APPENDIX E

VESTIBULAR COUNTERMEASURES TASK GROUP- SUPPORTING MATERIAL

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E - 2 NEUROLOGICAL COUNTERMEAURES SUMMARY CHARTS

B TRIED AND ACCEPTED COUNTERMEASURES

EARLY SHUTTLE PHASE

CM # 1. **PROMETHAZINE INJECTION.**

Rationale:	Promethazine has had proven efficacy in ground-based nausea and vomiting due to illness, drug toxicity and motion.[1]
Supporting Research:	Shuttle trials have shown efficacy but no double-blind, placebo controlled trials have been performed. Crew member acceptance is high.
Risk/Benefit Ratio:	Appears to dramatically reduce the impact of SMS on early flight days but a small concern regarding performance remains.
Efficacy:	Although results show improvement in SMS symptoms in 90% of those treated, the improvement varies from major to minor.
Cost-effectiveness:	Inexpensive medication.
Operational ease of use:	Requires crew training for non-physician crew medical officers. Time loss on orbit is minimal. Requires preflight drug testing.
Interference with other countermeasures:	May cause drowsiness at therapeutic doses. More serious side effects mitigated by preflight drug testing. Performance decrements have been noted in ground-based trials; however, drugs such as dexedrine have reduced side effects. Performance decrements on orbit have been minimal since drug is used to treat crew members who are already ill and the pre sleep period is used for treatment when possible.

Recommendations:

(1) Continue using promethazine for SMS symptoms early in mission. (2) Consider small trials of newer medications in the KC-135 for possible future use. (3) Develop an alternative delivery system for dexedrine acceptable for space flight (intranasal, sublingual, patch, injectable, etc.) in case of emergencies which require peak performance after promethazine use. (4) As part of debriefings and review of medical records, more complete information should be gathered on the side effects of promethazine.

[1]Jennings, R.T., "Managing Space Sickness," presented at the NASA/NIH Workshop on Vestibular-Autonomic Regulation, Pittsburgh, PA, April 23-24, 1996.

C TRIED AND ACCEPTED COUNTERMEASURES

EARLY SHUTTLE PHASE

CM # 2. **CREW TRAINING / BRIEFINGS.** ***Examples include "limit head movements, maintain 1-G attitude early inflight, maintain cool cabin temperature, use LCG cooling, limit food intake unless hungry, low fat - high carbohydrate diet, maintain hydration, avoid odors, contain vomitus, limit activities that are provocative".***

Rationale:	Previous crew experiences concerning factors which seem to initiate or exacerbate SMS should be included in crew training.
Supporting Research:	Minimal
Risk/Benefit Ratio:	Essentially no risk
Efficacy:	Variable
Cost-effectiveness:	No cost
Operational ease of use:	It is not always possible to maintain cool cabin temperature. Doffing of the ACES causes head movements. Certain activities following "Go" for orbit ops require stowage of items and movement. Spacelab activation requires movement. Payload operations require movements.
Interference with other countermeasures:	None

Recommendations:

Continue present activities with crew training and briefings.

D TRIED AND ACCEPTED COUNTERMEASURES

EARLY SHUTTLE PHASE

CM # 3. **TIMELINE ADJUSTMENTS.** ***Examples include: "establish minimal duration of flight past SMS period, EVA on Flight Day 3 or later, EVA on Flight Day 2 only in contingencies after crew status check, no EVA on Flight Day 1, crew cross-training, reduced load on crew scheduling on Flight Days 1 and 2.***

Rationale:	Minimize crew work load during the time frame in which SMS is a problem. Timeline adjustments have helped to prevent early mission impact from vestibular disturbances, but impact operations during the first two days of flight.
Supporting Research:	Minimal
Risk/Benefit Ratio:	Each of these flight rules could be broken by real time decision making after assessing the crew status and risk of delay to the Orbiter, crew, and mission.
Efficacy:	No situation has arisen yet that required EVA before Flight Day 3. Most crews have performed well enough to complete activities that were critical early inflight. Increased mistakes have been noted by crew members on Flight Days 1 or 2 and they often cross check with each other on critical tasks.
Cost-effectiveness:	No cost
Operational ease of use:	Easy to implement
Interference with other countermeasures:	None

Recommendations:

Continue present approach for scheduling timeline.

E DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

EARLY SHUTTLE PHASE

CM # 1. PREFLIGHT ADAPTATION TRAINING (TTD AND DOME)

Rationale:	Exposure to training using visual-vestibular mismatch, such as PAT, will facilitate adaptation to microgravity and reduce SMS.
Supporting Research:	A large number of ground-based studies have been performed to develop the stimulus conditions and training schedules which support the rationale.
Risk/Benefit Ratio:	Risk is very low, benefit is potentially high in reducing SMS.
Efficacy:	Preliminary results indicate that education, demonstration of and experience with novel perceptual phenomena in PAT devices led to an overall 33% improvement in SMS symptoms.
Cost-effectiveness:	Training devices and adaptation protocols have already been developed, i.e. no development costs. The training requires minimal crew time.
Operational ease of use:	All training is completed preflight. The only inflight activity would be recording information concerning evaluation criteria.
Interference with other countermeasures:	There are no known or predicted problems with interference with other countermeasures. There is a recognized potential for training procedures to produce some motion sickness symptoms; the current incidence rate in ground-based studies is 5-10% (interference with crew comfort).

Recommendations:

Improve and develop predictors of who will get the greatest benefit; customize training for individual crew members.

F DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

EARLY SHUTTLE PHASE

CM #S2 AND 3. **UNUSUAL ATTITUDE EXPERIENCE** ***Anecdotal reports indicate that many crewmembers engage in a variety of activities involving exposure to unusual visual-inertial environments prior to a mission. Included among these are training in the WETF, training or other activity during parabolic flight in the KC 135 aircraft, performance of aerobatic maneuvers in high performance aircraft, SCUBA diving, PAT DOME training, and so on. This activity is based partly on anecdotal reports that pre-mission experience in unusual environments facilitates adaptation to prolonged microgravity.***

Rationale:	Suggested benefits from unusual environment experience is consistent with the view that coping with potential stressors can be facilitated by prior development of appropriate strategies and expectations
Supporting Research:	Crew debriefs, crew reports
Risk/Benefit Ratio:	Risk is very low, benefit is potentially high in reducing SMS.
Efficacy:	Anecdotal reports suggest alleviation of early SMS, but this has not been demonstrated
Cost-effectiveness:	Modest cost
Operational ease of use:	Modest increase in preflight training.
Interference with other countermeasures:	None identified

Recommendations:

Increase exposure to unusual attitudes using the WETF, parabolic flight, SCUBA diving and acrobatic flight in high performance aircraft. Unusual attitude experience should be recorded and correlated with SMS and other disturbances.

Identification of crewmembers likely to benefit from unusual attitude experience, as well as those likely to suffer negative consequences, should be attempted.

G TRIED AND ACCEPTED COUNTERMEASURES

SHUTTLE LANDING PHASE

CM # 4. **CREW TRAINING / BRIEFINGS.** ***Crews are given briefings on observed problems (visual illusions, tilt/translation reinterpretation, locomotor instability, etc.) to be expected during the entry, landing, and post landing phases. Advised to limit head movements and to make slow body/head movements initially. Trained to rely on visual cues rather than "seat of the pants" during performance of landing tasks.***

Rationale:	Information about expected alterations and proposed coping strategies assists crew members in avoiding situations which cause symptoms and in dealing with vestibular abnormalities which occur.
Supporting Research:	Crew debriefs, crew reports
Risk/Benefit Ratio:	Minimal risk, moderate benefit
Efficacy:	Avoidance of provocative situations and use of other sensory modalities (e.g. vision, Orbiter instruments) partially prevent or compensate for vestibular problems.
Cost-effectiveness:	Minimal cost.
Operational ease of use:	Only minor changes in operational timelines or procedures.
Interference with other countermeasures:	No interference with other countermeasures.

Recommendations:

Continue to brief crews about expected changes in function and coping strategies. Update information based on ongoing crew debrief data and crew reports.

