

SPACE PSYCHOLOGY AND PSYCHIATRY

2nd Edition

*1st Edition:
Winner of 2004 International Academy of
Astronautics Life Sciences Book Award*

N. Kanas and D. Manzey



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SPACE PSYCHOLOGY AND PSYCHIATRY

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Space Psychology and Psychiatry

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*Cover Photo of Earth from Space: View of Africa and the Indian Ocean taken in Dec. 1972,
by Apollo 17, the last of the Apollo missions to explore the Moon. Photo Courtesy of NASA.*

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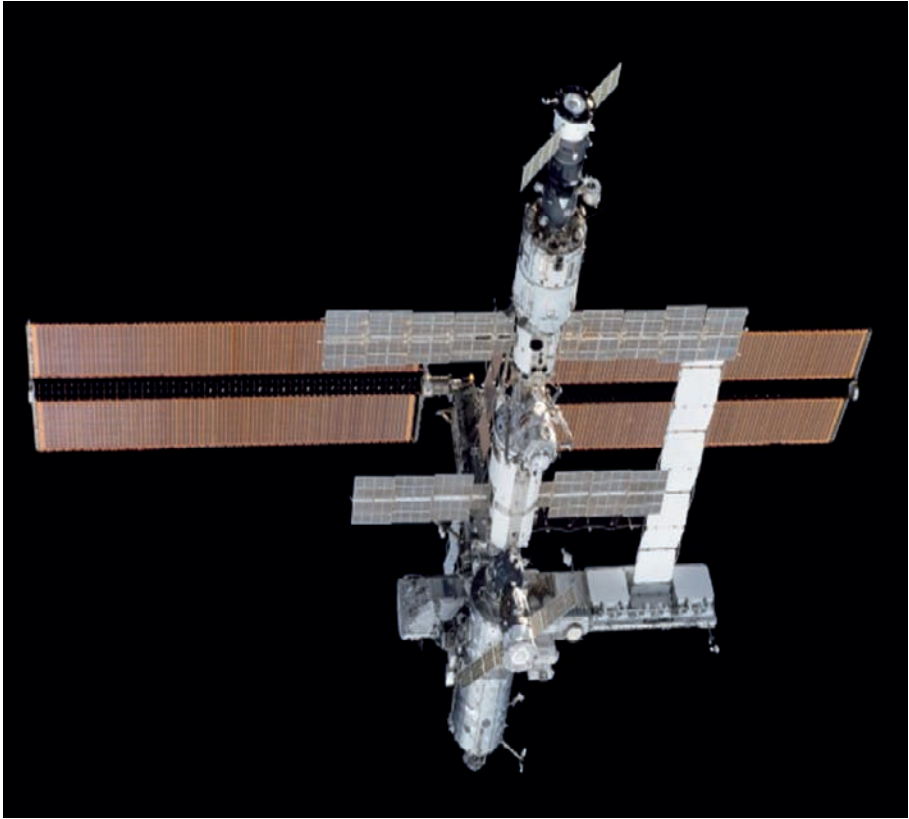
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The International Space Station is the most complex construction project ever attempted. It will ensure humankind's permanent presence in space for decades to come. “Backdropped by the blackness of space, this full view of the International Space Station (ISS) was photographed by a crewmember on board the Space Shuttle Atlantis following the undocking of the two spacecraft. Atlantis pulled away from the complex at 8:13 a.m. (CDT) on October 16, 2002.” (Photo and quoted description courtesy of NASA)

Preface (1st Edition)

With the construction of the International Space Station, and with plans being considered for manned missions to Mars and beyond, it is time to take an objective look at what is known about the psychological and psychiatric impact of long-duration space missions. During previous space flights, there have been occasions when the psychological stresses of living and working in space have created difficulties that have negatively affected the performance of crewmembers and their ability to relate with personnel in mission control. It is important to examine these psychosocial issues scientifically so that countermeasures can be developed for dealing with them promptly and effectively.

Up until now, books that have addressed psychological and psychiatric factors related to space travel have referred to anecdotal reports or studies from space analog environments on Earth, such as the Antarctic, submarines, and confined chambers. However, recent evidence suggests that none of these environments gives a complete picture of the psychosocial issues relevant to human space flight. For this reason, our book emphasizes psychological and interpersonal findings from studies conducted during actual space missions. Both of us have directed such studies in the past 10 years, but our findings have been restricted to scientific meeting proceedings and journal publications. In this book, our research results will be presented in a non-technical format that will be understandable to a wider non-professional audience. These findings will be integrated with the work of others around major topic areas in the field of space psychology and psychiatry, including individual adaptation and performance, human interactions, psychiatric issues, selection and training, and monitoring and support. Our hope is that this book will be used as a textbook for students as well as a reference for psychologically-oriented professionals and the general public who wish to know more about how people function in the exotic environment of space.

People who may especially find this book to be of value include: psychology and social science students and professors in universities; medical students and residents in psychiatry and aerospace medicine; human factors workers in space and aviation professions; individuals involved with Earth-bound isolated and confined environments, such as the Antarctic and submarines; and members of the general public who are interested in the human side of long-duration space missions. Since this book is co-authored by an American and a German who are involved in both academic and space-related activities, we hope that it will have wide readership in both countries, as well as in places that have active involvement with the International Space Station (e.g., member countries of the European Space Agency [ESA], Russia, Japan, the United States, and Canada).

In terms of the organization of this book, Chapter 1 will introduce the reader to the issues and basic assumptions that underlie the remaining chapters. Chapter 2 will consider important issues of adaptation that a person needs to make during space missions. Chapter 3 will deal with human performance and how it is affected

by the space environment. Chapter 4 will consider psychosocial issues at the group level in terms of crewmembers and their relationship with each other and with people on the ground. Chapter 5 will deal with psychiatric problems that can occur during long-duration space missions. Chapter 6 will consider countermeasures for coping with psychological and psychiatric issues before, during, and after the mission. Finally, Chapter 7 will deal with the challenges of space missions beyond Earth orbit.

As mentioned above, a special feature of this book is its emphasis on research actually conducted in the space environment that relates to psychological and psychiatric issues. Studies that have been done in this exotic setting will be placed in special sections labeled: "Empirical findings from space...". These sections are highlighted with underlines in the Table of Contents for those who wish to focus on such studies. Much of this information has never before been published in book form, and it represents the cutting edge of what has been done in space in the field of space psychology and psychiatry.

Photographs of astronauts and cosmonauts will be used to illustrate key ideas. All of these will come from missions to the Mir or International Space Station. It should be noted that individuals shown in the photographs may or may not have participated in our studies, and activities they are undertaking may or may not have been related to our areas of research. All space photographs have been provided courtesy of NASA. In addition, two chapters have been introduced by photographs of prints from antiquarian star atlases. Besides being beautiful works of art, these pieces illustrate an important theme related to the following chapter. These two contributions are from the Nick and Carolynn Kanas collection of antiquarian celestial books and prints.

This book could not have been written without the help and support of a number of people. Our Senior Publishing Editor at Kluwer, Dr. Harry Blom, and his Senior Assistant, Ms. Sonja Japenga, have been helpful in guiding us through the publishing process. Ms. Leena Tomi of the Canadian Space Agency and Mr. Oliver Angerer of the European Space Agency have provided helpful comments to a draft of this book, as did others mentioned below.

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Preface (2nd Edition)

It has been 5 years since the appearance of the 1st Edition of *Space Psychology and Psychiatry*. The book reached a fairly broad audience, including astronauts and cosmonauts, space agency officials, members of the scientific community, undergraduate and graduate students, and the general public. Much has happened in the field since then, with many advances in psychological space research. As a result, it seemed timely to cover these advances in a new edition of the book.

The 2nd Edition of *Space Psychology and Psychiatry* contains 45 new pages of text, a 23% increase over the 1st Edition. It also picked up a new publisher, as Kluwer Academic Publishers merged with Springer, a happy event for us and for the people involved with Kluwer who found themselves members of the Springer family. The basic structure and chapter orientations have not changed, but the text of every chapter has been reviewed and updated to reflect new realities. This is especially true of Chapters 2 and 6, which have been greatly revised and expanded. Several sections have been added describing new research with astronauts and cosmonauts, including operational challenges affecting junior and senior mission control personnel; human interactions involving crewmembers and mission controllers working with the International Space Station (comparing the findings with those from the Shuttle/Mir Program, reported in the 1st Edition); issues dealing with positive psychological aspects of space missions; surveys reporting cultural challenges involving international crews and cosmonaut views of an expedition to Mars; and results related to physiological, sleep/circadian, and performance issues in space. In addition, there is a new section on space tourism, which is a growing and exciting new industry. We have tried to preserve the spirit and structure of the previous edition, while at the same time adding new material to bring the content up to date.

We hope that these changes will enrich the experience of readers of the 1st Edition and encourage new people to read the book. We have enjoyed the process of writing the 2nd Edition and of being a part of the human exploration of space.

Nick Kanas, M.D.
Dietrich Manzey, Ph.D.
January, 2008



Real danger exists in space. Note the damage to the Mir space station and its solar panels (on the right) following its collision with a Progress resupply spacecraft during docking on June 25, 1997. “Russia's Mir space station is backdropped over the blue and white planet Earth in this medium range photograph recorded during the final fly-around of the members of the fleet of NASA's shuttles...” (Photo and quoted description courtesy of NASA)

Chapter 1

Introduction

1.1. Humans in space

With the building of the International Space Station (ISS), humans are committing themselves to a continuing presence in space. This enterprise follows earlier space stations under the Salyut, Skylab, and Mir programs. But the ISS represents a change. With its several modules contributed to by a number of countries and space agencies, crewmembers on-board will be multinational in composition. Furthermore, missions will be several months long, with the opportunity to conduct scientific and other important activities that will better the human condition. Finally, the ISS will serve as a training and embarkation point for longer term, expedition type missions to the Moon, the planets, and beyond. In order to tolerate such activities, it is important for people who are involved to understand the stresses that are produced by living and working in space habitats. Especially important during complex, long-duration space missions are psychological and psychiatric issues that may affect the crewmembers. These issues can mean the difference between successful missions that accomplish mission goals and lead to a productive experience for the people involved, and unsuccessful missions characterized by poor morale, psychiatric problems, and tragic consequences for the crewmembers, their mission control support staff, and family and friends back home on Earth.

1.2. Stressors and stress in space

In considering such issues, it is useful to examine two concepts as they apply to space missions: stressor and stress. A *stressor* is a stimulus or feature of the environment that affects someone, usually in a negative, arousing manner. In space, there are four kinds of stressors: physical, habitability, psychological, and interpersonal. Examples of each are given in Table 1.1. Some of these stressors are related to others. For example, microgravity and radiation dictate certain habitability constraints that produce vibration and increased ambient noise. Similarly, habitability features create physical environments that influence one's experience of confinement and danger and influence the impact of crew size.

Many physical and habitability stressors are engineering "givens" that go beyond the scope of this book. Others will be dealt with in Chapter 6. Psychological stressors on individual and interpersonal levels directly relate to the subject matter of this book, since they can be influenced using psychological and interpersonal interventions at several time points: during pre-launch selection and training, during in-flight monitoring and support, and during post-mission readaptation to Earth. For

Table 1.1. Examples of Stressors Encountered During Human Space Missions.

Physical	Habitability	Psychological	Interpersonal
Acceleration	Vibration	Isolation	Gender issues
Microgravity	Ambient noise	Confinement	Cultural effects
Ionizing radiation	Temperature	Danger	Personality conflicts
Meteoroid impacts	Lighting	Monotony	Crew size
Light/dark cycles	Air quality	Workload	Leadership issues

example, monotony and workload stressors can be minimized by carefully planning work-rest schedules pre-launch, and interpersonal stressors related to gender and cultural differences can be minimized by careful crewmember selection and training.

A *stress* pertains to the reaction produced in someone by one or more stressors. In space, there are four kinds of stress that affect human beings: physiological, performance, interpersonal, and psychiatric. Examples are given in Table 1.2.

Physiological, performance, and interpersonal stresses tend to be normalizing attempts of crewmembers to adapt to the conditions of off-Earth environments. In contrast, psychiatric stresses tend to be abnormal responses to these conditions, although there are intermediate forms in some cases. For example, some long-duration space travelers have experienced feelings of depression or mild asthenic reactions that can be resolved with increased audio-visual contact with family and friends on Earth and never evolve into full-blown psychiatric syndromes. It is important to understand and deal with the impact of these stresses since they can adversely affect the health and well-being of the crewmembers, interfere with their relationships with each other and with people in mission control, create dangerous

Table 1.2. Examples of Stresses Encountered During Human Space Missions.

Physiological	Performance	Interpersonal	Psychiatric
Space sickness	Disorientation	Tension	Adjustment disorders
Vestibular problems	Visual illusions	Withdrawal/territorial behavior	Somatoform disorders
Sleep disturbances	Attention deficits	Lack of privacy	Depression
Bodily fluid shifts	Error proneness	Scapegoating	Suicidal thoughts
Bone loss and hypercalcemia	Psychomotor problems	Affect displacement	Asthenia

situations, and prevent the accomplishment of mission goals. Issues related to these four kinds of stress will be dealt with in great detail in Chapters 2–5.

1.3. Sources of information

In considering psychological and psychiatric issues in space, there are three sources of information that inform us as to the key issues: anecdotal reports, studies from space analogs and simulations conducted on Earth, and research performed during actual space missions.

1.3.1. Anecdotal reports

There are several types of anecdotal information, and these are listed in Table 1.3 along with references.

Being anecdotal, the above sources are subjective and sometimes are dramatically presented. However, they often reflect the feelings and thoughts of space travelers and give a vivid picture of what it is like to live and work in space. Consequently, anecdotal reports are good places to start in developing ideas and hypotheses for more formal studies.

1.3.2. Space analog and simulation studies

1.3.2.1. Settings

A second source of information consists of analog and simulation studies conducted on Earth. These settings have many features in common with those that are characteristic of space. Analog studies are more naturalistic, where variables are not strongly controlled, whereas in simulation studies one tries to alter the environment to make it as relevant as possible to the issues in space that are being studied. Examples of different kinds of analog and simulation settings are listed in Table 1.4.

Table 1.3. Types of Anecdotal Information of Relevance to Psychological and Psychiatric Issues in Space.

Space agency documents [Belew, 1977; Connors et al., 1985; Kanas and Feddersen, 1971; Morgan, 2001]
Surveys of people who have flown in space [Kelly and Kanas, 1992, 1993, 1994; Santy et al., 1993]
Publications of diaries from space travelers [Chaikin, 1985; Lebedev, 1988]
Newspaper and magazine articles [Associated Press, 1995; Benson, 1996; Carpenter, 1997]
Books written by space travelers [Aldrin, 1973; Linenger, 2000; Pogue, 1985]
Books written by people who have never traveled into space [Burrough, 1989; Cooper, 1976; Freeman, 2000; Harland, 1997; Harris, 1996; Harrison, 2001; Oberg, 1981; Santy, 1994; Stuster, 1996]

Table 1.4. Examples of Analog and Simulation Settings on Earth of Relevance to Human Space Missions.

Arctic and Antarctic expeditions
Mountain climbing expeditions
Submarines and ships at sea
Remote sea-based oil drilling platforms
Underwater simulators (e.g., marine science habitats)
Land-based simulators (e.g., hyperbaric chambers)
Aircraft cockpit simulators
Hypodynamia (bedrest) study settings

1.3.2.2. Relevance to actual space missions

There have been over 100 space-related studies conducted in Earth-based environments, and these have been well documented in published reviews [Baranov, 2001; Connors et al., 1985; Harrison et al., 1991; Kanas, 1985, 1987, 1990, 1991; Kanas and Feddersen, 1971; Lugg, 2005; Palinkas et al., 2000; Sandal, 2000; Sandal et al., 1996; Santy, 1983; Stuster, 1996, 2005; Vaernes, 1993]. However, no analog or simulation environment can completely reproduce the environment of space. For example, the unique cluster of features of microgravity, lack of atmosphere outside the habitat, true danger, and inability to conduct a rapid rescue cannot be reproduced on Earth.

Sells [1966] evaluated 11 social systems that he felt were pertinent as analogs for long-duration space missions. After first developing 56 characteristics of such missions, he rated the social systems on each characteristic and concluded that submarines and polar exploration missions were the most similar to actual space missions. However, his study did not evaluate more recent land-based analogs or non-submarine underwater environments. Nevertheless, his study reminds us that space analogs can vary in terms of fidelity to actual space missions.

Suedfeld [1991] has argued that it is not the physical environment per se that is important but the psychological meaning that a space analog or simulation environment holds for the individuals involved. This idea has been supported by a review made by Sandal et al. [1996], where differences were found between studies conducted in land-based hyperbaric chambers, where there was no real danger and where someone could easily be evacuated in a medical emergency, and in polar environments, where neither of these features existed. People working in the chambers experienced low overall anxiety and steadily decreasing levels of anxiety over time, whereas people on polar expeditions showed higher levels of anxiety, particularly during the first and third quarters of the mission. The limitations of analog and simulation environments are especially apparent where psychological and psychiatric issues are being studied, especially with reference to long-duration multi-cultural space missions. These comments remind us that the ideal way to

study what happens to people in space is to study people in space! With these caveats in mind, however, there still is reason to conduct space-related analog and simulation studies on Earth. Space missions are expensive, high-danger, complicated enterprises involving a handful of people. Some research areas are early in their development, and piloting them on the ground is a more economical and safer way to try out new ideas. Also, more variables can be controlled in simulators than in space, where mission-related operational considerations usually are given precedence over research. Many studies depend on large sample sizes to statistically test effects, and these can be achieved more easily in ground-based settings. Kanas [1997] has discussed ways in which analog and simulation environments could contribute to the study of a number of psychosocial issues, such as social and cultural factors, career motivation, monotony and reduced activity, leadership and authority, and the relationship between crewmembers and ground personnel.

1.3.3. Research in space

The final source of information related to important psychological and psychiatric issues in space consists of studies conducted during actual space missions. Whereas a number of such studies have been done in other human-related areas (such as the effects of microgravity on cardiovascular status and bone loss), little has been done until recently in the psychological and psychiatric areas. In part, this has been due to the short-term nature of many space missions, where psychosocial factors are less problematic than in longer-term missions. However, with the construction of the International Space Station, there has been renewed interest in studying psychological and psychiatric issues as space agencies focus on complicated multi-cultural missions involving heterogeneous crews whose members must get along for months at a time. In addition, plans for expedition-type missions to Mars or beyond extend the flight duration to years, where support from Earth will become less possible as the spacecraft travels farther away. In a sense, the ISS provides an excellent way to study the psychological and psychiatric impact of living and working in space. Some of the advantages of the ISS for such research are given in Table 1.5.

Table 1.5. Advantages of the ISS for Psychological and Psychiatric Research.

It has state-of-the-art research facilities.
Crewmembers are on-board for months at a time, allowing for studies of long-duration effects.
Space Shuttle and Soyuz missions to the ISS will occur, allowing for studies of short-duration effects.
Since the ISS orbits close to Earth, research supplies can be sent up or down easily.
ISS crews interact with mission control personnel, allowing for studies of the relationship between these groups.
The ISS can serve as a platform to test issues and countermeasures being considered for expedition-type missions, such as a trip to Mars.

1.4. Basic assumptions

There are a number of basic assumptions related to future space missions that underlie the areas dealt with in this book. These assumptions will be discussed in more detail in the different chapters of the book, but it is worthwhile to mention them now as an orientation to the rest of this book.

1.4.1. Human performance

The first assumption is that the maintenance of efficient performance in astronauts during their stay in space represents an important psychological challenge of long-duration space missions. During the early days of space flight, the main focus was on demonstrating that humans could simply survive in this exotic environment. Consequently, effort was spent on investigating the effects of microgravity on bodily functions. Today, space has become an important work place for humans, where astronauts accomplish complex scientific and operational tasks that put high demands on cognitive functions and psychomotor skills [Morphew et al., 2001]. Thus, attention increasingly is being paid to factors that affect human performance in space, and this will be even more important in the future when astronaut tasks and work devices will become more complex.

Furthermore, degradations of human performance in space can become a serious safety issue during long-duration space missions. This has been emphasized by the investigations of a severe accident that occurred on the former Mir space station, when one of the modules was hit and damaged during the manual docking of an upcoming Progress spacecraft. Analyses of this accident revealed that issues of skill maintenance and performance decrements due to fatigue were among the factors contributing to this accident [Ellis, 2000].

In order to better assess the risks arising from possible impairments of performance during future space missions, knowledge is needed about the impact of the extreme working and living conditions in space on human performance functions. This not only includes knowledge about possible effects of microgravity on cognitive and psychomotor processes, but it also includes knowledge about the performance impact of the other stressors present during space missions, such as workload, monotony, isolation, and confinement.

1.4.2. Crew heterogeneity

The second assumption is that future human space missions will consist of heterogeneous crews made up of people of different genders, career motivation and experiences, and personality. In the early days of space flight, the crews were more homogeneous: white males from one country who had similar personalities and were trained to pilot the spacecraft [Wolfe, 1979]. But these days are gone, and the complexity and politics of future missions will result in more diversity in crew make-up.

Heterogeneity may be a bit of a two-edged sword. In the short run, it may complicate crewmember interactions as people take time to adjust to one another. This may lead to interpersonal stress that may adversely affect performance and the accomplishment of mission goals. However, if the crewmembers are able to accept

their differences over time, heterogeneity may enrich the interpersonal environment, and this may help counter boredom and monotony. Much depends on how diversity is viewed by the crew: as a negative irritant or as a positive feature that adds spice to the mission.

1.4.3. Cultural differences

The third assumption is that future crews will be made up of people from different cultural backgrounds. Culture can have three aspects, as Helmreich [2000] has discussed with reference to the aviation and medical communities as analogs for space missions: national, organizational, and professional. With reference to the first aspect, space crewmembers will have different ethnic backgrounds, nationalities, and native languages. This may lead to differences in behavior, some obvious, others more subtle (e.g., using body gestures to emphasize a point). Cultural differences may be misconstrued as a personal affront, disinterest, or simply as an annoyance, and this may lead to interpersonal or group tension.

The second aspect of culture pertains to features of the employment organization of which the individual is a member. For example, it has been written that each of the major space agencies involved with the ISS possesses different “macrocultures” that affect the way they do business [Committee on Space Biology and Medicine, 1998]. For example, NASA tends to extensively train their astronauts to deal with a variety of possible contingencies in preparation for their missions, whereas the Russian Space Agency tends to focus on the major issues and to rely on the use of experts to resolve problems that come up. In addition, astronauts get a fixed salary for their duties, whereas cosmonauts might receive a bonus or a reduction in pay based on their performance in space. Such differences in organizational philosophy can affect how crewmembers from different space agencies behave on the job and interact with one another.

The final kind of cultural effect is related to one’s profession, discipline, or career motivation. People on space missions may have quite different backgrounds and roles. For example, some space travelers come from piloting or engineering backgrounds, and their mission tasks are related to flying and maintaining the space vehicle. Others come from scientific backgrounds, and their tasks are related to conducting experiments and performing non-operational duties. People from these two groups may have developed different professional norms, values, and traditions prior to the mission, and it is important that these be understood and amalgamated so that the crew operates cohesively as a unit to accomplish mission goals. This has not always been the case, as will be discussed further in Chapter 4.

1.4.4. Time effects

The fourth assumption is that time is an important factor in studying psychological and psychiatric issues in space. One aspect of time pertains to mission duration. For example, psychological and psychiatric issues may not be problematic during short-duration space missions, such as flights involving the Space Shuttle that typically last a week or two, since most people can tolerate the stressors of space in this time frame. However, problems may occur during long-duration missions that last 6 weeks or longer, not only because human adaptive abilities become strained, but also

because additional stressors come into being (e.g., monotony that occurs once the novelty of being in space has worn off, personality conflicts due to the magnification of minor interpersonal irritants).

In addition, there is evidence that groups of people living and working in isolated and confined environments go through stages that are time-dependent. Some people believe that psychosocial changes occur after the halfway point of a mission, especially the third quarter [Bechtel and Berning, 1991; Gushin et al., 1993, 1997; Palinkas et al., 2000; Sandal, 2000; Sandal et al., 1995; Stuster et al., 2000], when people realize that they still have half of the mission to go before they can return home. Others conceive of changes occurring in terms of three sequential phases of the mission: initial anxiety, mid-mission boredom, and terminal euphoria [Chaikin, 1985; Grigoriev et al., 1987; Rohrer, 1961]. However, not all space analog studies have found such stages [Kanas et al., 1996; Steel and Suedfeld, 1991; Wood et al., 1999, 2005], and as we shall see in Chapters 2 and 4, empirical findings from space also question the existence of group stages on-orbit.

1.4.5. Crew-ground relationship

The fifth assumption is that the relationship between crewmembers and people on the ground is very important for crew performance and morale. During on-orbit missions such as those involving the ISS, this relationship is easy to see. Crewmembers depend upon personnel in mission control for scheduling, support, information, and trouble-shooting. The flow of information and the interpersonal interactions between these two groups are important issues for mission success. In addition, the ability of the crewmembers to interact privately and frequently with family and friends can enhance their morale and help them maintain critical contact with loved ones on Earth. Finally, many astronauts and cosmonauts have a great interest in current events taking place on their home planet, and they enjoy receiving news from the ground on a regular basis [Kelly and Kanas, 1994].

