6. Temperature settings during the caloric experiments in flight were 37°C in each ear at the start of the experiment. Thereafter, the temperature settings in the right and left ears, respectively, were 44° and 30°; 44° and 20°; 44° and 15°; 20° and 44°; and 15° and 44°. For each pair of values the static phase was 2 minutes and the dynamic phase 30 seconds.
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10. Inflight measurements of angular vestibulo-ocular reflex are not yet available.
11. These experiments were sponsored by the German Department of Research and Technology and by the French Centre Nationale d'Etudes Spaciales.

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Vestibulospinal Reflexes as a Function of Microgravity

Abstract. *The idea that sustained microgravity will result in altered otolith input requiring a modification of postural control was explored by using the pathway that links the otolith organs and spinal motoneurons. Two related methods were used. First, the Hoffmann reflex was used to measure at specific times the excitability of the soleus-spinal motoneuron pool during a brief unexpected linear acceleration. Second, extensive dynamic postural testing with a moving platform was done before and after flight. The Hoffmann reflex amplitude, reflecting otolith-modulated motoneuron sensitivity, was low in flight after adaptation, and its postflight potentiation may have been dependent on rate of adaptation. The strength of inflight motion sickness symptoms was related to postflight Hoffmann reflex amplitude. Dynamic posture tests showed significant deviations from the results obtained before flight. The strategy used for balance on the moving platform was modified, and the behavior of the subjects suggested a decrease in awareness of the direction and magnitude of the motion.*

Data from previous manned spaceflights suggest that significant alterations occur in vestibular, neuromuscular, and related sensory system function on exposure to microgravity (*1*). The observed changes may be a function of adaptation induced by altered otolith input. The purpose of this Spacelab 1 experiment was to investigate this adaptation as it occurred in flight and after flight, and to relate the observed changes to mechanisms underlying space motion sickness.

To explore this concept, we used the anatomic pathway that links the otolith organs and spinal motoneurons. The overall sensitivity of the spinal motoneurons was tested by two related methods: (i) electrical excitation of neural tissue and recording of vestibulospinal reflexes in conjunction with a brief linear acceleration (*2*) and (ii) measurements of dynamic postural ataxia.

Vestibulospinal reflex mechanisms. Excitation of the neural tissue was accomplished by the classical Hoffmann reflex or H reflex technique (*3*). The H reflex was obtained through elicitation of a monosynaptic reflex recorded from the soleus muscle by electrical stimulation of large group I afferent fibers in the popliteal nerve. A needle electrode, which served as the cathode, was inserted in the popliteal fossa at a permanently marked (tattoo) location on the right leg. The anode, a plate electrode, was secured over the patella. A 1-msec constant current pulse limited to a maximum of 20 mA was delivered through an isolation unit under computer control. A differential bipolar electrode configuration was used to record the reflex from the soleus muscle. The reflex was a two-part response: a direct orthodromic muscle response (M wave) with a latency of 5 to 10 msec that was followed 15 to 20 msec later by the monosynaptic H reflex. Because the M wave represented a direct muscle response, it was used as a control during vestibular stimulation. The H reflex amplitude reflected the sensitivity of the spinal motoneurons as set by the descending postural control signals.

Vestibular stimulation during preflight and postflight testing was provided by dropping the subject over a short distance (10 to 14 cm), using a quick-release helicopter cargo hook. In flight, we used the Canadian "hop and drop station" (*4*) and calibrated bungee cords to pull the subject to the floor of Spacelab. All drops were under computer control (*5*).

For each drop, the subject was shocked three times. The first shock, used to condition the neural tissue, was followed 3 seconds later by a shock that elicited a control response, and the third (3 to 5 seconds later) was delivered at predetermined delay times during the drop. Before and after flight these drop-to-shock delay times ranged in 10-msec increments from a shock that was coincident with the computer command to drop, to a shock that was delayed 80 msec. In flight, eight shock-to-drop delays ranging from 0 to 70 msec in 10-msec increments were used. Approximately four responses (*6*) were collected at each viewpoint during each test period (that is, on $F - 10$, $F + 24$ hours, $R + 0$, and so on). This method permitted tracking of the H wave amplitude as a function of both time (shock delay) and acceleration across test days.

