Anecdotal Information on Space Adaptation Syndrome

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Compiled by:

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NOTE: Sources include personal recollections, recent direct contact with 18 astronauts, and related NASA publications.

I. INTRODUCTION

There has been considerable press and professional attention focused on the recent physiological problems Space Shuttle crew members have had during their adaptation to spaceflight. Depending on the individual, symptoms of space adaptation syndrome (SAS) have ranged from mild headaches to repeated episodes of vomiting.

The question being asked by many is, "Are these symptoms a serious threat to the usefulness of man in space?" The answer to this question is "no" when our entire space experience is viewed as a whole. There have been no significant losses of planned objectives on any U.S. mission as a result of the symptoms which accompany space adaptation. However, the symptoms are present frequently enough in the first few days of relatively short Space Shuttle flights to be a significant constraint on the level of routine activities that can be accomplished and, therefore, planned during that time. On the other hand, the problem is not as serious as some would make out.

First of all, no significant space adaptation symptoms were apparent during the Mercury and Gemini missions (Johnston et al., 1975 pp. 5-6 and p. 574) during which little whole body motion was possible except during EVA. On U.S. Apollo and Skylab spaceflights lasting more than 10 days, full adaptation has occurred in all but one crew member to the extent that the symptoms cannot be induced after that length of time. In fact, most obvious space adaptation symptoms are gone within four days. Readaptation to Earth conditions has occurred just as routinely.

Also, whenever stressful, first-day-in-space activities have been required, such activities have been performed without significant symptoms of space adaptation syndrome. Recognition of this fact should allay some of the concerns of those who envision critical, short duration, high activity missions.

This paper will attempt to put in context 20 years of information on spaceflight adaptation that has been available to the author. This includes personal experience related to Apollo 17, informal interaction with other astronauts, recent correspondence with astronauts who have been in space, published spaceflight biomedical reports, and general conversation with many interested scientists and flight surgeons. Simultaneously with the final preparation of this paper, Oman et al. (1984), have presented a detailed description of crew SAS symptoms associated with the flight of STS-9/Spacelab Mission One. As this is the first formal publication of such observations, it should be reviewed in conjunction with the material included here. Probably the greatest incentives for developing a fuller understanding of SAS and countermeasures to reduce its symptoms are, first, the need to increase man's productivity on short duration flights; second, the need to make certain that no readaptation problems can jeopardize the entry and landing of the Space Shuttle; third, the desire to make spaceflight as enjoyable and rewarding as possible for the rapidly increasing numbers of persons going into space; and, fourth, the requirement to make sure that extremely adverse symptoms are avoided in those rare individuals who are particularly susceptible to SAS. An additional, incalculable benefit of understanding SAS will come from a more complete understanding of human physiology, particularly, that wonder of biological wonders called the human central nervous system.

The organization of this compilation of anecdotal information is based on, first, the symptoms associated with the two principal changes in environment encountered by humans in space, the absence of weight and the absence of the Schumann (extremely low frequency) electromagnetic field resonance; second, the symptoms associated with readaptation during entry and landing; and third, symptoms associated with one-sixth gravity.

Finally, the symptoms reported are those of individuals and, although others may or may not have shared them, the data are inadequate to generalize on how prevalent or unique any given symptom might be. In addition, the effect of unknown or uncontrolled intake of medicines and food have not been correlated with the presence or absence of symptoms.

Acknowledgements. The authors wish to express their appreciation to Jack Sevier of the Universities Space Research Association for his continuing assistance in tracking down data for this compilation. Also, we wish to thank the many astronauts who have shared their personal recollections with us.

II. ADAPTATION SYMPTOMS RELATED TO WEIGHTLESSNESS

Head

Fullness of the head (facial edema)—lasting for the duration of flight. Almost without exception inflight and post-mission
debriefings of astronauts repeatedly contained expressions of having experienced “fullness of the head” or of having observed puffy features on flight colleagues.

“I did have the ‘puffy head’ syndrome during both flights.”

“Some people complain of headaches, full sinuses or head pressure.”

“. . . a heady, dizzy, bug-eyed or euphoria feeling, possibly followed by a flushed feeling, awareness of neck pulse, distended veins in the forehead and neck. . . . The euphoria is short-lived.”

“I observed ___ and ___ to have redder than normal faces.”

“In addition to a feeling of fullness in my head, I had a fuzzy feeling in the throat.”

“Sometime [after insertion], both crew members noted that the other crew member had ‘fat’ faces.”

“One feels this strange fullness in the head and this sensation of having a cold, and one sees the puffy look on the faces of his fellow crewmen and hears their nasal voices.” (Johnston et al., 1977, p. 27)

“Early in the flight we experienced a sensation of head fullness. This is caused by a shift of the body fluids to the upper part of the body when one first enters into zero-g. One notices that the eyes turn red which in my case, happened after about a day or so. The eye sockets themselves become a little puffy, the face a little rounder and a little redder, veins in the neck and forehead become distended and one’s sinuses feel congested. These conditions did not change significantly in-flight, they just tapered off. The eyes gradually cleared but the congested sinuses, while not too bothersome, were always there. On our flight the Pilot noticed the effects of fluid shift during the rendezvous; he had the head fullness during the docking, experienced some headache and some general malaise and felt, as he described it, pretty much like he had the flu. To be helpful, we said, ‘Why don’t you have some food; it will make you feel better.’ He took some tomatoes and very shortly after that returned them to us. That was the only episode of vomiting we had on our flight. After approximately 24 hours, his headache disappeared. The congestion for all of us remained, although I think it was probably a little more severe for him. The Commander and I noticed this feeling of head fullness and the accompanying symptoms for the first 2 weeks or so. For the last 2 weeks of the mission the Pilot felt good and essentially equivalent to 100 percent on the ground.” (Johnston et al., 1977, p. 23)

“Several variables were observed to affect the fluid symptoms and the sensation of head fullness. One was exercise. We always felt a lot better for about a half hour to 2 hours after we exercised on the bicycle. Perhaps the effect of drawing the blood down into the larger muscles of the body took it away from the head and left it feeling clearer. The Commander on our flight also experienced this lessening of fullness to some degree after eating. The last effect is associated with the time of day. As on Earth, if one is bothered by something, it always feels worse towards the end of the day; the same was true up there with the sensation of head fullness.” (Johnston et al. 1977, p. 23)

Pressure in eyeballs—lasting for 2–3 days.

“Fullness of the head is accompanied by a feeling of pressure in my eyeballs.”

“. . . immediately after going into orbit I noted a feeling of increased pressure in my eyeballs.”

Slight headache—lasting for 2–3 days. Informal discussions among astronauts exposed to weightlessness commonly contain occasional references to slight to moderate headaches during the first few days of flight. These headaches have been reported as “frontal” and as “occipital,” but general rather than specific in location. They also are reported as being associated with motion and sharp changes in lighting and/or visual scene. They disappear gradually if motion and visual disturbances are stopped. The published clinical reports of the Apollo missions contain references to the use of aspirin which may reflect the existence of mild headaches (Johnston et al., 1975 pp. 67–71).

“. . . sharp changes in light contrast or visual scenes gave me a slight temporary headache. There was a gradual fading of the headache symptoms I experienced until they disappeared after the third night’s sleep. There was one exception to this absence of symptoms after the third day. On the return to earth, during the eleventh day the command module pilot performed an EVA to retrieve film from two special mapping cameras in one of the outside bays of the spacecraft. My job was to “stand” in the open hatch and support the CMP’s activities. After about an hour of repetitive movement from inside the spacecraft to outside, I noticed I again had a slight frontal headache.”

“As for me I fell into the category of slight headache and stomach awareness.”
“Soon after I unstrapped from my couch in earth orbit to prepare for launch from earth orbit to the moon by rearranging some stored items other symptoms became evident. Within 10 or 20 minutes of starting to move around I noted to myself that I had a slight headache and a slight stomach awareness. These two mild symptoms were identical to those I experience after 45 minutes to 1 hour of flying aerobatics in a T-38 jet trainer. These symptoms went away after each occurrence following about 10 minutes of inactivity.”

“...did not experience the temporary headaches. I have had, however, less than a dozen headaches in my life.”

*Moderate headache (associated with repeated head movements)—lasting for 3–4 days.*

“...and I were never ‘sick’ although I had a mild headache and I took several aspirins each day... On the day of our EVA my headache went away even before I got in the suit and did not return until the following day (approximately 24 hrs). I used a little Afrin prior to suiting up to preclude any ‘blocking’ and maybe that helped my headache.”

*Strong to severe headache—lasting 3 days to a week or more.* Several astronauts who experienced strong to severe headaches described them as accompanied by strong stomach awareness both of which came on rapidly after some extended period of movement around the spacecraft. This combination of symptoms also is accompanied by a general loss of initiative or “malaise.”

“I got a severe headache at 0800 GET [a few hours after orbit insertion]. The headache was one of the worst I ever had and lasted all night.”

*Distended veins and bloodshot eyes—no information on duration.* Although references to distended veins are relatively common in astronaut descriptions, there are few available references to bloodshot eyes.

“...a heady, dizzy, bug-eyed or euphoria feeling, possibly followed by a flushed feeling, awareness of neck pulse, distended veins in the forehead and neck. ...the euphoria is short-lived...”

*Head congestion—no information on duration.* A general reference to feeling congested was made by many astronauts in part in the context of describing fullness of the head. It appears that head congestion is relieved temporarily by eating and exercise.

*Facial flush or redness—lasting for 2–3 days.*

“One notices that the eyes turn red which in my case, happened after about a day or so. The eye sockets themselves become a little puffy, the face a little rounder and a little redder, veins in the neck and forehead become distended and one’s sinuses feel congested. These conditions did not change significantly inflight, they just tapered off. The eyes gradually cleared but the congested sinuses, while not too bothersome, were always there.”

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**Stomach**

*Slight stomach “awareness”—lasting for 1–3 days.* Slight stomach awareness is the one of the most commonly reported symptoms and is associated with motion (particularly pitch motion) and/or sharp changes in lighting or visual scene. It disappears gradually if motion and visual disturbances are stopped.

