THE EFFECTS OF DEUTERIUM ON STATIC POSTURE CONTROL

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ABSTRACT

A significant operational problem impacting upon the Space Shuttle program involves the astronaut's ability to safely egress from the Orbiter during an emergency situation. Following space flight, astronauts display significant movement problems. One variable which may contribute to increased movement ataxia is deuterium (D^2O), an isotope of hydrogen. Deuterium is present in low levels within the Orbiter's water supply but may accumulate to significant physiological levels during lengthy missions. Deuterium has been linked to a number of negative physiological responses, including motion sickness, decreased metabolism and slowing of neural conduction velocity. The purpose of the present study was to investigate the effects of D^2O on static postural control in response to a range of dosage levels. Nine subjects were divided into three groups of three subjects each. The groups were divided in to a low, (50 g/70 Kg body water), medium (100 g/70 Kg body water), and a high (200 g/70 Kg body water) D^2O dosage group. The subjects static posture was assessed with the use of the EquiTest system, a commercially available postural control evaluation system featuring movable force plates and a visual surround that can be servoed to the subject's sway. In addition to the force plate information, data about the degree of subject sway about the hips and shoulders was obtained. Additionally, surface electromyographic (EMG) data from the selected lower limb muscles was collected along with saliva samples used to determine the amount of deuterium enrichment following D^2O ingestion. Two baseline testing sessions were performed using the EquiTest testing protocol prior to ingestion of the D^2O. Thirty minutes after dosing, subjects again performed the test. Two more post-dosing tests were run with an intertest interval of one hour. Preliminary data analysis indicates that only subjects in the high dose group displayed any significant static postural problems. Future analyses of the sway and EMG is expected to reveal significant variations in the subjects's postural control strategy following D^2O dosing. While functionally significant static postural problems were not commonly observed, subjects in both the medium and high dosage groups displayed significant, and in some cases, severe voluntary movement problems. These problems included locomotion and hand-eye coordination deficits.

INTRODUCTION

It is well documented that Space Shuttle crews are posturally ataxic following flight. This instability results from neurovestibular readaptation to a unit gravity environment, muscle deconditioning, and to some extent, cardiovascular deconditioning. Postural instability is a significant operational problem impacting upon rapid emergency egress from the Orbiter. Understanding the processes involved in movement control problems is critical if countermeasures are to be developed to increase the probability of successful emergency Shuttle egress.

One possible factor contributing to movement problems following space flight is an increase in the levels of deuterium oxide (D^2O) in the crew's physiological systems. Such an increase is likely to occur because of the presence of D^2O in the Shuttle's drinking water at levels exceeding those found in the nation's water supply. While the absolute levels of deuterium oxide in the Shuttle water are limited, it can be expected that a potentially physiologically significant amount may accumulate during extended duration flights. This increase results from the fact that D^2O is not "washed out" of the system with continuous ingestion of the Orbiter's drinking water.

While deuterium oxide has been shown to have a number of negative effects on mammals, few studies have attempted to assess the effects of D^2O on humans. In an effort to understand the impact of deuterium oxide on postural stability, a pilot study was conducted in June, 1990, as part of the Neurophysiology Laboratory's ongoing effort to probe the inherent complexities of the human motor control system. This project was undertaken in conjunction with the Nutritional Biochemistry Laboratory.

BACKGROUND TO THE PROBLEM

Deuterium oxide, the non-radioactive isotope of hydrogen, has been reported to have a variety of effects on physiological systems. Some of the effects include decreased metabolism rate (Reuter, et al., 1985), decreases in peripheral nerve conduction velocity (Thompson, 1963), decreases in maximum muscle twitch tension (Sato and Fujino, 1987) and positional alcohol nystagmus(Money and Myles,1974). While these symptoms are observed in response to

relatively high dose levels of D^2O, it can reasonably be expected that the physiological processes responsible for these symptoms are functioning similarly in response to lower levels of deuterium oxide. Thus, it becomes important to investigate what role, if any, the isotope plays in the disruption of normal functioning.