On expedition-type missions, such as a trip to Mars, the distances involved will mean that audio-visual communications will take minutes or even hours. This means that crewmembers and ground personnel will have to develop strategies that factor in these delays. It also means that crewmembers will be much more autonomous in their actions, since advice concerning issues and problems will not be in real time, and resupplies of people and material will not be possible. Medical and psychiatric emergencies will have to be taken care of on-board, and crewmembers will need to be trained for all kinds of trouble-shooting activities. Finally, no human being has ever had the experience of seeing his or her home planet as a distant “star” in the sky. The psychological impact of the realization that all you hold near and dear to you is distant and insignificant is unknown, and crewmembers need to be prepared for this experience.

1.4.6. Psychological countermeasures

The final assumption is that the adverse effects of stressors that astronauts are exposed to during long-duration space missions can be mitigated or even prevented by appropriate psychological countermeasures. One set of countermeasures focuses on an accommodation of the working and living conditions during space missions to

the psychological capabilities and needs of humans. These include different aspects of habitability and ergonomics, as well as organizational factors related to work design and appropriate work-rest scheduling. A second set of countermeasures focuses on adapting individuals to the psychological vicissitudes of space missions. This can be achieved by selecting astronauts whose personalities are most suitable to meet the demands of space missions; by composing space crews of individuals who are compatible with one another; by giving relevant psychological and interpersonal pre-flight training that prepares astronauts for their life and work in space; and by providing psychological support to individual astronauts and entire crews while they are on-orbit [Manzey et al., 1995]. Such actions can contribute to the success and safety of human space missions. This long has been recognized in the Russian (formerly Soviet) space program, where psychological countermeasures have been an important element since the beginning of long-duration space missions [Garshnek, 1989; Kanas, 1991]. Similar countermeasures also are being used in current ISS operations, and they will be an indispensable factor during future expeditionary space missions that go beyond Earth's orbit.

1.5. Summary

- There are four kinds of stressors encountered during human space missions: physical, habitability, psychological, and interpersonal.
- There are four kinds of stress encountered during human space missions: physiological, performance, interpersonal, and psychiatric.
- There are three sources of information that educate us about important psychological and psychiatric issues affecting human space missions: anecdotal reports, space analog and simulation studies on Earth, and research conducted during actual missions.
- Although anecdotal reports and analog and simulation studies offer several advantages, the ideal way to study what happens to people in space is to study people in space!
- The International Space Station is an excellent facility for conducting human research related to psychological and psychiatric issues in space.
- Maintaining human performance in space will be a challenge, particularly during long-term missions.
- Psychological and psychiatric issues become most relevant during space missions that are long-duration and consist of heterogeneous crews composed of people with different cultural backgrounds.
- The relationship between crewmembers and people on the ground is very important for maintaining crew performance and morale and for enhancing the success of the mission.
- Countermeasures need to be developed and applied that will help astronauts and cosmonauts deal with the stressors that are encountered during human space missions.

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Accomplishing the tasks of a space mission requires the use of complicated equipment. Adjusting to microgravity and learning to adapt to the space environment is essential for such actions to be done successfully. “Astronaut Philippe Perrin, STS-111 mission specialist, floats near the Microgravity Science Glovebox (MSG) in the Destiny laboratory on the International Space Station (ISS). Perrin represents CNES, the French Space Agency.” (Photo and quoted description courtesy of NASA)

Chapter 2

Basic Issues of Human Adaptation to Space Flight

2.1. Space as an extreme environment

Any environment to which humans are not naturally suited, and which demands complex processes of physiological and psychological adaptation, can be considered as an “extreme” environment. Earth-bound examples of such environments include the polar region, high mountain areas, or underwater habitats. Since the first space flight of Yuri Gagarin on April 12, 1961, the Earth’s orbit and outer space also have become extreme living and working environments for humans. Two sets of factors contribute to the extremity of space. The first set relates to the unique physical characteristics of space flight [Nicogossian and Robbins, 1994]. The most striking of these characteristics is the almost complete lack of gravitational force impacting on the human body. Technically speaking, this “microgravity” results from a counterbalancing of the gravitational force factor by the centrifugal force imparted to an orbiting spacecraft. The subjective feeling is more appropriately described as “weightlessness” because it feels like being weightless to stay and move in microgravity. As will be shown, this fundamental alteration in space as compared to Earth has a dramatic impact on almost all physiological systems and also can affect specific cognitive and psychomotor functions. A second physical characteristic of space flight that makes it different from life on Earth is the altered natural dark-light cycle. In an orbiting spacecraft traveling at about 28,000 km/h around our planet, the time between sunrises is reduced to about 90 min. This marks an important difference to the 24-h day-night cycle that we are accustomed to on Earth and can conflict with the circadian system of humans. Finally, a third physical feature which makes space an extreme environment for humans concerns the specifics of space radiation, particularly ionizing radiation (i.e., radiation resulting from galactic cosmic rays, trapped belt radiation, and solar particle events which directly can destroy, transform, or mutate living cells). Without the usual shield provided by the atmosphere of the Earth, this radiation may induce acute and delayed health effects in the human body [Nicogossian and Robbins, 1994].

From a physiological and psychological point of view, microgravity and the altered dark-light cycle in space are the most interesting physical characteristics of space flight because they call for complex adaptive processes. This is related to the fact that these particular features conflict directly with the two most important natural constants that have shaped the human organism during its evolution on Earth: gravity and the natural alteration of day and night resulting from the mass and the self-rotation of our planet, respectively.

The second set of factors contributing to space as an extreme environment for humans is related to the numerous habitability, psychological and interpersonal

stressors present during space flight. These result from the harsh living conditions in a space habitat, the restricted range of environmental cues, the specific workload imposed on astronauts, and the psychosocial situation that is often characterized by a lack of privacy, enforced social contacts with other crew members, and separation from the usual social network of family and friends. Most of these factors are not specific for space flight conditions but are universal for confined and isolated environments [Suedfeld and Steel, 2000]. Yet they represent important aspects of the extreme living and working conditions in space, particularly during long-duration space flight. Similar to the unique physical conditions of the space environment, they represent stressors which astronauts have to adapt to in order to maintain a high level of individual and crew efficiency.

The psychological effects of the extreme conditions of space flight on individual well-being and performance, and on crew interactions represent the major focus of this book. As a starting point, this chapter addresses some of the more basic issues related to human adaptation to space flight. In particular, it will provide information about (1) selected issues of physiological adaptation to space, (2) issues of sleep and circadian rhythms during space flight, and (3) general aspects of human adaptation to confinement and isolation during long-duration space missions.

2.2. Issues of physiological adaptation

The main challenge for physiological systems in space is the lack of gravitational force. During evolution on Earth, all physiological systems have been optimized for life in gravity. This particularly is obvious for the vestibular system but also is true for the cardiovascular system, the sensorimotor system (which is responsible for movement coordination and control), and the system of bones and muscles. In fact, there is almost no physiological system in humans that has not been shaped by the specific gravity conditions on Earth. As a consequence, lacking this force in space induces several physiological changes that call for complex adaptive processes in the human organism [Clément, 2005; Grigoriev and Egorov, 1992; Nicogossian et al., 1994].

In this section, we will review the impact of the environmental conditions characteristic of space missions on three different physiological systems: cardiovascular, vestibular/sensory-motor, and musculo-skeletal. The effects on the first two of these systems impair the individual well-being and fitness of astronauts during short-duration space flight, or the first few days and even weeks of a long-duration space mission. Both represent immediate responses that develop within minutes or hours after exposure to microgravity. In contrast, the effects on the musculo-skeletal system develop more slowly, and its strength directly depends on the duration of the stay in space. All of these physiological responses eventually lead to a physiological de-conditioning in space which might interfere with a healthy return to Earth if no countermeasures are applied. In the present context, a review of microgravity-related effects on human physiology certainly cannot be complete and can only provide a very basic understanding of what travel into space means from a physiological point of view. More comprehensive reviews of the physiological responses to microgravity, including considerations of effects on other systems and functions (e.g. endocrine system, metabolic functions), can be

found in the classical book edited by Nicogossian et al. [1994], as well more recent books by Buckey [2006] and Clément [2005].

2.2.1. Cardiovascular system

The main elements of the cardiovascular system are the heart and blood vessels (e.g., arteries, veins, and capillaries). Its main function is to support continuous blood circulation in order to deliver oxygen and nutrients to all parts of the body and to remove carbon dioxide and other waste products of cell metabolism. On Earth, this system is adapted to the constraints provided by gravity. In humans, a hydrostatic pressure gradient develops along the vertical body axis, with the arterial blood pressure increasing from head (about 70 mmHg) to feet (about 200 mmHg). Both the heart and blood vessels work against this effect of gravity. This not only requires a certain level of “pump activity” of the heart in order to transport enough blood upward to the brain against gravity, but it also requires the development of sophisticated mechanisms in the lower body veins to support an upward return of blood to the heart and prevent any “back-flow” in the direction of the gravitational force. Moreover, the system is able to adjust quickly to changes of the hydrostatic pressure gradient that are induced by changes of body orientation in relation to gravity. The latter occurs, for example, if one moves from a supine to an upright position and vice-versa. It can subjectively be perceived by transient feelings of dizziness if one moves too quickly from a lying to a standing position. This dizziness is related to a short-term reduction in blood pressure in the head and upper part of the body, which gets rapidly corrected by what is called the baroreceptor reflex. This reflex represents one of the most important control mechanisms in the cardiovascular system. It involves a reflexive regulation of heart activity and vascular peripheral resistance based on information from arterial pressure receptors (“baroreceptors”), which keeps the arterial blood pressure on a more or less constant level.

After entering the space environment, the gravitational force suddenly decreases. The cardiovascular mechanisms that have been established on Earth to deal with gravity at first remain unchanged and act as if this force is still present. This results in a shift of body fluids into the upper parts of the body, which is continuous for the first 6–12 h in space. The result is a dramatic redistribution of body fluids compared to Earth conditions. This is illustrated in Figure 2.1. Whereas on Earth the overall volume of body fluids is equally distributed between upper and lower parts of the body (Figure 2.1A), a clear pooling of body fluids in the chest and head can be observed after the first hours and days in space (Figure 2.1B). Direct visible consequences of this shift include considerable changes in leg volume (i.e., the circumference of the legs can decrease by 10–30%) [Moore and Thornton, 1987], and there is a striking facial swelling around the eyes (“puffy face”). On the subjective level, the internally-perceived consequences of this shift can interfere with subjective well-being. For example, astronauts often complain about nasal stuffiness and headache during the first hours or days in weightlessness that most likely result from the headward shift of body fluids. Furthermore, the senses of smell and taste might be altered due to fluid changes in the nasal region [Clément, 2005]. Interestingly, the interpersonal communication of astronauts seems to be

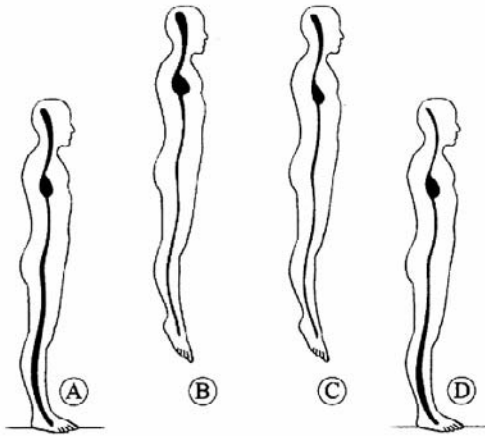


Figure 2.1. Illustration of the Effects of Body Fluid Shift in Space. Shown is the relative distribution of body fluids in different parts of the human body: (A) pre-flight on Earth, (B) early in-flight, (C) in-flight after primary adaptation, and (D) early post-flight after return from space to Earth. (Source: Clément, 2005; reprinted with permission).

affected by the consequences of this shift. In a questionnaire survey of 54 astronauts and cosmonauts who had flown in space [Kelly and Kanas, 1992], “facial swelling” was among the few factors that were identified as hindering communication between crewmembers during short-term space flight. One reason for this can be assumed to be due to an increased difficulty in perceiving and interpreting facial expressions correctly, which usually provide important non-verbal cues [Cohen, 2000].

On a physiological level, the redistribution of body fluids under microgravity involves transient increments of central blood volume and intracranial pressure, which in turn initiate complex adaptive effects in the cardiovascular, endocrine, and blood systems [Charles et al., 1994]. The main consequence resulting from these adaptive effects is an elimination of excess body fluids in the chest and head region. This is achieved by a reduction of blood plasma volume, which decreases by about 22% due to an increased output by the kidneys [Clément, 2005]. After this adaptation, the volume of fluid in the upper part of the body is successfully restored to a more or less normal level, although the difference in distribution of body fluids between the lower and upper part of the body tends to remain different from Earth conditions for the entire stay in space; i.e., there is relatively less fluid in the trunk and legs (Figure 2.1C). Associated with the loss of blood volume is also an adaptation of heart activity to the conditions in space. The lower demands on its pump activity is reflected in a decrease of heart volume that develops after some time in space.

All in all, the cardiovascular functions show an efficient adaptation to the specific conditions of microgravity, beginning in the first few days of a space mission. This is also reflected in the fact that maximum exercise capacity, defined

by the duration of time a given level of work can be performed up to the level of maximum oxygen consumption, does not seem to be significantly affected in space. However, the main cost of this adaptation is a de-conditioning of cardiovascular functions compared to Earth standards. Without effective countermeasures, this de-conditioning leads to a loss of orthostatic tolerance, which in turn may become a serious issue for astronauts returning to Earth (see Section 2.2.4). For example, the loss of overall blood volume in space may result in low blood pressure and a reflexive increase of heart rate in upright astronauts immediate after landing. This is related to the fact that under Earth's gravitational conditions, a considerable amount of blood re-shifts to the legs, which given the reduced overall volume, produces a state of hypotension in the head (Figure 2.1D). Dependent on the duration of the space mission, this might make it impossible for astronauts to leave the spacecraft in an upright position after landing. In addition, the function of the baroreceptor reflex can become impaired in space and might need to be "re-trained" after return to Earth. This results from the microgravity-induced lack of a hydrostatic pressure gradient within the circulatory system. Because of this, the body no longer needs to compensate for pressure differences associated with changes of body orientation (e.g., from supine to upright position) in order to maintain a stable blood pressure. As a consequence, this adaptive function will not be used in space. Dependent on the duration of the mission, this can result in reduced effectivity of the baroreceptor reflex and contribute to cardiovascular problems during re-adaptation to Earth conditions [Clément, 2005].

2.2.2. Vestibular and sensory-motor system

Even more challenging for an effective adaptation to the space environment are the microgravity-related changes of signal processing in the vestibular system and the sensory-motor system. The vestibular system consists of the non-auditory parts of the inner ear, which include the three semicircular canals and the otolith organs [Howard, 1986a]. The three canals are sensitive to rotations of the head (i.e., they indicate any kind of angular accelerations of head and body). The otolith organs, which include the utricles and saccules, are sensitive to linear accelerations of the head and – most important in this context – to changes of the body's position with respect to the direction of gravitational force. During evolution, the human vestibular system has been optimized to support two important functions: the upright orientation and movement on Earth, and the coordination of head and eye movements. This mainly is achieved by means of two subcortical mechanisms, the vestibulo-spinal reflexes and the vestibulo-ocular reflexes [Howard, 1986b]. The former ones are based on nerve pathways between the otoliths and motor neurons in the spine and are involved in the regulation of muscle tone and postural control. The latter ones are responsible for the coordination of eye movements. This includes counteracting or compensating for movements of the head in order to maintain ocular fixation on visual targets. Gravity-dependent signals from the otolith organs provide important input for both of these mechanisms. Yet under *microgravity*, the afferent information from the otolith organs is significantly altered due to the elimination of gravity-related signals. That is, the otolith organs no longer provide information about the direction of the head or body with respect to the vertical but

remain only sensitive to linear accelerations of the body. This alteration has important consequences, which require complex adaptive processes and which can affect the well-being and performance of astronauts during their adaptation to the space environment

The first consequence regards the coordination of body posture and movement. This coordination represents an autonomous process that is based on complex sensory-motor programs which coordinate the activity of muscles in the trunk and limbs with incoming (afferent) signals from the eyes, the vestibular organs, and proprioceptors in ankles, joints and muscles. On Earth, this system has been optimized with respect to postural control and body movements under gravity. The nearly absent gravitational force in space challenges this system to a considerable degree by changing the usual pattern of afferent sensory information. For example, this directly affects vestibulo-spinal reflexes as well as other mechanisms of postural control, which show characteristic changes immediately after return from a space flight compared to pre-flight assessments [Reschke et al., 1998]. The lack of gravity not only alters afferent sensory information, but it also affects the mechanical conditions under which postural control and movements must be performed. Astronauts need to learn how to move without using their legs in a 3-dimensional environment that has negligible frictional forces. This requires new strategies of sensory-motor coordination and the acquisition of new locomotion skills. Normally, this learning process develops very quickly, and the necessary skills to move smoothly under microgravity conditions are acquired within the first 4 weeks in space. The effects of this adaptation can be studied by comparing movement patterns of astronauts pre-flight and post-flight. Most astronauts exhibit some kind of postural and gait instability after they return from a space mission, which suggests that they have developed specific sensory-motor programs for control of movements in space that are different from those needed for moving on Earth.

Even more important consequences of the alteration of vestibular signals in space involve the distortion of the visuo-ocular reflexes, indicated by disturbances of eye-movements and gaze stability [André-Deshays et al., 1993; Clarke et al., 2000; Clément, 1998], as well as a loss of the usual congruence between visual, vestibular and proprioceptive signals. The latter induces sensory conflicts which, on the one hand, lead to disturbances of spatial orientation and several visual illusions, which will be described in more detail in Chapter 3. However, the most severe consequence of these conflicts seems to be the development of space motion sickness (SMS), which can considerably degrade the well-being and fitness of astronauts during the first days in space [Lackner and DiZio, 2006; Reschke et al., 1994, 1998].

The main characteristics of SMS are summarized in Table 2.1. In general, the symptoms of SMS resemble those of terrestrial motion sickness, including enhanced malaise, loss of appetite, lack of initiative, stomach awareness, brief and sudden vomiting, nausea, and drowsiness. The only notable exception is that pallor usually is not present, which can easily be explained by the excessive blood volume in the head resulting from the fluid shift effect [Lackner and DiZio, 2006].

Table 2.1. Main Characteristics of Space Motion Sickness. Sources: Davies et al. [1988]; Lackner and DiZio [2006]; Matsnev et al. [1983]; Reschke et al. [1994, 1998].

Main Characteristics of Space Motion Sickness	
Onset	Within minutes to 1–2 h after exposure to microgravity in most susceptible subjects; delayed onset after more than 24 h in space occasionally has been observed
Duration	Usually 1–3 days; occasionally up to 7 days
Symptoms	Malaise Loss of appetite Stomach awareness Brief and sudden vomiting (often without prodromal nausea) Flushing or (less often) pallor Nausea Lack of initiative Impaired concentration Drowsiness
Incidence	44%–67% for astronauts on their first flight Up to 85% for less trained non-career astronauts
Provoking Factors	Fast movements of head or body
Countermeasures	Pre-flight training to familiarize astronauts with the kind of vestibular stimulation and sensory conflicts arising from altered vestibular input in space Preventive autogenic feedback or biofeedback training to enhance individual control over autonomic responses Anti-motion sickness medication such as promethazine

Most of the symptoms of SMS occur within the first hours after exposure to microgravity and last for up to 4 days in affected astronauts. Interestingly, none of these symptoms were observed in the first US astronauts traveling in Mercury and Gemini capsules, where the room to move was very limited. This points to another important characteristic of SMS: its sensitivity to fast head and body movements. Both anecdotal reports from astronauts and cosmonauts, as well as systematic observations during space flight, suggest that such movements evoke or exacerbate the symptoms of SMS [Lackner and DiZio, 2006].

The incidence rates of SMS are quite high. According to Russian and American sources, 44%–67% of space travelers develop SMS to some degree, and this rate can increase to 85% for non-career individuals such as scientists, who are less well trained [Davis et al., 1988; Matsnev, et al., 1983]. Given this high incidence and the impact of SMS on an astronaut's general fitness, SMS has to be regarded as one of the most important issues of primary physiological adaptation to the weightless conditions in space. Corresponding problems can also occur after re-entry and landing, particularly if astronauts return from long-duration space missions. However, only a few reports are available of this “mal débarquement”, and systematic research is still lacking [Clément, 2005; Lackner and DiZio, 2006].

Several theories have been proposed to account for the underlying factors causing SMS. The most commonly accepted one today is the “sensory conflict theory” [Lackner and DiZio, 2006]. According to this theory, any kind of motion sickness develops if sensory signals from different receptors provide incongruent information about an ongoing movement of the body, or if the afferent signals associated with a movement do not fit expectations. In space, this kind of conflict particularly arises between visual and vestibular inputs, at least until the astronaut has become used to the microgravity-related changes in otolith functions. In addition, initially unfamiliar patterns of proprioceptive input from muscles, ankles and joints during voluntary movements under weightless conditions may contribute to sensory confusions during the first days in space. The fact that head and body movements have been found to be highly-provoking factors for symptoms of SMS is consistent with this explanation, although the detailed physiological mechanisms are as yet largely unknown. Alternatively, it has been suggested that the development of SMS might closely be related to increases in intracranial and vestibular pressures induced by the headward shift of body fluids described in Section 2.2.1. However, the empirical support for this “fluid shift hypothesis” has been limited and not very convincing [Lackner and DiZio, 2006].

The fact that 77% of astronauts who have been found susceptible to SMS during their first flight also develop symptoms on following flights [Davis et al., 1988] suggests that stable individual characteristics might contribute to this susceptibility. Accordingly, attempts have been made to identify individual predictors for SMS-proneness and ability to adapt to microgravity in astronauts. These attempts have included studies of individual personality characteristics, personal history of motion sickness events assessed by specific motion sickness questionnaires, and performance in specific susceptibility tests on the ground. As yet, none of these approaches has been successful predicting likelihood of SMS [Lackner and DiZio, 2006].

Different countermeasures for SMS have been proposed, both pre-launch and during the mission. Pre-flight countermeasures include training to familiarize astronauts with the kinds of complex vestibular stimulation and sensory conflict to be expected in space [Reschke et al., 1994]. One example of this approach is the NASA Pre-Flight Adaptation Trainer, which confronts astronauts with sensory conflicts between visual and vestibular stimulation similar to those occurring during space flight. According to Clément [2005], first experiences with this kind of training reveal it to be a promising approach for reducing the severity of SMS symptoms in space. In fact, it seems to be more efficient than other kinds of

vestibular training (e.g., rotating chairs), which usually are highly demanding for astronauts.

In-flight countermeasures include pharmacological treatment, which is either applied preventively or after the first symptoms of SMS have developed. Anti-motion sickness drugs used for this purpose have included combinations of scopolamine and dexedrine, as well as (even more commonly) promethazine [Lackner and DiZio, 2006]. The main disadvantage of these drugs is their side effects, which can considerably degrade cognitive and psychomotor performance functioning. Possible alternatives to pharmacological treatment of SMS are behavioral techniques such as biofeedback or autogenic feedback training [Cowings and Toscano, 1982]. Such training works by training the astronaut to effectively control her/his autonomic responses to sensory conflicts in space, thus reducing their adverse effects. However, the effectiveness of these behavioural techniques relative to pharmacological treatment is a matter of dispute [Cowings and Toscano, 2000; Lackner and DiZio, 2006], and more work needs to be done to evaluate their usefulness in space.

2.2.3. Musculo-skeletal system

The third system that is significantly affected by the loss of gravitational force in space is the system involving muscles and bones. During evolution, this system has been shaped to support the weight of humans induced by gravity, as well as to allow for an upright posture and movement against the mechanical impact of the gravitational force. In fact, more than half of all muscles in the human body are involved in dealing with gravity. In particular, this holds for most skeletal muscles in the legs and lower back. Similarly, the main weight-bearing bones of the legs and the lower spine are mostly loaded by gravitational force.

During spaceflight, microgravity progressively leads to a significant decrease of muscle volume and strength (i.e., muscle atrophy), as well as a reduction of fatigue resistance, particularly in those muscles that are required to oppose gravity [Jaweed, 1994]. In addition, hypoactivity due to confinement in a comparatively small living environment contributes to these effects. Muscle atrophy can be observed after the first few days in space. If no appropriate countermeasures are applied (see Section 2.2.4), astronauts can lose up to 20% of muscle mass during short-term missions and up to 50% during long-term missions. This decrease of muscle mass significantly contributes to the weight loss that is usually observed in astronauts during space missions. Moreover, the decrement of muscle mass is associated with structural alterations that affect the contraction strength of the muscles. This effect is more pronounced in muscles supporting activities against the gravitational force. According to Clément [2005], the combination of effects on muscle volume and strength in space is similar to that seen in bed rest patients or the elderly. As a consequence, the returning astronaut can have severe difficulties maintaining a stable upright position or moving effectively on Earth, depending on the duration of his/her stay in space.