H TRIED AND ACCEPTED COUNTERMEASURES

SHUTTLE LANDING PHASE

CM # 5. **RECENCY OF TRAINING** ***(Equipment is provided to enable crew members to practice those parts of the landing tasks which are possible close to flight and inflight.)***

Rationale:	Skill in performing nominal tasks necessary for landing improves the ability to perform these tasks when complicated by vestibular changes. The more recent the practice, the greater the skill.
Supporting Research:	Recent training in the IFR aviation flight environment has repeatedly been found to reduce accident rates.
Risk/Benefit Ratio:	Low risk, moderate benefit
Efficacy:	Crews report enhanced performance after proficiency training.
Cost-effectiveness:	cost of equipment purchase and maintenance, training time, and on orbit operation/practice judged effective by crews and managers.
Operational ease of use:	Minor timeline impact
Interference with other countermeasures:	None

Recommendations:

Continue to provide crews with adequate training close to flight and in-flight on tasks required during and after landing.

I TRIED AND ACCEPTED COUNTERMEASURES

SHUTTLE LANDING PHASE

CM # 6. **OPERATIONAL RECOMMENDATIONS.** ***To the greatest extent possible, and in keeping with other operational requirements, landings are planned in such a manner as to decrease the chances of causing vestibular problems or being unable to compensate for them. Examples include: selecting runway with best visual cues, flying a low G HAC, selection of crew members best suited to perform landing tasks (e.g. who have landed the Shuttle after shorter duration flights without difficulty).***

Rationale:	Preventing, as much as possible, situations which contribute to vestibular problems lessens the chance of operational difficulties.
Supporting Research:	
Risk/Benefit Ratio:	Minimal risk, some benefit
Efficacy:	When they can be implemented these preventive measures lessen but do not eliminate vestibular derangement.
Cost-effectiveness:	Some cost impact to some recommendations (e.g. landing at Edwards vs. KSC) but judged appropriate.
Operational ease of use:	No major impact to operations
Interference with other countermeasures:	None with other countermeasures, some with other flight requirements.

Recommendations:

Continue to modify operational landing requirements to create best “vestibular” environment based on what is currently known and augmented with data that becomes available.

J TRIED AND ACCEPTED COUNTERMEASURES

SHUTTLE LANDING PHASE

CM # 7. **INFLIGHT EXERCISE.** ***Proper use of exercise inflight to maintain strength and performance of antigravity muscles aids in locomotion postflight.***

Rationale:	Disuse atrophy of antigravity muscles adds to the locomotor instability seen post landing.
Supporting Research:	Greenisen study on aerobic capacity.
Risk/Benefit Ratio:	Low risk, good benefit.
Efficacy:	Exercise of proper muscles to the proper extent will prevent muscle deconditioning.
Cost-effectiveness:	Modest cost for providing proper equipment and on orbit time to exercise.
Operational ease of use:	Moderate overhead to set up equipment and perform adequate exercise.
Interference with other countermeasures:	Type of exercise chosen to prevent antigravity muscle loss may not be best to provide aerobic or skeletal fitness. Exercise may induce vestibular problems (SMS).

Recommendations:

Define best exercise protocols to prevent anti-gravity muscle loss or coordination deficits, and attempt to integrate with other exercise countermeasures.

K DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

SHUTTLE LANDING PHASE

CM # 4. **MEDICATIONS DURING/AFTER ENTRY AND LANDING**

Findings:

Rationale:	Vestibular suppressant medication should help relieve motion sickness symptoms on a short-term basis. Based on clinical use of these drugs for vestibular symptoms.
Supporting Research:	Multiple clinical studies showing efficacy of drugs in treating vestibular symptoms and motion sickness.
Risk/Benefit Ratio:	Risk is related to drowsiness side-effect of medication. In this environment the side-effect profile is low. Benefit of reduction of symptoms outweighs risks.
Efficacy:	Anecdotal reports from two to three crewmembers indicate that the nausea/vomiting are much improved.
Cost-effectiveness:	Very low cost (cost of a few pills). Used by crewmembers who do not have entry/landing tasks or after landing is completed.
Operational ease of use:	No or minimal impact on operations.
Interference with other countermeasures:	Potential interference with data for vestibular and cardiovascular studies postflight.

Recommendations:

Obtain data on actual use of medications during/after entry and landing. Determine individuals most likely to benefit from use of medications. Define criteria for use of post-flight drug use.