For analysis, the H reflex response to each drop was normalized as a difference percentage with respect to the control H reflex. To obtain a stable reference response, the control H reflex responses were averaged for each crew member for all preflight, inflight, and postflight test periods. The preflight drop H reflex responses for each drop-to-shock delay were then averaged ($N = 180$) for each crew member.

The H reflex results for a single crew member (subject A) are presented in Fig. 1. Drop H reflex amplitude expressed as a difference from the control H reflex is plotted as a function of drop-to-shock delay and test period. The drop-to-shock delay times were adjusted to account for a 20-msec delay between the computer command to drop and the time of the actual fall. Data for this crew member are representive of general trends found with the shape of the drop-to-shock H reflex potentiation curve but not of peak amplitude changes found between subjects. Before flight there was an initial potentiation of the H reflex in response to the drop for shocks delayed 20 to 40 msec. Peak amplitudes for this subject occurred with drop-to-shock delays of 80 msec. Inflight H reflex peak amplitudes recorded at a mission elapsed time of 24 hours showed a gain analogous to the preflight values. By mission day (MD) 7, the H reflex amplitude was low and showed little or no change as a function of drop-to-shock delay times.

After flight, a general potentiation was recorded. The amplitude for subject A on $R + 0$ showed an approximately 30-fold gain. The $R + 1$ and $R + 2$ values indicated amplitudes lower than that obtained on $R + 0$. However, on $R + 4$ and $R + 6$ a potentiation greater than that recorded on $R + 0$ occurred. This observation may have been due to an intervening parabolic flight on $R + 3$. A two-way analysis of variance for repeated measures on these data showed a significant difference as a function of test day ($P < 0.001$). The M wave amplitude changes were not significant when subjected to the same two-way analysis of variance ($P < 0.50$), confirming that a constant electrical stimulus was applied and that H reflex amplitude changes represent the state of excitement within the spinal motoneuron pool.

Data for subject B showed a reduced gain on MD7 similar to that recorded for subject A (data were not collected at F + 24 hours for subject B). Postflight amplitudes reflected a gain pattern consistent with that for subject A, but by R + 6 the return to baseline was almost complete. Subject D showed little or no change between preflight and postflight responses, while subject C showed slight potentiation on R + 1 and R + 2 over preflight levels, and a return to baseline by R + 4 (no inflight or R + 0 data were collected on subjects D and C).

When the magnitude of amplitude changes recorded before flight and after flight was compared with inflight motion sickness susceptibility a clear correlation was established. When rated for sickness, subjects B and A had severe symptoms that persisted through the third day in flight, subject D had few or no symptoms, and subject C showed slight to moderate susceptibility. When this rating was compared with the H reflex peak amplitude changes recorded on R + 0 and R + 1, it was observed that subjects who had significantly increased H reflex amplitudes (over preflight levels) were highly susceptible. The one crew member who had no postflight changes was judged not to be susceptible in flight.

Dynamic postural alaxia measurements. In this experiment the subjects were given postural disturbances by moving their base of support fore and aft in the horizontal plane with three basic types of motion: sinusoidal, pseudorandom, and transient or step displacements (*7*). Each motion type was shaped to provide smooth transitions between velocities consistent with a bandwidth of 2 Hz. Subjects were instructed to stand erect on the platform with arms folded and knees straight but not locked. For eyes-open (EO) trials they were instructed to view a target on the wall directly in front of them; for others they stood with eyes closed (EC). Subjects were not given information on the order of motion types within the protocol or on magnitudes, time of occurrence, or bandwidth.

Six discrete-time sequences lasting 20 seconds were collected for each trial. Two channels recorded platform position and velocity while the remaining four were devoted to subject data: shoulder position, hip position, soleus electromyogram (EMG), and tibialis anterior EMG. Position data were derived from two 512-pixel line scan cameras viewing the subject silhouetted against a light background on an axis orthogonal to the direction of motion (*8*). EMG signals were acquired by conventional surface electrode techniques and envelope detection electronics.

We have completed analysis of the hip and shoulder position data resulting from the pseudorandom stimulations, using a systems identification program which derives parametric transfer functions between platform position and hip and shoulder position. The method is a modified Kalman filter analysis which iteratively converges to the transfer functions and process noise spectra (*9*). Although several features emerge from this analysis, the following are pertinent to the present discussion: (i) oscillatory motion derived from model parameters, (ii) gain (subject and platform position) at 0.2 Hz, (iii) phase lag at 1.4 Hz, (iv) noise bandwidth, and (v) signal-to-noise ratio (SNR; transfer function variance divided by noise model variance).

