ed modulation was used for data acquisition. The flight unit was battery-driven. An identical unit was used to collect the ground-based data.

On the ground the central venous pressure was measured by the arm-down method. Peripheral venous pressure was measured with the astronaut lying on his back, keeping his arm almost perpendicular to his trunk. After the venous pressure measurements blood was drawn to determine the hematocrit and other values (*3*). Body weight was determined before the measurements.

Procedure. Measurements were made and blood drawn in the morning before breakfast. After entering the laboratory the subjects rested for 15 minutes. The last data points on the ground were obtained 8 days and 1 day before flight (days F − 8 and F − 1). During flight, data were taken 22 hours after launch on mission day 0 (MD0) and on MD2 and MD7. Postflight data were obtained 1 hour after recovery (R + 0) and 12 hours later (R + 1). Four astronauts took part in the experiments.

Results. During the prelaunch phase at least four measurements could be made on each subject. The central venous pressure levels were characteristic for each subject. One subject always had rather low levels while another showed high ones. During the mission ten measurements were scheduled and successfully completed for the four subjects. Figure 1 shows body weight, hematocrit, and peripheral and central venous pressure as a function of time from 8 days before flight to 8 days after recovery. The results are for two astronauts but are representative for all four subjects. From day F − 8 to F − 1 all subjects experienced a weight gain, a drop in hematocrit, and an increase in central and peripheral venous pressure. They all showed the highest pressure levels on day F − 1. For instance, in subject R.P. (Fig. 1a), central venous pressure was 9.5 cm H_2O and in subject U.M. (Fig. 1b) it was 15.2 cm H_2O. On MD0 and MD7, the respective numbers were 6.5 and 2.6 cm H_2O for R.P. and 6.5 and 7.7 for U.M. Under microgravity conditions, it can be assumed that the pressure in an arm vein is close to the intrathoracic venous pressure, since in all likelihood an open connection between intra- and extrathoracic veins existed. In space the hematocrits were markedly increased.

On recovery day all subjects had lost 4 to 5 percent of their body weight as measured on day F − 1. To our surprise, at that time the hematocrit was always lower than during flight, despite their negative water balance. The venous pressures were comparatively high. Twelve hours later the hematocrit had almost reached preflight levels, while the venous pressures showed a decrease and reflected the hydration level of the body better than they had 12 hours before. Later in the recovery period, until day R + 8, the subjects gained weight; however, the central and peripheral venous pressure patterns were different.

Conclusions. The fluid shift from the lower to the upper parts of the body that occurs during spaceflight and its reversal immediately after recovery seem to be highly dynamic processes which take place within 3 to 6 hours. This conclusion is based on our findings in the early recovery period. One hour after landing the retranslocation of fluids stored somewhere extravascularly in the upper parts of the body is fully under way, diluting the blood as indicated by a decreasing hematocrit and keeping the venous pressures unexpectedly high. At this time there is apparently a discrepancy between the central venous pressure and the hydration status of the body. Twelve hours later this discrepancy has been overcome since the central venous pressure has dropped to low levels.

If the same pattern applies to the headward movement of body fluids in microgravity, then our findings 22 hours after launch are understandable. Fluid migration had already taken place. In the time between launch and 22 hours after launch there might have been a phase where the central and peripheral venous pressures were elevated. However, this pressure peak disappeared as soon as the fluid had left the intravascular space, and a negative water balance followed, explaining the high hematocrit. This has been predicted by ground-based studies (*4*) and is in agreement with findings published by Pourcelot *et al.* (*5*).

Important questions in cardiovascular physiology in space still remain open. For instance, where is the fluid located during spaceflight and what forces drive the fluid toward the upper parts of the body?