While meclizine, phenergan, and other medications are effective, over the last decade receptor antagonists specific for the H1 receptor have been developed. It is likely that at least one these (zamifenacen) may be successfully used to counter SMS without drowsiness as a side effect. Newer, more receptor-specific drugs should be evaluated for their potential to successfully treat post-flight symptoms without adverse side effects.

L DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

SHUTTLE LANDING PHASE

CM # 5. **PILOT** ***(Laptop computer and hand controller provided to practice the landing tasks while on orbit.)***

Rationale:	Practicing certain portions of the landing tasks may improve ability to perform tasks with conflicting vestibular inputs.
Supporting Research:	Crew reports, debriefs.
Risk/Benefit Ratio:	Low risk, moderate benefit.
Efficacy:	Crews report improvement of skills.
Cost-effectiveness:	Moderate cost in providing hardware and crew training and on orbit time.
Operational ease of use:	Minor timeline impact.
Interference with other countermeasures:	None.

Recommendations:

Continue to use; improve landing task simulators.

M DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

SHUTTLE LANDING PHASE

CM # 6. **HEAD MOVEMENTS DURING ENTRY** ***Crewmembers often perform head motions in pitch roll and yaw during entry and immediately post landing.***

Rationale:	Suggested benefits from active, voluntary head motion are consistent with an extensive research literature which demonstrates that voluntary action facilitates adaptation to sensory rearrangement and re-adaptation to nominal environments.
Supporting Research:	Crew reports, debriefs.
Risk/Benefit Ratio:	Low risk, moderate benefit.
Efficacy:	Anecdotal reports suggest re-adaptation may be facilitated by active head movements during entry. However, some crewmembers have reported that head movements induced or exacerbated disturbances.
Cost-effectiveness:	Modest cost
Operational ease of use:	Modest increase in preflight training.
Interference with other countermeasures:	None.

Recommendations:

Systematically collate and analyze crew de-brief data to determine the efficacy of head movements in re-adaptation.

Based on this data, as part of a DSO-type investigation, develop a standardized head motion protocol, record implementation of that protocol by crewmembers and correlate with postflight disturbance during structured debriefing.

Crewmembers should be familiar with their individual motion sickness syndrome pattern; entry/landing head motions should be terminated if they experience symptoms.

The efficacy of alternative protocols should be determined.

Identification of crewmembers likely to benefit from entry/landing head motions as well as those likely to suffer negative consequences should be attempted.

N DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

SHUTTLE LANDING PHASE

CM # 7. **CREW ASSISTED EGRESS**

Findings:

Rationale:	Less affected crew members can assist other crew members in an emergency egress.
Supporting Research:	
Risk/Benefit Ratio:	Potential risk to assisting crew member in delaying egress in order to help someone. Benefit is helping to ensure that all crew members egress in an emergency.
Efficacy:	Has not been needed or tried. Training on egress indicates that it is feasible.
Cost-effectiveness:	No cost involved.
Operational ease of use:	No or minimal impact on operations.
Interference with other countermeasures:	None
Interference with life:	None

Recommendations:

Egress training should include scenario of assisting an ill crew member out of the Shuttle. Define procedures or hardware changes to assist egress.

O DEVELOPED, ANECDOTAL, NOT ROUTINELY IMPLEMENTED

SHUTTLE LANDING PHASE

CM # 8. PREFLIGHT ADAPTATION TRAINING (PAT).

Rationale:	Pre-flight training to dual adapt the vestibular system to 0G and 1 G should decrease or prevent illusions and motion sickness during return to Earth.
Supporting Research:	Studies reported in the literature support the rationale for this training. A large number of ground-based studies have been performed that demonstrate "proof of concept" of adaptation and dual-adaptation in the PAT devices, and led to development of current training protocols and schedules.
Risk/Benefit Ratio:	Risk is low, and the potential benefits are high.
Efficacy:	The dual-adaptation training protocol has not been implemented and devaluated to determine efficacy.
Cost-effectiveness:	The simulators (trainers), training protocols and schedules have been developed. Minimal cost in crew time.
Operational ease of use:	No impact on inflight operations.
Interference with other countermeasures:	None known or anticipated. Minimal (5 - 10% incidence rate) of motion sickness symptoms associated with training in PAT devices.