The majority of studies employing human subjects are designed to investigate the effects of deuterium oxide on the vestibular system. Money and Myles (1974) reported that their subjects experienced dizziness, nausea, and strong sensations of bodily rotations following D^2O ingestion. These symptoms primarily occurred while the subjects were lying on their sides. It was also reported that the subjects displayed a variation of positional alcohol nystagmus (PAN I) while in the lateral position. Nystagmus is an involuntary oscillating movement of the eyeballs in which they repeatedly turn slowly in one direction and then rapidly reverse direction. The direction of the nystagmus is identified based on the direction of the fast phase of the eye movements. Drinking large amounts of ethyl alcohol results in the eyes moving to the right during fast phase of the nystagmus if the head is held with the right side down. PAN I is called positional because it occurs when the head is maintained in a certain position relative to gravity.

After drinking D^2O, Money and Myles subjects displayed what these authors termed as PAN II. PAN II differs from PAN I in that the direction of the fast phase of the nystagmus is in the direction opposite from the side the head held in the lateral position. For example, if the subject is lying on his or her left side the fast phase is to the right. Nystagmus can be observed with the use of Fresnel lenses placed over the subjects eyes. These specially designed spectacles provide an opaque display to the subject while magnifying the subject's eyes to the observer. In this manner, rapid movements of the eyes can readily be detected.

Money and Myles (1974) suggested that deuterium oxide elicits nystagmus by the following mechanism. The cupula of the semicircular canal floats in a surrounding liquid (endolymph) which has the same density. Under normal circumstances, angular accelerations cause the cupula to move as a result of circular endolymph movements. However, because of its neutral buoyancy the cupula is not moved by linear accelerations or by gravity. Following ingestion of deuterium oxide, the cupula acquires D^2O faster than the surrounding endolymph because of the prominence of blood

capillaries near the base of the cupula. The cupula's neutral buoyancy is therefore lost as it becomes heavier than the surrounding endolymph. This imbalance allows gravity to move the cupula, thus, producing positional nystagmus responses when the head achieves specific orientations relative to gravity.

Greven, et al., (1977) have also reported similar responses to D^2O. More importantly, perhaps, is their finding that the speed of the fast phase of the PAN II nystagmus was increased during exposure to G-loads of 2 and 3 G. Thus, increased level of gravity appear to enhance the response of the vestibular system to deuterium oxide.

The reported findings have important implications for astronauts attempting rapid egress from the Space Shuttle as it is well known, from work with vestibular patients, that altered vestibular input is disruptive to both postural and movement control. Greven, et al's. (1977) results suggest that even low levels of D^2O in the astronaut's physiological systems may pose a problem during the high gravity loads experienced during re-entry. This report describes a preliminary attempt to characterize the effects of three different dosage levels upon static postural control.

PROJECT SUMMARY

Methods

The static postural control of nine volunteer subjects was tested both prior to and following ingestion of deuterium oxide. The nine individuals were divided into three groups of three subjects each. Each group was administered a different dose level which were characterized as low, medium or high doses. The absolute amount of D^2O administered to each subject varied as levels were adjusted to percentage of body water levels based upon percentage of body fat measures. The three dosage levels were equivalent to: a) 50 g/70 Kg body water; b) 100 g/70 Kg body water and c) 200 g/Kg body water. The dosage levels were consistent with the range of levels reported in the literature. The D^2O supply was 99.9% atom percent (ICON Services).

The standing static posture of the subjects was tested using the EquiTest protocol (Neurocom International). The EquiTest system consists of a motor-driven footplate, capable of translations in the

anterior-posterior directions and rotations about the ankle joint. A motor-driven visual surround allows for rotational movements about the subject's ankles. The force platform provides information about the ground reaction forces exerted along the X,Y,and Z axes and horizontal sheer. Sway bars interfaced with potentiometers, are attached to the shoulders and hip area and provide information about the degree of movement about these two joints. The testing protocol was comprised of a series of movement coordination and sensory organization tests. The subjects attempted to maintain equilibrium without lifting their feet from the platform while their arms remained folded across their chest.

The movement coordination test was subdivided into four unique tasks.

1. Anterior translations (resulting in backward sway)
2. Posterior translations (resulting in forward sway)
3. Toes-up rotations
4. Toes-down rotations

Subjects experienced three trials of Conditions 1 and 2 and five trials of the two remaining conditions.

The sensory organization test is designed to determine the relative contribution of different sensory systems to the subject's overall equilibrium strategy. This can be accomplished because of two features of the EquiTest system. The visual surround can be made to move in response to the pressure exerted by the subject's feet on the force platform. As a subject sways forward, the visual surround sways forward an equivalent distance. In this situation, visual feedback about the degree of subject sway is nulled out. If a subject were to rely exclusively on visual input to maintain balance he or she would soon fall forward. Thus, to maintain upright stance, the subject must learn to utilize vestibular and proprioception inputs.