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Mass Discrimination During Prolonged Weightlessness

Abstract. *Thresholds for mass discrimination under zero gravity in flight were found to be higher by a factor of about 1.8 than those for weight discrimination before flight. This suggests that humans are not as sensitive to inertial mass as they are to weight, and that adaptation can only partially compensate for loss of gravity. Weight discrimination thresholds were raised for 2 or 3 days after flight, suggesting an aftereffect of adaptation to weightlessness.*

When comparing the weights of objects, it is normal to pick them up and jiggle them. This method yields lower discrimination thresholds that does static pressure (*1*). The improvement is partly due to the involvement of the kinesthetic senses in addition to the pressure receptors (*2*). It may also be due to the availability of inertial cues to mass, sensed through the force required to accelerate the objects. In a 1-*g* environment it is difficult to distinguish between the contributions of weight and mass to what is usually called "weight discrimination." In a 0-*g* environment weight cues are effectively absent, and the discrimination can be made only by accelerating the objects and using inertial cues. An experiment was therefore conducted to compare thresholds for the same test, when performed on the ground and under weightless conditions in Spacelab 1.

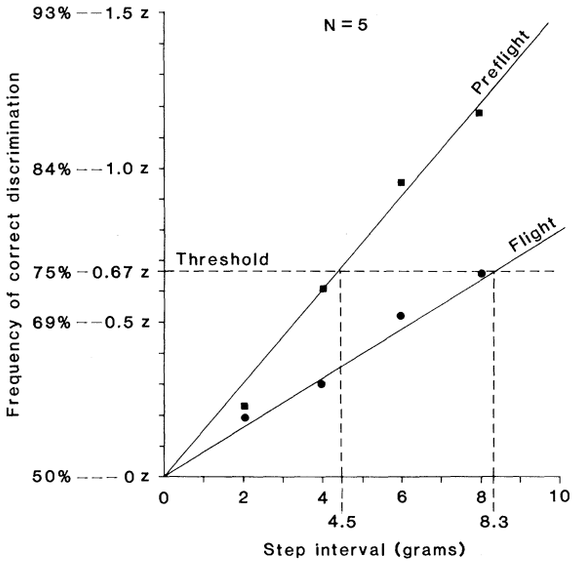

Fig. 1. Mass discrimination under 1 *g* before flight and under 0 *g* in flight.

The apparatus consisted of a box containing 24 weighted balls and a set of record cards. It is described in greater detail elsewhere (*3*). The balls had a diameter of 30 mm and varied in mass from 50 to 64 g in 2-g steps, with several duplicates. They were fabricated from lead and epoxy resin, the lead being in the form of a spherical shell whose diameter and thickness were formulated to yield balls which all had a measured polar moment of inertia of 4.0×10^{-6} to 4.1×10^{-6} kg-m^2 irrespective of their mass (*4*). The balls were stored in holes in the box under retaining straps and were labeled with letters. The box also contained record cards, listing 72 pairs of letters. The lists comprised 18 repetitions of 2-, 4-, 6-, and 8-g pair intervals, with the heavier mass equally often first or second, in random order. No letter combinations were repeated.

For each test session the subject opened the box and fastened it to a work top. Using his left hand, he picked out the first ball on the list from its hole, shook it, and replaced it. He then did the same for the second ball of the pair. He decided which felt heavier, and marked the corresponding letter on the list, using his right hand. All subjects were right handed. He repeated this for all 72 pairs, then posted the completed record card in a slot in the box. The test lasted about 12 minutes on the ground and 17 minutes in space.

Two payload specialists and two mission specialists were thoroughly trained to perform the test. Baseline data were then collected on four occasions between 5 months and 3 days before flight. The pilot was also tested at 1 month and 3 days before flight. Inflight tests were performed by these crew members on two to five occasions each. The earliest was at 8 hours after liftoff, and the last was on the tenth flight day. Postflight data were collected at Dryden Research Center (Edwards Air Force Base, California) 5 hours after landing for one payload specialist and 1, 2, and 4 days after landing for all four Spacelab crew members. The pilot was retested in London 2 months later. The mean number of errors before flight was 18.0 (25 percent), and in flight 24.7 (33 percent). All subjects had more errors in flight ($P = 0.031$, sign test, one tail). Errors were also high after flight [mean 23.0 on the first day after landing (R + 1)] but returned to baseline level by R + 4. There were, however, no systematic changes with time in error rates of the tests performed before flight or during flight. There was considerable variation in error rates between subjects, those with vigorous shaking techniques giving fewer errors (particularly the pilot, who also used his right hand for the tests before flight and during flight). Group differential thresholds (DL's) (75 percent correct level) were derived from preflight and inflight data by calculating the percentage of correct judgments for each step interval and subject and weighting all five subjects equally. The percentages were converted to z scores, and a straight line was fitted through the origin (Fig. 1). There were insufficient data to derive reliable DL's for each postflight day separately. The mean DL was 4.5 g before flight and 8.3 g in flight. The corresponding Weber fractions were 0.083 and 0.153, taking as denominator the mean mass of 54.1 g.