The decreased mechanical load on the body in space also affects the weight-bearing bones in the legs and lower spine. In these bones, a decrease of mass results that is due to a process of bone demineralization [Jaweed, 1994]. This is also

reflected in an elevated urinary excretion of calcium, the main mineral incorporated in the bones. The process of bone demineralization leads to a progressively diminished bone mineral density that is similar to that observed in the elderly or in people suffering from osteoporosis. The main risks associated with bone demineralization are an increased risk of bone fracture and an increased risk of renal stones due to the elevated calcium excretion. However, both risks can be reduced if appropriate countermeasures are applied, which usually represent a combination of exercise (see Section 2.2.4) and nutritional diet. In addition, preventive pharmacological treatment may help [Clément, 2005].

The similarity of bone demineralization in space to the aging processes and to osteoporosis has made this effect of microgravity an interesting topic for physiological and medical research. However, not all of this research needs to be conducted during actual space missions. Instead, so called “bed rest” studies can be used to study these effects on Earth. During bed rest studies, individuals are kept in a horizontal position for several days or even weeks or months, usually combined with a 6° head-down bed tilt. This leads to physiological effects that resemble those of microgravity (e.g., hypoactivity, decreased mechanical force on weight-bearing muscles and bones, absence of a hydrostatic pressure gradient along the head-foot axis). Accordingly, this approach not only has been used to study effects analogous to those in space on muscles and bones, but also on the cardiovascular system in an Earth-bound setting.

2.2.4. Physiological deconditioning and countermeasures

Most of the physiological functions that are acutely affected by microgravity show a rapid adjustment to this new environmental condition during the first 3–14 days in space, and most of the physiological systems reach a new steady state of “normal” functioning within 4–6 weeks [Nicogossian et al., 1994]. This appears to be the period needed to fully adapt to the physical peculiarities of the space environment. The only exceptions are changes in muscles and bones, which continue throughout the entire stay in space (if no countermeasures are employed – see below).

It is important to understand that the effects described above reflect normal physiological responses to the environmental conditions of living and working in space. Certainly, they cannot be regarded as pathological, and they demonstrate that humans are highly adaptive organisms. However, this adaptivity is associated with considerable “costs” which become apparent as soon as an astronaut returns to Earth. Some of these costs have been described above in discussing the cardiovascular and musculo-skeletal systems (e.g., loss of orthostatic tolerance, muscle atrophy, bone demineralization).

However, the degree of de-conditioning in these systems and their related risks can be reduced to a considerable degree by applying specific countermeasures during the flight. The most important countermeasure in this respect is exercising on a regular basis [Nicogossian et al., 1994; Kozlovskaya et al., 1995; Bogomolov et al., 2007]. For this purpose, specific exercise devices have been available on the Space Shuttle and orbital space stations (e.g., Salyut, Skylab, Mir, ISS). For example, on ISS the main exercise devices available to the cosmonauts and astronauts include a cycle ergometer, a treadmill, and a resistive exercise device.

The cycle ergometer (CVIS¹) can be driven by hand or foot and is mainly used for maintaining cardiovascular functions and endurance of leg muscles. In addition, specific arm training and pre-breathe exercises are performed on this device as preparation for extra-vehicular activities (EVA). The device supports exercising in the supine or sitting position, and it can be operated in a manual or electronic mode with a maximum load of 350 W. Optional waist straps and back support are available to fix the position of the astronaut in weightlessness.

The treadmill allows for walking and running exercises, as well as deep knee bends and resistive training (i.e., training against an induced force). Two spring-loaded cords attached to a harness around the astronaut's waist keep him or her in a stable position. For resistive training, the treadmill can be equipped with a subjective loading device (see below). This device induces loads on the astronaut of up to 100% of his body weight in order to simulate the impact of 1-g forces while exercising. Exercising on the treadmill is used as a countermeasure for impairments of cardiovascular functions, decrements of muscle endurance, and loss of bone mass. In addition, it provides training of neurophysiological pathways and reflexes needed to walk under the impact of gravity when the astronaut returns home.

The multi-purpose resistive exercise device (RED) is specifically designed to support exercises preserving bone density and muscle strength, particularly in the lower part of the body, which is most affected by the detrimental effects of micro-gravity. It consists of a pair of crank canisters connected to a shoulder harness which are used to passively exert a selectable load on the astronaut. Typical exercises on the RED include squats, heel raises, or deadlifts. In addition, the RED can be combined with the treadmill for resistive training.

The duration of exercise on the different devices is dependent on the length of the mission and the individual characteristics of the astronaut. During typical short-term missions lasting up to 2 weeks, astronauts usually exercise for about 30 min per day. During long-term missions, this time is considerably prolonged. For ISS crews, flight surgeons commonly recommend daily exercise sessions of about 2–2.5 h in order to counter the detrimental effects of de-conditioning. The results of these exercise programs are evaluated on a regular basis by specific fitness tests while the astronauts are in space. Based on the results of these tests, the details of the exercise programs are adapted and tailored to the individual needs of astronauts. These general characteristics of exercise programs in space are essentially the same for astronauts and cosmonauts. However, Russian countermeasures for cosmonauts also involve the wearing of so called Penguin loading suits, which make it necessary to perform movements against some opposing force [Bogomolov et al., 2007].

In addition to the general in-flight exercise program, more specific countermeasures are applied before astronauts return to Earth from a long-term mission. These countermeasures include “lower body negative pressure”(LBNP) training and fluid loading by intake of a water-salt additive. LBNP training is done by using a device that makes it possible to establish low-pressure conditions in the lower part

¹ The acronym stands for “Cycle Ergometer with Vibration, Isolation and Stabilization”. Vibration, isolation and stabilization refer to specific elements that prevent vibration of the space station that might result from astronauts who are working out. Vibration needs to be avoided because it is annoying and because it might disturb ongoing scientific experiments.

of the body, as compared to the ambient pressure. The astronaut dons a “trouser”-like device that completely encloses the legs and lower abdomen and can be progressively de-pressurized down to a pressure difference of -60 mmHg with respect to ambient conditions. This induces conditions in the lower part of the body that are similar to those experienced by an upright individual on Earth. The immediate consequence is a pooling of body fluids in the legs. This in turn challenges the cardiovascular system to increase the blood pressure and the muscle tone in the leg vessels in order to maintain the return of blood to the heart. Because this procedure involves the risk that the astronaut may become dizzy or unconscious if the depressurization is performed too fast, a close monitoring of heart rate and blood pressure is required during LBNP training.

Fluid loading with a saline solution may compensate to a certain degree for the general loss of body fluid volume in space. This can further contribute to a reduction of problems associated with low blood pressure and increased heart rate after re-entry and landing.

The foregoing description should have made it clear how much effort is needed and invested to counteract the problems of de-conditioning in space. However, even this effort is by no means sufficient to completely maintain all bodily functions and the physical fitness needed for life on Earth. While astronauts returning from long-duration space missions might be able to walk short distances on their own after landing, this capability usually is limited, and it usually takes several weeks of post-return rehabilitation until the former maximum exercise capacity has returned. This might not present too big problem for astronauts returning home from missions lasting a few weeks or month, but it would be of much more concern with respect to future expeditionary missions to other planets. For example, astronauts traveling to Mars will be exposed to several months of microgravity before finally arriving at the Red Planet, and then they would have to cope with gravitational force again (albeit reduced compared to Earth). Because intensive “post-flight” rehabilitation programs like the those employed after return to Earth would probably not be available, the need to avoid de-conditioning effects during the long transfer phase from Earth to Mars will be even greater during these missions. This has led to ideas of applying some kind of “artificial gravity” to astronauts during such expeditionary missions [Young, 1999].

Despite the expense and engineering challenges, artificial gravity would have the advantage of reducing the detrimental effects of microgravity in all relevant physiological systems simultaneously. Principally, two options could be considered. The first involves the provision of artificial gravity on a permanent basis. This could be achieved, for example, if the whole spacecraft was slowly rotated while moving through space. The extent of g-forces that might be induced by this approach depends on the frequency of the rotation and the distance from the center of rotation (i.e., the radius of rotation). Technological options to establish permanent artificial gravity on a mission to Mars have been discussed by Zubrin [1997] and, more recently involving the Space Shuttle, by Bukley et al. [2007]. However, beside its technological complexity, such a solution would create problems related to vestibular functioning (e.g., coriolis and other effects), which may be a limiting factor to this approach [Clément, 2005]. As a possible alternative, intermittent

exposures to artificial gravity have been discussed that might be applied by means of short-arm centrifuges available onboard the spacecraft. Such devices have been used for research in space, but they have not been operationally applied for countermeasure purposes during actual space missions [Clément et al., 2001, 2004]. However, with respect to extremely long missions such as a trip to Mars, the part-time provision of artificial gravity may represent the best “integrated countermeasure” [Bukley et al., 2007] for de-conditioning effects, and it is hoped that research and suitability studies addressing artificial gravity will become more important in the future.

2.3. Sleep and circadian rhythms

For the first 2 decades of human spaceflight, issues of sleep and circadian rhythms in space did not get much attention. In contrast to the amount of physiological research conducted on cardiovascular and vestibular functions, or the impact of microgravity on bones and muscles, the effects of the space environment on the circadian system of humans and processes of sleep regulation remained largely unexplored. However, this situation has changed. It has become recognized that sleep disturbances and fatigue, as well as alterations of circadian rhythms in astronauts, are among the most important factors contributing to impaired well-being, alertness, and performance during space missions. This is supported by data from Russian space flights. Analyses of crew errors observed during 14 Mir missions involving 28 cosmonauts and 342 weeks on-orbit revealed a significant correlation between the occurrence of errors and deviations in the usual sleep-wake cycle (e.g., prolonged work shifts or other operational shifts of work-rest times) [Nechaev, 2001].

As a consequence, research exploring the nature of sleep and circadian rhythms has increased. Optimizing the work-rest schedules of astronauts, as well as monitoring them for fatigue, are viewed as important factors in maintaining behavioral health and performance efficiency in space [Flynn, 2005; Mallis and DeRoshia, 2005].

2.3.1. Empirical findings from space: phenomenology of sleep disturbances

Subjective reports from astronauts, as well as objective studies of sleep during American and Russian space missions, show that sleep in space is shorter, more disturbed, and often shallower than on Earth, with a considerable degree of inter-individual variation [Frost et al., 1976; Santy et al., 1988; Stoilova et al., 1990, 2003; Gundel et al., 1993, 1997, 2001; Monk et al., 1998, 2001; Dijk et al., 2001]. Most of these effects have been observed during short-duration space flights, and first results from long-duration missions suggest that they primarily occur during the first 2–4 weeks of a space mission, although the database for such a conclusion is very small [Frost et al., 1976; Gundel et al., 2001].

Table 2.2 summarizes the results of an analysis of subjective reports on sleep quantity during U.S. Shuttle missions [Santy et al., 1988]. It is evident that sleep on-orbit is considerably restricted compared to sleep on Earth, with an average duration

Table 2.2. Average Sleep [Hours] of American Astronauts During Single-Shift and Dual-Shift Shuttle Missions. For comparison: average sleep of an astronaut control group on the ground: 7.9 h. Source: Santy et al. [1988].

Mission Day	1	2	3	4	5	6	7
Single-Shift [n=36]	5.7	6.2	6.2	6.1	6.2	6.0	5.3
Dual-Shift [n=22]	5.7	6.2	6.4	6.3	6.3	6.1	5.8

of about 6 h. Many of the astronauts involved in this study reported that they had less than 4 h of sleep at least once in-flight, and one astronaut even reported having less than 5 h of sleep every night in space. Furthermore, 50% of the astronauts on dual-shift flights, and 19.4% of single-shift crewmembers, acknowledged using sleep medications at least once during the mission to get an appropriate amount of sleep on-orbit. This is in good accordance with recently published data, which show that hypnotics are the second most used medications during space flight, surpassed only by drugs for space motion sickness [Putcha et al., 1999].

These subjective reports of astronauts coincide remarkably well with results of sleep monitoring studies during space flight based on polysomnography; i.e., monitoring of brain electrical activity during sleep by means of EEG-recordings, [Frost et al., 1976; Gundel et al., 1993, 1997, 2001; Monk et al., 1998; Dijk et al., 2001]. All of these studies provide objective evidence for reduced sleep quantity and more disturbed sleep during the first 30 days of a space mission. In addition, they point to changes of sleep structure in space. Normal sleep consists of several cycles of two different phases referred to as REM sleep (characterized by comparatively shallow sleep associated with *rapid eye movements*) and non-REM sleep. Each of these cycles lasts approximately 90 min, with non-REM sleep followed by initially short phases of REM sleep, which become progressively longer during the course of the night. Within non-REM phases, four different stages of sleep can be distinguished, with stages of deep sleep characterized by increased portions of slow “delta” activity in the EEG signal (i.e., brain electrical activity of comparatively low frequency, < 4 Hz, and high amplitude). Accordingly, these stages of sleep are also referred to as “slow wave” sleep. During space flight, some subtle but significant alterations of this sleep architecture have been found. Gundel et al. [1997] investigated the sleep of four astronauts on short-duration and long-duration flights to the former Russian space station Mir. Whereas overall sleep efficiency was maintained in space, the duration of the initial non-REM sleep was shortened (i.e., the first episode of REM sleep occurred earlier), and the amount of slow wave sleep was found to be increased in the second non-REM phase compared to sleep on the ground. In contrast to the reductions of sleep duration that were only observed during the first 30 days on-orbit, none of the above other effects showed an adaptation throughout the mission. For one cosmonaut, they remained visible

even after more than 400 days in space [Gundel et al., 2001]. Monk et al. [1998] analyzed the sleep of four astronauts on a U.S. Shuttle mission. In these astronauts, no alterations of REM sleep were found, but there was a general decrease of slow wave sleep that indicated that sleep in space became shallower than on Earth. Other studies did not observe comparable alterations of in-flight sleep [Frost et al., 1976; Dijk et al., 2001]. However, they found a considerable increase of REM sleep and a reduction of REM latency during the first week after return to Earth, which they assumed might be related to the transfer back from microgravity to a normal gravity environment. Even though these different results lack consistency with respect to the specific pattern of alterations of sleep architecture and point to considerable inter-individual differences, they all suggest that space flight is associated with a general reduction of sleep duration, increased sleep disturbances, and specific changes of sleep regulation processes.

2.3.2. Empirical findings from space: sleep disturbances and circadian rhythms

What do we know about the origins of these effects? As becomes evident from anecdotal reports, sleep disturbances and reductions of sleep duration of individual astronauts in space often are due to obvious external factors like uncomfortable ambient temperature, constantly high noise level induced by the fans of the life-support system, space motion sickness, emotional arousal and excitement, or general discomfort due to uncomfortable sleeping bags or lack of familiar proprioceptive cues [Mallis and DeRoshia, 2005; Monk et al., 1998; Santy et al., 1988; Stuster, 1996]. In addition, workload and deviations of the scheduled work-rest cycle may contribute significantly to reductions of sleep times in space. This is suggested by findings that bedtimes in space are often delayed due to operational demands or social/recreational activities [Gundel et al., 1997; Dijk et al., 2001]. In contrast, wake-up times are mainly controlled by mission control personnel, and they are fairly stable throughout a mission. As a consequence, any delay in bedtime directly leads to a reduction of the time originally scheduled for sleep. Since this effect is most pronounced during early flight, it would also explain the recovery of sleep times to an almost normal amount in the course of a long-duration mission [Frost et al., 1976; Gundel et al., 2001].

Alterations of sleep may also be affected by the adverse impacts of the space environment on the physiology of sleep regulation. According to commonly accepted models, two interacting processes are involved in this regulation [Achermann, 2004; Borbély, 1982]. The first one is referred to as “Process S”. It represents a homeostatic process that is reflected in an increase of sleep propensity over the waking phase and a decline of this propensity during sleep. A direct physiological marker of this process is the portion of slow wave activity in the human EEG, which increases progressively over the duration of wakefulness (i.e., it is low after awakening and high before going to sleep). After sleep onset, this accumulated sleep propensity is reduced rapidly during the first three hours of sleep, which represents the most restorative sleep phase. This is reflected in the time course of slow wave activity in the sleep EEG. Under normal conditions, this “slow wave sleep” only emerges within the first non-REM sleep periods. After about three

hours of continuous sleep, it typically is reduced to a considerable extent, or it does not occur at all anymore [Borbély, 1982]. However, as has been described above, subtle changes in sleep architecture have been observed in some astronauts in space. This suggests that the Process S of sleep regulation might be directly affected by either the microgravity environment or the general stress related to confinement during space flight. More specifically, the effects of gravity have been assumed to play a role in the observed alterations of non-REM/REM sleep regulation during and after space missions. These are primarily reflected in reduced REM latencies on-orbit [Gundel et al., 1997] and the consistent finding of increased REM sleep and decreased REM latencies during re-adaptation to the gravity environment after return to Earth [Frost et al., 1976; Dijk et al., 2001]. In addition, the finding of reduced amounts of slow wave sleep [Monk et al., 1998] can be taken as an indicator of alterations of Process S in space. However, the specific underlying mechanisms of these effects are unknown, and further research is required to substantiate this hypothesis.

The second major physiological process affecting sleep regulation is the circadian process, which relates to rhythmical changes of virtually all physiological and psychological functions throughout the day-night cycle and is an adaptation of the human organism to the natural change of day and night on Earth. During evolution, these circadian rhythms have been shaped to physiologically support activity during the day and rest and sleep during the night. The underlying mechanism includes an endogenous pacemaker (“internal clock”) located in the hypothalamus. In the absence of any external time cues, this pacemaker runs with an autonomous period of 24.2 h [Czeisler et al., 1999]. But normally, it becomes entrained and synchronized with the external 24-h day by environmental time cues (“zeitgebers”). The most important zeitgeber for humans is the alteration of daylight and darkness, yet social and cognitive cues (e.g., timing of meals, social contacts and physical activity, awareness of clock time) also contribute to synchronizing the processes controlled by the internal clock [Zulley, 2000]. One important marker of this circadian process is body temperature, which is highest during the late afternoon and early evening and lowest in the early morning between 3 and 7 o’clock. The latter marks the nadir of the circadian process, where all physiological functions affected by it are in a kind of “rest state”.

As has been shown in laboratory studies and studies on jet-lag and shift-work, a misalignment of internal biological rhythms and the work-rest schedule can lead to sleep disturbances, daytime sleepiness, and impairments of well-being and performance. In particular, this holds for a shift of phase relationship between circadian changes of body temperature and the sleep-wake cycle. Increased sleepiness usually coincides with the circadian minimum of body temperature at the onset of the night, and falling asleep at this time seems to be an important condition for undisturbed and restorative sleep [Czeisler et al., 1980; Monk and Moline, 1989; Zulley et al., 1981].

A disturbing misalignment of temperature rhythm and sleep-wake cycle can result from two different effects [Folkard and Monk, 1983]. First, it can be due to a de-synchronization of the circadian system, which often has been found in the laboratory when individuals were kept isolated from any external time cues for a

certain period [Wever, 1979]. In this case, the temperature rhythm and the sleep-wake cycle start to “free run” with different periods. Second, it can result from an internal dissociation of circadian phase relationships; i.e., where both rhythms are kept entrained to a 24-h schedule but show a constant difference between their circadian phases, resulting from a phase advance or delay of the sleep-wake cycle relative to an unchanged temperature rhythm or vice versa. Such alterations of circadian phase relationships are typical for single episodes of night work, or for the first days after traveling across different time zones on Earth (“jet-lag”). In addition, such shifts also have been found in environments where the strength of the natural zeitgeber is weakened. For example, Gander et al. [1991] analyzed changes in the circadian system of three participants of an expedition to Antarctica during the polar summer when photic zeitgebers are absent due to permanent daylight. In these individuals, the temperature rhythms showed a phase delay of about 2 h (i.e., the minimum of body temperature occurred 2 h later than usual). Because bedtimes remained unchanged, this led to a shift of the circadian phase relationship between temperature rhythm and sleep-wake cycle, leading to an elevated temperature during sleep associated with difficulties falling asleep, increased sleep disturbances, and feelings of poor sleep quality.

Space habitats also share the issue of absent, or at least weakened, photic time cues. Given the speed of an orbiting space craft, each complete cycle of sunrise and sunset takes about 90 min, and the level of indoor lighting usually is too low to compensate fully for this lack of natural daylight time cues. Moreover, operational demands often make it necessary to advance or delay the work-rest schedule, or even to shorten its period to less than 24 h during space flight [Dijk et al., 2001]. As a consequence, disturbances of circadian rhythms, particularly an internal dissociation of temperature period and sleep-wake cycle, might be expected to arise during space flight and to contribute to sleep disturbances in space. Only a few studies have addressed this issue [Gundel et al., 1997; Monk et al., 1998; Dijk et al., 2001]. No study has revealed any indication of a complete “free run” of the circadian temperature rhythm in space. Obviously, the strict organization of diurnal routines, including a regular schedule of wake-up times and meals, combined with alterations of indoor illumination aboard a space habitat, are sufficient to entrain the human circadian system to a more or less stable 24-h rhythm in space. However, it does not seem to be sufficient to keep the internal circadian rhythm completely aligned with the sleep-wake schedule or to prevent changes in the waveform of rhythms. Similar to the results reported from Antarctica, phase delays of the temperature or cortisol rhythms relative to the sleep-wake cycle have been found in some astronauts [Gundel et al., 1997; Dijk et al., 2001]. Others showed a reduced circadian amplitude and altered waveform of body temperature rhythm [Dijk et al., 2001]. All of these effects seem to be related to the weakened strength and altered structure of zeitgebers in space and may contribute to sleep disturbances, increased fatigue, and impairments of well-being during space flight.

2.3.3. Operational significance

What are the operational consequences of the observed alterations of sleep and circadian rhythm in space? The first consequence involves possible risks that can

arise from chronically restricted sleep times in space. The studies described above provide consistent evidence for reduced sleep in astronauts, at least during the first 2–4 weeks of a space mission, with an average sleep duration of slightly more than 6 h. Thus, the sleep of astronauts in space is decreased by 1–2 h, as compared with their optimum sleep time of 7–8 h. In addition, the report of an average sleep time of 6 h implies that there are a number of sleep episodes where astronauts sleep even less than this amount [Santy et al., 1988].

The possible effects of sleep restriction on wake-time cognitive performance, wake-time sleepiness, and sleep physiology have been addressed in a number of recent studies [Belenky et al., 2003; Dinges et al., 1997; van Dongen et al., 2003]. The results of these studies suggest that mild to moderate restrictions of sleep to less than 6 h per night result in cognitive performance decrements after two consecutive nights. These decrements include increased response times and number of lapses in simple reaction time tasks, slowing of performance in mental arithmetic tasks, or impaired working memory functions. If the sleep restrictions persists for a longer time, performance impairments accumulate over time until opportunities for recovery sleep are provided. The strength of these effects are directly related to the amount of sleep restriction; i.e., they display a sleep dose-dependent effect. After 14 consecutive nights of sleep limited to 4–6 h, the accumulated performance decrements correspond to those found under conditions of one or two nights of complete sleep loss [van Dongen et al., 2003]. A complete recovery from performance decrements accumulated across several nights of sleep restriction can take longer than might suspected. The data of Belenky et al. [2003] suggest that even three nights of unrestricted recovery sleep are not sufficient to return performance to a normal level after seven consecutive nights of moderately restricted sleep (< 7 h). Similar, albeit weaker, effects are observed in subjective ratings of sleepiness. These ratings usually indicate a sleep dose-dependent increment of sleepiness after the first night of limited sleep, but they do not show the same strong tendency for accumulation over time.

Overall, these results provide evidence that sleep restrictions as those usually observed during short-term spaceflights represent a serious issue that can affect the wake-time performance and sleepiness of astronauts. Therefore, every provision should be made to improve the conditions for an undisturbed and recuperative sleep of sufficient duration on-orbit. Such provisions can include improvements of habitability, like private and comfortable crew rest quarters with adequate shielding against noise and light, as well as comfortable sleeping bags or restraints according to the individual preferences of crewmembers [Gundel et al., 1997; Santy et al., 1988]. A particular problem relates to a better management of ambient temperature during sleep. This factor has often been complained about in recent subjective reports [Monk et al., 1998].

However, the most important countermeasure for inappropriate sleep in space represents a work-rest schedule that takes into account the sleep needs of astronauts. This involves the avoidance of prolonged work shifts that restrict the time allocated for rest and sleep. Realistic planning and organization of time lines for astronauts are required, along with a strict adherence to defined crew schedule constraints that have been included to protect rest and sleep times in space (see Chapter 6). In those

cases where sleep restrictions cannot be avoided for some reason, it must be ensured that they do not persist for longer than two consecutive nights, and that they are compensated for within a short time. The most effective compensation is prolonged time for sleep during the following night(s). Alternatively, the provision of opportunities for short sleep episodes (“naps”) during the work day prior to or following a night of restricted sleep might represent a sufficient compensation. The latter is suggested by empirical findings that show that the total duration of sleep obtained within a 24-h period is the most important factor for ensuring the restorative functions of sleep, regardless of whether the sleep is provided within one uninterrupted nocturnal episode or by splitting it between an anchor sleep period at night and additional diurnal naps [Mollicone et al., 2007].