Recommendations:

Develop and improve predictors of who will get the greatest benefit, and customize training for individual crew members.

P TRIED AND ACCEPTED COUNTERMEASURES

LONG DURATION RETURN

CM # 8. ASSISTED EGRESS

Findings:

Rationale:	Nominal procedure for egress of a crew member returning from a prolonged space station tour. Egress will be accomplished by ground personnel.
Supporting Research:	Reported by the Russians.
Risk/Benefit Ratio:	Risk could occur from delayed egress of crew member in a contingency. The benefit of ensuring safe nominal egress of crew member outweighs the unlikely necessity for rapid egress in a contingency.
Efficacy:	Russians have long history using assisted egress as their nominal procedure.
Cost-effectiveness:	Highly cost effective since it involves use of ground personnel only and no flight hardware development.
Operational ease of use:	No or minimal impact on operations.
Interference with other countermeasures:	None
Interference with life:	None

Recommendations:

Since the potential for an off-nominal landing is so remote, the use of assisted egress for a crew member returning from a prolonged space station tour seems to be the most efficacious approach. Post-flight symptoms of crew members returning from long duration flights should be monitored to see if they are qualitatively or quantitatively different from those seen on missions of shorter duration. As countermeasures are developed for the shorter duration missions, their applicability to longer duration missions should be assessed and implemented as required.

E - 3 Vestibular Task Group Supplemental Reports

<u>Head Movement Monitoring/Dynamic Restraint/Training Systems</u>

Astronaut head movements represent the dominant stimulus causing space sickness during the first few days of spaceflight, and reentry and postflight disorientation and earth sickness, which becomes more severe after longer flights. Astronaut head movements have been measured on some Spacelab and DTO missions, but the monitoring equipment has been too large and uncomfortable to be practical. There exists a need for improved, lightweight measurement technologies to monitor head and body position, orientation and movement to support a several types neurovestibular countermeasures.

Finding and Recommendation

NASA should exploit recent developments in miniaturized, solid state angular rate sensors (e.g. gyrochip) and linear accelerometers, by developing ultralightweight head motion monitoring technology usable for a variety of neurovestibular, biomechanical, and human factors countermeasure applications. The minimum system consists of a multiaxis ratesensor and linear accelerometer chip which attaches to the forehead via adhesive, or to a communications headset, and connected to a pocket battery/data processing package. A data port to a compatible IR telemetry system would be provided.

Three potential neurovestibular countermeasures are recommended for further study:

- <u>Preflight head movement training system.</u>
  System which teaches crewmembers to automatically restrict their head movements, particularly in pitch and roll, and develop new head/eye coordination strategies appropriate for the early days of 0-G. Useful for enforcing head movement restrictions in simulations of early mission days, and reentry/landing cockpit procedures.

- <u>Early on-orbit head movement restriction system.</u>
  Device which monitors the accumulating "head movement dose", and provides early warning when a crewmember moves about too vigorously, particularly in pitch and roll, for too long a time early in the mission, and conversely could also be used in a training procedure to more rapidly adapt crewmembers to weightlessness. (Companion linear accelerometers worn on the chest could monitor the vehicle microgravity disturbance forcing functions when the crewmember is moving about.)

- <u>Reentry/landing head movement monitoring system</u>
  Device worn within LES re-entry suit which monitors the head movements and actual orientation of the head and body of individual crewmembers vs. time, so illusions which occur and sickness which develops can be related temporally to the physical stimulus. A LED display keyed on G level and angular rate could be provided, to provide crewmembers when head movements can safely be made.

Finding and Recommendation

There exists a need for a new technology usable for measuring the angular orientation and/or position of ambulatory IVA or EVA crewmember's head and/or body with respect to the vehicle in order to determine the validity of the head movement hypothesis. Electromagnetic, optical, and GPS technologies appear to be impractical for most applications. New methods are under development in the VR industry, and should be evaluated for possible use on Shuttle and Space Station.