“If I sat still the stomach awareness went away almost immediately. My overall symptoms went away in less than a day.”

“My only space adaptation problem was that I didn’t feel up to par the first day. It was more like the uneasiness associated with going to sea on ship. I never did even approach the feeling of dizziness, upset stomach or anything like that; I just didn’t feel like I wanted to make any quick movements which might stimulate something... I had a real concern before the spaceflight because I had gotten sick to the point of vomiting on every zero-g airplane practice flight.”

“As for me, I fell into the category of slight headache and stomach awareness. I always felt best right after a meal so I spread my menu to four light meals a day... In the last few years I have noticed a pronounced similarity between the symptoms I had then with jet lag symptoms today. I cope with the jet lag the same way—more frequent, lighter meals.”

“Preflight we flew T-38 aerobatics primarily to reduce our sensitivity to motion sickness. We also did some work in a rotating chair with the use of scopolamine/dextroamphetamine sulfate ( scop/dex). We never used scop/dex when flying a T-38 because it gave us a feeling of being lightheaded and we did not want to be flying in that condition. The preflight T-38 flying, I thought, was the most significant part of our vestibular-
type training. We did aileron rolls while putting our heads in one of six different orientations. Fifteen to 25 rolls in a row while putting the head down, to one side, or back, or one of the three opposite directions could greatly stress one's semicircular canals. We noticed significant improvement in our ability to tolerate vestibular stress (airplane and rotating chair) after we had made several flights.

Next let us consider the relationship between our vestibular stimuli and nausea by making a comparison between myself and another crewman. He did get sick early in the mission. If anybody should not have gotten sick, it was him. He had many years of flight experience and used to fly with the Thunderbirds, the Air Force Aerobatic demonstration team. When he was first tested, he was able to go at 25 revolutions per minute (rpm) in the rotating chair for 150 head motions. We called him 'old lead ear.' He had no problem whatsoever on the ground. On the other hand, I'm relatively new at the flying game. I had about 2000 hours of flying time before I went up and was just normal in my tolerance in the chair. Maybe 12.5 rpm was what I could take initially, although I was able to work up to 30 before I went because of the T-38 flying. Both of us did about the same amount of moving about in the Command Module, which was very small. But he got sick after about 7 or 8 hours into the mission. I experienced minimal symptoms and never really anything in the way of discomfort at all. So, the conclusion here is that we have got to look for something else other then what we normally call 'motion sickness' as a generator of nausea! We suggest fluid shift may be intricately tied up in this reaction." (Johnston et al., 1977, p. 24)

"...rotation and head movement in weightlessness do not elicit motion sickness. I don't believe Dr. Graybiel will state it quite that strongly, but certainly we never reached the threshold. And that was most surprising." (Johnston et al., 1977, p. 28).

See quotes under Slight Headache.

**Moderate stomach discomfort—lasting for 2-3 days.**

"I noticed in one of my flight companions a prolonged period of apparent stomach discomfort that persisted for about three days. It was accompanied by a loss of initiative except where planned activities needed to be performed. As we approached the more intense activities associated with lunar orbit operations these symptoms apparently disappeared."

"Onset symptoms varied drastically. Most people get ill on the second or third day [of shuttle flights], but on my flight only one person became ill and he was sick within minutes of orbit insertion.

Some people complain of headache, full sinuses or head pressure; others feel nauseous or bloated; some vomit without ever really 'feeling sick.' In one case vomiting was definitely triggered (two identical incidents with same crew member) by looking out the window when removing the shades after sleep, but other people become ill on the mid-deck with no external visual cues.”

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**See quotes under Moderate Headache**

**Strong stomach discomfort—lasting for 3-6 days.** It is clear from informal conversations in the astronaut corps, supported by available medical debriefings and a variety of incidental data, that an average of about one crewmen per Apollo and Skylab mission and approximately one out of every three crewmen on Space Shuttle missions have experienced strong stomach discomfort after a few hours to two days of active whole body motion in weightlessness.

Such discomfort may or may not be associated with moderate to severe headaches. There is a general consensus that if whole body motion is totally restrained discomfort is reduced or eliminated until whole body motion is resumed. It is perhaps useful to note that none of the stomach awareness or stomach discomfort symptoms were reported or discussed by crewmen participating in the Mercury and Gemini programs or by crewmen in other programs during periods of activities which were challenging above and beyond the mere implementation of the mission plan.

"The Lunar Module Pilot experienced motion sickness and vomited twice, once while preparing for transfer to the Lunar Module and again after transfer. After about 50 hours of flight, he still was not feeling well but had experienced no further vomiting. He reported that his motion sickness symptoms subsided when he remained still." (Johnston et al., 1977, p. 69)

"The Lunar Module Pilot awoke on the second day of the mission with a moderately severe headache. He took two aspirin tablets with only fair results. After eating breakfast and engaging in physical activity, he became nauseated and vomited. His symptoms began to subside over the next 12 hours as adaptation to weightlessness took place." (Johnston et al., 1975, p. 70)

"I never had anything more than very mild [stomach] awareness until I got [a severe] headache [a few hours after orbit insertion]. Then I upchucked after eating a can of stewed tomatoes. I did have about three to five minutes warning which transitioned progressively and steadily while remaining very still to mild epigastric awareness to awareness to salivating. There was some periodic regression of symptoms. The first time I returned from such a regression of symptoms I called the others to get me a sick bag and lasted a minute or more before
vomiting. I had virtually no steady symptoms following the vomiting episode."

“One crewman had vomiting and then diarrhea several hours after onset of vomiting [possibly due to intestinal flu contracted prior to launch]."

“Preflight I was evaluated on the rotating chair using a standard protocol. I was surprised to find that my tolerance to the rotating chair was minimal. On my first ride the protocol had to be terminated early due to nausea.” [This crewman reported no nausea during his two spaceflights or during KC-135 zero-g activities.]

Unexpected vomiting—occurs during the first 3-4 days. In contrast to single or repeated episodes of vomiting associated with strong stomach discomfort, there is a style of vomiting generally described as unexpected or explosive. Onset of this “projectile” type of vomiting appears to be associated with unexpected visual scenes and possibly with awakenings from sleep when strong head motion is undertaken. There appears to be no retching following the initial episode and the episode itself provides temporary relief from any associated stomach discomfort.

“The crewman moved slowly per plan and seemed to be enjoying zero-g for several hours before he commented on having a headache and “knot” in his stomach. These symptoms came and went throughout the remainder of flight-day one and into flight-day two. Toward the middle of flight-day two the crewman experienced two sudden waves of nausea. The first one passed quickly and the second resulted in one short episode of explosive vomiting. As soon as this episode was over all symptoms disappeared permanently.”

“...some vomit without ever really ‘feeling sick.’ In one case vomiting was definitely triggered (two identical incidents with same crew member) by looking out the window when removing the shades after sleep, but other people became ill on the mid-deck with no external visual cues.”

Repeated vomiting after gradual increase in discomfort—lasting 3 days to several weeks. General information makes it clear that one Apollo astronaut, one Skylab astronaut, and several Shuttle astronauts have experienced repeated vomiting which has proved very difficult to control. Each vomiting episode appears to be separated by a period of relief followed by gradually increasing discomfort. (Oman et al., 1984)

Increased tolerance to induced motion sickness—lasting from about 10 days in flight to several weeks after return to earth. Post-mission reports from the Skylab program indicate that tolerance to provocative body rotation in head motion increased after several days of flight to the point where symptoms of motion sickness could not be induced in flight nor for several weeks after return to earth.

Cardiovascular

Heart rate. Reports given to the crew by the ground were that resting heart rate decreased at least during the first few days in weightlessness. However, published data is sparse and ambiguous.

“I did notice a ballistocardiographic effect a couple of times when I was trying to take pictures through a window and was just holding on to the adjoining structure rather lightly; I noticed that the whole Skylab cluster was beating at around 60 beats per minute. This was evidenced several times. It required that I hold myself down rather firmly to get around this.” (Johnston et al., 1977, p. 25)

“As I was dozing off, I noticed that my heart’s pumping action moved my body back and forth slightly in the longitudinal direction.”

Fluid shifts.

“We were also able to see the leg volume changes because of the fluid shift. First of all, we could see the muscles shrink when we got up there. It was obvious to the eye, and it could be confirmed by measurements. A couple of times we measured the call after exercise on the treadmill. It increased about a half inch or so after a reasonable amount of exercise and then it shrank down fairly rapidly (15 to 30 minutes) as soon as we stopped.” (Johnston et al., 1977, p. 24)

“One can almost see the fluid draining out of the legs of his fellow crewmen making them look little and skinny like crows’ legs, and one knows that one’s physiology is changing.” (Johnston et al., 1977, p. 27)

Lower body negative pressure tests.

“When we used the Lower Body Negative Pressure Device in-flight, the distress was subjectively higher than on the ground. This effect is discussed in chapter 29. About 4 to 6 weeks into the mission was worst for us, and that, too, is confirmed by the data. We used the symptoms of presyncope as a cutoff for the Lower Body Negative Pressure test. We monitored pulse pressure and heart rate, but primarily, we used the subjective symptoms of the individual. In some cases, the pulse pressure and heart rate would get into the same ranges as they had been on a previous day for that individual,
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but he might say: "No, that's it. I feel as though I'm going under and you better terminate now." Other times we could go right through the test without any problem. We really had to consider the crew symptoms in addition to all the other variables." (Johnston et al., 1977, p. 24)

**Visual.**

*Change in near-field acuity—lasting for duration of flight.* There have been occasional debriefing references as well as other indications of changes in the optical characteristics of the eye under reduced gravity conditions. The lunar astronauts were known to generally underestimate both near and far field distances and sizes. The Skylab astronauts reported some decrease in the quality of near vision.

"I noted that I needed my reading glasses to comfortably use the flight data file in any lighting condition. This was in contrast to my experience in training where I seldom needed to use my glasses except with poor lighting or poor xerox copies. Another crewman had not noted any change, however after being asked, he thought his corrective lenses did not seem as strong on orbit as on the ground but the difference was not enough to cause any difficulty."