The second feature of the EquiTest systems which enables investigators to determine to what extent a subject relies on a specific sensory input is the platform's ability to sway in response to changes in the subject's applied foot pressure. For instance, if the subject begins to exert pressure on the front of the platform the support surface begins to rotate downward. In this situation the subject receives inappropriate proprioception information from the ankle joints. If the subject were to rely exclusively on this inappropriate input, which is indicating to the subject he or she is

not actually swaying forward because the initial ankle angle is being maintained, the subject would soon lose balance. By combining the above two features in either eyes open or eyes closed conditions, a complete profile of the relative weighting each subject gives to the various sensory inputs can be achieved.

The sensory organization test was subdivided into six unique tasks.

1. Normal vision, fixed support surface
2. Absent vision (eyes closed) fixed support surface
3. Sway-reference vision, fixed support surface
4. Normal vision, sway-reference support surface
5. Absent vision (eyes closed), sway-reference support surface
6. Sway-reference vision, sway-reference support surface

Each task was 20 seconds in duration with tasks 3,4,5 and 6 being repeated three times.

The following parameters are routinely derived from the above testing protocol and are a output from the system in a hardcopy format following completion of the testing.

Movement Coordination Tests:

Static Symmetry: Average right/left weight distribution during test.

Force Latency: Time from onset of support surface perturbation until initial active force response. This is calculated separately for each leg.

Strength Amplitude: Average slope of initial active force response to support surface perturbation. This is calculated separately for each leg.

Dynamic Symmetry: Average right/left strength amplitude distribution during test.

Sway Amplitude: Average (rms) and peak-to-peak amplitudes of anterior-posterior sway calculated for center of mass, ankle angle, hip displacement, shoulder displacement, and head displacement.

Adaptation: Relative decrease in sway amplitude occurring with repeated presentation of the ankle rotation stimulus.

Strategy: Relative contributions of ankle and hip joint motions to sway control following support surface translations.

Sway Amplitude: Average (rms) and peak-to-peak amplitudes of sway calculated for center of mass, ankle angle, hip displacement, shoulder displacement, and head displacement during test.

Strategy: Relative contributions of ankle and hip joint motions to sway control during test based on force, transducer and joint position measurements.

Equilibrium: Relative stability of the subject's sway control during each individual test.

Composite Equilibrium:: Composite estimate of the relative stability of the subject's sway control based on weighted sums of individual test equilibrium scores.

In addition to the above parameters, surface electromyography (EMG) was used to monitor the activity of the following muscles of the left lower limb: soleus, gastrocnemius, bicep femoris (hamstring), and rectus femoris (quadricep). EMG data from the movement coordination tests was analyzed by obtaining latency and amplitude variables. Latency measures were obtained by determining the initial increase in muscle activity relative to platform movement. Amplitude measures were defined as the average (rms) amplitude from platform movement onset until the end of the active force response. Both variables were determined independently for each muscle, for each trial. The Pensacola Coriolis Sickness Scale was administered throughout the testing procedures in order to monitor the subject's level of possible physical discomfort. The Pensacola Coriolis Sickness Scale has been extensively used to obtain a subjective measure of motion sickness.

All testing was completed in the Dynamic Posture Laboratory located in the KRUG Life Sciences' portion of the Intermetrics building (1100 Hercules Drive, Houston, Texas). Subjects arrived at

the testing site and were prepared for EMG collection. This involved shaving and lightly abrading the skin above the electrode placement sites. The electrodes where then positioned over the muscles and skin impedance measures were obtained. Before the subjects mounted the platform, they donned a safety harness. The safety harness attached to a safety bar that looped over the platform such that it was impossible for the subjects to collapse if postural equilibrium was completely lost. Once the subjects stepped onto the platform the EMG lead were connected to the amplifiers and EMG signal quality was checked. The testing procedures began by positioning the subject's feet precisely on the platform and asking the subject to fold their arms across their chest. Headphones providing white noise designed to eliminate external cues from the platform, were then placed on the subjects.