Vibro-Tactile Orientation System (VTOS)

VTOS Concept:
Terrestrial spatial orientation is maintained by three sensory systems (visual, vestibular and somatosensory) providing redundant/concordant information. In the dynamic aerospace environment, the only reliable source of information is that obtained visually. The VTOS has demonstrated the novel concept that spatial orientation can be continuously maintained by providing veridical aircraft or astronaut position/motion information through the underutilized sense of touch. The approach uses a torso harness fitted with a pattern of tactors (miniature vibrators) that continuously updates the operators awareness of orientation/motion. The tactile system can be connected to a portable sensor, or directly interfaced with shuttle/EVA instrumentation. Using this intuitive source of information pilots have flown aerobatics and approaches blindfolded!

Findings And Recommendations
Shuttle Landing: Although current data concerning landing accuracy show no correlation with mission length, such information should continue to be gathered and analyzed in order to identify pilot control issues which may arise in the future.

Emergency Egress: In the event of an emergency egress with reduced visibility (smoke or water) or unusual attitude the astronauts will be aware of their orientation. Additionally, it is feasible to provide directional cues to the exit.

EVA: Impaired situational awareness occurs due to difficulty in establishing visual contact with objects in the four to eight o'clock positions. Astronauts occasionally report a sense of falling when leaving the confines of the shuttle. These problems can be addressed by haptic presentation of position and velocity cues.

Sensory Illusions: The most serious vestibular illusions with respect to adverse control of the shuttle are the G-excess and otolith-Tilt-Translation-Reinterpretation illusions. By providing true translation and orientation information through the compelling channel of touch it my be possible to either prevent or reduce these potentially disastrous illusions.

Medications

While Space Motion Sickness (SMS) is currently treated with IM promethazine (a histamine receptor antagonist) and although the drug appears to resolve 90% of reported SMS episodes, there remain several issues with this drug.

> Despite promethazine treatment, SMS continues to be a problem for approximately 10% of astronauts.
>
> Promethazine produces sedation or drowsiness as a side effect, which typically requires the astronaut to be given the drug just before sleep. Thus, in case of an emergency, the astronaut must be aroused and will likely receive a CNS stimulant to overcome the drowsiness.
>
> Current protocol uses IM injection, which because of the altered body fluid composition during space flight, slows its absorption and effect. Suggestions have been made to give the drug IV to more rapidly provide relief.

Finding And Recommendation

While promethazine is effective, this older antihistamine acts as a receptor antagonist at multiple histamine (H1 and H2) receptors. Over the last decade, receptor antagonists specific for the H1 receptor have been developed, and it is likely that one of these (Zamifenacen) can be successfully used to counter SMS without drowsiness as a side effect. It may be that this drug, or one like it, is more efficacious for SMS for a larger percentage of the population. It is noteworthy that more specific receptor antagonists are also available for the cholinergic muscarinic receptor, for which scopolamine has been previously targeted and used. Our overall recommendation is that, despite the current use of and satisfaction with promethazine, newer more specific drugs should be evaluated.

If promethazine continues to be used and quick arousal is necessary, we recommend the use of amphetamines in low doses to counter that drowsiness. While IM injection may have its problems, IV injections carry the potential risk of more severe side effects, as well as the risks of improper dosing due to the altered gravitational environment, needle stick of the operator, bleeding, and thrombophlebitis, etc. We recommend continued use of IM injection route.

Artificial Gravity

There is ample motivation for the development of and testing an artificial gravity rotating device to prevent the major physiological deconditioning associated with long duration space flight. The space station, which is to be largely devoted to investigation of the problems of human long duration flight, will eventually afford the opportunity to test a variety of countermeasures which could be used for a Mars exploration mission. Before embarking on the expensive research program associated with human artificial gravity in space it is important to assess the neuro-vestibular implications of this "ultimate countermeasure".