A second set of operational consequences can be derived from the observed alterations of circadian rhythms in space. These are usually smaller than have been expected. None of the studies conducted so far have found any indication of a “free run” of circadian rhythms in space. However, findings of phase delays and lowered amplitude of the temperature rhythm, which can lead to an internal dissociation of temperature and sleep-wake cycle, point to effects of the weakened structure of zeitgebers on the circadian rhythms of astronauts. This might present a problem, specifically for the in-flight circadian shifting of work-rest schedules required by operational demands. For example, on the ISS a shift of sleeping times of space crews often is necessary to match the work-rest schedules of the station crew with those of a visiting Space Shuttle crew, or to support docking maneuvers of an arriving re-supply Progress capsule. Each of these shifts represents a “stressor” for the circadian system, and it remains to be shown whether the weakened zeitgebers in space are still strong enough to keep the circadian system entrained, even after several such events during a long-duration mission. As a consequence, the planning of sleep shifts and the strategy of implementation of such shifts should be considered very carefully.

Although it has been recommended to implement sleep shifting in space by a step-by-step approach, operational reality often shows that shifts are implemented abruptly with advance or delay periods of several hours introduced in one step (“slam shifting”). From a circadian system point of view, such a shifting strategy runs the risk of alertness and performance problems, as well as impairments of well-being. Most problematic in this respect are shift advances (e.g., a change of sleep time from 2200 to 1800 h, which shortens the working day during the shifting period). Given that the natural circadian rhythm is a bit longer than a usual 24-h day, the shortening of days is less well tolerated than a prolongation. The best strategy of shift-advancing a work-rest schedule remains a matter of debate. A recent set of empirical studies have investigated different alternatives in introducing a 6-h shift advance in space [Monk et al., 2004, 2006]. The results suggested that a shifting schedule involving small 30-min advances across 12 days was less disturbing on the circadian system and the entrainment of the internal clock and work-rest schedule than nine 2-h shift delays. Thus, the duration of steps of shifting might represent a more important feature for an effective change in bedtimes than its direction.

Finally, knowledge about the physiological processes involved in the regulation of sleep and circadian rhythms might be used to schedule optimum times for complex and safety-critical tasks of astronauts (e.g., extravehicular activities). For this purpose, theoretical models are needed that predict levels of alertness and performance of astronauts based on circadian phase and sleep history. Such models already have been developed for applications on Earth (e.g., the predictions of alertness and performance of truck drivers, locomotive engineers, or airline pilots) [Akerstedt et al., 2004; van Dongen, 2004]. Usually they are based on the two-process model of sleep regulation, described above. In addition, a third component is sometimes added to account for the specific effects of sleep inertia after awakening. These models do not fully address the alertness and performance of astronauts on-orbit, but they are a good start. Further attempts in this direction have been initiated by the NASA/Ames Fatigue Countermeasure Group [Mallis and DeRoshia, 2005]. It can be expected that this effort will lead to the development of more effective strategies for the management of alertness and fatigue during space flights in the future.

2.4. Psychological adaptation to long-duration space flight: general characteristics

2.4.1. Stages of adaptation over time

Reports of people working in isolated and confined environments have suggested that adaptation to these extreme conditions proceed in stages characterised by different changes of mood, performance, and interpersonal interactions of the people involved [e.g. Lebedev, 1988; Stuster et al., 2000; Rivolier et al., 1991]. This has led to the development of stage-models of human adaptation to confinement, isolation and extreme physical environments [e.g. Bechtel and Berning, 1991; Palinkas and Houseal, 2000; Rohrer, 1961].

Based on a review of early results from Antarctica and submarine research, Rohrer [1961] has invoked a three-stage model to describe individual reactions to prolonged isolation and confinement: a first stage marked by increased anxiety, a second stage involving depressive reactions to monotony and boredom, and a final stage shortly before the end of confinement, where emotional outbursts and sometimes open hostility occur. Other models refer to what is known as the “general adaptation syndrome” from classical stress research [Selye, 1956] in order to describe the time course of human reactivity to extreme environments. For example, Rivolier [1992; see also Decamps and Rosnet, 2005] proposed three stages of adaptation of humans to the extreme polar environment which he viewed as the normal temporal dynamic of what he called the winter-over mental syndrome. The first was an “alarm stage”, where the participant of a polar expedition doubted whether he or she could cope with the demands and wanted to return. This was followed by a “resistance stage”, characterized by crewmembers protecting themselves and controlling their environment and/or psychological condition. During this stage, a transient improvement of individual mood was observed, suggesting the implementation of successful coping mechanisms [Palinkas and

Houseal, 2000]. However, aggressive outbursts and conflicts with other crew members also occurred, along with tendencies to withdraw, and crewmembers invested much effort and resources in order to cope. This eventually led to a depletion of resources characteristic of a third stage of adaptation, the “exhaustion stage”. During this period, the affected crewmembers became more fatalistic and accepted that they could not change their environmental and psychological conditions.

The most influential adaptation stage model is that proposed by Bechtel and Bering [1991]. This model states that the third quarter of a mission in an isolated condition is the most critical psychological phase, where emotional and interpersonal problems start to increase significantly (“third quarter phenomenon”). On the one hand, crewmembers have the feeling that they already have passed the halfway point of their time under the extreme conditions of isolation and separation from family and friends. On the other hand, they realize that the other half of the mission is yet to come before they can return home. Interestingly, it is assumed that this effect emerges independent of the absolute duration of a specific mission (i.e., it can be observed during short-term missions of several weeks, as well as long-term missions of several months or even years). Because of its simplicity and high plausibility, this model has become very popular for an understanding of human adaptation to extreme environments.

2.4.2. Empirical findings from ground research: stages of adaptation in analog environments and isolation studies

Research addressing the various stage models of human adaptation to extreme environments has mainly been conducted in analog natural environments (e.g., Antarctica) or as part of ground-based simulations of space flight. Most of these studies have addressed the proposed “third-quarter phenomenon”. Several studies have found support for this effect (e.g., a general decline of mood and an increase of interpersonal tension after the halfway point of the mission) [Palinkas et al., 1998, 2000; Sandal, 2000, 2001; Sandal et al., 1995; Stuster et al., 2000] However, other studies did not report any clear temporal pattern of emotional and mood-related effects [Kanas et al., 1996; Steel and Suedfeld, 1991; Wood et al., 1999, 2005].

A recent study by Décamps and Rosnet [2005] suggests that this inconsistency might be related to the fact that adaptation to extreme environments does not represent a coherent phenomenon but may be due to different time courses for different aspects of mood and behavior. In this study, adaptive responses of 27 individuals who participated in an over-wintering in Antarctica were monitored across the entire duration of their mission, which lasted almost 1 year. Data collected included systematic observations of different stress reactions in all individuals that were obtained from the mission physician on a weekly basis using an observational grid technique. Based on earlier work of Cazes et al. [1989], four different categories of adaptive response were monitored, including thymic reactions/mood changes (e.g., muteness, anxiety, boredom), social reactions (e.g., aggressive reactions towards others, withdrawal), somatic reactions (e.g., sleep disturbances, headaches, alcohol abuse), and occupational reactions (e.g., inability to complete tasks, withdrawal from work, overestimation of workload). The results

showed that the time course of adaptive reactions were different for the four categories. A clear third-quarter-phenomenon only emerged with respect to mood changes (thymic reactions). As expected, mood was more or less constant during the first six month in Antarctica, but it became significantly more negative after the halfway point of the mission. However, other time courses emerged for other categories of behavior. For example, the number of negative social reactions increased over the course of the mission, with a transient reduction in the second half; somatic reactions displayed a decrease during the first half of the mission and remained constant thereafter; and no significant variations over time were observed for occupational reactions.

Other studies suggest that specific characteristics of the physical and psychosocial environment may produce a moderating effect on the time course of adaptive responses. For example, Palinkas and Houseal [2000] investigated mood changes of polar expeditioners who participated in an over-wintering at polar stations with different physical (e.g., altitude) and psychosocial (e.g., crew size) characteristics. Different profiles of mood change over time were found for the different stations.

All in all, these data from Antarctica and other analog environments suggest that the basic assumption of a “third-quarter-phenomenon” should not be over-generalized. Even though most of the data show that the time course of adaptation to extreme environment does not represent a linear process and might be described more appropriately as a sequence of stages, the detailed structure and number of stages seem to be dependent on not only the kind of reactions studied, but also the specific features of the environmental conditions.

2.4.3. Empirical findings from space: stages of psychological adaptation during space missions

Most of the data available about the general aspects of individual psychological adaptation to long-duration space missions are based on anecdotal reports, yet. One important source consists of observations during Russian long-duration space missions [Grigoriev et al., 1987, 1988; Gushin et al., 1993; Lebedev, 1988; Myasnikov and Zamaletdinov, 1998]. These observations suggest that human adaptation to long-duration space flight may be described as a sequence of four different stages which bears some similarities to the stage models mentioned above [Gushin et al., 1993]. Table 2.3 illustrates these stages based on observations made during a 5-month space mission to the Russian space station Salyut 6.

The first stage involves basic adjustments to the novelty of being in space. During this stage, the astronaut has to adapt to the conditions of microgravity and the accompanying physiological changes, as well as to the other environmental conditions in the space habitat. In addition, the astronaut has to adapt to the new work-rest cycle and the workload according to the flight program. Impairments of mood and well-being can be expected to result primarily from unpleasant side-effects of physiological changes (headache, space motion sickness) and work overload. The second stage represents a period where the astronaut has fully adapted to the conditions of space flight and does not yet suffer from the negative effects of confinement and isolation, the lack of comfort in the habitat, or the social

Table 2.3. Stages of Adaptation of a Russian Space Crew During a 5-month Space Mission. Source: Gushin et al. [1993].

Stage	Characteristics of Psychological State
1	Decreased work capability Vestibular discomfort Acute period of adaptation to microgravity
2	Period of complete adaptation
3	Sleep disturbances Narrowed sphere of interest Decreased activity Irritability, fatigue fixation Period of asthenic state of nervous system
4	Excitation, agitation Lack of self control, euphoria

monotony within a small crew. According to Grigoriev et al. [1987], this adaptation occurs by 6 weeks into a mission, and this time coincides with the estimations of the time needed for sufficient physiological adaptation to microgravity (see above Section 2.2).

The most critical stage, according to Russian experiences [Grigoriev et al., 1987; Gushin et al., 1993], starts sometime between the 6th and 12th week of the mission, when the crewmembers settle into the routine of work in space. This stage can last until just before the end of the mission and show similarities to the “third-quarter-phenomenon” observed in analogue environments. Significant psychological changes can take place during this stage, mainly in mood, in response to the monotony and boredom that result from low workload, hypo-stimulation, and restricted social contacts due to separation from family and friends. Observed behavioral reactions include emotional lability and hypersensitivity, increased irritability, and a considerable decline of vigor and motivation. Also, more subtle psychological changes have been reported to develop, and there are some indications that perceptual sensitivities may be altered during long-duration space missions. For example, Grigoriev et al. [1988] noted that during Salyut 6 and 7 missions, some cosmonauts experienced increased sensitivity to loud sounds after 3–5 months in space. Similar perceptual hypersensitivity was reported by Kelly and Kanas [1992] in their survey of astronauts and cosmonauts who had flown in space. Other observations point to a change in preference for certain types of acoustic stimulation. For example it was observed that cosmonauts started to prefer stimulating music after several weeks in space or even expressed the wish to hear some Earthbound sounds or noise [Grigoriev et al., 1987]. Finally, psychiatric developments have been reported from this stage of the flight. In particular, a syndrome referred to as “asthenia” by Russian space psychologists has been described. This syndrome is associated with feelings of exhaustion, hypo-activity, low motivation, low appetite, and sleep disturbances. It might eventually be followed by states of euphoria, depression, and

an accentuation of negative personality traits [Myasnikov and Zalmaletdinov, 1998]. Such reactions may be considered as signs of behavioral illness and will be dealt with in great detail in Chapter 5. Finally a fourth stage is reached shortly before the end of the mission. This stage has been described as a very busy period, where feelings of euphoria prevail but which also may involve concerns about how it will be to return to Earth after several months of confined living in space [Lebedev, 1988].

However, only few empirical spaceflight studies have systematically addressed issues of time-course of adaptation in space. Manzey et al. [1998] monitored subjectively perceived mood changes over time in one cosmonaut as part of a performance monitoring study that will be described in more detail in Chapter 3.

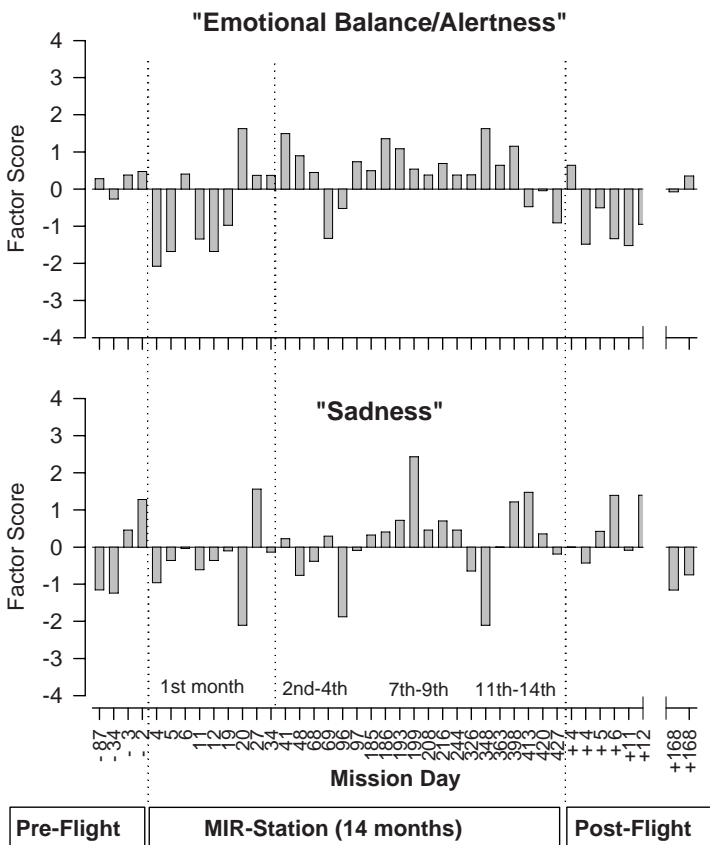


Figure 2.2. Variations of Subjective Mood and Alertness During a Long-Duration Space Flight. The data represent factor scores derived from a principal component analysis of subjective mood ratings of one cosmonaut before, during, and after a 438 day space flight in the Russian orbital station Mir.

Mood was assessed by 16 bipolar rating scales at 29 different time points during a 438-day Mir mission. Factor analyses of these data revealed two different factors of mood reflecting “emotional balance and alertness” and feelings of “sadness”, respectively. The time course of mood changes across pre-flight, in-flight, and post flight periods as reflected in the factor scores is shown in Figure 2.2. As becomes evident, the first factor reflected a primary adaptation period that lasted during the first 3–4 weeks of the mission and was marked by considerable drops of perceived emotional balance and alertness compared to pre-flight ratings. However, after this adaptation period, there was little indication to support the kinds of stage models that were described above. Only slightly elevated scores for the “sadness” factor between flight days 185 and 244 might point to a possible deterioration of mood around the midterm of the mission. A statistical evaluation was not possible, and the relatively low frequency of mood assessments might have masked some effects in this study.

Other research from space has addressed individual adaptation issues with particular focus on time-related changes of crew interactions and crew-ground communication [Kanas et al., 2001]. Although there is some evidence for crew adaptation to space early on in the mission, there was little indication of group stages during the mission itself. These studies will be described in detail in Chapter 4.

Thus, the current empirical basis for a stage model of adaptation in space is rather small and inconsistent. Given this inconsistency of empirical results, it remains an open question whether such a model really provides an appropriate framework for a description of general aspects of individual psychological adaptation to the specific conditions of long-duration space flight. However, at least the basic differentiation between a first stage of primary adaptation, which lasts about 2–6 weeks, and a second one that includes most of the remaining time of a mission seems to be suggested by the presently available data base.

2.5. Summary

- The space environment is an extreme living and working environment to which humans are not naturally suited and which demands complex processes of psychological and physiological adaptation.
- The main challenge for *physiological* adaptation in space is the lack of the usual gravitational force. In particular, microgravity-related effects on the cardiovascular and the vestibular system can considerably degrade well-being and fitness during an early flight period. These effects include sensory conflicts due to changes in the vestibular system that can lead to space motion sickness, and a shift of body fluid into the upper part of the body that can be associated with headache.
- Long-term physiological effects related to microgravity can be observed in the musculo-skeletal system. These effects are directly dependent on the duration of a space mission and are mainly reflected in a progressive atrophy of those

muscles needed to oppose gravity, as well as a loss of mass and strength of weight-bearing bones due to a progressive process of de-mineralization.

- Most of the physiological functions that are acutely affected by microgravity show a rapid adjustment to this new environmental condition during the first 3–14 days in space. The effects of this adaptation involve a de-conditioning of important physiological systems by Earth standards and an associated loss of “orthostatic tolerance”. In order to reduce de-conditioning effects in space, several countermeasures need to be applied. The most important countermeasure is physical exercise performed on a regular basis.
- Sleep in space is shorter and more disturbed than sleep on Earth. Beyond that, some alterations of sleep architecture have occasionally been reported that might reflect an effect of microgravity on sleep mechanisms.
- Circadian rhythms remain entrained with a 24-h schedule in space, although the natural time cues provided by sunlight and darkness are considerably altered. The daily routine of work and rest is sufficient to avoid a “free run” of the human circadian system. However, a phase delay and reduced amplitude of temperature rhythms have been observed, which may contribute to sleep disturbances and fatigue during space flight.
- Based on experiences from Russian space flight and data from analog environments, psychological adaptation to long-duration space missions describes the presence of a sequence of different stages. Empirical research suggests the occurrence of at least two stages: a first stage of primary adaptation that has occurred by the first 6 weeks in space, and a second stage that represents the remaining time of a mission.

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Many activities in space require good eye-hand coordination. Cognitive abilities need to be at a high level for the successful performance of such activities. “Astronauts Ellen Ochoa (foreground) and Carl E. Walz, STS-110 mission specialist and Expedition Four flight engineer, respectively, work the controls of the Canadarm2 in the Destiny laboratory on the International Space Station (ISS).” (Photo and quoted description courtesy of NASA)

Chapter 3

Human Performance

3.1. Basic issues

This chapter addresses the effects of the extreme living and working conditions during space flight on human performance. This is chosen to cover all aspects of performance that are related to the different stages of information processing; i.e., perceptual processes, central cognitive processes, psychomotor processes, and processes of attentional control [Wickens and Hollands, 2000]. The significance of dealing with these issues is obvious. The work of astronauts usually includes a variety of tasks like operating complex technical systems, conducting scientific experiments, or performing specific tasks during extravehicular activities. All of these tasks place high demands on different cognitive and psychomotor functions. Thus, maintaining a high level of performance efficiency is of direct importance for overall mission success and crew safety.

The general success of human space missions and the numerous examples of spectacular tasks that have successfully been accomplished in space may be taken as evidence for the high efficiency of human performance during space flight. However, the mere fact that overt performance decrements in highly trained tasks rarely have been reported does not mean that cognitive functions remain unimpaired in space. In fact, since the early days of human space flight, a number of anecdotal reports and observations have provided evidence for disturbances in cognitive functioning on-orbit, including reports of spatial disorientation and visual illusions, alteration of time sense, impairments of attention and concentration, disturbances of motor skills, and a general slowing of task performance [Christensen and Talbot, 1986; Kubis et al., 1977; Leonov and Lebedev, 1975]. Similarly, anecdotal information and research from analog environments have suggested that human performance may indeed decline under conditions similar to those of space flight [Harrison and Connors, 1984; Weybrew, 1963].

Despite the obvious relevance of human performance for space operations, life science space research long has remained limited to investigations of the biomedical aspects of human adaptation to microgravity [Christensen and Talbot, 1986; Taylor, 1989]. Only since the early 1990s has knowledge about human performance during space flight accumulated, even though the number of studies still is small [Casler and Cook, 1999; Fowler et al., 2000b; Leone, 1998; Manzey and Lorenz, 1998a]. Two different lines of research can be distinguished in this area. The first addresses the impact of microgravity on specific functions of human information processing. Cognitive neuroscience research in this area includes experiments on topics such as visual information processing, spatial perception, or the execution of voluntary movements. Even though the objectives of this research are related to an

understanding of the role of microgravity as a frame of reference for human information processing, the results also are important with respect to the general aspect of human performance in space. The second line of research is represented by a broad-band strategy of human performance assessment referred to as performance monitoring [Manzey, 2000a, Manzey and Lorenz, 1998a]. This approach involves repeated probing of different performance functions during a space mission in order to describe the pattern and time course of performance changes that may arise under the impact of stressors that are present in this unique environment. Its main objective is related to a delineation of possible human factors problems of space flight, and it corresponds to other efforts of stress research that focus on the impact of environmental stressors on human performance [Hockey, 1986].

In the following, knowledge gained from these two lines of research will be summarized. However, before dealing with empirical data from space flight, let us begin with some theoretical considerations about the possible origins of cognitive decrements in the environment found during human space missions.

3.2. Possible origins of cognitive performance decrements in space

At least two factors can be distinguished which may impair the cognitive and psychomotor performance of astronauts. The first factor involves the direct effects of microgravity on specific brain mechanisms, particularly the vestibular and sensorimotor system. The second factor includes non-specific stress effects related to, for example, cumulative sleep loss, workload, or the physical and emotional burden of adapting to the extreme conditions of living and working in a space habitat. In contrast to microgravity, these effects do not directly affect processing functions, but they can entail indirect effects on human performance by altering the level and pattern of (central) physiological activation [Hockey, 1986].

3.2.1. Effects of microgravity on specific brain mechanisms

During space missions, several neurophysiological changes have been observed that might affect perceptual, cognitive and psychomotor processes [Newberg, 1994]. One particularly important effect is the alteration of signal processing within the vestibular system. As has been described in Chapter 2, the lack of gravitational force in space alters the function of the gravity-sensitive otolith organs. These organs no longer provide information about the direction of a common vertical but remain sensitive only to linear accelerations of the body. This leads to a disruption of the usual congruence between vestibular signals and signals from other (e.g., visual, tactile, proprioceptive) receptors. The resulting sensory conflicts seem to be the basic mechanism underlying a number of adverse effects, including space motion sickness, and disturbances of eye movements and gaze stability. Gravitational cues from the vestibular system also affect the processing of (visual) information on a cortical level [Leone et al., 1995a]. As a consequence, alterations of afferent signals from otoliths may have an impact on higher cognitive functions, such as those involved in spatial orientation, spatial perception, or pattern and object

recognition [Glasauer and Mittelstaedt, 1998; Leone et al., 1995b, 1998; McIntyre et al., 2001].

Another class of direct effects of microgravity on neurophysiological functions regards processes of motor control (i.e., processes involved in programming and executing voluntary movements). Planning and control of coordinated movements involve a combination of both central motor programs responsible for generating the efferent control signals to the peripheral system of muscles, as well as mechanisms of control and adjustment of ongoing movements based on the processing of afferent feedback [Cruse et al., 1990]. Central motor programs can be considered as memory representations of the basic characteristics of different classes of movements that are acquired by training [Summers, 1989]. Technically speaking, they are conceived as prototypical force-time curves of certain movements (e.g., representations of the motor pattern defining a goal-directed movement with arm and hand to reach and grasp a distant object). From these programs, muscle commands are derived that then produce the intended movement. However, during movement execution, afferent feedback signals need to be processed in order to monitor the appropriateness of movements and to initiate on-line adjustments if necessary. These afferent feedback signals usually include visual signals from observations of the movement and proprioceptive signals from joints, muscles, and skin.

The effectiveness of both of these elements of motor control – central programming of movements and processing of feedback signals during movement execution – can become degraded under changed gravitational forces [Bock et al., 1992, 1996]. For example, many central motor programs established on Earth have incorporated gravity as an important factor [Pozzo et al., 1998]. Accordingly, these programs represent force-time curves that have been adapted to the specific mechanical constraints given by the gravitational force (e.g., upward movements of a limb have to be performed against gravity whereas downward movements are supported by gravity). Yet under *microgravity*, these mechanical constraints are substantially altered. Consequently, if central motor programs acquired on Earth are applied in space, they can lead to movements that are no longer appropriate without correction. In addition, proprioception from joints, muscles and skin seems to be altered and more variable in space. Support for this assumption is provided, for example, by impairments of awareness of limb position under simulated microgravity conditions [Bock, 1994]. This can considerably disturb the execution of movements in space, given the fact that distortions of proprioceptive feedback usually entail more adverse effects on movements than a complete elimination of these feedback signals [Cruse et al., 1990].