**Sensitivity to strong contrast in lighting—lasting for 3-4 days.**

"...immediately after going into orbit I noted... that sharp changes in light contrast or visual scenes gave me a temporary headache."

"In one case vomiting was definitely triggered (two identical incidents with the same crewman) by looking out the window when removing the shades after sleep..."

**Distance estimates in error—lasting for the duration of lunar stay.**

"Based on reports of difficulties in estimating distances on the moon I devised a first EVA comparison of the actual length of my shadow with its apparent length. At the time of the comparison my shadow was actually nine feet long but appeared about six feet. I subsequently applied this ratio of actual to perceived length with seemingly good results in estimating near-field distances and sizes."

**Miscorrelation of vision and reach—no time duration data.** Astronauts have made occasional references to reacting in the wrong direction, that is, a miscorrelation of vision and intended reach by left and right hands, when "upside down" relative to a "learned" spacecraft orientation (see *Illusory* symptoms below).

**Detail on other space objects unnaturally clear—lasting for duration of flight.* Most astronauts report the impression that objects viewed at a distance in space are unusually clear and sharp not unlike the impressions visitors to high mountain country have on earth.

**Illusory**

*Strong visual dependency for orientation reference—lasting for duration of flight.* Several astronauts who appear to have had few if any space adaptation symptoms report conscious and unconscious reliance on visual references within the spacecraft rather than on "learned" up and down impressions.

"[During Shuttle EVA] I never experienced a separation phenomenon either from the spaceship or from the earth. I had no sense of the earth being down, in fact I had no down reference at all. My frame of reference was the cargo bay of the orbiter. For some reason I immediately oriented to weightlessness. I was totally at home in zero gravity and felt extraordinarily comfortable in a no-down environment. I trained myself not to expect to see a 'down.' I was prepared to tell myself that the floor of the spaceship was down and to keep myself oriented that way, but I found that I didn't need a down. To me, the earth was neither down nor up. It was just there." (Breo, 1983)

"Closing one's eyes made everything go away. And now one's body is like a planet all to itself, and one really doesn't know where the outside world is. The first time I tried it, my instinct was to grab hold of whatever was nearest and just hang on, lest I fall. It was the only time in the mission when I had anything like a sensation of falling." (Johnston et al., 1977, p. 27)

"One other interesting point relating to the vestibular area was our in-flight perception of orientation. For example, being upside down in the wardroom made it look like a different room than the one we were used to. After rotating back to approximately 45 degrees or so of the attitude which we normally called 'up,' the attitude in which we had trained, there was a very sharp transition in the mind from a room which was sort of familiar to one which was intimately familiar. All of a sudden it was a room in which we felt very much at home and comfortable with. We observed this phenomenon throughout the whole flight." (Johnston et al., 1977, p. 24)

"I feel strongly that anyone living and working in a zero gravity field can benefit by psychologically anchoring himself to his egocentric coordinate system and referencing everything else to this constant. It is the way I avoided (almost totally) the problems from disorienting visual inputs while in orbit. This was
but he might say: 'No, that's it. I feel as though I'm going under and you better terminate now.' Other times we could go right through the test without any problem. We really had to consider the crew symptoms in addition to all the other variables." (Johnston et al., 1977, p. 24)

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"[During Shuttle EVA] I never experienced a separation phenomenon either from the spacecraft or from the Earth. I had no sense of the Earth being down, in fact I had no down reference at all. My frame of reference was the cabin of the orbiter. For some reason I immediately oriented to weightlessness. I was totally at home in zero gravity and felt extraordinarily comfortable in a no-down environment. I trained myself not to expect to see a 'down.' I was prepared to tell myself that the floor of the spacecraft was down and to keep myself oriented that way, but I found that I didn't need a down. To me, the earth was neither down nor up. It was just there." (Breo, 1983)

"Closing one's eyes made everything go away. And now one's body is like a planet all to itself, and one really doesn't know where the outside world is. The first time I tried it, my instinct was to grab hold of whatever was nearest and just hang on, lest I fall. It was the only time in the mission when I had anything like a sensation of failing." (Johnston et al., 1977, p. 27)

"One other interesting point relating to the vestibular area was our in-flight perception of orientation. For example, being upside down in the wardroom made it look like a different room than the one we were used to. After rotating back to approximately 45 degrees or so of the attitude which we normally called 'up,' the attitude in which we had trained, there was a very sharp transition in the mind from a room which was sort of familiar to one which was intimately familiar. All of a sudden it was a room in which we felt very much at home and comfortable with. We observed this phenomenon throughout the whole flight." (Johnston et al., 1977, p. 24)

"I feel strongly that anyone living and working in a zero gravity field can benefit psychologically anchoring himself to his epoecentric coordinate system and referencing everything else to this constant. It is the way I avoided (almost totally) the problems from disorienting visual inputs while in orbit. This was true whether we were past the window or in the foreground, or in the background with no spacecraft, comfortable with what was really relative to me. It change my perception of flying over it instead." (Johnston et al., 1977, p. 24)

"Our crew was affected by the sickness problems which are among our first, and the impression of a down force and the outside world sense of the up force, where the Earth was where you were looking at it."

"I adopted a conscious aural strategy (upward/downward environmental roll) to adopt different up directions based on what you simply ignore upward and downward, and reorient to the other way, and the external reference which normally worked great..."

"The other problem...was that we went out to the edge of space and feet in the floor of the wardroom, and space itself...I looked down and...432 kilometers..."

"[During Shuttle EVA] I felt it was a real help."

"We never had a problem."

We experimented in a rotating chair for only 20 forward and...the apparent motion was lasting for days..."
true whether I was maneuvering within the spacecraft, looking past the window to the earth with the spacecraft in the foreground, or looking at the earth from close to the window with no spacecraft in the foreground. I could feel perfectly comfortable when the spacecraft interior was upside down relative to me. When looking out the window it was easy to change my perception from one of diving under the earth to flying over it inverted.”

“Our crew was fortunate enough not to run into the motion sickness problem in any clinical or full-blown form. Therefore, among our first pleasant or different impressions was the impression of a very changed relationship between ourselves and the outside world and, I would say there was no vestibular sense of the upright whatsoever. I certainly had no idea of where the Earth was at any time unless I happened to be looking at it”. (Johnston et al., 1977, p. 27)

“I adopted a ‘self-centered’ frame of reference; that is, I consciously ignored/mentally disregarded any and all of the usual up/down references. I refused to think in terms of floor/ceiling or space/earth. In my case, I decided in advance (before flight) to adopt a ‘mind set’ that zero gravity would be much like underwater swimming where you can be in any attitude and you simply ignore your previously formed concepts of up and down, and react to what you observe in real time. Stated another way, I conditioned myself to ‘let go’ mentally of external reference frames and accept without resistance or reservation whatever spatial relationships I encountered. That worked great for me.”

“The other ‘down’ I noticed was a very exhilarating one, and that was outside during the extravehicular activities. When I went out to the end of the Apollo Telescope Mount, had my feet in the foot restraint and leaned back, I felt very far away from the space station. I no longer felt a part of it, and when I looked down, I suddenly realized that it really was a very long 432 kilometers (270 mi).” (Johnston et al., 1977, p. 25)

 “[During Skylab EVA] the sensation of the earth being down was a real heart stopper.”

“We never had stomach awareness when we were up there. We experienced a sensation of tumbling after we were in the rotating chair and during acrobatics in the workshop. After 15 or 20 forward rolls or gainers in a row I got really severe nystagmus but I never had any coupling to the stomach.” (Johnston et al., 1977, p. 24)

**Apparent misorientation of spacecraft interior or exterior—lasting for duration of flight.** Many astronauts, but not all, report temporary visual disorientation when moving from one spacecraft to another which has a different orientation relative to that “learned” in spacecraft simulators in which thousands of hours had been spent during training. In addition, several astronauts have reported a similar phenomenon when working in the vertical Shuttle orbiter on the launch pad which, of course, has a different orientation than the simulator.

“I noted that whenever I went from one spacecraft to the other through the connecting tunnel between the command module and the lunar module I was visually disoriented until I looked at a familiar spacecraft panel. Instantly my mind reoriented itself and I went about my business. In this case my mind apparently had a ‘learned’ orientation from lying on my back during training in the command module simulators that was 90° different from that learned while standing on my feet during training in the lunar module simulators.”

“I had several experiences in which I noted visual disorientation when going from the Skylab workshop to the multiple docking adaptor or to the command module.”

“I also noticed the feeling of ‘down.’ I experienced it a couple of times when I was working in the multiple docking adaptor or the airlock. When moving around in those vehicles, I attached no direction to my motion at all. But, after I looked out the window for a long period of time, in particular the window for the Earth Resources Experiment Package, and then moved away from the window and looked from the multiple docking adapter to the airlock, I strongly felt that I was looking ‘down.’ In the back of my mind I said, ‘I’m going to fall if I don’t hold on.’ Of course, I knew that it was not true, and just pressed right on. But that thought did flicker through my mind several times.” (Johnston et al., 1977, p. 25)

“I agree with reports of visual disorientation on going through the tunnel between the command module and the lunar module. Sometimes I seemed to be looking upward through the open tunnel and sometimes it seemed to be vertically down. I never recall it seeming to be horizontal. By the time the flight was over I felt comfortable in all orientations. On landing [in the Pacific] we went to ‘Stable 2’ [orientation] and I saw a perspective I hadn’t seen in our recovery training. It was a genuine surprise.”

“[References to visual disorientation associated with transitioning between the command module and lunar module are] identical to entering the multiple docking adaptor—with circular geometry—even after 60 days.”
"I do recall becoming temporarily disoriented in floating from the command module to the lunar module but it didn't seem to bother me going from the lunar module back home to the command module." [This astronaut was trained almost entirely in the command module.]