One of the considerations in choosing an artificial gravity design is the tradeoff between radius and rotation rate to achieve a given g-level at the rim. Human factors issues largely determine the rim velocity and g-level, whereas physiological requirements influence the choice of radius (for g-gradient), glevel and exposure time. Vestibular considerations come into play in two ways. First of all, an adequate artificial gravity stimulus, combined with active head movements and locomotion, would presumably avoid some of the problems leading to re-entry and post landing disorientation and postural instability, although it is possible that astronauts might not be able to adopt a successful "dual state" adaptation. Secondly, the vestibular disturbances associated with cross-coupled angular acceleration when making out-of plane head movements, or Coriolis accelerations when making radial or tangential head movements, can create intra-sensory conflicts leading to motions sickness. These accelerations are directly proportional to the artificial gravity rotation rate. It has been widely assumed that a rotation rate of 1-2 rpm is easily tolerated, and that adaptation by steps can bring tolerance up to 6 rpm. Further extension of the rate to 10 rpm may be possible, especially in weightlessness without the disturbance of the conflicting earth vertical acceleration, but need flight testing to prove its acceptability. (With a 10 rpm rotation rate 1-g requires about a 10m radius and 0.5 g's only about 5m.) In order to determine the minimum radius to make an artificial gravity device acceptable form the point of view of the neuro-vestibular system, as series of research activities are required. These should begin with ground studies using a short radius centrifuge to determine the radius, g-level and rotation rate to provide an acceptable environment for intermittent stimulation and to prevent bone, muscle and cardiovascular deconditioning. Other studies using a slow rotating room will be necessary to assess the human factors issues and the problems of adaptation schedules. Only after proving the feasibility of the concept should we proceed to space experiments, beginning with a small (4m diameter) human centrifuge which can be accommodated in the Space Station for intermittent stimulation. finally, if all signs are positive, the definitive studies for long duration protection would be carried out with a large (1 km) tethered Variable Gravity Research Facility designed to co-orbit with the Space Station.

Findings

Artificial gravity, as the "ultimate countermeasure" may be limited in rpm by vestibular constraints.

Ground based research using bed-rest models, can be used to evaluate short arm centrifuges.

Relatively inexpensive, but long duration, development and testing can begin now to support a future Variable Gravity Research Facility and to use the Space Station for countermeasure development.

Recommendations:

Begin short radius centrifuge studies to determine radius, g-level, exposure and rotation rate for acceptable and effective prevention of deconditioning.

Use slow rotating room to determine human factor constraints and adaptation schedules.

Begin feasibility study for small (4m diameter) human centrifuge for Space Station.

Plan for design of a large Variable Gravity Research Facility to validate artificial gravity as a long duration countermeasure.

Gravity Replacement Earth Adaptation Training ("GREAT")

Findings

Currently, there are no proven counter-measures that will allow the neurovestibular system to function appropriately both in space and on Earth following space flight. Disruptions of perception, oculomotor control, psychomotor performance, posture, balance, and locomotion have been well documented both in-flight and post-flight.

Accuracy of performance in landing the shuttle, and rapid egress after landing have been identified as possible operational problems with potentially serious consequences. These problems most likely stem from changes in neurovestibular and sensory-motor integration that occur during space flight. Following long duration flights, these problems are exacerbated.

Recommendations

We recommend a study to determine the presence and seriousness of any operational consequences of spatial illusions or motion sickness during landing. If these prove to be of concern, then we suggest a ground study to test the practicality, acceptability and efficacy of intermittent exposure to a very short arm (1.0 meter) centrifuge, exposing the subject to primarily x-axis acceleration. If both of these studies support further work, we recommend subsequent development of a proposed countermeasure based on performing active head movements in an artificial gravity environment created by a short (approximately 1.0 meter) radius centrifuge. This will be accomplished by intermittently exposing crew members to centrifugation at 1.0 Gx while they make pitching head movements about an axis that is parallel to the axis of rotation.

The proposed countermeasure is expected (1) to maintain adequate terrestrial sensory-motor functioning in space, while simultaneously allowing for adaptation to the micro-gravity environment, and (2) to prevent debilitating neurovestibular effects, while simultaneously allowing for appropriate functioning upon return to Earth.

This countermeasure can be implemented using existing devices and those currently under development; it could be deployed in the shuttle middeck or in a Spacehab module, and it can be validated with existing information collected over the past several years. Although an integrated countermeasure for simultaneous resolution of cardiovascular, musculoskeletal, and neurovestibular problems, utilizing a larger radius centrifuge, may be developed in the future, the proposed effort will provide results that can be used sooner to develop specific operational solutions for the neurovestibular problems.