Generally, the microgravity-induced changes in the sensory-motor system have been described as inducing a state of *sensory-motor discordance*, which is characterized by a disruption of the usual relationships among efferent and afferent signals during the execution of movements [Bock, 1998]. This discordance degrades the usual efficiency of motor planning and control and has to be compensated for by complex adaptive mechanisms, including a re-weighting of afferent signals, an adjustment of central motor programs, and/or more effortful cognitive or visual control processes during movement execution. Even though these mechanisms are usually very effective, it is likely that the performance of perceptual-motor tasks

(i.e., tasks involving the transformation of visual input into appropriate motor responses) suffers in space, at least during primary adaptation to the conditions of space flight, where a full adjustment to microgravity has not yet been achieved.

3.2.2. Effects of stress on mental performance

Another possible source of human performance decrement during space flight relates to non-specific stress effects. The extreme working and living conditions in space may induce certain stress states in astronauts that are not only associated with impairments of individual well-being but also with degradations of cognitive and psychomotor performance. Examples of such stress states include states of decreased alertness and fatigue, states of high workload, and states of emotional stress due to interpersonal tension or the long-term effects of confinement and isolation. Since such states may arise in other work settings or environments as well (i.e., they do not represent anything specific for space flight), any effects related to these states are considered as “non-specific” in the current context.

Several theoretical models have been invoked to account for the effects of stress on human performance. Most of these models assume a link between energetic and cognitive processes; that is, a link between neurophysiological processes of central activation (arousal) and the efficiency of human information processing functions. One of the earliest and still most prominent ideas assumes an “inverted U” relationship between arousal and performance, also referred to as the *Yerkes-Dodson Law* [Yerkes and Dodson, 1908; Wickens and Hollands, 2000]. This “law” includes two assumptions: (1) cognitive performance is best at a certain level of arousal; i.e., considering arousal varying from low to high, performance first increases as arousal reaches an optimum, and then it subsequently declines as arousal further increases (this is what is termed the “inverted U” relationship); and (2) the optimum level of arousal is lower for difficult than for easy tasks. Within this framework, external or internal stressors are assumed to affect the efficiency of any cognitive process by either lowering (e.g., stressors like monotony, understimulation, sleep deprivation), or raising (e.g., time-pressure, noise, anxiety) the arousal level into non-optimum regions. An example would be the performance of a pilot that is expected to decline in both states of low arousal (e.g., fatigue) as well as states of very high arousal (e.g., perceived danger to life in case of emergencies).

Although this model has been very influential in modeling possible indirect effects of stress on human performance, it is too simple, in part because arousal and performance are conceptualized as unidimensional concepts. According to more recent models of stress and human performance [Hockey, 1986; Sanders, 1983], stressors do not cause any general effects on human performance by altering generic unidimensional arousal. Rather, different stressors seem to produce somewhat specific patterns of psychophysiological, biochemical, and cognitive change. This is suggested by both multidimensional neurophysiological models of cortical activation [Pribram and McGuinness, 1975] as well as results from laboratory research that suggest that the effects of different stressors on cognitive performance are not uniform but may be described by specific profiles of effects across different indicators of performance [Hockey and Hamilton, 1983].

A thorough review of this latter research has been provided by Hockey [1986]. According to this review, human performance under stress usually suffers from impairments of attentional and/or central cognitive processes. The specific pattern of impairment can be described by considering five different indicator variables: (1) general alertness, (2) attentional selectivity, (3) speed of cognitive processes, (4) accuracy of cognitive processes, and (5) working memory capacity. Among these different indicator variables, *alertness* does not strictly reflect a change in a specific cognitive function but is an indicator of the overall effect of a stressor on the attentional state, which can also be perceived subjectively. Considering the other indicators, *attentional selectivity* is one of the most sensitive ones. It has been defined as a reduced range of cues that can be attended to simultaneously, and it can be reflected in a reduced capability to divide attention between different input signals or to work on concurrent tasks at the same time.

Another issue that has to be taken into account in considering the possible effects of stress on human performance pertains to the active coping processes of individuals. That is, even though single performance functions may become impaired under the impact of stressors, this may not necessarily lead to overt performance decrements in complex tasks. Instead, the individual can take actions to compensate for these stress effects and protect overall performance. One way to achieve this involves mobilizing some extra effort (i.e., trying harder to achieve task goals). For example, astronauts under time stress might try to perform a given operational or scientific task more rapidly than usual. Alternatively, subjects under stress might choose to apply less effortful performance strategies in order to compensate for impairments of attentional and cognitive functions. An example would be a pilot focusing on the flying task but neglecting the monitoring of technical systems in states of stress, or an astronaut relying more than usual on written standard procedures in order to lower the memory demands of a task. However, even though these strategies might be adaptive to protect performance in the main task, they also contain some risks. For example, the astronaut working more rapidly on a task may be less careful in controlling different actions or may feel more exhausted and fatigued after task completion. Additionally, the pilot neglecting monitoring tasks may miss some important malfunction, which later might add to the stress already present. In cases such as these, stress effects may not lead to overt performance decrements but nevertheless may affect performance in a more subtle and concealed way.

This is the essence of the compensatory control model of stress and performance proposed by Hockey [1993; 1997]. According to this theory, the effects of stress on task performance are often masked because subjects apply some kind of performance protection strategy. In particular, this can be expected in operational work contexts, where commitment to task goals and motivation is high, and where the tasks are sufficiently complex to provide options for adjusting performance strategies [Hockey, 1993]. As a consequence, stress-related effects in such tasks are often only reflected in latent performance decrements that are somewhat difficult to detect. As has been illustrated by the examples above, such latent effects can include impairments of performance in subsidiary components of a task, indications of higher effort invested in task performance, indications of strategic shifts, or

fatigue after-effects [Hockey, 1997]. Impairments of performance in subsidiary components of a task (see the example of the pilot above) correspond to the known attentional selectivity effects in states of high arousal. Yet in the framework of the compensatory control model, they are considered as a compensatory reaction to reduce the attentional demands of a complex task. Fatigue after-effects are assumed to result from the extra effort associated with performance protection under stress. Even though individuals might be able to protect performance in a certain task despite the presence of stressors, the costs of this protection are reflected in increased fatigue or overt performance decrements in specific probe tasks at the end of exposure to stressors.

To sum up, stress can be expected to affect human performance in different ways. A summary of these effects is provided in Table 3.1. The extreme conditions of space flight can induce certain stress states in astronauts that may be associated with impairments of attentional and/or cognitive processes that are reflected in a specific pattern of effects across different indicator variables (i.e., attentional selectivity, speed and/or accuracy of cognitive processes, capacity of working memory). Although these impairments can reduce the cognitive efficiency of astronauts and may represent a principal risk for mission success, they do not need to directly cause performance decrements in highly trained operational mission tasks. Instead, it is likely that astronauts are able to protect performance in these tasks from possible impairment, at least for some time, by compensatory control

Table 3.1. Possible Types of Performance Decrements under Stress. Partially adopted from Hockey [1993, 1997].

Type of Decrement	Characteristics
Overt performance decrements in primary tasks (to be best observed in specific probe tasks)	Impairments of primary task performance <ul style="list-style-type: none"> ▪ Attentional selectivity ▪ Impaired speed and/or accuracy ▪ Decreased working memory capacity
Latent performance decrements in complex (real work) tasks:	
Subsidiary task failure	Selective impairment of (currently) low priority task components <ul style="list-style-type: none"> ▪ Neglect of subsidiary activities
Compensatory costs	Strain of active control during performance <ul style="list-style-type: none"> ▪ Increased mental effort ▪ Increased sympathetic activation ▪ Negative affect
Strategic adjustment	Within-task shift to simpler strategies <ul style="list-style-type: none"> ▪ Less use of working memory
Fatigue after-effects	Post-task preference for low-effort strategies <ul style="list-style-type: none"> ▪ Subjective fatigue ▪ Performance decrements in probe tasks

strategies. In this case, overall mission task performance does not represent a valid indicator of the current performance capability of an astronaut. As a consequence, early signs of stress-induced performance decrements may be found in specific probe tasks that are particularly sensitive to stress effects [Bittner et al., 1986]. They also may be reflected in more subtle (latent) performance changes in mission activities (including raised psychophysiological costs of performance) that can only be detected by sophisticated analyses of task performance.

3.3. Empirical findings from space: cognitive neuroscience research

What do we know about the effects of microgravity on human information processing? Some answers to this question are provided by neuroscientists who have investigated the impact of vestibular and sensory-motor changes in weightlessness on different cognitive functions in space. Microgravity-induced impairments of cognitive functions would be expected to affect the performance efficiency of astronauts during early adaptation to the space environment until sufficient physiological adaptation has been achieved.

However, the current knowledge in this field is somewhat limited. This is mainly due to the fact that neuroscience space research long has focused on fundamental issues related to the most important interactions between the vestibular organ and other systems (i.e., those involved in coordination of head-eye movements, and postural control), and the development of space motion sickness [Reschke, et al., 1994a,b]. Whereas this research has included investigations of spatial orientation and perceptual illusions, other issues of cognitive functioning in weightlessness have rarely been examined. However, during the last decade neuroscientific investigations of cognitive processes during space flight have received more attention [Leone, 1998]. Experiments conducted in space have addressed a number of issues related to spatial information processing, recognition of forms and objects, mass discrimination, and visuo-motor processes involved with voluntary movements. Most of this research has been aimed at raising the understanding of the significance of gravity as a frame of reference for cognitive processes. Yet knowing the impact of microgravity and its possible consequences for overt performance is relevant for a number of human factors issues, including ergonomic design of working tools and operational systems, different aspects of habitability, and scheduling of work specifically during the first days or weeks in space [Young, 2000]. In the following, the most relevant findings from neuroscience space research on human information processing are reviewed. This review is structured according to five different areas: (1) spatial orientation, (2) spatial perception and representation, (3) Mental rotation and object recognition, (4) mass discrimination, and (5) aimed voluntary movements.

3.3.1. Spatial orientation

Spatial orientation refers to the capability of orientating oneself within a three-dimensional environment, which is relevant for navigational tasks within a large space station. One important aspect of this capability concerns the accurate perception of the

spatial relationship between one's own body and the external space. This requires that a frame of reference be available that provides a stable coordinate system for defining one's own position, orientation and motion. On Earth, spatial orientation is usually achieved by taking gravity as such a frame of reference. The orientation of the gravitational force provides a reliable cue for determining the subjective perception of verticality and any deviation of body orientation from an upright position. In addition, visual cues from the environment (e.g., orientation of houses, trees, other people) are highly significant for the perception of spatial orientation. In fact, the influence of visual information can be so strong that it partially or even completely overrides the signals provided from otolith organs and other proprioceptive receptor systems [Howard et al., 2000]. In this case, distortions of spatial orientation may occur. Examples from Earth include well-known illusions of orientation or self-motion. Some spectacular kinds of such illusions are feelings of falling or other displacements through space induced in cinerama movies or illusions of orientation induced by completely furnished rooms that are tilted around a stationary subject [Howard et al., 2000]. Other examples are known from everyday experience (e.g., sitting in a stationary train but getting the feeling of self-motion by viewing a slowly accelerating train on an adjacent track). In both cases, visual cues are in conflict with vestibular and somatosensory ones, and it requires extra effort to maintain correct spatial orientation under these circumstances. However, if visual information is lacking (e.g., with eyes closed or in complete darkness), the afferent information from the vestibular system and the other receptor systems are usually sufficient to maintain a more or less accurate picture of one's own orientation and movement.

In space, where gravity as a frame of reference is lost, the influence of visual impressions is reinforced, and spatial orientation becomes significantly disturbed. In a survey of 104 Russian cosmonauts [Kornilova, 1997; Kornilova et al., 1995], 98% reported states of partial or complete disorientation and the occurrence of spatial illusions, particularly in darkness or with eyes closed. Lacking a clear visual reference, astronauts may not be able to correctly identify their own position, orientation, or motion with respect to the spacecraft. Direct empirical evidence for such an effect has been provided in an experiment by Glasauer and Mittelstaedt [1998]. In this experiment, blindfolded astronauts were passively turned around and were not able to identify accurately their position during or after the turn. The effect is further supported by results suggesting that astronauts have considerably more difficulty in space than on Earth in maintaining an accurate spatial map of their surroundings without vision [Watt, 1997; Young et al., 1993].

Even with eyes open, several disturbances of spatial orientation may occur, mainly related to three types of spatial illusions [Kornilova, 1997]. The first includes the perception of surrounding movements associated with movements of the head. For example, moving the head while looking at a control panel may induce the perception of a displacement of instruments. These effects are related to the disturbances of vestibulo-ocular reflexes and gaze-control after entering weightlessness. A second type of illusion consists of erroneous perceptions of self-motion comparable to those known on Earth in situations when visual impressions override the input of the vestibular system. These can include a variety of different illusions

of tumbling, falling, or rotating. Such illusions seem to be related to the increased influence of vision on spatial orientation in space, given the lack of any gravitational information that could be used to correct visual impressions. This is suggested by the results of “rotating dome” experiments, where astronauts are exposed to a visual dot pattern slowly moving around them. The intensity of sensations of self-rotation produced by this stimulus has been found to be considerably increased in space compared to Earth [Young and Shelhamer, 1990]. Finally, a third kind of illusion includes distortions of body orientation. One particularly interesting example is the feeling of hanging upside down, which often occurs in astronauts with eyes either closed or open, and which seems to be closely related to the development of space motion sickness. This illusion is called the “inversion illusion” and is among the most often reported illusions in states of weightlessness [Kornilova, 1997; Kornilova et al., 1995; Lackner and DiZio, 1993].

Most of the described difficulties of spatial orientation occur immediately after entering the microgravity environment and only persist for minutes or hours. But some can persist for up to 14–30 days before sufficient adaptive coping strategies have been developed and/or physiological adjustment has been achieved. In addition, many spatial illusions have been observed to reappear after some time (30–50 days) during a space mission, suggesting some de-stability of adaptive processes [Kornilova, 1997].

Surprisingly, the lack of gravitational cues in space does not necessarily lead to a complete loss of subjectively perceived verticality. Although some astronauts lose any sense of up and down in darkness or with eyes closed, a considerable number of astronauts maintain a subjective perception of verticality, even in states where external references from visual or tactile cues are blocked. Rather than feeling indifferent with respect to the vertical when eyes are closed, these astronauts report a definite feeling of being upright or of being inverted [Glasauer and Mittelstaedt, 1998; Mittelstaedt and Glasauer, 1993]. Only after some days in space do illusions of inversion disappear. Most of these astronauts perceive “up” and “down” with respect to a stable egocentric body-reference (i.e., they always perceive “up” where their head is – this egocentric reference can even override visual cues provided by the spacecraft interior) This is suggested by experimental results from Glasauer and Mittelstaedt [1998] showing that astronauts who are tilted 180° off the vertical polarity of the spacecraft with eyes open (i.e., they become inverted relative to the spacecraft interior) still tend to perceive “up” where their head is. After 30 days in space, some indications were found that the astronauts became more independent of the egocentric reference and were better able to accurately perceive their orientation with respect to the spacecraft, even after passive turns with eyes closed.

However, at least during the first few days of a space flight, astronauts try to avoid any disturbances of spatial orientation that arise from possible sensory conflicts between their egocentric reference and the visual surround. Systematic behavioral observations of astronaut motor behavior during short-duration space flight suggest that they prefer to align their own posture with the vertical polarity of the spacecraft [Tafforin and Lambin, 1993].

3.3.2. Spatial perception and representation

Other aspects of spatial information processing that have been investigated during space flight include the impact of microgravity on the perception of spatial relationships between two external objects, the mental representation of three-dimensional figures, and the proneness to geometric visual illusions. All of these aspects are highly relevant, not only for neuroscientists but also for an understanding of the basic cognitive processes needed for efficient work in space.

For example, a consistent assignment of spatial coordinates (e.g. “up”, “down”, “left”, “right”, “below”, “above”) to a perceived object is essential for communicating about it with others. For this kind of assignment, a common cognitive representation of space is needed based on a certain frame of reference. On Earth, several perceptual cues are available which might be used as such a reference. These include external cues provided by the coordinates of the visual background, the intrinsic coordinates of the perceived object or form, and the gravitational coordinates provided by vestibular and somatosensory receptors. In addition, egocentric cues might be used like the coordinates of the retina (i.e., coordinates of the visual field) or one’s own body orientation. Usually very few conflicts arise between all of these different perceptual cues, and in normal (upright) position all of them are perfectly aligned.

But what happens in space when the gravitational cues get lost? This was investigated in an early study by Friederici and Levelt [1987, 1990]. In this experiment, the astronauts were presented visual stimuli consisting of two balls (one black, one white) in different orientations along with line drawings of an intrinsically oriented object (tree) on both sides providing visual background cues. The task was to describe the spatial relations between the balls (e.g., “black ball left above the white ball”) under varying conditions of retinal orientation, orientation of background cues, and gravitational force. The results revealed that a consistent assignment of spatial coordinates still was possible in weightlessness. However, the dominant frame of reference used for this purpose was altered. On Earth, spatial assignments reported by the subjects largely were based on the gravitational vertical. In space, however, an egocentric frame of reference was chosen; that is, spatial assignments predominantly were determined by retinal coordinates and were only slightly affected by background cues. This corresponds nicely to the findings of subjectively perceived verticality in space described above. What remains to be investigated is how long the observed effect persists in space. Because the study involved astronauts during a relatively short space mission (eight days), nothing is known yet about possible effects of adaptation. Given the evidence discussed above (Section 3.3.1) that feelings of subjective verticality seem to diminish after about one month in space, it might be speculated that the same holds true for the significance of an egocentric frame of reference for spatial assignments. Clearly, more research is needed in this area.

The foregoing results suggest the importance of a retinal frame of reference for the perception of spatial relationships if gravitational cues are lost. A similar effect is reflected in a decreased proneness to well-known geometric visual illusions; e.g., the reversed T, the Müller-Lyer, or the Ponzo illusion. This has been shown from research during parabolic flights [Villard et al., 2005]. The basis of these illusions

are ambiguous visual arrangements consisting of vertical and horizontal lines that include misleading depth cues for a spatial (i.e. three-dimensional) interpretation of the arrangements. This in turn leads to false judgements about the relative size of the different lines. Under microgravity, the proneness to these illusions is significantly reduced for most people, and some individuals are able to perceive these figures as what they really are: two-dimensional drawings. Villard et al. [2005] take this as an indication of the significance of gravitation for the perception and interpretation of visual stimuli from the environment. In particular, they assume that gravitational and somatosensory cues usually represent an integral element of visual information processing, which supports a spatial (i.e. three-dimensional) interpretation of visual stimuli. The lack of graviceptive input in space seems to remove this tendency, at least to a certain extent.

3.3.3. Mental rotation and object recognition

Of specific importance for performance in space is the capability of recognizing objects seen in other orientations than normal (“upright”). Since free-floating astronauts are able to view the external world from any position they want, they often perceive the objects of their surroundings (including their own crewmates) in non-customary orientations. However, the orientation of forms or objects may affect recognition [Rock, 1986]. This particularly is the case if objects are perceived in extreme disorientation (e.g., inverted), which might easily happen in space. In classical studies on Earth, subjects were required to discriminate whether a rotated letter was presented in normal or mirror-reversed versions, and discrimination time was found to increase with the deviation of the letter from its normal upright position. In order to account for this effect, it has been suggested that spatial patterns like letters (but also other forms and objects) are first cognitively represented in a format corresponding to their normal orientation, and that the letter had to be “mentally rotated” to this position before a discrimination could be made [Cooper and Shepard, 1973]. Furthermore, there are examples where familiar objects perceived in non-customary orientations can hardly be recognized at all. One particularly interesting example concerns the perception of faces and the interpretation of facial expressions. Whereas it is possible to verify that a face is still a face if shown in inverted orientation, it is very difficult to identify it, even if it is a familiar one, and it is even more difficult to recognize any cues of facial expression, which would become immediately evident if the same face would be perceived in an upright position [Valentine, 1988].

It has been argued that processes of mental rotation involved in the perception of disoriented forms and objects might be facilitated in space due to the lack of gravitational cues or the larger opportunities of free-floating astronauts to accommodate to unusual visual angles [Clement et al., 1987]. However, this was based on evidence from anecdotal reports and could not be verified in recent space experiments conducted during long-duration space missions of up to seven months [Leone et al., 1995a,b]. Instead, the results of these studies suggested that mental rotation processes needed to compare two objects shown in different orientations were essentially the same in space as on Earth. Even more interesting, the “face inversion” effect remains in space. This was demonstrated by an experiment of de

Schonen et al. [1998]. In this experiment, astronauts learned photographed faces and had to recognize them afterwards when they were shown together with new ones. The results suggested that astronauts had considerably more difficulty recognizing previously learned faces if shown in inverted position, and this effect turned out to be independent of whether the faces were learned on the ground or during the first few days in microgravity.

This effect and the results from the mental rotation experiments give us a better understanding of the cognitive representation of complex forms and objects. The mental representation of such objects remains orientation-dependent (i.e., they are mentally represented in an upright position) even in the absence of gravity, which is of theoretical relevance for the field of visual cognition [Leone, 1998]. However, the finding of a persistent “face inversion” effect in space also has some psychological significance for the face-to-face communication between astronauts. In particular, it suggests that astronauts should assume the same orientation during face-to-face communication in order to avoid the disturbances and misunderstandings that arise from difficulties in correctly perceiving and interpreting facial expressions (which provide important non-verbal cues for interpersonal communication) [Cohen, 2000]. Interestingly, the same idea is suggested by the finding of egocentric frames of reference for perceiving verticality and making spatial assignments. Only astronauts who communicate with each other in the same body orientation will use the same frame of reference in talking about spatial relationships between objects in their surroundings.

3.3.4. Mass discrimination

A unique characteristic of the weightlessness space environment is the decoupling of weight and mass of objects. On Earth, the weight of objects can be sensed directly by analyzing proprioceptive information that is provided by pressure-receptors in the skin. Weight and mass together can be sensed by analyzing proprioceptive signals from skin, joints, and muscles when objects become accelerated by an active movement. Furthermore, the weight of an object provides a perfectly reliable cue for its mass. In space, weight information is no longer available and only the mass of objects can be sensed, requiring active accelerating movements.

Does this affect the sensitivity of mass discrimination? This question has been addressed by two psychophysical experiments during short-duration space flights [Ross et al., 1986, 1987]. In these experiments, astronauts were required to pairwise compare the mass of small balls by shaking them. The results of both of these experiments suggested that mass discrimination was impaired in space. More specifically, discrimination thresholds were raised by factors of 1.2 to 1.9 compared with those on Earth, depending on the amplitude and frequency of the shaking movements. However, it is not clear whether this was due to the loss of weight information or to disturbances of motor control and proprioception during shaking. In the latter case, it might be expected that impairments of mass discrimination diminish in the course of adaptation of the sensorimotor system to microgravity during prolonged space missions.

3.3.5. Aimed voluntary movements

As was described above, microgravity exerts several effects on the human sensorimotor system that may interfere with processes of motor programming and the execution of movements (see Section 3.2.1). If these effects are not fully compensated for by the human sensorimotor system, they can affect the precision and speed of voluntary movements, and eventually this becomes a limiting factor of astronaut performance in space, at least during the early flight phase. Indeed, some observations from the Skylab missions suggest that performance during the first few days in space can suffer from a slowing of movements as compared to performance on Earth [Kubis et al., 1977]

The preferred neuroscience paradigm which has been used to analyze the possible effects of microgravity on the speed and accuracy of voluntary movements is the analysis of aimed arm movements. In this paradigm, subjects are required to point to targets briefly presented at different positions in the frontal plane. Experimental conditions usually vary with respect to the direction of movements (vertical, horizontal) and to whether or not visual feedback is provided during movements. Several studies of this kind have addressed the *accuracy* of such pointing movements. Most of the early studies were conducted in aircraft during parabolic flights, where short-term (about 15–20 sec) periods of weightlessness alternated with states of hypergravity (2 g) [Bock et al., 1992; Gerathewohl et al., 1957; Ross, 1991; Whiteside, 1961]. The results from these studies suggested that the precision and reliability of aimed arm movements declined under the impact of microgravity. Yet the specific pattern of impairments differed. Whereas in some studies an overshooting of targets was found (which would be expected if the altered mechanical force induced by a lack of gravity was not compensated for during movement execution [Bock et al., 1992; Gerathewohl et al., 1957; Ross, 1991]), at least one study reported a consistent *undershooting* of targets [Whiteside, 1961]. This latter finding did not seem to be related to weightless effects on motor programming or control but was explained by a visual effect referred to as the “elevator illusion” (i.e., a visual mislocalization of targets as too high due to the effects of the altered gravitational forces on eye muscles).