All subjects showed poorer performance under 0 *g*, by an average factor of 1.84. This is less than the factor of 2.15 found during brief periods of 0 *g* (<25 seconds) in parabolic flight (*5*), though there were too few data to compare the results statistically. The difference may be due to fluctuations in the microgravity level in the KC-135 aircraft, or to the brief time available for adaptation to loss of arm weight. Sudden changes in arm weight are known to impair weight discrimination, but the effect is reduced if time is allowed for adaptation (*6*). Discrimination remained impaired even after 9 days in orbit, when adaptation must have been complete. This result suggests that gravity does indeed play an essential role in weight discrimination, and humans are not as sensitive to inertial mass as they are to weight. Insofar as the sense of heaviness is related to force, objects judged through inertial mass alone should feel like very light weights. Indeed, objects were judged to be about half their weight during the 0-*g* phase of parabolic flight (*5*), but there was also a tendency to "mass constancy" despite changes in the force environment (*6*). The Weber fraction is roughly constant for the middle range of weights, but increases for weights below 50 g (*7*). Poor discrimination under 0 *g* may therefore be an artifact of the low range of masses used. Higher masses might yield equal DL's under 1 *g* and 0 *g*, although simulations with air-bearing tables and horizontal arm movements suggest that this may not be so (*8*).

Results from postflight tests on four of the crew members suggest that the state of adaptation is also an important variable. The crew reported feeling heavy, and suffering from other postural aftereffects for a day or two after return to the earth (*9*). Their weight DL's were also raised, but returned to baseline within 3 or 4 days. This poor discrimination may have been due to tiredness. However, the aftereffect was exactly that predicted from experiments on water immersion and changed arm weight (*6*), as well as from the reported feelings of heaviness of the crew and other astronauts on landing (*5*). It is likely that this was a genuine phenomenon, mirroring some adaptation to weightlessness that occurred during the first day or two of spaceflight before the majority of the mass discrimination tests were undertaken.

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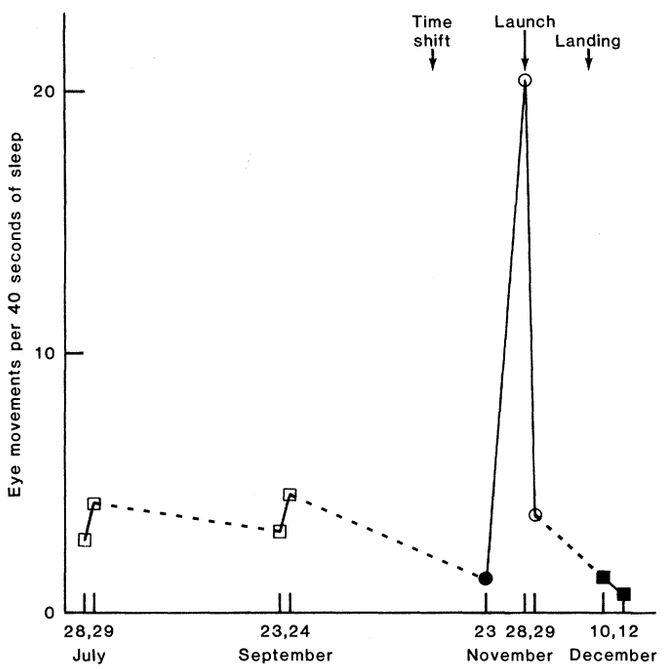
Eye Movements During Sleep in Weightlessness

