performed the visual task, to estimate the contributions of vestibular reflexive mechanisms in HP movements. Results showed that exposure to unloaded locomotion caused a significant increase in HP movements, whereas in the LD patients the HP movements were significantly decreased. Astronaut subjects’ results showed a heterogeneous response of both increases and decreases in the amplitude of HP movement. We infer that BLS-mediated somatosensory input centrally modulates vestibular input and can adaptively modify head-movement control during locomotion. Thus, space flight may cause a central adaptation of the converging vestibular and body load-sensing somatosensory systems.

Comparison of postural recovery after short and long duration spaceflights

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Introduction: Post-flight postural ataxia reflects adaptive changes to vestibulo-spinal reflexes and control strategies adopted for movement in weightlessness. Quantitative measures obtained during computerized dynamic posturography (CDP) from US and Russian programs provide insight into the effect of spaceflight duration in terms of both the initial decrements and recovery of postural stability.

Methods: CDP data were obtained on 117 crewmembers after Shuttle flights lasting 4–17 days, and on 64 crewmembers following long-duration missions lasting 48–380 days. Although the number and timing of sessions varied, the goal was to characterize postural recovery by pooling similar measures from different research and flight medicine programs. This report focuses on eyes closed, head erect conditions with either a fixed or sway-referenced base of support. A smaller subset of subjects repeated the sway-referenced condition while making pitch head movements (± 20° at 0.33Hz). Equilibrium scores were derived from peak-to-peak anterior-posterior sway. Fall probability and recovery curves were modeled using Bayesian statistical methods.

Results: The standard Romberg condition was the least sensitive. Longer duration flights led to larger decrements in stability with sway-reference support during the first 1–2 days, although the time course of recovery was similar across flight duration with head erect. Head movements led to increased incidence of falls during the first week, with a significantly longer recovery after long duration flights.

Conclusions: The diagnostic assessment of postural instability, and differences in the time course of postural recovery between short and long flight durations, are more pronounced during unstable support conditions requiring active head movements.
Validation of centrifugation as a countermeasure for otolith deconditioning during spaceflight: Preliminary data of the ESA SPIN study

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In the framework of further space exploration, countermeasures to combat the drawbacks of human space flights are essential. The here described study focuses on the influence of microgravity on the otolith-ocular reflex and aims to verify the hypothesis of artificial gravity being an adequate countermeasure for the deconditioning of the aforementioned reflex. The so-called SPIN-study serves as control experiment for the Neurolab mission (STS-90) during which 4 crewmembers of the space shuttle were subjected to in-flight centrifugation on the visual and vestibular investigation system (VVIS). After their mission, they did not suffer from orthostatic intolerance and spatial disorientation. In addition, the relevant parameters of the otolith-ocular interaction remained unaffected. For this study cosmonauts from a long duration stay in the International Space Station that were not centrifuged in-flight were tested on the VVIS (1 g centripetal interaural acceleration; consecutive right-ear-out anti-clockwise and left-ear-out clockwise measurement) on 6 different days. Three measurements were scheduled about one month and a half prior to launch and the remaining 3 immediately after their return from space (on R+1, R+4, R+9; R = return day from space). The ocular counter roll was measured on several steady state moments before, during and after the rotation using infrared video goggles. The perception of verticality was monitored using an ultrasound system. Optokinetic stimuli were offered during the rotation and the change of the orientation of the velocity vector of the optokinetic nystagmus was investigated. Analysis of the results indicates a large inter subject variability. The preliminary results of 4 cosmonauts will be shown.

Galvanic vestibular stimulation replicates post-flight deficits in posture, gait, gaze and operator proficiency

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Background: Crewmembers returning to a gravitational environment after prolonged microgravity exposure exhibit decrements in balance, locomotion, gaze and manual control. Currently there is no ground analog for the sensorimotor effects of spaceflight. Here we summarize 5 years of development and validation of a novel analog of post-flight sensorimotor dysfunction utilizing Galvanic vestibular stimulation (GVS).

Methods: The GVS system delivers a pseudorandom (sum of sines, 0.16, 0.32, 0.43, 0.61 Hz, max ± 5 mA) transmastoidal current via surface electrodes [1, 2].

![Fig. 1. The GVS system. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/VES-2010-0411)](image)

Results:
Posture
The equilibrium scores in normal subjects (N = 12) exposed to acute GVS during computerized dynamic posturography (CDP) accurately reproduced deficits in anterioposterior sway observed in returning shuttle crewmembers [1].

Gait:
Head stabilization (linear vestibulo-colic reflex) was degraded in subjects (N = 20) exposed to GVS during treadmill locomotion, equivalent to that observed in shuttle astronauts on landing day. Time to complete an obstacle course increased 21% during GVS, equivalent to an ISS astronaut 5 days post-landing [2].

Dynamic Visual Acuity (DVA):
DVA decreased by 0.06 logMAR with GVS, equivalent to the reduction in acuity observed in astronauts 6 days after return from extended missions aboard the ISS [2].

Operator Proficiency:
Pilot performance was assessed during shuttle landings in the Vertical Motion Simulator (NASA Ames). Subjects (N = 11) flew 8 pairs of identical landing profiles with and without GVS. Touchdown speed wason target (204 kts) without GVS but increased significantly during GVS exposure and was at the upper limit (209 kts) of the target range. The rate of unsuccessful (crash) landings tripled, and hard landings (> 214 kts) almost doubled, with GVS relative to the no-GVS baseline [3]. These results were consistent with a review of the first 100 shuttle missions [4], which reported touchdown speed above specified limits in 20% of landings.

Conclusion: GVS is an effective analog of sensorimotor deficits following spaceflight.

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References

10–3 [#3013]
Stimulus characteristics for vestibular stochastic resonance to improve balance function

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Stochastic resonance (SR) is a mechanism by which noise can assist and enhance the response of neural systems to relevant sensory signals. Studies have shown that imperceptible stochastic vestibular electrical stimulation, when applied to normal young and elderly subjects, significantly improved their ocular stabilization reflexes in response to whole-body tilt as well as balance performance during postural disturbances. The
goal of this study was to optimize the amplitude characteristics of the stochastic vestibular signals for balance performance during standing on an unstable surface. Subjects performed a standard balance task of standing on a block of foam with their eyes closed. Bipolar stochastic electrical stimulation was applied to the vestibular system using a constant current stimulator through electrodes placed over the mastoid process behind the ears. Amplitude of the signals varied in the range of 0–700 microamperes. Balance performance was measured using a force plate under the foam block, and inertial motion sensors placed on the trunk and head. Balance performance with stimulation was significantly improved in the range of 10%–25% compared with no stimulation. The signal amplitude at which performance was maximized was in the range of 100–400 microamperes. Optimization of the amplitude of the stochastic signals for maximizing balance performance will have a significant impact on development of vestibular SR as a unique system to aid recovery of function in astronauts after long-duration space flight or in patients with balance disorders.

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