However, to some extent the effects of parabolic flight seem to be related to the relatively short exposures to microgravity and the alteration with states of hypergravity, which make any adaptation difficult. In fact, only few impairments of accuracy have been reported from space flight, where pointing movements usually are investigated after several hours or even days in space. For example, Bock, Fowler and Comfort [2001] investigated pointing movements to stationary targets during a 16-day space mission. Targets were presented at a distance of 6 cm left, right, above, or below the center of a laptop computer screen. Comparisons of pre-flight, in-flight and post-flight performance did not reveal any significant decline of pointing accuracy, even though a slight increase in the variability of movement amplitude was found. In another study, horizontal pointing movements to the left and right of the center of the subject’s visual field were analyzed during short-duration and long-duration space missions [Berger et al., 1997]. Corresponding to the results from Bock et al. [2001], accuracy of these movements remained largely

unimpaired in space as compared to Earth, and this effect appeared to be independent of mission length.

Some deviating results were reported from studies where astronauts had to memorize the position of five targets and point to them in defined order with eyes closed. Under this condition, a consistent undershooting of target positions was found [Watt, 1997; Young et al., 1993]. However, this does not appear to reflect any disturbances of motor control or proprioception but to arise from difficulties in maintaining an external spatial map if vision to the targets is blocked.

In summary, investigations of accuracy of pointing movements during parabolic flights and in space have revealed a somewhat inconsistent pattern of effects that is difficult to explain. Although several different factors have been identified which in principle may contribute to a loss of precision of aimed voluntary movements in microgravity [Bock et al., 1992], it is hard to predict whether or not these factors will really lead to overt performance decrements and what the specific characteristics of these decrements will be.

More consistent results have been obtained from space flight studies where speed and kinematic characteristics of pointing movements have been analyzed. Results from these studies suggest that aimed arm movements, independent of their accuracy, are executed significantly slower in space [Berger et al., 1997; Bock et al., 2001]. Interestingly, this effect does not appear to be limited to this kind of movement but also can be observed in fine manual control movements [Newman and Lathan, 1999; Sangals et al., 1999]. For example, Sangals et al. [1999] analyzed the accuracy and kinematic pattern of movement in a discrete cursor positioning task during a short-duration space flight. In this task, the astronaut was required to align a screen cursor with a target position of varying distance by means of discrete left-right joystick movements. With respect to accuracy, no differences were found between pre-flight, in-flight and post-flight sessions. However, movement times increased in space, and analyses of the kinematic characteristics revealed significant alterations of the spatio-temporal pattern of movements. More specifically, a significant reduction in acceleration and velocity was found in the first part of the movement. This was compensated for in later parts by a prolonged deceleration phase in order to avoid an undershooting of targets and to maintain a sufficient level of accuracy. Somewhat surprisingly, these effects did not show a clear indication of adaptation in the course of the mission and were seen to the end of the 20-day space flight.

Several different factors have been invoked to account for the observed slowing of voluntary movements in space. One factor relates to an assumed higher dependency of movements on visual control, given that other feedback channels usually involved in motor control are likely to be disturbed in microgravity. However, effects of slowing also emerged in conditions with eyes closed [Bock et al., 2001] or when visual control of movements was blocked [Sangals et al., 1999], which casts some doubts on this explanation. Alternatively, it has been suggested that executing voluntary movements with the same speed and precision as on Earth requires a raised cognitive or attentional effort in microgravity. In order to reduce this extra effort, astronauts might choose to slow down movements; i.e., the effects observed would reflect some kind of speed-accuracy trade-off under the rigors of space flight [Bock et al., 2001]. This explanation has some plausibility given

additional findings from tracking tasks where speed must be maintained, and accuracy often has been found to be impaired during space flight or parabolic flight [Bock et al., 2001, 2003; Manzey and Lorenz, 1998a]. Yet this explanation appears to be too general to account for the specific alterations of kinematics found in the study by Sangals et al. [1999].

More likely, these latter effects can be explained by what has been referred to as the “re-interpretation hypothesis” [Bock et al., 1996]. According to this hypothesis, gravity-related changes in the weight of objects (including one’s own extremities) can easily be misinterpreted by the human motor system as changes of mass instead of changes of gravitational force. This seems to be obvious given the “natural” relationship between weight and mass on Earth, where the weight of an object (resulting from gravity) usually provides a direct and reliable clue to its mass. In the “weightless” environment in space, this direct relationship does not apply. As a consequence, the motor control system might erroneously underestimate the mass of extremities to be moved, which then results in specifying incorrect force-time characteristics for movements of arm, hand, or fingers which need to be corrected during movement execution [Sangals et al., 1999]. Depending on how fast such a correction can be performed, movement times may be prolonged to varying degrees.

To sum up, there are some consistent findings that aimed voluntary movements slow down in space, at least if there is no task-inherent force to maintain a certain work pace. This effect seems to emerge for a variety of different movements, ranging from movements of the whole arm to delicate movements of hand and fingers, and it is in line with earlier observations of a slowing of working speed in space that also has been attributed to disturbances of movements [Kubis et al., 1977]. The specific sources of this slowing still are under investigation. Nevertheless, the currently available data from space flight suggest that this effect is related to microgravity-induced changes in the sensorimotor system, which impairs the efficiency of motor programs acquired on Earth, and which have to be compensated for by enhanced control processes during movement execution in space.

3.4. Empirical findings from space: human performance monitoring

The results of experiments reviewed so far have specifically addressed the effects of one particular stressor, microgravity, on different cognitive and psychomotor functions. Although the described effects can impair the performance efficiency of astronauts during the first days in microgravity, most of these effects are rather specific and do not provide a comprehensive description of performance and operational capability in space. In particular, they do not take into account possible impairments related to non-specific stress effects induced by other space-relevant stressors (e.g., workload, sleep disturbances, emotional tension).

A second line of research on human performance during space flight consists of performance monitoring studies [Manzey and Lorenz, 1998a; Manzey, 2000a]. These studies expand the scope of view in two respects. First, the main objective of performance monitoring studies is to describe performance changes that occur

during the course of a space mission, independent of the specific stressors that cause these effects. Thus, the variety of information processing functions that are assessed are increased and include not only functions that might be expected to suffer from microgravity but also those that have been found to react to environmental stressors in general (e.g., attention, memory, reaction time). In typical studies of this kind, performance assessment is done by using short-term laboratory tasks that are based on sound theoretical models and have been shown by ground-based research to probe some defined processing functions. Second, the time course of effects is considered in more detail. That is, performance assessments usually are conducted repeatedly throughout a space flight in order to describe possible variations in performance efficiency, which are dependent on time.

Below, results from performance monitoring studies during short-duration and long-duration space missions will be described in some detail. Particular emphasis will be placed on the results of a research program that included three studies during different space missions to the former Russian space station Mir, including the only available quantitative study of astronaut performance during an extraordinary long-duration space mission [Manzey, 2000a,b]. A list of all the different performance functions probed and tasks used in space flight performance monitoring studies conducted during the last 15 years is provided in Table 3.2.

3.4.1. Results of performance monitoring during short-duration space flight

Most of the performance monitoring studies conducted in space have monitored the performance of astronauts during short-term spaceflights lasting up to two weeks. With respect to the kind of performance functions probed they might be classified into two groups.

One set of studies primarily has focussed on some basic cognitive performance functions like, e.g. visual search, memory and response choice [Benke et al., 1993; Kelly et al., 2005; Ratino et al., 1988]. The very first study of this kind was conducted by Ratino et al. [1988]. They monitored the performance of four astronauts at flight days 2, 3, and 4 of a 6-day Shuttle flight. The test battery of this study included a simple reaction time task, a choice reaction time task, and a time estimation task. The two reaction time tasks were chosen as general indicators of speed and accuracy of cognitive performance. The time estimation task was chosen as a result of anecdotal reports from astronauts that suggested an altered time sense in space. The latter was assumed to contain “elements of excessive mental workload, information overload, and cognitive processing involving inferences, judgment, and decision-making” [Christensen and Talbot, 1986, p. 204]. However, only subtle performance effects were observed in this study. Choice reaction time was found to be impaired in three astronauts during the second and/or third day in space and was associated with reported symptoms of mild space motion sickness. Performance in the time estimation task showed a tendency to decline as the mission proceeded, with most striking impairments during the fourth day in space and immediately after reentry and landing. In particular, an overestimation of brief time intervals (2 sec) was found in all astronauts, which suggests that the perception of the passage of time had slowed down. The time course of this effect indicated that it might be related to non-specific stress effects, probably resulting from cumulative

workload at the end of the space mission and the burden of reentry. Yet the effect was small, and the comparison to pre-flight performance became statistically significant only for the first assessment back on Earth immediately after landing.

Only minor changes in cognitive processing also were reported from a second performance monitoring study involving one cosmonaut during a 6-day Mir flight [Benke et al., 1993]. In this study, a test battery was used consisting of two kinds of tasks: The first one including “classical” cognitive tasks (simple reaction time, choice reaction time, Stroop-like interference task) and the second one including several visuospatial tasks (e.g. spatial perception, spatial memory). Whereas the former were used in order to assess non-specific stress effects on speed and accuracy of fundamental cognitive functions, the latter set was used to monitor specific effects of microgravity on spatial processing functions. However, none of these tasks revealed any significant performance decrements during the flight compared to the pre-flight baselines.

Table 3.2. Summary of Performance Functions Probed and Tasks Used for Performance Assessment in Performance Monitoring Studies during Space Flight.
Performance usually has been assessed by speed and/or accuracy measures.

Performance Function/Task	Description	Study
<i>Reaction Time (RT)</i>		
Simple RT	Manual response to stimulus (one stimulus-response alternative)	Benke et al., 1993; Ratino et al., 1988;
Choice RT	Manual response to stimulus (2–9 different stimulus-response alternatives)	Benke et al., 1993; Ratino et al., 1988;
<i>Spatial Processing</i>		
Matrix Rotation	Comparison of spatial patterns	Eddy et al., 1998; Schiflett et al., 1995
Line Task	Comparison of direction of different lines	Benke et al., 1993
Spatial Memory Task	Memorizing of spatial patterns	Benke et al., 1993
Manikin Task	Evaluation of orientation of small “Manikin” figures	Eddy et al., 1998 ; Schiflett et al., 1995
<i>Working Memory</i>		
Memory-Search Task	Comparison of probe letters with a set of previously memorized letters (memory load varied by size of the memory set: 1–6 letters)	Eddy et al., 1998; Kelly et al., 2005; Manzey et al., 1993, 1995, 1998; Newman and Lathan, 1999 ; Schiflett et al., 1995
Continuous Recognition Task	Continuous memorizing and retrieval of letters	Eddy et al., 1998; Schiflett et al., 1995
<i>Reasoning</i>		
Grammatical Reasoning	Verification of truth values of sentences	Manzey et al., 1993, 1995, 1998
Mathematical Processing	Adding/subtracting of three single-digit numbers	Eddy et al., 1998; Schiflett et al., 1995

(Continued)

Table 3.2. (Continued)

Performance Function/Task	Description	Study
<i>Attention</i>		
Attention Switching	Performance of two randomly alternating tasks (Mathematical Processing and Manikin)	Eddy et al., 1998 ; Schiflett et al., 1995
Dual-Task	Simultaneous performance of two tasks (memory search and unstable tracking)	Manzey et al., 1993, 1995, 1998; Eddy et al., 1998; Schiflett et al., 1995
<i>Psychomotor Performance</i>		
Unstable Tracking	Compensation of deviations of a randomly moving cursor from target position by means of joystick movements	Eddy et al., 1998; Manzey et al., 1993, 1995, 1998, 2000; Schiflett et al., 1995
Fittsberg Task	Positioning of a cursor on targets of varying distance and size by means of input device (e.g., joystick, trackball)	Newman and Lathan, 1999
<i>Others</i>		
Interference Task	Response to congruent and incongruent stimulus configurations (cognitive processes of response inhibition and selection)	Benke et al., 1993
Time Estimation Task	Estimation of time intervals of 2s–16s (internal time processing)	Kelly et al., 2005; Ratino et al., 1988
Acquisition of response sequences	Learning of specified 10-response sequences (e.g. 3-7-7-1-9-1-3-9-3) on a keypad across repeated trials (memory for response sequences)	Kelly et al., 2005
Digit-Symbol Substitution	Complex stimulus-response mapping (combination of visual search, visual encoding, and memory)	Kelly et al., 2005

In line with this general pattern of results are the results of the recent study that was conducted with four astronauts during a 10-day Shuttle mission [Kelly et al., 2005]. In this study, four different performance tasks were used, including a time-estimation task, a Sternberg memory task with memory load differing between one and six digits, a digit symbol substitution tasks probing a combination of visual search, memory and response functions, and a response acquisition task. The latter represented an interesting expansion of tasks as compared to earlier studies by involving aspects of sequence learning. But even this study did not reveal any clear performance effects during spaceflight. There were only a few indications of performance decrements found, which suggested that memory load might affect performance to a larger extent in space than on Earth. But these effects were small and not easy to explain.

All in all, the results of these three studies suggest that the extreme conditions of spaceflight do not lead to obvious performance decrements in basic cognitive functions. However, one main limitation of this set of studies can be seen in the selection of tasks used for performance monitoring. Although all of these tasks were well-chosen with respect to their psychometric properties and validity, they did not probe some of the functions that may be most sensitive to direct and indirect effects of spaceflight-related stressors, such as divided attention and complex psychomotor functions (see Section 3.2.2).

These latter functions were included in a second set of performance monitoring studies [Eddy et al., 1998; Manzey et al., 1993, 1995; Newman & Latham, 1999; Schiflett et al., 1995]. Manzey et al. monitored the performance of one cosmonaut during an 8-day mission to the Mir station. All tasks used for performance assessment were chosen from the Standardized Tests for Research with Environmental Stressors (STRES) [AGARD, 1989]. Specifically, the following tasks were used (see Manzey et al., 1993, 1995 for a detailed description of these tasks): (1) Grammatical Reasoning, (2) Memory Search (two different levels of memory load), (3) Unstable Tracking, and (4) a dual-task involving concurrent performance of tracking and memory search. The reasoning behind this task selection was to probe information processing functions, which are known to react sensitively to adverse effects of environmental stressors or which might become impaired by direct effects of microgravity on sensory-motor processes. More specifically, the Grammatical Reasoning task and the Memory Search task were used to monitor speed and accuracy of cognitive functions involving working memory under varied memory load. The dual-task was chosen to capture possible attentional selectivity effects, and the Unstable Tracking task was selected to monitor perceptual-motor functions by a task cognitively more complex than those usually analyzed in neuroscience research (e.g., aimed arm movements). A total of 13 performance assessments were conducted during the first seven days of the mission. Results were compared to pre-flight and post-flight data that were obtained during the week before launch and after landing, respectively. The main results of the study are presented in Figures 3.1 and 3.2.

In accordance with the results of Ratino et al. [1988], Benke et al. [1993], and Kelly et al. [2005], no impairments of speed and accuracy of basic cognitive functions were found during the flight. With one exception (a significant slowing of grammatical reasoning speed at mission day 4), neither grammatical reasoning nor memory search performance declined significantly during the stay in space (Figure 3.1). Instead, significant improvements in performance were observed during some single sessions in space and at several post-flight sessions. However, as expected clear disturbances of tracking and dual-task performance emerged, which provided evidence for the impact of space flight-related stressors on perceptual-motor and attentional functions (Figure 3.2). Tracking performance decrements exhibited a striking triphasic time course. Compared to the pre-flight baseline, tracking errors significantly increased during the first three days in space, showed a brief intermediate recovery to baseline performance, and increased again significantly in

the last three days of the space mission (Figure 3.2, upper graph). Dual-task performance decrements apparently emerged independent of the difficulty of the memory search task during the entire stay in space and were indicated by increased single-to-dual performance decrements in tracking and/or memory search, compared with pre-flight baseline performance. Figure 3.2 (lower graph) illustrates this effect

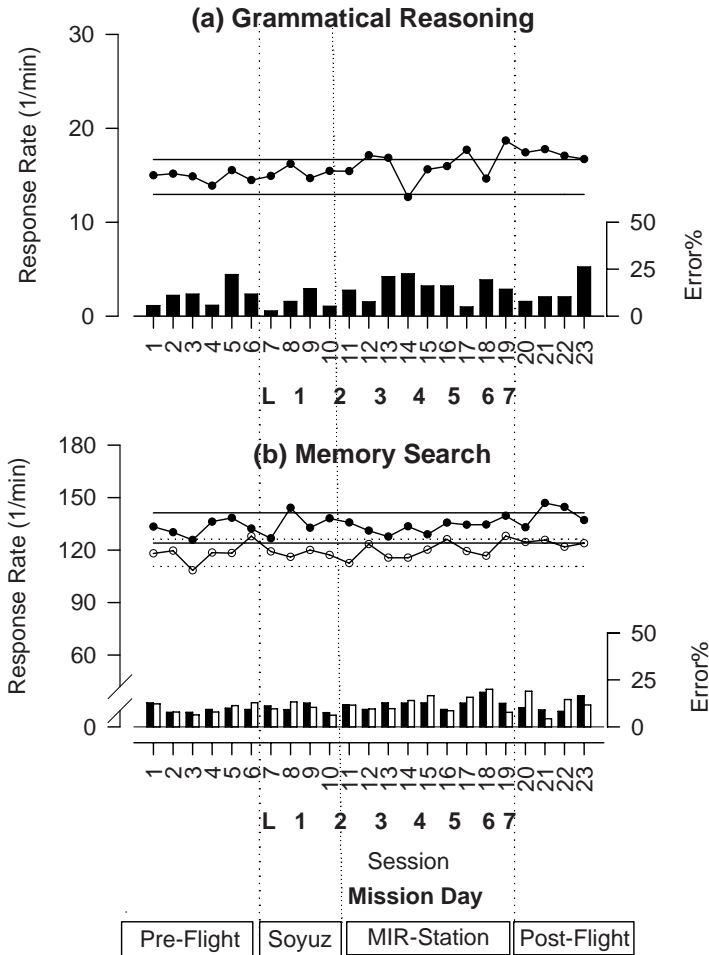


Figure 3.1. Performance effects during 8-day spaceflight. Mean response rates (lines) and error rates (bars) as a function of experimental sessions for (a) grammatical reasoning and (b) memory-search. Memory-search data are presented separately for both levels of memory load: two-letter search (dark circles/bars) and four-letter search (light circles/bars). The horizontal lines in the graphs correspond to the upper and lower confidence limits defining average pre-flight performance as the reference for pairwise comparisons (Bonferroni contrasts) with performance at each subsequent session. Adapted from Manzey et al. [1993, 1995].

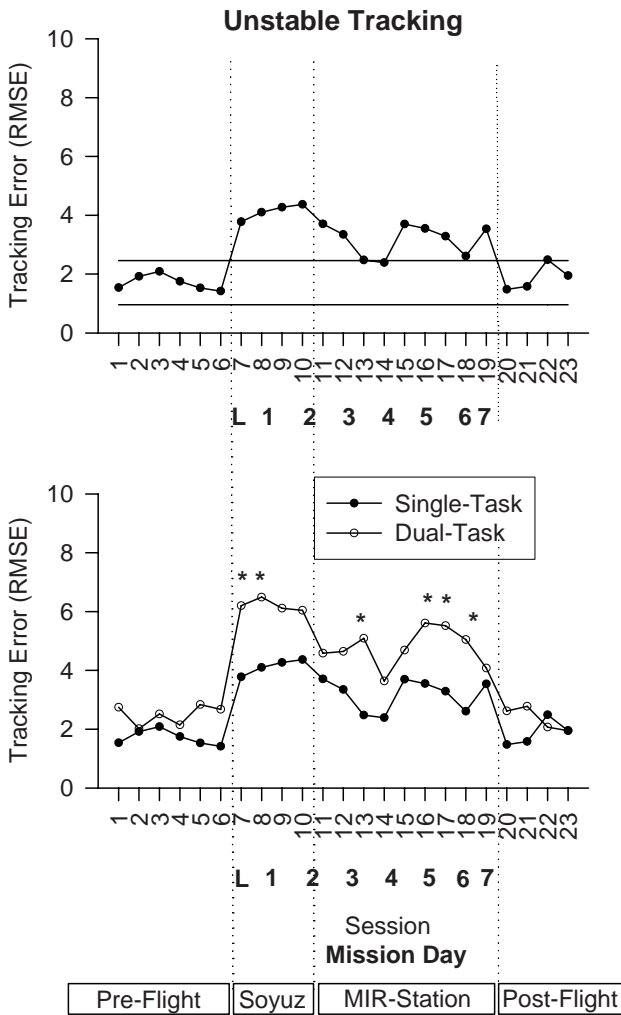


Figure 3.2. Tracking Performance Effects during 8-day Space Flight. *Upper graph:* Single-task tracking error as a function of experimental session. *Lower graph:* Contrast of single-task tracking error and dual-task tracking error. Since dual-task tracking performance was not affected by the difficulty of the memory search tasks, it has been pooled across memory load conditions. The horizontal lines in the *upper graph* correspond to the upper and lower confidence limits, defining average pre-flight performance as the reference for paired comparisons (Bonferroni contrasts) with performance at each subsequent session. The asterisk in the *lower graph* indicate significant increments of single-to-dual performance differences compared to pre- and post-flight baseline. Adapted from Manzey et al. [1995].

for the tracking task. During both pre-flight and post-flight sessions, tracking performance remained almost unaffected by concurrent memory search (i.e., only slight performance differences emerged between the single-task and both dual-task conditions). However, in space significant single-to-dual performance decrements were observed that occurred independent of the induced memory load.

Although these results were obtained from a single astronaut, they seem to represent replicable effects. This is suggested by very similar patterns of effects that have been reported from two performance-monitoring studies conducted during American Shuttle flights [Newman and Lathan, 1999; Schiflett et al., 1995]. Newman and Lathan [1999] probed the performance of four astronauts by means of complex tasks combining memory search and a psychomotor task that required subjects to superimpose a cursor with a defined target position as fast as possible ("Fittsberg" task). Similar to the results above, they did not find any performance decrements in the memory search task, but they found significant disturbances of positioning movements in space that were reflected in a significant slowing of movement times across different input devices (joystick, trackball). Schiflett et al. [1995] assessed the performance of three astronauts during a 13-day space flight. Three of the performance tasks used in this study were similar to those used by Manzey et al. [1993, 1995] (i.e., memory search, unstable tracking, and dual-task). The other probe tasks included another memory task (continuous recognition) and an attention switching task, where two tasks, involving spatial orientation ("Manikin") and mental arithmetic ("mathematical processing"), had to be performed in randomly alternating order. Comparisons of daily in-flight assessments with performance predicted on the basis of pre-flight learning curves revealed significant degradations of tracking, dual-task, and attention-switching performance in two of the three subjects. Even more interesting, these performance decrements – similar to the results of Manzey et al. [1993, 1995] – emerged most clearly at the beginning and the end of the space mission, with the latter related to subjective reports of raised fatigue. In contrast, all other tasks showed a somewhat inconsistent pattern of effect, with some degradation in two subjects and considerable improvements in the third.

Altogether, these different studies from short-duration space flights provide a fairly consistent pattern of effects. Whereas elementary cognitive functions like memory, reasoning, sequence learning or spatial processing remained more or less unimpaired in space, or even improved in some subjects [Benke et al., 1993; Kelly et al., 2005; Manzey et al., 1993; Newman and Lathan, 1999; Schiflett et al., 1995], performance decrements were consistently observed in psychomotor tasks and tasks demanding higher attentional functions [Manzey et al., 1993, 1995; Newman and Lathan, 1999; Schiflett et al., 1995]. In addition, simple and choice reaction times seem to slow down only in periods of acute space motion sickness [Ratino et al., 1988].

In contrast, Eddy, Schiflett, Schlegel, and Shehab [1998] failed to find impairments of tracking and dual-task performance in four astronauts during a 18-day space flight but reported some performance decrements in a mathematical processing task. They also found a considerably reduced flexibility in attention switching in two of the subjects. However, in this study persistent learning effects and a conservative statistical approach, which only allowed for an overall testing of

performance effects across all in-flight sessions, might have masked subtle performance changes in single sessions. Learning effects were most pronounced in one astronaut who showed a sudden improvement of tracking performance shortly before launch and in space, which the authors attributed to the detection of a more efficient tracking strategy [Eddy et al., 1998, p. 202]. However, a re-analysis of the data by applying a more sophisticated single-case statistical approach [Shehab and Schlegel, 2000] suggests that also in this study significant decrements of tracking performance occurred in two of the four subjects during the first performance assessment in flight [Shehab, personal communication].

3.4.2. Results of performance monitoring during long-duration space missions

Do effects similar to those observed during short-duration space flight also emerge during long-duration missions? And if yes, how long do they persist? Do they represent chronic phenomena, or do they diminish in the course of adaptation to the conditions of space flight? These questions were addressed in the only performance monitoring study that has been conducted so far during a long-duration space flight [Manzey et al., 1998]. This study was performed during the 438-day mission of the Russian cosmonaut V. Polyakov on board the Mir station, which set a new world record for human duration in space. The results of this single-case study are particularly interesting because they suggest that the impairments of individual performance are closely related to adaptation to the extreme living and working conditions in space over time. In addition, the results provide first insights into the stability of human performance after complete adaptation to the space environment, as well as possible performance-related effects of re-adaptation to Earth conditions after an extraordinary long-term stay in a space habitat.