"I had no idea of the relationship between one compartment of the spacecraf and another in terms of feeling for 'up or down'; this has some peculiar effects when one passes from one compartment into the other and walls turn into ceilings and ceilings turn into floors in a very arbitrary way. But all one had to do is rotate one's body to the more familiar orientation and it all comes to right. What one thinks is up, is up." (Johnston et al., 1977, p. 27)

Deep-well illusion—lasting for duration of flight.

"When standing on my head relative to the design orientation of the Skylab workshop and looking over my shoulder toward the multiple docking adaptor between the workshop and the command module I felt as if I were looking down an extraordinarily deep well."

Slight vertigo.

"For about one hour after insertion into orbit I remained in the launch position, only moving from the neck up in pitch and yaw. I noted a slight amount of vertigo with head motions in the yaw direction."

Psychological

General malaise—lasting for 3-6 days with two prolonged exceptions. In informal conversations with astronauts who experienced severe stomach discomfort and/or severe headaches, there is a common description of their overall psychological condition as being one of a general malaise or lack of initiative for anything beyond what was already in the flight plan. There was a particular reluctance to take on any unplanned or unscheduled tasks, particularly those initiated by mission control center. This condition was also observed in some of the Apollo astronauts. In two instances this problem appears to have persisted for a week or more and was associated with particularly severe and persistent space adaptation symptoms.

"When one is working for a long time on the bike, 15, 20, 30 minutes or so at fairly high workloads, one needs mental diversion. If we had a window right by the bicycle, it would have been good. We did use a tape recorder and music and I found the music stimulated us and we could go a lot longer and harder with it. This small point changed the amount of exercise which we could consistently do." (Johnston et al., 1977, p. 23)

Inhibitors to space adaptation symptoms—most obvious during first two days.

"It is clear from the performance of astronauts and from informal conversations with them that the symptoms of space adaptation are reduced or at the very least delayed during periods of high emotional stress beyond the stress represented by normally scheduled activities. The best examples of this phenomenon occur during preparation for launch from earth orbit into a lunar flight trajectory, the extreme difficulties surrounding the Apollo XIII emergency, extravehicular activity, and the launch of satellites from the Shuttle. There are no reports of significant space adaptation symptoms in astronauts with direct responsibilities for the successful conduct of these activities."

Sleep

Loss of sensory perception of limbs—lasting duration of flight. There have been occasional direct and indirect references to a loss of sensory perception of limbs prior to sleep or upon awakening in weightlessness. In addition to the reference by an Apollo astronaut given below, there is one report of a Gemini astronaut awakening to see watches floating in front of him while realizing they were attached to his wrists. On the other hand, even under questioning, many astronauts do not recall noticing this phenomenon.

"The first night in space when I was drifting off to sleep in the weightless confines of a loose sleeping bag attached to hand points beneath the Apollo couch I suddenly realized that I had lost track of the position of my arms and legs. For all my mind could tell, my limbs were not there. However, with a conscious command for an arm or leg to move, it instantly reappeared only to disappear again when I relaxed."

Intermittent sleep—lasting for a few days to the duration of the flight. The nature and style of sleeping reported by the astronauts is highly variable, however it appears that for the most part sleep is intermittent with a few reported exceptions. The normal pattern appears to be to sleep for one or two hours, wake up, re-establish an orientation reference, and then go back to sleep for one or two hours more before awakening again. Within two or three days most astronauts report sleeping well but generally less than they are used to sleeping on Earth. The published clinical reports for the Apollo missions contain numerous references to the use of Seconal to induce sleep (Johnston et al., 1977, pp. 67-71).

"In general my ability to sleep in weightlessness and in 1/6 gravity was good though intermittent. It seemed that only five hours of total sleep was required to feel as refreshed as after my normal seven hours of sleep on earth. The drug Seconal seemed to augment the quality of sleep, but I could easily sleep through the awakening."

"My sleep lasted for about 6.5 to 7 hours with a steady and consistent pattern of awakening every 1.5 hours."

Disorientation on awakening from sleep, or during flight. The skill of an astronaut in disorientation on turning around spacecraf or touching something in weightlessness while drinking or vomiting into the sink has been called attention to.

"In the course of floating in my sleeping bag without any reference to the external orientation of the spacecraft, the dim lights of my consciousness seemed to drift off to sleep."

"There were times I woke up feeling like I had been in a dream. Although I was feeling well, I had no idea where I was or which side was up. (After the first week of flight)"

"The reference framework is a strange one. "I am my self" (in the first week of flight)."

No sleep for me in this case! (The above in some cases can be interpreted as an improved ability to adapt to weightlessness.)

"Normal waking hours were normal with the exception of the unexpected part by the astronauts who were exposed to different hours of illumination during the day."

"I was able to get a good hard sleep during the 19 hours of the 'day' and the 7 hours of the 'night' with no difficulty and felt refreshed."

"I found that a comfortable hard sleep could be obtained even though the 'night' lasted longer than the 'day.'"

"I do recall that I was able to sleep well even when I was only able to get about 1 hour out of every 2 hours of the sleep cycle, which was the only way I could get any sleep at all."

"I was able to sleep pretty well all night."

"I was able to sleep well most of the time."

"I was able to sleep well during the 19 hours of 'day' and the 7 hours of 'night.'"
seemed to help to lengthen periods of sleep in weightlessness, but I could not notice any improvement in my feeling upon awakening."

"My sleep was intermittent for the first two nights."

"The first couple of nights were less than ideal, but I adjusted by simply deciding to quit worrying about being strapped down in order to feel something against my back. The third night was the first that I really slept soundly, for six or seven hours."

"Sleep lasted six hours for me most nights. It was sometimes steady and sometimes restless."

**Disorientation upon awakening—lasting duration of flight.** There are occasional astronaut reports of sensing disorientation immediately upon awakening in a darkened spacecraft which persisted until some known object was seen or touched. In one instance there was an occurrence of vomiting immediately upon awakening which may or may not have been associated with such disorientation.

"In the darkened Apollo spacecraft, when sleeping free-floating in the sleeping bag, I apparently would rotate slowly without any awareness. Upon awakening I would be without a orientation reference until I rotated slowly and caught sight of the dim lights of the caution and warning system. Immediately my conscious orientation reappeared and I would begin to drift off to sleep again."

"There was one circumstance that produced a strong up/down feeling for me. During the first few waking moments after sleep, I had the distinct impression that I was lying on my right side and 'up' was to my left and perpendicular to my body. (After the flight I realized that I often sleep on my right side, and my impression of 'up' while waking-on-orbit may be a 'learned' response.) Amazingly, as I became more fully awake, my reference frame 'rotated' clockwise until 'up' was aligned with my 'self centered frame'. The sensation was so definite and strong that I could almost feel myself rotating 'the other way,' (i.e., counterclockwise)."

**No sleep first night.** Most astronauts who have commented in some detail about their sleep in weightlessness have indicated that sleep was more difficult the first night but improved significantly on succeeding nights until it seemed normal within three or four days. In a few instances however, there was no sleep during the first night. This data is biased in part by the fact that in early missions crewmen tried to sleep at different times, a process which is very difficult in the confines of a small spacecraft.

**Leg and arm muscles "tight" upon awakening—lasting for duration of flight.** In contrast to the absence of muscle soreness after exercise, several astronauts have noted that leg and arm muscles felt "tight" upon awakening as if they had slept in one position for too long. This appears to be a temporary phenomenon that disappears with normal flight activities.

**Felt need for familiar tactile reference before going to sleep—duration of the flight.** A number of astronauts reported the need to restrain their head or portions of their bodies before they drifted off to sleep in weightlessness. On the other hand several astronauts were able to sleep totally unrestrained.

"I found that I needed to wedge my head between two soft storage bags attached to the command module wall below the right hand couch before I could go to sleep. When I was on watch on the couch I found it necessary to place one of the shoulder harness straps across my head in order to go to sleep."

"Now, I'm a 'side sleeper,' and I like to change to different positions throughout the night. But since there's no up or down in space, I really couldn't sleep on my side. No matter what position I tried to take, the zero gravity would keep me locked in a neutral position—neither up, down, or sideways. I couldn’t twist and turn and hold a new positon. I was tempted to take a strap and lock my knees in a crouched position, just to get some variety, but I never did." (Breo, 1983)

"We all found it was useful to sleep using the device that we had up there. It was a cot outfitted with four straps which held us down and made us feel as though we were sleeping in something similar to bed. On several occasions, I tried sleeping by just floating free in the workshop. It was kind of fun, but I could only catnap that way. I floated pretty much with my arms out, as I would in a relaxed position underwater. I'd mash into a wall rather slowly and 5 minutes later come up against another one. My mind was always half awake, waiting for the next contact. I could never really get a sound sleep that way." (Johnston et al., 1977, p. 26)

"He feels his body assume the strange posture that one has in weightlessness, with the shoulders hunched up, the hands out in the front and the knees bent. Sleeping in that posture is not comfortable initially but every time one relaxes, one's body goes back to that posture." (Johnston et al., 1977, p. 27)

**Uncomfortable feeling of falling just prior to sleep—lasting for 2 days.**
"The sensation of going to sleep and not having a bed—or anything else—under you is one I can best compare to the nightmare of falling through space and never hitting. Just prior to dozing off our subconscious would signal the falling sensation and we would be fully awake with arms flailing. But after adjusting to zero-g, it's better than any Posturepedic or feather bed I ever slept on." (Cunningham and Herskowitz, 1977)

Appetite/Gastrointestinal

Moderate to severe loss of appetite and thirst—lasting for 3-4 days. The majority of astronauts have reported and considerable indirect evidence indicates that there is a moderate to severe loss of appetite during the first few days of spaceflight. In the early days crew reports indicated that the food was very unappealing as to taste. During Apollo and Skylab the food became increasingly more appetizing making it easier to eat even in the absence of appetite. In fact it became a general routine in the Apollo and Skylab missions to eat and drink more than one actually desired. Associated with this loss of appetite was a craving for spicy or otherwise flavorful foods and it was common to find the few spicy foods consumed very early in the mission.