Although preliminary, the following observations are interesting and significant against a background of large numbers of normal and abnormal (sensory and neurological) subjects previously observed in our laboratory.

There was evidence of an immediate strategy change in the postflight responses, revealed by more motion of the waist relative to the shoulders and by decreased damping in the EC condition (subjects A, B, and C) and the EO condition (subject D) and sometimes a fundamental change from a critically damped system to one with overshoot behavior in the EC case (subjects A and B). Increased waist motion allows for faster displacement of the center of gravity and therefore faster postural stabilization.

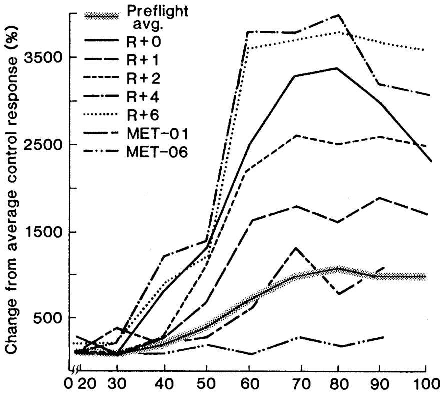

Fig. 1. Hoffmann reflex amplitude as a function of delay time and test day. These curves represent a completed data set for one crew member (subject A). The preflight average was obtained from five preflight test days (F − 151, F − 121, F − 65, F − 44, and F − 10). R + 0 represents measurements taken approximately 6 hours after landing, MET-01 refers to data obtained approximately 24 hours in flight, and MET-06 represents day 7 of the flight. Drop-to-shock delay times have been adjusted to factor in delay times of approximately 20 msec that existed between the computer-controlled command to drop and the actual release time of the drop hook.

Continuous adaptation in the postural control system was revealed by a steady climb in the SNR of both the EO (all subjects) and EC (subjects A and C) responses for the waist and shoulders. In the EC case the noise variance rose slightly and transiently, partly due to a widening of noise bandwidth (subjects B and C), and then decreased. The EC signal variance did not change significantly. In contrast, the noise and signal variance rose in the EO responses, with the signal variance increase being more significant 2 to 6 days after flight. Thus, in the EC case, the energy expended in tracking the platform motion remained roughly the same as before flight (except for the increase in waist motion) while noise at R + 0 was greater. On the other hand, significantly more energy was spent in tracking in postflight than preflight EO responses. This high-SNR type of EO response is similar to those of sensory-deficient subjects previously tested in our laboratory. Transfer function order, dead time, and phase at 1.4 Hz remained constant before and after flight, indicating no fundamental change in timing or model structure.

There were subjective comments by the crew on their perception of motion on the posture platform. The most significant was a decrease in awareness of the direction and magnitude of motion. Most of the subjects attempted to adjust their strategies on the platform to compensate for these perceptual difficulties, and thus there was a general trend to a more conservative approach to tracking the platform. This behavior would probably have been more pronounced if the postflight testing had been carried out at preflight motion magnitudes. These observations show that interesting changes occur in posture parameters after flight and indicate that we are likely to find even more as the analysis continues. Almost all the parameters indicate that our subjects had not returned to their preflight values over the 6-day postflight test period. This may mean that the recovery time constant is longer than previously thought or that our methods of testing were too fatiguing to allow normal recovery.

Conclusions. The data on vestibulo-spinal responses, as measured with the H reflex, during a brief vertical drop suggest that postural adaptation in spaceflight can be measured. The inflight results demonstrated a trend toward posture modification, which implies that responses normally observed in a normal-gravity environment are no longer appropriate in weightlessness. The results also suggest a concept of otolith signal reinterpretation which is consistent with the sensory conflict theory of space motion sickness. Well-being in space may be related to the ability of the central nervous system to modify response patterns. Individuals with less plastic responses will exhibit more severe symptoms.

The H reflex and dynamic posture tests also provide data on the reestablishment of terrestrial norms of motion behavior. Both tests were extremely sensitive and suggest that more than a single time constant may be involved in man's ability to return to baseline values. While both the sample size and number of measurements were small in this study, the results indicate that an effort to continue this research is warranted. A more complete analysis of the data will appear later (*10*).