Performance was assessed by the same set of laboratory tasks from the AGARD-STRES battery that has been described above. The study included a total of 41 experimental sessions: 4 pre-flight assessments, 29 in-flight assessments (8 assessments during the first month and 7 assessments each during the 2nd to 4th, 7th to 9th, and 11th to 14th months in space), 6 post-flight assessments during the first two weeks after return to Earth, and 2 follow-up assessments half a year after the mission. In order to get a comprehensive picture of the cognitive and emotional state in space, performance assessment was supplemented by subjective ratings of mood and workload.

Clear impairments of grammatical reasoning and memory performance were found in the last two experimental sessions *prior* to launch, compared to baseline assessments three months and one month before. After entering the space environment, performance in these tasks recovered rapidly to baseline levels and remained more or less stable across all in-flight, post-flight, and follow-up assessments. This is shown for speed and accuracy of grammatical reasoning in Figure 3.3a, and a similar picture emerged also for the memory search task. A different pattern of effects, however, was found for tracking performance (Figure 3.3b). Even though tracking performance also was significantly impaired at one of the pre-flight sessions close to launch, more pronounced tracking performance decrements were found during the first week in space. This effect turned out to

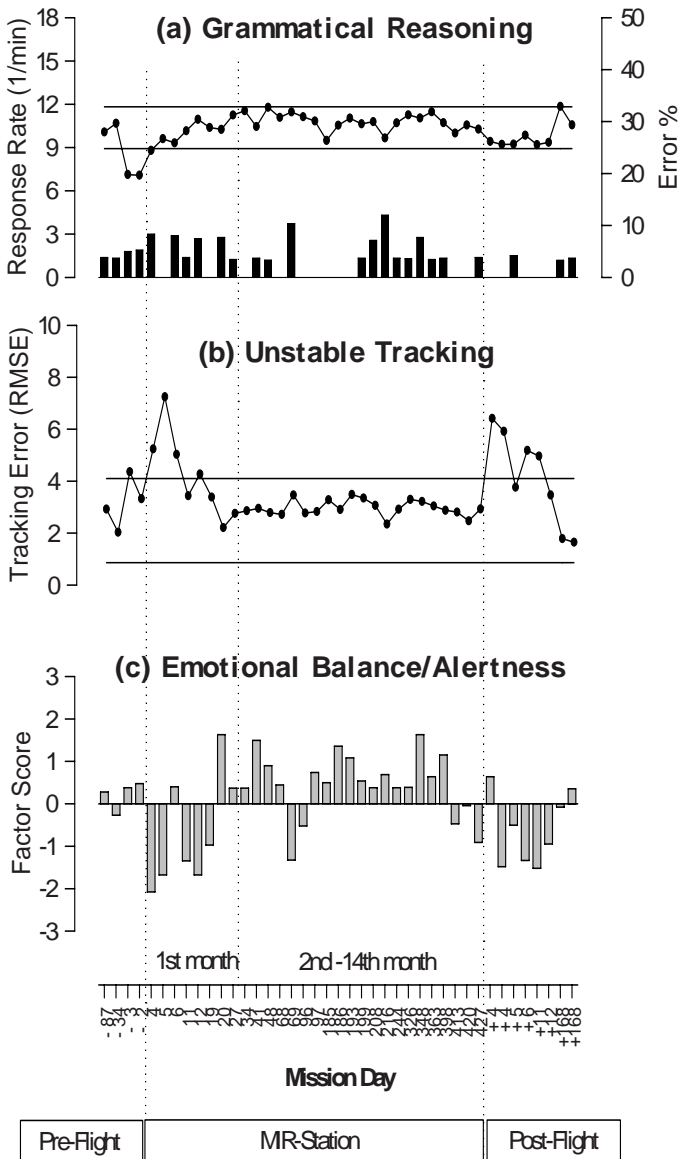


Figure 3.3. Performance Effects during Long-term Space Flight. (a) Grammatical reasoning performance (mean response and error rates) as a function of experimental session. (b) Root mean squared tracking error (RMSE) as a function of experimental session. (c) Factor scores of mood factor "Emotional Balance/Alertness" as a function of experimental sessions. The *horizontal lines* in the graphs "a" and "b" correspond to the upper and lower confidence limits defining average pre-flight performance at mission days -87 and -34 as the reference for paired comparisons (Bonferroni contrasts) with performance at each subsequent session. Adapted from Manzey et al. [1998].

represent a transient phenomenon, however. After the first three weeks in space, tracking performance was back to pre-flight baseline levels and remained stable at this level throughout all of the remaining in-flight sessions. However, clear disturbances of tracking performance reappeared during the first two assessments after the flight when the subject was forced to re-adapt to Earth conditions. Again, a recovery of performance was observed across post-flight assessments, and impairments of tracking were not seen any more at the follow-up sessions. Further performance decrements were observed in the dual-task, indicating increased difficulties in dividing attention between tracking and memory search in space. Even though these effects were less pronounced than those found during the short-duration space flight, it was striking that they also occurred during the first two to four weeks in space and again emerged independent of the memory load [Manzey et al., 1998]. Comparisons of the time course of performance effects and subjective mood and workload ratings revealed that the impairments of performance were closely associated with alterations in perceived mood and workload. Changes of mood emerged for a mood factor mainly representing ratings of "emotional balance" and "alertness" (Figure 3.3c). These changes indicated that during the first three weeks in space and the first two weeks after return to Earth, alertness and emotional balance were perceived as low, compared to pre-flight and most other in-flight sessions. This would be expected to have an impact on performance. Correlation analyses revealed a significant relationship between the reported changes of mood and both tracking and dual-task performance. In addition, doing the different performance tasks was perceived as more effortful during these periods.

What can be learned from these results? First, the findings for the two elementary cognitive tasks (grammatical reasoning, memory search) provide more empirical support for the conclusions drawn from studies during short-duration space flight that impairments of basic cognitive processes are not to be expected in space or, at least, can be fully compensated for by increased efforts of the astronaut. In addition, they prove the generalizability of this assumption to prolonged space missions.

Second, the findings of tracking performance decrements and increased dual-task interference effects during the first in-flight phase support the previous findings of disturbed visuo-motor and attentional processes during space flight. Beyond that, they suggest that these phenomena represent only transient effects that disappear within the first month in space. This period seems to represent a critical adaptational phase that is associated with impairments in subjective mood and well-being. Furthermore, the effort to accomplish pre-trained tasks may be perceived as being greater in space during this period than on Earth. This agrees well with a 2-stage model of human adaptation to long-duration space flight, with the first stage of primary adaptation to space lasting up to 6 weeks (see Chapter 2). It is further in line with early reports from Skylab astronauts, where work speed was observed to slow down during the first week in space [Kubis et al., 1977; see below Section 3.5], and it coincides with the novelty effect reported by Kanas and his colleagues [2001] that seemed to affect the emotional and interpersonal state of American astronauts during their first few weeks on-orbit on the Mir space station (see Section 4.8.2).

Third, the full recovery from performance and mood disturbance in space, and the stability of mood and performance during more than 400 days, suggest that it is possible (after successful adaptation to the space environment) to maintain performance efficiency on a comparatively high level, even during long-duration space missions.

Finally, the post-flight effects observed during the first two weeks after landing suggest that during re-adaptation to Earth conditions after a long-duration space mission, similar performance and mood-related effects are to be expected as during adaptation to the space environment. However, the results of follow-up assessments half a year after the mission reveal that even extremely long stays in space do not lead to long-lasting performance disturbances after returning to Earth.

3.4.3. Impairments of tracking and dual-task performance in space: effects of microgravity, stress, or both?

How do the impairments of performance observed during short-duration and long-duration space missions relate to the two sets of factors, microgravity and non-specific stress effects, which have been thought to cause performance decrements in space? A straightforward explanation is clearest for the dual-task performance decrements and perhaps also for the increased difficulties in attention switching observed in different studies [Eddy et al., 1998; Manzey et al., 1995, 1998; Schiflett et al., 1995]. These effects seem to result primarily from attentional selectivity effects; i.e., a reduced capability to divide attention between different tasks or task goals. Originally, attentional selectivity was assumed to result from a reduced spatial distribution of attention in states of high arousal [Easterbrook, 1959]. In more recent theoretical approaches, however, attentional selectivity has been defined as a compensatory performance adjustment under stress and high workload which is characterized by focussing attention on some (high-priority) task requirements at the expense of other (secondary) elements in order to reduce the overall attentional demands [Hockey, 1997, see Section 3.2.2]. Given that attentional selectivity has been found to accompany a variety of stress states induced by internal or external stressors (e.g., fatigue, anxiety, noise, heat), it appears most likely that the dual-task performance decrements observed during space flight reflect such a stress-related effect that arises from the heavy burden of adapting to the extreme living and working conditions in space. In line with this interpretation is the finding that dual-task performance may remain unimpaired during space flight if a dual-task is used that only places minimum demands on divided attention by providing a highly compatible combination of tasks, with the second task embedded into the first [Fowler et al., 2000a].

In contrast, the explanation of the tracking performance decrements observed in space is less clear-cut [Manzey and Lorenz, 1998a; Manzey et al., 2000]. Visuo-motor tracking represents a perceptual-motor task that not only demands perceptual-motor functions (e.g., fast transformations of a visual input into appropriate movements of a joystick) but also places comparatively high demands on attentional processes. Thus, the tracking performance decrements observed in space, similar to the dual-task effects, can be related to non-specific stress effects leading to decreased attentional capacity. This is suggested by the obvious associations

between tracking error and subjective fatigue or mood ratings in some studies [Manzey et al., 1998; Schiflett et al., 1995]. It further is supported by findings of similar (though weaker) disturbances of tracking performance in Earth-bound simulations of space flight, which obviously cannot result from any stressor specific to the space environment but seem to arise from confinement and/or the decreased quality of the ambient atmosphere [Lorenz et al., 1996; Manzey and Lorenz, 1998b].

On the other hand, the degradations of tracking performance found during the first assessment(s) in space [Manzey et al., 1993, 1998; Schiflett et al., 1995] and after return to Earth from long-duration space missions [Manzey et al., 1998] suggest that the well-known effects of microgravity on motor control processes might have contributed to these performance deficits as well. These considerations have led to a two-factor hypothesis of tracking performance in space [Manzey, 2000a; Manzey and Lorenz, 1998a; Manzey et al., 1998]. According to this hypothesis, impairments of tracking performance during space flight are related both to microgravity-induced changes in the sensory-motor system as well as impairments of attention due to non-specific effects of workload and fatigue. It is assumed that the first factor disturbs tracking performance early in flight, whereas the second primarily is responsible for tracking performance decrements after some time into the mission.

This hypothesis has been addressed in a space flight study involving one cosmonaut on a 20-day space mission to Mir [Manzey et al., 2000]. In this study, the same unstable tracking task was used as in the studies before. Tracking performance was assessed repeatedly at 6 pre-flight, 6 in-flight, and 7 post-flight sessions. The results provided empirical evidence for the two-factor hypothesis. In accordance with the results from the earlier research, a comparison of pre-flight and in-flight performance revealed significant tracking performance decrements in space. These emerged at the first attempt to perform the task after exposure to microgravity and re-appeared after an intermediate recovery during the second and third week of the mission (Figure 3.4a). In addition, tracking errors increased during the first post-flight week. Analyses of subjective data suggested some correspondence between the tracking performance decrements that occurred later in-flight and the post-flight sessions, with increases of workload or decreases of alertness (Figure 3.4b).

In contrast, only subtle changes of alertness and workload were observed early in-flight. Fine-grained analyses of tracking performance based on control-theoretical models of tracking behavior revealed a qualitative difference between tracking impairments at the early and late flight phases, which is in keeping with the two-factor hypothesis. In particular, the performance decrements observed early in-flight were almost exclusively related to an increase of the effective time delay during tracking; i.e., a prolongation of the time needed to transform the visually perceived tracking signal into appropriate control movements. Such an effect was not found during any assessments on Earth and appears to result from microgravity-related disturbances of the internal processing of the tracking signal or of the generation of control movements in space, similar to those responsible for the slowing observed in other voluntary movements (see Section 3.3.5). However, the tracking impairments

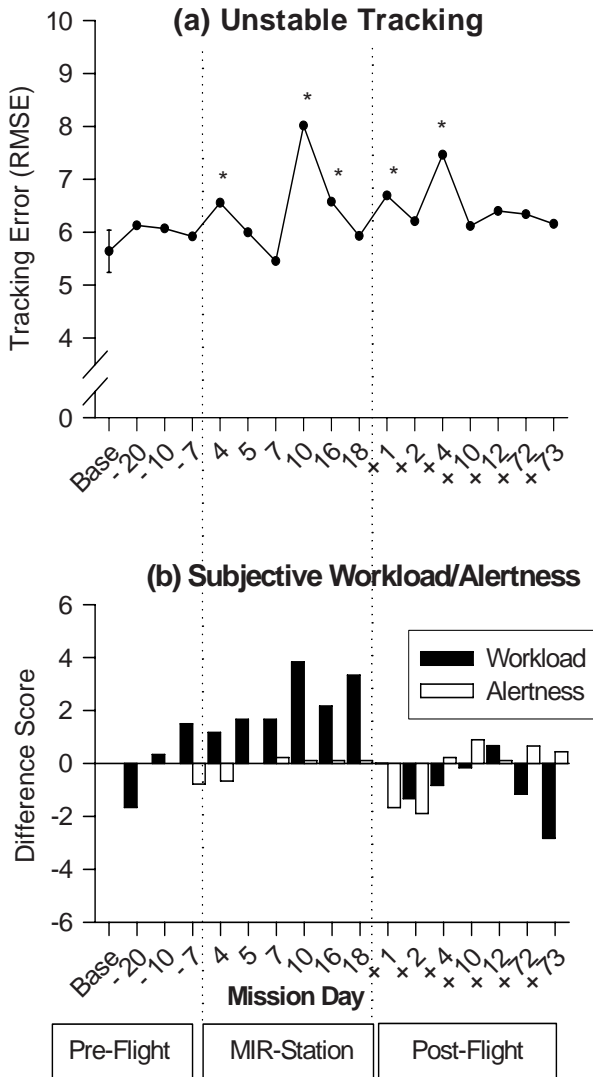


Figure 3.4. Tracking Performance and Subjective Ratings of Workload and Alertness during 20-day Space Flight. (a) Root mean squared tracking error (RMSE) as a function of experimental session. The error bar represents the standard deviation of performance across the three sessions that have been pooled to derive the baseline value. Significant increments of tracking error revealed by paired Bonferroni comparisons of baseline tracking performance with performance in all other experimental sessions are marked by an asterisk. (b) Subjective alertness and workload ratings. Shown are difference scores with respect to baseline ratings. Adapted from Manzey et al. [2000].

observed at later in-flight and post-flight sessions also seemed to be caused by impairments of attentional processes. That was concluded from the finding of reduced movement amplitudes (reduced “tracking gain”) and an increase of movements uncorrelated to the tracking signal (“remnant”); i.e., effects that usually are reported from ground-based research when subjects perform a tracking task in states of raised workload or reduced attention [e.g. Wickens and Gopher, 1977].

In conclusion, the results of performance monitoring studies during short-duration and long-duration space missions supplement and extend the knowledge gained from neuroscience research related to information processing. The finding of tracking performance decrements fits nicely with the results of the analyses of aimed arm and fine motor control movements described in Section 3.3.5.. These latter effects have been explained by the “re-interpretation hypothesis”, which states that motor control in space might be affected by the de-coupling of mass and weight that in turn can lead to a mis-calibration of muscle forces needed to execute certain movements. It might be assumed that these same mechanisms have contributed to the decrements in tracking performance, at least during the first assessments in space. This assumption receives some support from a re-analysis of the Manzey et al. [2000] data, which suggests that observed tracking performance decrements in space might be explained by inappropriate calculations of muscular forces that likely results from an underestimation of masses due to weightlessness [Heuer et al., 2003]. Even though impairments arising from these effects can be compensated for very rapidly if visual feedback is provided, as in the tracking task, these compensatory processes seem to raise the attentional demands of the task. This probably makes them particularly prone to the adverse effects of stress and workload, at least for the first four weeks of a space mission. Furthermore, the capability of working on two tasks simultaneously can become degraded during adaptation to space flight. This impairment seems to result from non-specific stress effects leading to attentional selectivity or a change to less attention-demanding task strategies. Because comparable effects have not been observed in ground-based simulations of space flight [Manzey and Lorenz, 1998b; Shehab et al., 1998], the finding of dual-task performance decrements in space may be taken as evidence for the highly demanding conditions of real flights. However, neither performance decrement has been found to persist for more than the first four weeks of a space mission. Thus, they seem to be transient phenomena, which are mainly associated with primary adaptation to the altered living and working conditions in space.

In contrast, performance on tasks that probe basic cognitive processes like memory-retrieval, logical reasoning, or spatial processing show a surprising resiliency against the detrimental effects of the space environment, even though deteriorations occasionally have been observed in these functions [Eddy et al., 1998; Schiflett et al., 1995]. The finding of unimpaired spatial processing in space is in line with corresponding conclusions from cognitive neuroscience studies and generalize it to a variety of different spatial processing tasks. Furthermore, the general result of unimpaired cognitive performance is in accordance with similar results from ground-based space flight simulations [Vaernes et al., 1993] and prolonged bed rest studies with head-down tilt, a situation often used to simulate certain effects of space flight (hypokinesia, cardiovascular de-conditioning) [Pavy-Le Traon et al., 1994; Shehab et al., 1998]. Yet the mere fact that no overt performance decrements have been found in these cognitive tasks does not

necessarily indicate that the underlying cognitive processes remain unchanged in space. Alternatively, it can be assumed that it is easier in these tasks to protect performance against the detrimental effects of the space flight environment (e.g., by increased effort) than it is in tracking and dual-tasks, which already require a comparatively high level of attention and effort.

These conclusions are based on a comparatively small data base [Casler and Cook, 1999]. This holds in particular for the data from long-duration space missions, where only one subject's performance has been monitored so far. However, the convergence of results of performance monitoring and cognitive neuroscience research during short-duration space flights and the early periods of long-duration space missions are striking, and they suggest at least some generalizability of the observed performance effects during adaptation to space.

3.5. Complex cognitive and perceptual-motor skills

Cognitive neuroscience research and performance monitoring studies have been restricted to investigations of relatively elementary cognitive functions probed by specific laboratory tasks. Even though this presents an advantage in identifying the possible effects of space flight-related stressors on specific aspects of human information processing, it leaves the question open as to what extent the findings can be generalized to more complex cognitive and perceptual-motor skills, such as those involved in performing real operational or scientific mission tasks in space.

According to the compensatory control model of stress and performance described above (Section 3.2.2), performance of complex tasks can be better protected against stress effects than performance of simple tasks. This is assumed because individuals usually are concerned more with maintaining performance during such tasks. In addition, complex tasks usually provide more degrees of freedom for adaptive changes of performance strategies. However, this does not mean that the underlying skills are invulnerable to stress effects. Rather, it suggests that in this case stress effects may not be reflected in overt performance decrements but only in more subtle (latent) effects; e.g., increased effort or changes in the strategies applied to master a certain task.

3.5.1. Ground-based studies

Specific studies addressing this question have been conducted during ground-based simulations of space flight and in analog environments [Hockey and Wiethoff, 1993; Hockey and Sauer, 1996; Sauer et al., 1999a, 1999b, 1999c]. In these studies, the effects of simulated space flight conditions on complex task performance were analysed by means of a "micro-world" (i.e., a computer-based task environment that is sufficiently complex to simulate important features of real operational tasks). For example, a simulated "Cabin Air Management System (CAMS)" was used to investigate complex cognitive skills in three studies involving ground-based simulations of a short-duration (6 days) and a long-duration (135 days) space mission, as well as in a study conducted during a wintering-over expedition to Antarctica for eight months [Sauer et al., 1999a, 1999b, 1999c]. In this task,

subjects monitor and control several parameters of a simulated life-support system. Performance scores can be derived on different levels, providing information not only about overall task performance (i.e., how well the subjects can keep the different parameters within given limits) but also about several aspects of individual performance strategies (i.e., certain aspects of their monitoring and control behavior). Using this task for the monitoring of performance of six participants during a 6-day simulated space flight did not reveal any impairments in any measure during the confinement period [Sauer et al., 1999c]. This might be taken as more evidence for the conclusions drawn from the performance monitoring studies described above that performance decrements early in flight are due mainly to effects of microgravity, which cannot be simulated on the ground.

However, a somewhat different picture emerged by applying the same task for performance monitoring during a simulation of a long-duration space mission [Sauer et al., 1999b]. Even though overall performance again did not show any decrements, subtle performance changes were found that might reflect compensatory reactions in response to mission-related stressors. Specifically, a reduction of monitoring activity combined with increased control activities were observed in two of the three subjects in the second half of a 135-day period of confinement. This pattern of effects indicated a shift to a less effortful but clearly more risky strategy of task performance during the course of confinement. However, this effect could not be replicated in the wintering-over study [Sauer et al., 1999a], nor were similar effects observed in any other simulation study. Thus, it currently represents a unique result that is difficult to assess. Furthermore, all of the ground-based studies conducted so far have suffered from methodological weaknesses that clearly limit their conclusiveness. One particular difficulty relates to persistent learning effects due to insufficient pre-mission training that might have masked possible performance effects in most of these investigations.

3.5.2. Empirical findings from space: effects of stressors on complex cognitive and perceptual-motor skills

Even fewer quantitative studies have been published that have investigated the effects of space-related stressors on complex cognitive and perceptual-motor skills during actual space missions. All of these studies have involved some kind of monitoring of astronaut performance during real mission tasks. Two of these studies were conducted during Skylab missions in the 1970s, and another one was based on analyses of crew errors during Mir missions. Garriott and Doerre [1977] analyzed the crew efficiency of Skylab astronauts by means of comparing the number of working hours spent on defined tasks divided by the number of hours awake. This provided a very rough efficiency score reflecting on how much of the available waking time actually was spent working during different mission phases. Decrements in crew efficiency were only found during the first four days in space and were related to episodes of space motion sickness. In the course of the mission, crew efficiency improved considerably from an efficiency ratio of about 0.5 during the first week to a ratio of up to 0.75 at later mission phases. However, the measure of "crew efficiency" in this study clearly was too rough and general to reveal any detailed information about the actual performance of the astronauts.

Kubis et al. [1977] performed time-and-motion studies for different defined tasks in space and compared the results with similar data obtained during pre-flight training. For tasks like assembling and using a camera system or experimental and exercise equipment, or preparing food, they found significant performance disturbances (mainly a slowing of performance) only for the first execution in space. In line with the results from cognitive neuroscience and performance monitoring studies, most of these disturbances related to transient impairments of fine motor skills and showed a rapid recovery during the first week(s) in space. Most of the tasks could be performed as fast as on the ground during the second trial in-flight, which usually was scheduled during the second week of the mission.

Finally, in a more recent study, the operational performance of 28 cosmonauts was analysed during 14 Mir missions of different length [Nechaev, 2001]. In this study, performance was assessed by recordings of “crew member errors”, defined as any deviations from standard performance (including incorrect execution of procedures, forgetting of necessary actions, or conducting unnecessary actions). The number of errors was found to vary across space missions, which suggested some instability of individual performance. Closer inspection of the data revealed a significant correlation between crew errors and stress arising from disturbances in the usual work-rest schedules, episodes of particularly high workload, or psychosomatic discomfort. This suggested a relationship between decrements of operational task performance and states of decreased alertness and fatigue.

However, the conclusiveness of the above results again is limited. First, only one study [Kubis et al., 1977] compared in-flight with pre-flight performance. The other studies were based on intra-mission comparisons of performance efficiency, which did not result in clear conclusions about the general level of performance in space. Second, all of the above studies used rather general measures of performance efficiency, which did not provide detailed information about the nature of possible performance decrements in complex skills, and which might have missed subtle (latent) performance changes arising from “performance protection strategies” (see Section 3.2.2). Nevertheless, the significance of gaining more knowledge about the impact of space flight-related stressors on mental efficiency and complex cognitive and perceptual-motor skills is obvious, and the approach of analyzing performance in mission tasks or simulated “micro-worlds” seems to be an important complement to the more basic performance research presented above.

3.6. Summary

- Human performance in space can suffer from both microgravity effects involving vestibular and sensorimotor processes as well as non-specific stress effects related to workload, sleep disturbances, and other factors of the extreme living and working conditions in space.
- Important effects of microgravity include disturbances of spatial orientation, alterations of spatial perception, reduced sensitivity of mass discrimination, and a slowing or loss of precision of voluntary movements. Most of these effects

persist for a comparatively short time and diminish in the course of adjustment or the establishment of effective compensatory mechanisms.