"Appetite was generally diminished, however, it is not obvious if this should be attributed to the environment or to the pace of crew activity. The appeal of the food itself lessened during the end of the mission and by the evening meal on flight day 7 the crew had to search the pantry and meal packages looking for something they wanted. It appeared that although each food retained a distinctive flavor it all took on an aura of sameness. Perhaps one way to describe this would be as if the food had all picked up a common unappetizing taste/smell." [Space Shuttle astronaut]

"I had a total lack of appetite and did not eat for two days. By the end of the second day I felt run down and out of gas. At this time I began to push food and juices down even though I still was not hungry." [Space Shuttle astronaut]

"The food prepared for Skylab was of excellent quality and variety but palatability was compromised by a metabolic experiment that restricted the use of condiments. A pleasant byproduct of eating was temporary relief of head congestion."

"I was not particularly hungry during the first three days of flight but found it relatively easy to eat in spite of this. One quickly finds out that there are certain foods you prefer and in my case it was protein-rich fructi cole and the meats and peanut butter in US Army wet-packs. In addition it was much easier to maintain fluid intake by drinking various juices than by merely drinking the water. Throughout the entire flight, it is safe to say that eating was more a matter of routine than it was a matter of pleasure."

"We noticed, especially early in the mission, that we tended to get hungry in 3, 4, maybe 5 hours after a meal as opposed to the normal 6 to 7 hours as one does on Earth." (Johnston et al., 1977, p. 22)

"We discovered that after a few days of decreased appetite in flight we were able to eat all our food. Indeed, as the missions progressed the amount of food the crew was allowed to eat increased and their exercise increased, they were essentially eating the same amount of food as they ate on the ground." (Johnston et al., 1977, p. 28)

Lack of obvious gastrointestinal activity—lasting for 2-5 days. During most of the early space flight missions including the Skylab missions, astronauts made it a point to eat low residue diets for several days prior to launch in an attempt to reduce the frequency of bowel movements. Although there may have been other factors involved, this procedure seems to have worked, as bowel movements were infrequent to nonexistent for most crewmen during the first two to six days of flight. Exceptions to this rule include one case of possible intestinal flu which resulted in diarrhea during the first day of flight and the frequent bowel movements experienced by the Apollo XVI crew which had elevated levels of potassium in their diet in an attempt to improve electrolyte balances.

"My GI tract literally shut down until the sixth day of flight. I did not eat anything for the first two days but began to push food and juices down after that, however, there was still no bowel movement until the sixth day when it occurred as a real event. Bowel movements were normal subsequent to this."

"None of the three crewmen had any bowel movements for several days although there was considerable passage of gas. Subsequently bowel movements occurred every two days until about eleven or twelve days of flight when frequent periods of diarrhea occurred. The diarrhea may have been the result of slightly elevated levels of potassium in our diet."

Bloating due to gas ingestion—lasting for the duration of flight. All astronauts experienced to varying degrees the increased presence of gas in their intestinal tract. It is not clear as yet whether this increase in gas is a phenomenon of weightlessness or merely the result of the ingestion of residual hydrogen contained in the water produced by the fuel cells. Discomfort from this gas was related to the crewman's ability to pass that gas as flatus.
“I found that I would begin passing gas as soon as I began to eat and drink during meal periods. This passage of gas would continue intermittently for an hour or so after the meal and then let up until the next ingestion of food and fluid. One of my crewmates found it very difficult to relieve gas build-up and for several days was very uncomfortable as a consequence. The other crewman seemed to share my experience of being able to relieve gas build-up at regular intervals.”

“Drinking itself was no problem but all crewmen commented or complained about excessive swallowing of air bubbles trapped in drinks. Swallowed air caused a bloated feeling that could not be relieved by a simple belch. Belching or burping cannot be done in weightlessness without risk of some regurgitation since food and liquid attach to all parts of the stomach surface. Ingested air must be passed as flatus.”

“Dryness” in the throat—lasting for a few days. The astronauts have occasionally commented on various symptoms of dryness in the throat soon after being exposed to weightlessness, however, there are no systematic observations of this phenomenon.

“. . . I had a fuzzy feeling in the throat.”

“My throat felt cottony.”

**Tactile**

*Increased sensitivity to accelerations—gradually increases with time in flight.*

“As the mission progressed, both crew members noted an increased sensitivity to low level accelerations. By the end of the mission, each vernier thruster firing could be sensed whereas they were transparent on the early days.”

“We all noted increased sensitivity to acceleration after a couple of days on orbit. We hardly noticed the orbital maneuvering system burns during orbit insertion, but two days later, orbital maneuvering system burns were very noticeable.”

**Muscular**

*No residual muscle soreness—duration of flight including work in 1/6 gravity. There are no known reports of persistent muscle soreness following extended exercise in weightlessness or 1/6 gravity. Upon questioning several Skylab astronauts who participated in very active exercise programs in weightlessness were unable to recall any residual muscle soreness the day after such exercise.*

“Work on the moon, which involved much use of fingers under pressurized suit conditions was very much like repeatedly squeezing a tennis ball. After an hour or so of this kind of activity, forearm muscles reached a steady state of fatigue and discomfort as one might have expected. This state continued throughout the course of nine to ten hours of pressurized work associated with each lunar excursion. After several hours of sleep and rest between each excursion the fatigue in these forearm muscles not only disappeared but there was no residual muscle soreness. It was as if little or no work had been performed the day before.”

“On Skylab we were reproducing preflight stress levels during exercise but I never had any sore muscles.”

“Another very pleasant surprise was our ability to maintain physical fitness—our ability to maintain the same exercise level as we had been maintaining on the ground.” (Johnston et al., 1977, p. 28)

*Lower back soreness—several days. Several Apollo crewmen reported significant soreness in their lower backs during initial exposure to weightlessness. (Oman et al., 1984)*

**Joints**

*Decompression sickness. Decompression sickness is a concern when pressure changes are expected such as during lift-off or EVA’s. Prebreathing 100% oxygen prior to decompression is the measure used by astronauts to prevent decompression sicknesses such as “bends.” Light exercise during prebreathing probably helps also.*

“He revealed that he had experienced dysbarism (bends) on his first space flight (Gemini 10) as well as on his second (Apollo 11). He described symptoms involving the left knee as a sharp, throbbing ache which gradually worsened and leveled off at a moderate but very uncomfortable level of pain. The symptomatology was less painful on Apollo 11 than it had been on Gemini 10.” (Johnston et al., 1975, p. 70)

**Miscellaneous**

“Many of us noticed, subjectively and without taking measurements, that the fingernails and toenails tended to grow a little bit slower in flight. Rather than trimming them once a week it was on the order of once a month or so.” (Johnston et al., 1977, p. 25)

“It was a surprise to us that we had no major illness, especially on our flight. We were working hard most all the time.
and got rather tired. We stayed tired for about the first half to
two-thirds of the mission [84 days]. If we had done that on the
ground, I don't think we would have gotten by without getting
at least a "good" cold. Up there, we did not have any major
problems and I cannot speculate the reason for it." (Johnston
et al., 1977, p. 25)

"The duration of our mission was 84 days. We felt that we
could have gone significantly longer than that, on the order of
a year, from the crew standpoint. We felt good physically,
especially the last month. Part of this feeling of well-being
resulted from having achieved the necessary efficiency to
become comfortable with our schedule." (Johnston et al.,
1977, p. 26)

III. ADAPTATION SYMPTOMS RELATED TO
ABSENCE OF SCHUMANN RESONANCE

The suggestion has been made (Richard Dickhant, personal
communication) that the absence of the Schumann electro-
magnetic resonance field in low earth orbit might cause central
nervous system processing problems due to the lack of a
"timing" reference signal. Such problems might be at the root
of some of SAS symptoms or be manifested as an increase in
performance errors. Future investigations may show the
validity of this hypothesis, however, there is indirect anecdotal
evidence of performance error rates in space significantly
above those seen in mission simulations. Most recently this
phenomenon has been reported with respect to the remote
operation of the ESA SPAS free-flying spacecraft. Evaluation
of performance error ratios should be possible comparing
historical simulation and flight data or by simple inflight tests.

IV. READAPTATION SYMPTOMS UPON ENTRY
AND LANDING

Perception that Shuttle entry attitude changes were greater
than actual.

"I had the distinct impression that the commanded Shuttle
attitude changes were significantly greater than actually
indicated on the attitude displays."

Sense of pitch-up.

"During [Shuttle] entry, both crew members experienced a
strong sensation of pitching up shortly after sunrise, possibly
associated with a small bank adjustment. The vehicle drag
acceleration at this point was quite low."

Tumbling sensation (vertigo). There have been a few reports
of "a tumbling sensation" or vertigo-like symptoms during
Shuttle entry activities, however, most crewmen report no
such symptoms.

"On return, we first experienced one-gravity after 84 days in
weightlessness, during the first deorbit burn. We all noticed a
rather strange sensation in the inner ear. It was like a tumbling
sensation, similar to what one gets when lying on a table and
someone puts cold or warm water in your ear. We did not feel
that we were tumbling in a given direction; it was just an
awareness of a sensory input that we had not experienced for
a very long period of time although we had no real parallel to
that sensation on the ground." (Johnston et al., 1977, p. 25)

"I experienced a tumbling sensation when turning my head
while flying around the heading alignment circle just prior to
landing."

"Also during entry you could 'tumble your gyros' by rapid
head motions or by reorienting your head (vestibular organs)
in the g field, however, I was able to leave my seat several times
during entry without difficulty."

"After recovery, we found rapid head movements produced
vertigo. Most crews have noticed this." (Johnston et al., 1977,
p. 25)

Feeling of heaviness during Shuttle entry. A number of
Shuttle astronauts have noted that they began to feel heavier
than normal as soon as Shuttle g loadings began to be sustained
during entry. This phenomenon appears to be the same as de-
scribed more extensively below relative to postlanding
symptoms.

Lack of sensitivity to "g" loadings.