Abstract. *The number of eye movements during sleep increased during the first sleep period in zero gravity but returned to normal by the second night. These rapid-eye-movement functions in flight may be the first variations of an oscillatory system. The ratio of the higher and lower eye movement frequencies oscillates within normal-gravity limits.*

Experiment 1ES030 was performed to record eye movements and the associated muscle activity during sleep on the Spacelab 1 flight. Measurements were made with Medilog electrophysiological tape recorders. Eye movements during sleep differ from those during wakefulness in frequency and amplitude. A further differentiation between wakefulness and sleep was obtained by recording movement artifacts with an electromyograph (EMG). In the evaluation of the Spacelab data, two variables were to be taken into account: a 12-hour time shift for the payload specialist (PS1) who carried out this experiment and zero gravity. Therefore, baseline measurements were made during sleep 120, 60, and 30 days before flight (days F − 120, F − 60, and F − 30). Measurements were also made during sleep on day F − 5. A 12-hour time shift started for PS1 2 weeks before the launch, the rationale being that most biological rhythms take 1 to 2 weeks to adapt to such a shift. Measurements were also made 2 and 4 days after recovery (days R + 2 and R + 4), but it must be realized that the effects of return to gravity were compounded with the effects of a return to local time. For various reasons, it was feasible to record the sleep parameters only during the early part of the mission. The electromyogram and electro-oculogram were recorded satisfactorily and the rapid eye movement (REM) sleep epochs were clear.

Observations. During the first sleep epoch (night 0) in space, the number of eye movements increased dramatically compared with any of the pre- or post-flight nights, but it returned to normal by night 1 (Fig. 1). Similar fluctuations were seen in the percentage of REM sleep as a function of total sleeping time. On night 1, REM sleep increased to 50 percent, whereas it is normally between 20 and 25 percent of total sleeping time. The abrupt increase is not pathological. Instead, it reflects a temporary imbalance of the REM mechanisms which include other autonomic variables such as heart rate and blood pressure. In pathological conditions, REM sleep decreases rather than increases. However, an increase in REM percent has been found in association with nausea and vomiting during the waking state. Total sleeping time was only 3 hours during the first night in space, but during the second night it increased to 6 hours, which corresponded to the average baseline level.

It has been shown that REM sleep is a sensitive indicator of how information is learned (*1*). This is true even for the rat (*2*). In humans, the informations may be internal (hormonal and metabolic) or external (for example, the learning of a new computer language) (*3*). During REM sleep, eye movement frequencies higher than 1 per second are specifically correlated with learning, whereas lower fre-



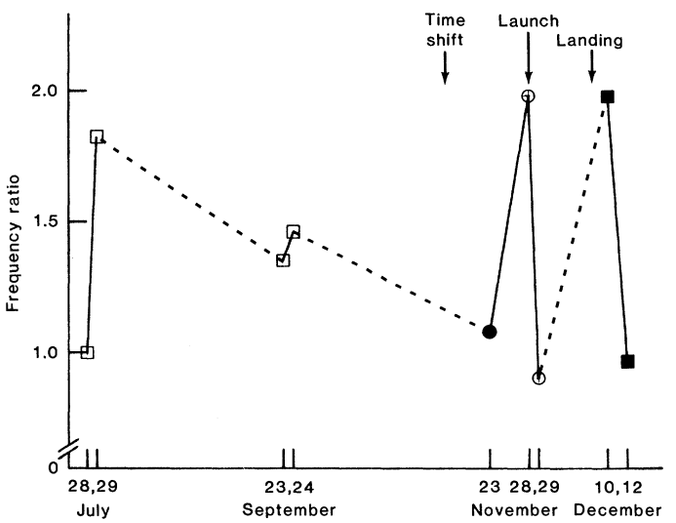


Fig. 1 (left). Number of eye movements per 40 seconds of sleep at various times. Fig. 2 (right). Ratio of eye movement frequencies higher than 1 per second to those lower than 1 per 2 seconds at various times.