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4. The initial design for this experiment called for use of the European space sled to provide a sinusoidal linear acceleration. When the sled was removed from Spacelab 1, D. G. D. Watt, a Canadian investigator associated with the MIT experiments, agreed to the use of his drop system as an alternative method of providing a brief-impulse linear acceleration.
5. Drops in a normal-gravity environment are not equivalent to those in microgravity. In the former the acceleration transition is from 1 *g* to 0 *g*, and in the latter it is from 0 *g* to −1 *g*. Physiologically the primary difference is the bias or position of the otoliths on the saccular maculae. Data from parabolic flight studies by our laboratory suggest that potentiation of the H reflex is sustained in 0 *g*. This supports the concept of a new bias point in a microgravity environment. However, the bias was nulled by adjusting the H reflex in both gravity environments so that it was at 50 percent of its maximum amplitude just before each drop.
6. A full set of responses at each drop-to-shock delay time was obtained before and after flight for all four subjects. Inflight data were collected on two crew members. On day F + 1 (approximately 24 hours into the flight) a complete set of data was obtained with only one of the two inflight subjects. At F + 6 both subjects participated; however, only two drops at each drop-to-shock delay were obtained.
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Prolonged Weightlessness and Humoral Immunity

Abstract. *Preflight, inflight, and postflight serum samples obtained from crewmen aboard STS-9 were analyzed for immunoglobulin content. Control studies for circadian rhythm were conducted to further validate the analyses. Quantitation of immunoglobulins G, M, A, D, and E indicated relatively minor fluctuations in the concentration of each class of immunoglobulin during the experiment. Thus, microgravity effects on immunoglobulin levels during a 10-day flight were considered insignificant.*

The space environment is characterized in part by the absence of gravity. Because weightlessness is an abnormal condition relative to a 1-*g* environment, microgravity can be considered biologically as a stress factor or perturbation of the normal state. Historically, important basic biological research has capitalized on comparisons between normal and altered states. For example, microbiologists have routinely induced genetic mutations to study basic molecular mechanisms. These artificially created, but controlled, modifications lead to a better understanding of normal states. Similarly, the human immune system is potentially a model for studies in a microgravity environment because of its intrinsic complexity. The human humoral immune response is predicated on poiesis, cell differentiation, complex cellular interactions, regulatory mechanisms, and mitogenic activation with subsequent synthesis and secretion of biologically specific antibody molecules. Such complexity increases potential sensitivity to a variety of external stimuli such as prolonged weightlessness.

The experiment described in this report was designed to analyze and quantitate the humoral immune response under prolonged weightlessness during the 10-day Spacelab 1 (STS-9) flight. The human immunoglobulin (Ig) population, which comprises the humoral response, consists of various classes designated IgG, IgM, IgA, IgD, and IgE. Major classes, such as IgG, also contain subclasses IgG1, IgG2, IgG3, and IgG4. Each class and subclass differs in a variety of properties such as antigenic distinctiveness, average serum concentration, serum half-life, and effector functions. These properties are important in terms of quantitating Ig populations in serum in order to measure the effect of certain conditions such as microgravity.

Four crewmen participated in the Ig studies and were designated MS1, MS2, PS1, and PS2. MS1 and PS1 were members of the red team, while MS2 and PS2 were part of the blue team.

Three separate studies were conducted to validate the Ig measurements and effects of a prolonged microgravity environment. First, in order to control for circadian rhythm effects (*1*), a study was conducted with serum samples from MS1 and PS1 in advance of the STS-9 flight. Serum samples were obtained over a 2-day period, reflecting a shifting of personnel from their routine diurnal

Table 1. Schedule of STS-9 experiment INS105.

Crew-man	Date of bleeding (1983)*							
	F − 30	F − 7	F − 1/1½	MD7	L + 0	L + 1	L + 8	L + 12/13
MS1	9/24	11/21	11/26	12/6	12/8	12/9	12/16	12/21
MS2	9/24	11/21	11/27	12/6	12/8	12/9	12/16	12/21
PS1	9/24	11/21	11/26	12/6	12/8	12/9	12/16	12/20
PS2	9/24	11/21	11/27	12/6	12/8	12/9	12/16	12/20

*Day F − 30 is 30 days before flight; MD7 is mission day 7; and L + 8 is 8 days after landing.