"During the entry alpha sweeps the vehicle n, varied between
1.8-g and 0.5-g yet neither crew member was aware of these
changes. This is in stark contrast with other comments about
our increased sensitivity to low level accelerations in
weightlessness."

Possible overcontrolling of pitch. There is one possible
indication of overcontrol in pitch axis during roll-out of the
Space Shuttle after landing. It is not presently known whether
or not this overcontrol is related to physiological factors or to
the system dynamics of the Shuttle during landing.

"Time compression." One of the common axioms of test
flying is that "time is compressed" relative to the perceptions
gained during training and simulation. Although this was not
noted during the pre-Shuttle space activities, it has been
observed during Shuttle entry and landing sequences. On the
other hand, many Shuttle pilots report that entry went very
much as in simulation. It is possible that there is a difference
in impression depending on whether the entry and landing sequences were performed manually or automatically.

"Time compression has been previously reported during entry and this mission was no exception. Unlike my previous experience with dense timelines where it is not uncommon to feel that the clock is running fast, this sensation is one where the clock is normal but it is taking longer than usual to execute mental activity."

Perception of being very heavy and having heavy arms, legs and head after landing—lasting for a few hours to 2 days post flight. From the long duration Gemini flights through the current Shuttle missions essentially all astronauts have reported feeling heavy during their first few hours of exposure to gravity during entry or after landing.

"Post landing, both crew members felt extremely heavy. I was not sure I was going to be able to get out of the seat without assistance. I discovered that I had adequate strength to do anything I wanted but it required an attempt to overdo major motions. I described it as being analogous to a closed servo loop with inappropriate gains on the output. In contrast to this experience, I never had any trouble working on the treadmill [in weightlessness] with the approximate 160 pound bungee forces. On reflection, one difference seems to be that the treadmill activity can be characterized as applying reactive loads, whereas the initial 1-g activities involved the body sending out a command open loop and waiting for a response. Another obvious difference is that the post landing activity came some time after the application of entry-1-g. I believe that the post landing ‘heaviness’ was much more pronounced following the Orbiter landing than I remember from Apollo, although the STS mission was of shorter duration. The only differences noted during entry were the g time profiles and the relative body g-vector orientation." [Shuttle astronaut]

"I felt that my head was almost too heavy to lift when lying on the medical examination table during the post landing physical on the carrier. This impression disappeared within a few hours, but it was initially very pronounced." [Apollo astronaut]

"Also, the brain did not seem to be coupled to the muscles in the same way as it was before we left; that is, we all felt very heavy. Every movement we made had to be worked at; rolling over in bed, moving an arm, walking; all had to be made with conscious effort. This lasted for a couple of days and was more severe at the beginning than at the end of those 2 days." [Johnston et al., 1977, p. 25]

"In addition to my head feeling very heavy when lying down, I was very aware of the 160 pounds of meat I had to carry again. This feeling did not disappear until two nights had passed." [Skylab astronaut]

"I felt very heavy while we were in the spacecraft waiting to be hoisted aboard the carrier." [Skylab astronaut]

"Physically, the one overpowering sensation we experienced on landing was one of heaviness. When the post flight medical checkup started and I lay down on the examining table, it felt as if I were going to sink right through it. I felt as if I were made out of lead, and this feeling persisted until the next day." [Apollo astronaut] (Cunningham and Herskovitz, 1977)

"During entry and after landing everyone remarked about 'feeling heavy,' 1.5-g felt like 2.5, etc." [Shuttle astronaut]

"I felt as if I were in control but had 'sea legs' and 'heavy feet.' " [Shuttle astronaut]

Uncertain in coordination of walking—lasting for a few hours to a few days post flight. Upon return to earth, most astronauts have reported or been observed to have problems of coordination during walking. This difficulty persists for only a few days with gradually decreasing severity. The principal symptom of this problem is the spread-leg walking stance that almost all crewmen adopt when walking for the first time after landing.

"We could go around corners fairly well, if we were careful. We tended to walk with our feet spread apart. I think that had we had any contingency on the return we would have been able to handle those which we had planned for, but certainly we were a bit less able to handle them than when we left. This was to be expected, and I still think we all felt fairly comfortable as we got out of the Command Module." [Johnston et al., 1977, p. 25]

"Typical coordination problems were experienced post landing with a very rapid relearning curve. The crew walked around and did mild exercise in the mid-deck for about 20 minutes before exiting the Orbiter. The initial efforts to climb down the ladder and walk around the Orbiter took substantial concentration. Several hours after landing the crew still had to think about walking, but could do it satisfactorily. By the time the crew arrived at Ellington Air Force Base they were able to negotiate normally." [Shuttle astronaut]
"I felt that it was either necessary for me to walk with my legs spread or to have my hand on a railing or some other support. If I did not do this I had the strong impression that I would wander to the left of the line which I was trying to walk." [Apollo astronaut]

Difficulty in judging turns while walking and driving—lasting for 1-7 days post flight. There are numerous stories within the astronaut corps of misjudgement of turns into doorways during the first few days after return to the gravity environment on Earth. In a few instances this apparently was a problem while driving a car.

"Upon stepping from the helicopter onto the deck of the carrier I realized I was only partially in control of where I wanted to go. Even though I had adapted very quickly to the 1/6 gravity of the lunar surface, and I had spent three days in that environment, I had expected to be unsteady on my feet on the carrier. After adapting to zero gravity and then having to walk in the one gravity field of Earth, other crews walked with their legs spread and moved with considerable wobble toward waiting microphones. On the other hand, I thought I would be able to control where I walked even if things were a little unsteady. In fact, I did not have complete control. I was trying to walk down the center of the red carpet to the reviewing stand and the best I could do was stay on the left edge." [Apollo astronaut]

"I felt as if I had low gain in my efforts to turn while walking for about one and a half days. I had no problem driving a car one day after landing, however, I was terrible at playing tennis." [Shuttle astronaut]

"I could not seem to walk to a straight line for 2-4 hours. It was similar to trying to walk down the passageway on a ship in a heavy rolling sea. However, in this case the aircraft carrier that picked us up was actually in a very calm sea." [Apollo astronaut]

"I felt unstable due to a wooden or heavy feeling in my lower legs but did not feel that I veered or did not walk a straight line." [Apollo astronaut]

"When I came off the Shuttle, I was a little wobbly. I had sea legs. But nothing serious. Within 24 hours, I was running." [Shuttle astronaut] (Breo, 1983)

"I had a lot of trouble with directional control post flight. I kept wanting to turn to the right. I also drove off the right side of the road twice during the first week after return." [Skylab astronaut]

Difficult in feeling Shuttle braking action. Some Shuttle pilots have noted that it is difficult to "feel" the braking action of the Shuttle during roll-out.

Appetite, thirst and visual acuity return to normal—within a few hours of landing. With no known exceptions, the appetites of the astronauts were at least normal within a few hours of landing as indicated by the sizeable consumption of food both on the carrier and back in Houston. Also it appears that visual acuity returns to normal very quickly.

"We all felt very thirsty on the recovery ship despite the fact that we had really forced the fluids before we returned. This was an expected reaction." (Johnston et al., 1977, p. 25)

"During the flight from Edwards Air Force Base to Ellington Air Force Base we noticed that our appetites had returned and that I no longer needed my glasses as I had on orbit." [Shuttle astronaut]

No sense of roll attitude change while flying aircraft—lasting for several weeks. There is one report from an astronaut who experienced no sense of roll attitude change while flying in a T-38 several weeks after return from a Shuttle mission. This was discovered when he was looking down into the cockpit during a moderately rapid roll maneuver performed by the second pilot of the plane. When he looked up he was surprised to see that they had indeed rolled significantly relative to the earth's horizon.

Difficult coordination of hand-eye motion—several days. There are occasional reports from astronauts of experiencing moderate hand-eye coordination difficulties for several days after return to Earth. There is little indication of how extensive this symptom may be.

"I had no problem driving a car one day after landing, however, I was terrible at playing tennis." [Shuttle astronaut]

"I do not recall any hand-eye coordination problems other than having some difficulty during the first few hours of remembering that most objects will not float in air in Earth gravity." [Apollo astronaut]

"I played racquetball 24 hours before I left earth and played 24 hours after returning. I played equally well both times." [Shuttle astronaut] (Breo, 1983)

Joint and tendon aches lasting a few days to weeks. Many crewmen returning from long missions have reported a variety of back, ankle, and knee joint aches often associated with relatively weak muscles and stiffness.

"After the mission, my legs were sore after walking around the Command Module." [Apollo astronaut]

Ear symptoms—"bubbling" during the flight and in the post-flight recovery period.
relatively rigorous exercise such as running and handball. Calf muscle and Achilles tendon aches also are reported in conjunction with postflight exercise.

"After return to one-g, the joints, especially the knees, felt sore after the little exercise. My leg muscles were sore; for the Commander, it was his back." (Johnston et al., 1977, p. 25)

Ear symptoms lasting one day. There are several reports of "bubbly fluid" in the middle ear and "reddening" of the eardrum in the postflight medical examinations of some Apollo crewmen.

V. ONE-SIXTH GRAVITY

No obvious adaptation or readaptation symptoms. Although it was pleasant to have a gravity reference during the one to three day lunar stays of the Apollo astronauts, there are no indications that the effect of 1/6 gravity was any different than the effect of weightlessness. During the first few hours there was little opportunity to observe coordination in this reduced gravity field because of the close confines of the lunar module. Once outside the spacecraft, however, coordination seemed to be good and to improve steadily during the first two or three hours. The only obvious difficulty was remembering that one's center of gravity was displaced a few centimeters to the rear as a consequence of the mass of the backpack. Unconscious adjustment to this took place fairly rapidly. It is possible that any readaptation symptoms one might have seen on the moon were masked by the inherent difficulties of working and moving around in the Apollo pressure suit. Most crewmen seemed to have found 1/6 gravity a very pleasant environment in which to work and sleep. It provides the tactile references one is used to on earth without the complications of ear gravity.