In order to obtain baseline values, the motor coordination and sensory organization test protocol were completed two times. There was a one hour intertest interval between the baseline collection sessions. Immediately following the second baseline testing session, the subjects ingested the pre-determined amount of deuterium oxide. The subjects then assumed a comfortable lying position on their left side.

Thirty minutes after dosing, subjects again mounted the posture platform and were subjected to the motor coordination and sensory organization tests. Then subjects then resumed their reclining position. Two additional post-dosing sessions were completed with an intertest interval of one hour. Both prior to mounting the platform and at the conclusion of each testing session the Pensacola Coriolis Sickness Scale was administered. Prior to each of the baseline testing sessions, a saliva sample was collected in order to determine the baseline levels of deuterium. Following D^2O dosing and prior to each of the enrichment of the sample. In some cases, Fresnel lenses were applied and the subject was checked for nystagmus. Following completion of the posture tests, the subjects drank two liters of water. This procedure was employed to increase the rate at which the deuterium oxide was "washed out" of the system.

Results and Discussion

The saliva samples were centrifuged at Johnson Space Center in the Nutrition Biochemisty Laboratory and then sent to University of Chicago Medical Center for stable isotope analysis. The results of this analysis are unavailable at the present time.

Preliminary analysis of the data obtained from the EquiTest system printout revealed that D^2O had little affect upon the subjects static postural control. This was especially true for the low dosage group. However, at the medium and high dosage levels, initial analysis of conditions 5 and 6 of the sensory organization tests, revealed subjects were less stable post-dose relative to baseline measures. This result is consistent with the previously reported findings that vestibular system functioning is altered as a result of deuterium oxide ingestion. Both condtions 5 and 6 are configured such that the subject must preferentially rely on vestibular input to maintain upright stance. Therefore, is was hypothesized that the results from these two conditions would be most sensitive to changes in postural stability following D^2O ingestion.

Results from the Pensacola Coriolis Sickness Scale revealed that none of the subjects in the low dosage group indicated any unusual physical sensations other than a feeling of being chilled. This finding may possibly be explained by the fact that deuterium has been reported to decrease metabolism. Similar sensations were reported by the subjects in the medium dosage group.

On the other hand, subjects in the high D^2O dosage group reported a variety of physical symptoms, including movement illusions both of their body and the environment. All three subjects in this group displayed nystagmus based on Fresnel lense observation. One subject vomited repeatedly. This subject's nausea was most violent following changes in body postion, i.e., moving from either a reclining position to standing or vice versa. Despite these symptoms, this subject was able to achieve static balance measures consistent with his baseline scores. Consistent with the reports of Money and Myles (1974), the only subject to become significantly nauseated refrains from all exposure to ethyl alcohol. The reason for this is unknown, but it may be that drinkers have developed compensatory processes allowing them to function relatively

unimpaired in response to low to moderate levels of alcohol consumption. These compensatory processes may have been operating in response to altered vestibular input resulting from deuterium ingestion.

One interesting phenomenon was observed in all members of this group and in one subject in the medium dosage group. These subjects reported (and displayed) numerous movement coordination problems when asked to make voluntary limb movements. The subjects became very unstable when asked to walk even short distances. This instability was compensated for by adopting wide gait patterns. This behavior closely resembled that of patients with cerebellar disturbances. These subjects also reported disturbances in hand-eye coordination. For instance, one subject displayed great difficulty in securing a buckle similar to a commen seat belt about his waist. It is possible that the above symptoms may be partially the result of neuromuscular processes which were impaired by the relatively high level of deuterium.

Due to both time limitations and technical problems, further analysis of the hip and shoulder sway data and the EMG data has not been completed. Sway data is currently being evaluated by members of the Dynamic Posture Laboratory working group. The EMG data will be analyzed in the coming months in the Neuromuscular Laboratory at Kansas State University.

Conclusions

The preliminary results of the present study indicate that high levels of deuterium in the body's physiological systems can result in significant movement problems, as well as produce epigastric sickness in some subjects. Static postural control appears to be only slightly impaired, even with relatively high dosage levels of deuterium. However, subsequent analysis of body sway parameters and EMG data is expected to reveal that the subjects were, in fact, less stable following ingestion of deuterium oxide. Future research should focus on the processes responsible for the observed voluntary movement problems displayed by the current subjects. Obviously, any factor which contributes to impaired movement control greatly impacts upon an astronaut's ability to safely egress from the Space Shuttle in an emergency situation.

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