VI. SUMMARY

The operational data in hand relative to SAS is grossly incomplete; however, they suggest that the basic cause of the symptoms of SAS is probably a neurological overload resulting from a wide variety of incompatibility error signals being received by the balance and orientation processing centers of the brain. Most of the overload appears to come from visual disorientation cues combined with head motion; however, the effects of fluid shift and the absence of Schumann resonance have yet to be evaluated. Prolonged exposure to this overload apparently results in a loss of initiative and a general malaise (parasympathetic neural response) in some individuals. In some cases, unexpected aggravation of the overload causes the rapid onset of a single episode of unexpected vomiting which temporarily suppresses high emotional stress (sympathetic neural response).

The known symptoms of space adaptation syndrome resemble those of increased intracranial pressure and high altitude sickness aggravated by sensory conflict within the autonomic nervous system rather than just those of terrestrial motion sickness. Further, there is no known correlation between susceptibility to SAS and susceptibility to terrestrial motion sickness. SAS symptoms vary in nature and intensity from person to person and from mission to mission; however, four general levels of severity can be defined as follows:

1. Fullness of the head with other associated symptoms
2. Slight stomach awareness and/or slight frontal headache
3. Strong stomach discomfort and/or severe headache combined with a general loss of initiative or malaise
4. Single episode vomiting that, temporarily at least, reduces the level of other symptoms
5. Frequent vomiting with prolonged adaptive period.

The process of adaptation is apparently one of the brain learning to ignore the inputs from various sources which conflict with visual inputs. This adaptation process generally takes one to four days. It possibly can be accelerated by pushing up to detectable symptoms and then backing off from them by stopping head and body motion and strong visual orientation changes. Timelines should be designed so that this cyclic adaptation procedure can be used as necessary during the first two days in orbit.

Significant SAS symptoms can be delayed, but probably only delayed, by highly challenging first day activities in which the crew is emotionally involved. This does not include, however, just a full timeline that allows no time for adaptation by those crewmen who need it.

The strong effects of spatial disorientation and head motion in inducing symptoms are clear. Methods should be explored to reduce crew visual dependency on "learned" orientations acquired during training and piloting experience in a one-gravity environment. Development of individual "egocentric" orientation references may be helpful. Consideration also should be given to using variable orientations with respect to gravity for Shuttle and Spacelab simulators and to increased visual and VFR instrument aerobic maneuvers that give variable orientation of Earth horizon references.

Accenting the visual orientation references in the Shuttle may make things worse by increasing visual dependency. The exception might be to provide illuminated or tactile orientation references during sleep periods as spatial disorientation can occur during sleep. At least two of the astronauts who have vomited in space did so immediately upon awaking.

There are many human physiological changes induced by a weightless environment any or all of which may play a role along with various sensory conflicts in inducing SAS symptoms. Among these are the following:

1. Fluid shift, possibly including cerebral spinal fluid
2. Cardiovascular adaptation
3. Head, neck, and spinal column position changes
4. reduction in kinesthetic sensitivity
5. increased cardiovascular efficiency in transport and metabolism
6. general electrolyte, fluid, endocrine and other chemical balances
7. hydrogen in the water supply (intestinal gas buildup)
8. diet and smells sensitivity
9. shift of internal organs
10. three-dimensional vision in near field
11. absence of Schumann resonance field.

Probably the most significant and most important aspect of the physiological experience on Shuttle is the apparent occurrence in some crewmen of readaptation symptoms during the long entry and launching sequences. In retrospect, this probably could be expected as that sequence is conducted in a heads-up attitude (like walking on the carrier) relative to a 0.5 to 1.6-g stress field.

The reported symptoms, such as the fact that a pilot thought the Shuttle responded more vigorously to control inputs than it really did, as well as some of Dr. Bill Thornton's measurements, suggest that the vestibular inputs to the brain temporarily have the wrong "gains." Reports of a feeling of heaviness and of difficulties in "feeling" the Shuttle braking action also suggest a "gain" problem. This would explain difficulty in getting to the center of the red carpet and other reports of "leaning" around turns and of turning into walls instead of through a door as intended. It would also explain the temporary postflight eyes-closed balance problems experienced by all astronauts tested during Apollo and Skylab.

Basically, in a very few minutes, during Shuttle entry and landing, we are trying to force the brain to use correctly those signals that it has learned to ignore in weightlessness. In previous space programs, we effectively had many days to reverse the body's space adaptation process. Critical tasks were not demanded of us in a 1-g environment. The correlation of reports (and nonreports) of readaptation symptoms during the entry and landing sequences of the first five Shuttle missions cannot be definitive; however, there is a strong suggestion that the following operational principles should be followed:

1. Continue fluid and electrolyte prophylactic procedures prior to entry.
2. Maximize the amount of manual control "time" during the entire sequence from entry to landing so that the brain has the maximum time possible to readjust the "gains" it uses in a g-field (make the autosystem back-up).
3. See if some means can be provided in orbit to assist in this readjustment of "gains."

It is remarkable that more problems have not been reported or observed. This is a hopeful sign that, with proper prophylactic and operational procedures there will be no difficulties than cannot be eliminated or accommodated. However, prudence would demand a far better analysis of past data as well as new clinical observations and research in order to understand the physiological basis for these entry and landing problems.

VII. REFERENCES.

Anecdotal Information from Published Apollo Mission Reports

Head

- The Commander reported that he felt less zero-gravity effect, such as fullness of the head, than he had experienced on his previous flight. All three crewmen commented that the lack of a gravitational pull caused a puffiness underneath their eyes and this caused them to squint somewhat, but none felt any ill effects associated with this puffiness.

(Apollo 11)

- Aspirin tablets were also taken by the crewmen, but the number of tablets per individual was not recorded. The Lunar Module Pilot recalled that he had taken two aspirin tablets almost every night to aid his sleep.

(Apollo 11)

- All crewmen reported the sensation of fullness in the head, a condition which remained for 1 or 2 days after lift-off. Their eyes were bloodshot for the first 24 hours of flight and their faces appeared slightly rounded or swollen throughout the flight. They also reported that their shoulders tended to assume a squared-off (or raised) position, rather than being sloped in the usual relaxed position.

(Apollo 12)

- All crewmen took Actifed to relieve nasal congestion at various times throughout the flight. The Lunar Module Pilot reported taking Actifed prior to lunar module descent to relieve symptoms developed after earth lift-off.

(Apollo 12)

- The Commander and the Command Module Pilot both reported a feeling of fullness in the head lasting for several hours on the first day of the mission. The Lunar Module Pilot reported a similar feeling and also that he felt like he was "hanging upside down." The Commander reported that all crewmen had red eyes the first day of the mission.

(Apollo 13)

- Upon awakening on the second day of the mission, the Lunar Module Pilot complained of a severe headache. He took two aspirin, ate breakfast, and became immediately engaged in unrestrained physical activity. He then became nauseated, vomited once, and lay down for several hours. He then experienced no further nausea. The Lunar Module Pilot continued to take two aspirin every 6 hours to prevent recurrence of the headache. After the inflight incident, he took aspirin on only one occasion.

(Apollo 13)

- No medications, other than nose drops to relieve nasal stuffiness caused by spacecraft atmosphere, were used during the mission. On the third day of flight, the Commander and the Lunar Module Pilot used one drop in each nostril. Relief was prompt and lasted for approximately 12 hours.

(Apollo 14)

- Adaptation to the weightless state was readily accomplished. Shortly after orbital insertion, each crewman experienced the typical fullness-of-the-head sensation that has been reported by previous flight crews. No nausea, vomiting, vertigo, or disorientation occurred during the mission and the crew did not observe distortion of facial features, such as rounding of the face due to lack of gravity, as reported by some previous crewmen.

(Apollo 14)

- Shortly after orbital insertion, each crewman experienced the typical fullness-of-the-head sensation that has been reported by all previous flight crews. The Commander adapted rapidly to weightlessness and noted that on this flight, in contrast to his Apollo 9 experience, he felt completely at ease in the weightless state and was able to move his head rapidly without discomfort.

(Apollo 15)

- Adaptation to zero-g and subsequent readaptation to one-g were immediate and very natural. The zero-g environment can best be described as exhilarating. The one lingering nuisance of the zero-g environment is that the sinuses never stay clear for very long.

(Apollo 16)

- Shortly after earth orbital insertion, two crewmen experienced the typical fullness-of-the-head sensation that has been reported by all previous flight crews. This sensation lasted for several hours. The Command Module Pilot did not experience this sensation. No redness of the face was observed by the crew and all three crewmen adapted rapidly to weightlessness and did not experience any giddiness, nausea, vomiting, or disorientation.

(Apollo 16)

- Two of the three crewmen experienced the typical fullness-of-the-head sensation, one immediately after earth orbital insertion and the other after a 6-hour exposure to weightlessness.

(Apollo 17)
Stomach

— Based on the crew’s postflight comments, the adaptation to weightlessness required approximately 1½ days. There were no instances of nausea, vomiting, or disorientation; however, all three crewmen did experience the need to limit their movements and perform the necessary movements slowly during the initial period of adaptation. In addition, all three crewmen had varying degrees of “stomach awareness” and a decreased appetite for the first 1½ days of flight. Once adapted, the crewmen were able to perform all types of movements without restrictions. No readaptation to weightlessness was required after residing for 75 hours on the moon at 1/6-g.

(Apollo 17)

Illusionary

— In donning and doffing the suits, they had no feeling of tumbling or the disorientation which had been described by the Apollo 9 crew.

(Apollo 11)

— The Command Module Pilot apparently experienced no difficulty in adapting to weightlessness, but the Lunar Module Pilot reported that his sensation of head-fulness lasted three days. In addition, the Lunar Module Pilot experienced slight giddiness which precluded rapid head or body movements. This sensation disappeared shortly after landing on the lunar surface and did not recur on returning to the zero-gravity environment.

(Apollo 15)

— One frequently asked question is, “Do you have any sensation of being upside down?” There were several times during the mission when the command module would appear to be in a stable II attitude (apex down). These instances seemed to follow periods in the lunar module and in the tunnel area with the head in the minus-X direction. There seemed to be a natural preference for the orientations used in training even though they were not the most efficient. On the other hand, the spacecraft orientation with respect to external objects was never annoying.

(Apollo 16)

Sleep

— It is interesting to note that the crewmen’s subjective estimates of amount of sleep were less than those based upon telemetered biomedical data. By either count, the crewmen slept well in the command module. The simultaneous sleep periods during the translunar coast were carefully monitored and the crew arrived on the lunar surface well rested. Therefore, it was not necessary to wait until after the first planned 4-hour sleep period before conducting the extravehicular activity. The crewmen slept very little in the lunar module following the lunar surface activity. However, the crewmen slept well during all three transearth sleep periods.

(Apollo 11)

— Sleep periods during translunar coast began approximately 7 to 9 hours after the crew’s normal bedtime of 11 p.m. The crew reported that they had no particular trouble in adapting to the shifted sleep periods. However, the first flight day was extremely long and the crew was thoroughly fatigued by the time the first sleep period began 17 hours after lift-off. The crewmen slept well in the command module during the translunar and transearth coast phases and the Lunar Module Pilot took at least two unscheduled naps during transearth coast. However, they reported their scheduled sleep periods were longer than necessary, since they would invariably awaken about 1 hour ahead of time and would usually remain in their sleep stations until time for radio contact.

— The lunar module crew slept only about 3 hours on the lunar surface prior to the second extravehicular activity period. In the next sleep period following rendezvous and docking, all three crewmen in the command module slept only 3 or 4 hours, which was less than desirable.

(Apollo 12)

— The crew reported sleeping well the first 2 days of the mission. They all slept about 5½ hours during the first sleep period. During the second period, the Commander, Command Module Pilot, and Lunar Module Pilot slept 5, 6, and 9 hours, respectively.

(Apollo 13)

— The shift of the crew’s normal terrestrial sleep cycle during the first four days of flight was the largest experienced so far in the Apollo series. The displacement ranged from 7 hours on the first mission day to 11½ hours on the fourth. The crew reported some difficulty sleeping in the zero-g environment, particularly during the first two sleep periods. They attributed the problem principally to a lack of kinesthetic sensations and to muscle soreness in the legs and lower back. Throughout the mission, sleep was intermittent, i.e., never more than 2 to 3 hours of deep and continuous sleep.

(Apollo 14)

— Following transearth injection, the crew slept better than they had previously. The lunar module crewmen required one additional sleep period to make up the sleep deficit that was incurred while on the lunar surface.

(Apollo 14)

— In contrast to the Commander’s Apollo 10 experience, he slept well during all the scheduled sleep periods. Typically, the Commander’s sleep was uninterrupted for 4 to 5 hours after which he would awaken, get a drink of water, and return to sleep for the rest of the night. The Lunar Module Pilot slept well.
— During the first two days of flight, the crew reported discomfort and soreness of the lower back muscles as has been noted on previous missions. The discomfort was sufficient in magnitude to interfere with sleep during the first day of the mission, and was attributed to changes in posture during weightlessness. Inflight exercise provided relief.

(Apollo 14)

— None of the crewmen experienced nausea, vomiting, or disorientation during any phase of the mission. An observation made by the crew was that their facial features were distorted because of the lack of gravity. The crew also reported the discomfort and soreness of the lower back muscles associated with postural changes during weightlessness.

(Apollo 15)

— Previous crews have commented on pains in the lower back. The Apollo 16 Command Module Pilot felt none of these.

(Apollo 16)

**Miscellaneous**

— The planned exercise program included isometric and isotonic exercises and the use of an exerciser. As in previous Apollo missions, a calibrated exercise program was not planned. The inflight exerciser was used primarily for crew relaxation. During transearth coast, the Lunar Module Pilot exercised vigorously for two 10-minute periods. His heart rate reached 170 and 177 beats/min, and the partial pressure of carbon dioxide increased approximately 0.6 mm Hg during these periods. The heart rates and the carbon dioxide readings rapidly returned to normal levels when exercise ceased.

(Apollo 11)

**Readaptation**

— The Lunar Module Pilot had a small amount of clear fluid with air bubbles in the middle ear cavity, but this symptom disappeared after 24 hours of decongestant therapy.

(Apollo 12)

— Both the Commander and the Command Module Pilot had a small amount of clear, bubbly fluid in the left middle ear cavity and slight reddening of the eardrums. These findings disappeared in 24 hours without treatment. The Lunar Module Pilot had moderate eyelid irritation in addition to slight redness of the eardrums.

(Apollo 14)

— The Commander had some sinus congestion which responded promptly to medication, and also a slight reddening and retraction of the right eardrum.

(Apollo 16)

— All crewmen were within normal limits during preflight tests. However, three days after recovery, two of the crewmen
exhibited a significant decrement when deprived of all visual sensory cues. Performance was similar to the preflight baseline when these crewmen were retested one week after landing. (Apollo 16)

SUMMARY OF THE LITERATURE

Several summaries of physiological changes have been published in the literature. Some of these are listed here.

Overview

Table 1: Physiological Changes Associated with Short-Term and Long-Term Space Flight. *Space Physiology and Medicine*, pp. 128-134.


Figure 6: Proposed Process of Adaptation to Weightlessness. [Pre-Skylab hypothesis] *Foundations of Space Biology and Medicine*, Volume II, Book 1., p. 322.

Cardiovascular

Figure 5: Suggested Cardiovascular Response to Weightlessness. *Space Physiology and Medicine*, p. 168.

Table 40-VI: Skylab Cardiovascular Summary. *Biomedical Results from Skylab*, p. 412.

Table 1: Percent Change After Designated Condition from Preflight Supine Resting Reference Values. *Space Physiology and Medicine*, p. 179.

Orthostatic Tolerance

A decrease in orthostatic stability was noted following the first manned spaceflights and has been confirmed repeatedly. This orthostatic intolerance is believed to be a result of dehydration changes and total circulating blood volume.

Table 6: Apollo Group Mean Values for Preflight Summary and Postflight Orthostatic Evaluations. *Biomedical Results from Apollo*, pp. 245, 246.

Cardiac Size

Standard chest x-rays, taken before and after spaceflight, show that the size of the heart decreases when man is exposed to weightlessness.

“Combining the data from 4 Mercury, 18 Gemini, 30 Apollo and 9 Skylab crewmen, postflight decrements in CT [cardio-thoracic] ratio averaged -.018.” *Space Physiology and Medicine*, p. 176.

Table 10: Apollo Crewmen Cardiordimensional Ratios During Orthostatic Evaluations (Ratios Based on X-Radiographs). *Biomedical Results of Apollo*, p. 253.

Muscle Mass

When the astronauts are exposed to zero-g for moderate periods their body begins an adaptation process. Part of this process is a loss of muscle mass which possibly includes the cardiac muscle. *Foundations of Space Biology and Medicine*, p. 321.

“In general, these analyses [biosterometric measurements] of body form revealed striking losses of volume in the abdomen, buttocks, and calves, and less striking losses in the thighs. The authors concluded that the losses observed in the abdomen and the buttocks are probably due mainly to loss of fat, and those observed in the legs, particularly the calves, are due partly to fluid losses and partly to the reduction in muscle mass associated with spaceflight.” *Space Physiology and Medicine*, p. 193.

“...muscle tissue is most affected by weightlessness early in flight...” *Space Physiology and Medicine*, p. 190.

“Investigation of skeletal-muscle function in both leg and arm flexor muscles, using electromyographic analyses, showed that muscle dysfunction characteristics found after 59 days of exposure to weightlessness in the Skylab 3 mission were also evident after only nine days of exposure (LaFever et al., 1977).” *Space Physiology and Medicine*, p. 15.

Limb Girth

As a result of exposure to a weightless environment, astronauts experience a decrease in the circumference of the calves. Muscle tone and strength also diminish during long exposures to zero-gravity. *Foundations of Space Biology and Medicine*, p. 318.

“Astronauts have typically demonstrated in-flight decrements in calf girth of up to 30%.” *Space Physiology and Medicine*, p. 166.
Skeletal.

The skeleton begins an adaptation process to the weightless environment. The general result is a loss of minerals, calcium and potassium, which contributes to overall musculoskeletal decay. Foundations of Space Biology and Medicine, pp. 318-325.

Table 13: Gemini 4, 5, and 7 and Apollo 7 and 8 Bone Mineral Changes During Flight. Biomedical Results from Apollo, p. 318.

“Among the most striking biomedical findings from space missions are the continuous progressive loss of calcium and the skeletal changes observed postflight.” Space Physiology and Medicine, p. 204.

Loss of eyes-closed balance

Visual cues seem to compensate for changes in postural balance in astronauts who have experienced zero-g. When postural balance was tested with eyes closed, appreciable changes were noted. Biomedical Results of Apollo, p. 338.

Blood, Fluid and Electrolytes

Many studies have been performed on the astronaut group to determine the biochemical changes in crew members exposed to weightlessness. There appears to be a complex series of interrelated events beginning with entrance into zero-g and the concurrent redistribution of body fluids.

Table 1: Hematological Changes Found in U.S. and Soviet Manned Missions. Space Physiology and Medicine, p. 212.

Table 4: Summary of Apollo Hematological Results. Space Physiology and Medicine, p. 201.

Table 40-XII: Skylab Hematology, Immunology and Cytology Summary. Biomedical Results from Skylab, p. 416.

Table 4: Summary of Apollo Serum Electrolyte Results. Biomedical Results from Apollo, p. 166.

Table 40-XI: Fluid/Electrolyte Area. Biomedical Results from Skylab, p. 416.

Table 23-V: Skylab Summary, Plasma Biochemical Results. Biomedical Results from Skylab, p. 209.

Table 40-IX: Skylab Mineral/Caloric, Fluid/Electrolyte Summary. Biomedical Results from Skylab, p. 413.

Table 23-V: Skylab Summary, Plasma Biochemical Results. Biomedical Results from Skylab, p. 209.

Table 3: Summary of Apollo Serum Biochemistry Results. Biomedical Results from Apollo, p. 190.