- A loss of a sense of verticality seldom has been reported from astronauts. Instead, they usually keep some kind of subjective verticality with respect to an egocentric frame of reference (e.g., “up” is where the head is). Similarly, spatial assignments to external objects usually are made with reference to the coordinates of the visual field. As a consequence, unambiguous communications about spatial relationships between two astronauts seem to be possible only if the orientations of both are aligned.
- The “face inversion” effect persists in space. That is, communication of astronauts whose orientation is inverted to each other can be severely disturbed by difficulties in perceiving and interpreting non-verbal cues correctly.
- Performance monitoring studies during space flight have revealed that tracking and dual-task performance are prone to disturbance effects during short-duration space missions. Impairments of tracking performance seem to reflect the effects of both microgravity as well as non-specific effects of workload and fatigue. Microgravity-related decrements occur only during the first trials under altered gravity conditions and can be compensated for later unless workload and fatigue are high. Impairments of dual-task performance seem to result primarily from non-specific stress effects on attentional processes.
- Little is known about the effects of long-duration space missions on cognitive functions. A first performance monitoring study suggests that the first two to four weeks of long-duration space flight, and the first two weeks after return to Earth, represent a critical period where fine motor control and attentional processes may be impaired. After successful adaptation to the space environment, cognitive performance can be maintained on a comparatively high level, even during long-duration space missions.
- Complex cognitive skills seem to remain intact during space missions and periods of long-term confinement and isolation. But analyses of crew errors during Russian Mir missions suggest a close relationship between the occurrence of errors in mission tasks and disturbances of work-rest schedules, periods of high workload, and physical discomfort.
- Even though several studies of cognitive performance have been conducted during short-duration and long-duration space missions, and during ground-based simulations, the currently available database still is small, and further research is needed in this area.

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Missions to the International Space Station are composed of heterogeneous crews. Both men and women and people from different cultural backgrounds interact over long periods of time. “The Expedition Five crewmembers pose for a photo in the Destiny laboratory on the International Space Station (ISS). From the left are cosmonaut Valery G. Korzun, mission commander; astronaut Peggy A. Whitson and cosmonaut Sergei Y. Treschev, both flight engineers. Korzun and Treschev represent Rosaviakosmos.” (Photo and quoted description courtesy of NASA)

Chapter 4

Human Interactions

4.1. Interpersonal issues

Interpersonal issues relating to how space crewmembers interact with one another and with people in mission control need to be addressed in order to enhance the possibility of mission success. Especially during long-duration space missions lasting more than 6 weeks (after the period of initial adaptation; see Chapter 2), psychosocial pressures take on an importance not found in shorter missions (Table 4.1). For one thing, the goals and activities are more complex, demanding more from crewmembers. In addition, periods of structured activity (which may be hectic at times) may alternate with periods of unstructured down-time (which may be relaxing to some but stressful to others who find them monotonous). Also, interpersonal irritants and problems that can be ignored for short durations become magnified and difficult to deal with during longer periods of time. Finally, the interactions of people working in isolation change over time, and these changes can be harmful if poorly understood and dealt with.

This chapter will focus on interpersonal issues that affect the dynamics and performance of crewmembers working in space. Group-level factors are not as easy to conceptualize as factors affecting individuals. For example, most people know what it means when an astronaut is feeling homesick, but less has been said about intra-crew tension or changes in cohesion over time. During stressful times in space, the ability of crewmembers to deal with problems is critical. Anything that negatively influences crewmember interactions has a direct effect on performance and the ability of the crew to function appropriately. Thus, it is important to clearly conceptualize and study interpersonal issues in order to advance our knowledge of their impact and to develop countermeasure strategies for dealing with them.

Table 4.1. Psychosocial Stressors Impacting on Long- Versus Short-Duration International Space Missions.

Stressor	Short-Duration (6 Weeks or Less)	Long-Duration (more than 6 Weeks)
Physical environment	Isolating and confining	Isolating and confining
Danger level	Potentially high	Potentially high
Mission goals	Limited to complex	Complex to highly complex
Activity level	Busy	Busy to boring
Interpersonal conflicts	Can be ignored	Can become consequential
Group dynamics	Relatively stable	Variable

Table 4.2. Important Interpersonal Issues and Their Sequelae During Long-Duration Space Missions.

Issue	Specific Harmful Sequelae
Crew heterogeneity due to: gender, cultural differences, career motivation and experiences, and personality	Intra-crew tension, scapegoating, long-eye phenomenon
Changes in cohesion over time	Withdrawal and territorial behavior, subgrouping
Language and dialect variations	Crew miscommunication
Crew size	Small crews of two or three people are more problematic than larger crews of six or seven and can lead to minority isolation Odd-numbered crews that are larger than three people can more easily achieve consensus than even-numbered crews
Leadership roles: task versus supportive	Leadership role confusion, status leveling
Crew-ground interactions: empathy, over-scheduling, autonomy, psychological closing, displacement	Crew-ground miscommunication, perceived lack of support from the ground, failure to deal with intra-crew problems, information filtration

A number of interpersonal issues may be identified that have relevance for long-duration space crews [Kanas, 2005]. These generally are by-products of small group interactions and can be found in social and work groups on Earth. Given the unique stressors of space, these issues may lead to problematic behavior that can produce intrapsychic and interpersonal stress and can affect the ability of crewmembers to accomplish mission goals. The various issues and their sequelae will be discussed below and are summarized in Table 4.2. Note that in the table, specific sequelae are listed that are most identified with the issue being described. However, there can be overlap in a given situation. For example, personality differences between crewmembers can not only lead to tension and scapegoating, as shown in the table, but the resulting interpersonal conflicts can cause crew miscommunication, leadership role confusion, and cohesion disruptions leading to withdrawal and subgrouping.

4.2. Crew heterogeneity

In the early days of space flight, crews were composed of male astronauts from the same country with piloting and engineering backgrounds. This reflected national considerations and the relative brevity of the flights. Currently, missions are more long-term, complicated and expensive, requiring international cooperation and the sharing of equipment and human talents. Consequently, crews are much more heterogeneous. For example, missions to the International Space Station (ISS) involve men and women with different career backgrounds from a number of countries who interact together in space for months at a time. The impact of this

heterogeneity needs to be evaluated in order to enhance the probability of mission success, especially for longer-term missions to the ISS or to Mars.

4.2.1. Gender

Mixed-gender crews have flown in space for over 2 decades, and women have performed on a par with their male colleagues. Historically, most mixed-gender missions have been short in duration, but in 1996 an American female astronaut, Shannon Lucid, completed a successful 6-month mission with two male Russian cosmonauts on board the Mir space station, showing that men and women from different cultures can interact in space for long periods of time. This trend has continued in missions involving the International Space Station. As of mid-2007, there have been three missions to the ISS where an American woman has lived and worked in space for over 5 months with at least two men (both Americans and Russians). Anecdotal reports have indicated that the crewmembers got along and that primary mission goals were achieved.

Studies on Earth have demonstrated that women perform well in space simulation environments. For example, on a Tektite submersible mission, the performance of a crew of five women was judged to be equal to or better than that of all-male crews participating in the project [Miller et al., 1971]. Kahn and Leon [1994] evaluated an expedition team composed of four women that spent 67 days in the Antarctic. They concluded that this team performed on a par with male or mixed-gender teams and may have been more sensitive to interpersonal concerns. Bishop [2004] reviewed all-female and all-male desert survival teams and concluded that the former were sensitive to interpersonal issues and team member welfare, whereas the latter were focused on task objectives, sometimes to the detriment of an individual member. Similarly, based on her review, Leon [2005] concluded that all-male expedition teams showed patterns of strong competitiveness and little sharing of personal concerns, whereas women in mixed-gender and all-female groups exhibited considerable concerns about the welfare of their teammates. Wood and her colleagues [2005] also found that women in Antarctic stations were more sensitive than men to decrements in crew cohesion. In a European Space Agency space simulation study called EXEMSI (Experimental Campaign for the European Manned Space Infrastructure), three men and one woman were secluded for 60 days in a hyperbaric chamber. During periods of interpersonal strife, the female crewmember was seen as being a peacemaker, playing an important role in lowering the overall tension in the group [Vaernes, 1993]. This finding was echoed by Leon [2005] in her review. Rosnet and her colleagues [2004] concluded that the presence of women during the wintering-over period at a French polar station had positive effects on the crew by reducing rude behavior in the male members.

However, there are some indications that interpersonal tensions may occur in male-female crews working under isolated and confined conditions. For example, sexual stereotyping was found during the 211-day Salyut 7 mission, when newly arriving cosmonaut Svetlana Savitskaya was greeted with flowers and a blue floral print apron and was asked to prepare the meals shortly after beginning her eight day visit on-board the space station [Lebedev, 1988]. Similar stereotyping also was noted during the 61-day joint Soviet-American Bering Bridge expedition from

Siberia to Alaska, and Leon and her colleagues [1994] concluded that the Soviet men were more chauvinistic than their American counterparts toward the female expedition members. Rosnet and colleagues [2004] found the presence of seduction behavior, rivalry, and sexual harassment in their polar station when the women were about the same age as the men. Finally, in a review of U.S. naval officers and enlisted personnel working at sea, women were viewed as performing well, but gender conflicts and stereotyping still occurred [Boeing Aerospace Company, 1983]. Thus, attitudinal issues may affect male-female relationships during isolated and confined conditions, even though intellectual or performance differences are negligible. But the personalities of the participants may play a role in ameliorating gender differences. Personality issues are discussed below in Section 4.2.4.

The possibility of pairing and sexual contact also needs to be considered during long-duration space missions. Will such activities lead to jealousies and problems in crew cohesion? In a recent space simulation project conducted in Moscow that involved several multinational teams of isolated and confined individuals (called SFINCSS, or Simulation of a Flight of International Crew on Space Station), a female participant reported unwanted sexual advances (including kissing) from a male participant. This resulted in a breakdown of cohesion and group rancor that affected not only the isolated teams but also the participating agencies [Inoue et al., 2004; Kass and Kass, 2001; Sandal, 2004]. Stuster [1996] has pointed out that similar unwanted sexual attention has occurred during Antarctic missions, and that disruptions in cohesion have taken place as a result of male-female pairings. He also stated that if a woman chooses to have a relationship during her stay in the Antarctic, it often is with one man, with a preference for senior over junior personnel. Although the other men usually accept the situation, disruptions may occur if the relationship involves the station leader, who is seen as having an unfair advantage. Along these lines, it is interesting that in the days of the polar explorers, the commanding officer of the ship or the expedition leader was permitted the luxury of taking his wife or mistress with him on the long voyage [Stuster, 1996]. Buckey [2006] has reviewed a number of the sexual and non-sexual tensions that might occur in a mixed-gender crew going to Mars. He suggests that the crewmembers could be observed under isolated and confined conditions during training to see how they come together as a team in reference to possible problems with harassment, flirtatiousness, or jealousy. Should such problems occur, further training or even replacement of offending crewmembers might be necessary for the actual mission.

One might argue that future crews should consist of married couples or stable male-female pairs in order to minimize competition and conflict. However, there is no reason to expect that such a crew composition would prevent secret liaisons and jealousies, since infidelity and extra-marital relations occur on Earth in less stressful interpersonal environments. Enforced platonic relationships and sexual abstinence also is a possibility, but it is difficult to imagine this as a realistic scenario for healthy energetic people who are confined together for long periods of time. Perhaps novel social systems and customs will evolve in space that are similar to those found in communes, where pairings and unpairings will be tolerated with a minimum of conflict and animosity.

4.2.2. Cultural differences

Another issue of crew heterogeneity relates to the different cultural backgrounds of crewmembers during international space missions [Ritsher, 2005]. As mentioned in Section 1.4.3, culture can be conceptualized as national, organizational, and professional (Helmreich, 2000). Issues related to national and organizational culture will be discussed in this section. Career-related issues arising from differences in professional culture will be considered in the next section.

National and organizational issues certainly can have an impact on space crews. During a Russian-operated Salyut 6 mission, a Czech visiting cosmonaut joked that his hands turned red in space since whenever he reached for a switch or dial, one of the Russian cosmonauts would slap his hand away and tell him not to touch anything [Oberg, 1981]. During the 211-day Salyut 7 mission, cosmonaut Valentin Lebedev wrote in his diary that he felt some discomfort at having a French visiting cosmonaut on-board in contrast to feeling more relaxed with Russian visitors 2 months later [Lebedev, 1988]. During his 115-day visit to the Mir space station, astronaut Norm Thagard reported feeling culturally isolated as the only American on-board with two Russian cosmonauts. He stated that such isolation could become problematic on a longer mission of 6 months or more [Benson, 1996].

Few systematic studies have addressed these issues. One of the first was conducted in 1992 at McDonnell Douglas and involved a survey of 74 individuals from NASA, the European Space Agency (ESA), the Canadian Space Agency (CSA) and the Japanese National Space Development Agency (NASDA) by means of a "Multicultural Crew Factors Questionnaire" [Lozano and Wong, 1996]. As a result of this study, 14 key cultural and interpersonal communication factors were identified which might impact multicultural crew operations and interactions. These factors are listed in Table 4.3.

Santy and her colleagues [1993] surveyed nine American astronauts who had flown on international space missions and recorded 17 incidents of miscommunication, misunderstanding, or interpersonal conflict that impacted on the mission. All of the respondents said that it was important to have pre-flight training in cultural issues, especially if this related to the backgrounds of fellow crewmembers.

Additional information about the significance of cross-cultural issues is available from space analog environments and simulation studies. For example, during the Bering Bridge expedition, one of the Russian members acknowledged that disagreements resulted from the fact that the Soviets were accustomed to doing things collectively as compared with the Americans, who approached tasks more individually [Leon, 1991]. More recently, results from the SFINCSS project suggested that cultural differences played a role in many of the misunderstandings and conflicts that took place; both national and organizational factors were implicated [Gushin and Pustinnikova, 2001; Gushin et al., 2001; Inoue et al., 2004; Sandal, 2004; Tomi, 2001]. In contrast, multinational crews participating in European Space Agency space simulations studied in a hyperbaric chamber that lasted for 28 and 60 days, respectively, interacted productively and were able to successfully accomplish their mission goals [Sandal et al., 1995].

Table 4.3. Key Cultural and Interpersonal Communication Factors that Affect Crew Operations and Interactions in Multicultural Crews. Source: Lozano and Wong [1996].

Language
Nonverbal communication styles
Task- and relationship-oriented behavior
Patience and tolerance
Decision making processes
Assertiveness
Interpersonal interest
Respect for other cultures
Personal hygiene and cleanliness
Gender roles and stereotypes
Conflict management and resolution
Trust in other people
Scheduling and time management
Sense of humor

Bluth [1984] has described a number of cultural traits that could create problems in space, many of which are subtle. For example, she has written that people from Arab and Japanese cultures accept physical closeness better than Americans, and they might tolerate the cramped quarters of a space station better than their Western counterparts. Pollis [1965] has pointed out that there is no word for “privacy” in Greek, possibly reflecting the notion that existence apart from family and friends is foreign to Greek cultural norms. Consequently, a Greek astronaut might perceive a fellow crewmember’s need for privacy as a personal affront rather than as a desire to get a little time alone.

Along these lines, Raybeck [1991] has written about a number of national and cultural traits which affect one’s concept of privacy. He states that in some cultures, people who prefer to be alone are regarded with suspicion or are seen as being deviant and non-conforming to the group norms. Such attitudes may influence the conception of one’s self and one’s relationship with others. He warns that such issues need to be addressed in planning for missions involving people working in confined environments for prolonged periods of time, such as in space stations.

Finally, a recent review on cultural issues during space missions has been provided by Kring [2001]. In partial overlap with the earlier results from the McDonnell Douglas study, he identified ten areas related to space missions that are influenced by the national culture of the participants. These are: communication; cognition and decision making; technology interfacing; interpersonal interactions;

work, management, and leadership style; personal hygiene and clothing; food preparation and meals; religion and holidays; recreation; and habitat aesthetics. Based in his analysis, Kring proposed a multicultural training approach for both crewmembers and mission control personnel that involves six steps: (1) providing all trainees with a brief overview of each person's cultural background, (2) describing the ten areas mentioned above in terms of their importance for the mission, (3) allowing the trainees to record their own mission preferences with regard to the ten areas, (4) facilitating a group discussion regarding the rationale for these preferences, (5) collectively agreeing on behaviors acceptable to everyone during the mission, and (6) recording a final set of guidelines. Training issues involving space missions will be considered further in Chapter 6.

4.2.3. Career motivation and experiences

Astronauts and cosmonauts find meaningful work important, especially during long-duration space missions. Gerald Carr, who commanded the 84-day U.S. Skylab space station mission, said that it was important for him to keep busy with an active work schedule [Bell, 1981]. In his diary, cosmonaut Valentin Lebedev [1988] described ways in which he kept busy during his long Salyut 7 mission. These included photographic activities that he planned to use to advance his professional career after returning to Earth. Astronaut Norm Thagard commented that he felt underworked during his Mir mission, which was especially awkward since he felt that his Russian crewmates were overworked [Benson, 1996].

But people vary in their work motivations. Career astronauts have different goals and priorities than mission specialists and visiting scientists. A similar situation occurs on Earth. For example, Gunderson [1968] conducted a study of five U.S. Antarctic stations at a time when their size, isolation, and degree of danger made them excellent space simulation environments. He found a higher incidence of psychological symptoms among the naval servicemen than in the general population. In addition, during the wintering-over period, the naval personnel, who were used to being outside and active, experienced more psychological problems than the civilians, who largely were scientists and technicians (Table 4.4). Since the scientists frequently used unstructured time to complete experiments and write up scientific reports, the confinement of wintering-over allowed them to do their work and was more congruent with their career motivations and experiences than was the case for the naval personnel.

Table 4.4. Emotional Problems from Beginning to End of the Wintering-Over Period at Five U.S. Antarctic Stations. Abstracted from Gunderson [1968].

Problem	Naval Personnel	Civilian Personnel
Insomnia	28% increase	4% increase
Depression	15% increase	2% decrease
Hostility	39% increase	21% increase

Also, conflicts between scientists and non-scientists can lead to open hostilities. In one case involving a scientific expedition at sea, where the scientists kept extending the mission in order to collect more data samples, angry members of the homesick crew snuck into the refrigerator room one night and tossed laboriously collected study samples overboard [Finney, 1991]. It is important for groups of people with different work backgrounds and motivations to respect each other's roles and to cooperate; otherwise, mission objectives may be compromised.

4.2.4. Personality

The selection of crewmembers who are psychologically compatible will minimize miscommunication and maximize their ability to get along during long-duration space missions. Currently, psychological issues are most emphasized at the time that candidates are evaluated to be astronauts, when formal testing is made as part of an attempt to select-out less desirable applicants. Formal psychological tests to select-in for compatibility have not been used historically by NASA to compose crews for space missions, although psychological assessment methods have been used for crew selection in the Russian (Soviet) program for some time. Traditionally, these methods have emphasized compatibility in psychophysiological reactions and individual stress resistance, as measured by responses to stressful events such as parachute jumps [Garshnek, 1989; Gzenko, 1980].

Interpersonally-oriented psychological tests have been used for crew selection in space simulation studies. Examples include the Fundamental Interpersonal Relations Orientation-Behavior (FIRO-B) test and sociometric questionnaires [Dunlap, 1965; Ferguson, 1970; Haythorn and Altman, 1963] and the Personality Characteristics Inventory (PCI) [Chidester et al., 1991]. In addition, Manzey, Schiewe and Fassbender [1995] described the use of behavioral exercises as part of an "assessment center" to select compatible crewmembers for the 60-day ESA-sponsored EXEMSI project. Based on the anticipated task demands of this mission, exercises that were related to social and leadership competence were constructed and used to observe potential crewmembers for psychological compatibility. The results of these observations assisted with the final selection of the 4-person crew. The use of such selection methods are described in more detail in Chapter 6.

Personality differences and complementarities have been shown to be important in space analog environments in addressing how people relate with one another. For example, in one ground-based study measuring the effects of isolation and confinement, 36 sailors were given psychological tests and then were paired according to different conditions of compatibility [Haythorn and Altman, 1963]. Some pairs were isolated for 10 days in cabins and given tasks to do. Others did the same tasks but were allowed to go home in the evening. Both groups were observed through a one-way mirror and rated on factors such as territoriality, disclosure, performance, and interactions. In the isolated condition, four pairs of men experienced a great deal of interpersonal conflict (e.g., arguing, fighting) and withdrawal from each other, and analysis of the individuals in these conditions revealed that three pairs had members who were both high in dominance on the Edwards Personal Preference Scale. In contrast, matched pairs in the non-isolated control condition performed well and experienced no arguments. In another study using the four-person School of

Aerospace Medicine space cabin simulator, similar problems were observed between immature, aggressive men who were confined for two to six weeks [Hartman and Flinn, 1964].

More recently, Sandal et al. [1995] studied six crewmembers who participated in a 4-week ESA confinement study called ISEMSI (Isolation Study for European Manned Space Infrastructures). The research team assessed crew behavior over time using a communications analysis, an adjective interpersonal rating method called SYMLOG, and a daily survey. They found that tension arose between the two crewmembers rated as being most dominant, one of whom was the commander. The person who was not the commander became more and more socially isolated from the other crewmembers, suggesting that personality incompatibility led to competition and interpersonal expulsion of this member from the group. Similarly, Gushin and his colleagues [1998] used a modified version of the Kelly Repertory Grid technique to evaluate 3-person crews participating in two space analog confinement studies in Moscow, one lasting 90 days (“ECOPSY”) and one lasting 135 days (HUBES, or HUMan BEhaviour Study). In both crews, the participants were unable to make their personal self-concepts become more similar to their concepts about fellow crewmembers. This resulted in crew “disintegration”, with one member in each crew becoming an outsider. Using a similar methodology, breakdowns in group integration also were found during the SFINCSS project [Gushin and Pustinnikova, 2001].

Work has been done evaluating personality features and ability to relate with other crewmembers in aircraft cockpits, another space analog environment. Three personality types have been identified and have been labeled: “right stuff”, “wrong stuff”, and “no stuff” [Bishop, 2004; Chidester et al., 1991, Musson and Helmreich, 2005]. As might be expected by the labels, those with the “right stuff” have been shown to be most successful in the confined environment of the cockpit (see also Section 6.4.3).

4.2.5. Problems related to crew heterogeneity

Crewmember heterogeneity can lead to intra-crew tension if interpersonal differences are highlighted and subtle miscommunications cannot be corrected. In his diary, cosmonaut Lebedev [1988] alluded to increased group tension during visits of “guest” cosmonauts, especially those from non-Soviet countries. He also reported incidences where he and his fellow crewmate became annoyed with one another during their 211-day mission, and he related this to fatigue and monotony as the mission progressed and to small disagreements that were unresolved. On Earth, the eight crewmembers (four men and four women) who were involved with the 2-year Biosphere 2 confinement project reported interpersonal tension, in part related to mixed-gender issues [Walford et al., 1996].

At times, one person can be blamed or scapegoated when a group of people cannot resolve issues that lead to intra-group tension. Often, the person who is most unlike the majority of the crewmembers based on demographic or personality traits is set up to become the scapegoat, especially if he or she espouses unpopular ideas. This also can occur if only one person from a subgroup is represented in a crew (e.g., one woman, one American, one scientist). From a social psychological

perspective, it is a good idea to have at least two such individuals represented, so long as qualified people can be found to accomplish mission goals.

In isolated and confined conditions, an excluded person may experience a syndrome that in polar missions is called the “long-eye” phenomenon [Rohrer, 1958]. A person affected by this syndrome may stare off into space and experience insomnia, depression, agitation, and psychotic symptoms (e.g., auditory hallucinations, persecutory delusions). These characteristics of the long-eye phenomenon may be transient and disappear once the excluded person is accepted back into the group. Scapegoating of an unpopular individual occurred during the International Biomedical Expedition to the Antarctic [Rivolier et al., 1991; Taylor, 1991], and it also has been reported during hyperbaric chamber isolation studies [Gushin et al., 1998].

However, crewmember diversity can produce a positive interpersonal environment, since differing points of view may help counter the monotony that occurs later on during long-duration missions. A lot depends on how differences based on gender, cultural background, career motivation, and personality are dealt with: as negative areas of mistrust or as positive areas of interest. In this regard, the issues raised by group heterogeneity are similar to those faced by many work and social groups on Earth.

In some cases, personality compatibilities can transcend potential negative effects related to crew heterogeneity. For example, in the EXEMSI study, the single woman in a crew composed of people from four different European countries was described as being mature, maternal, and a peace-maker. During the mission, she was able to intervene in a positive manner when the leader and another male participant began competing with each other over leadership issues [Vaernes, 1993]. In addition, during the Shuttle/Mir and early ISS missions, three of the crews were composed of a single American woman and two men. From all anecdotal indications, the crewmembers maintained their morale, related well with one another, and successfully accomplished the mission goals. In both of these examples, despite obvious heterogeneous factors related to gender and cultural background, personality compatibility contributed in a positive manner to overcome differences and lead to a positive outcome. More work needs to be done to identify positive factors that can lead to successful select-in procedures for future space crew selection.

4.3. Crew cohesion

4.3.1. Time effects and mission stage

To properly accomplish mission goals, it is necessary for space crewmembers to function in a cohesive manner. A number of factors can interfere, such as differences over mission goals, intra-crew miscommunication, and poor leadership. As mentioned in Chapter 2, there have been several models describing stages that occur over time to people working in isolated and confined environments. The first of these is Rohrer’s classic triphasic model [1961]. Based on observations made from submarine and Antarctic environments, Rohrer conceived of three stages during such missions: initial anxiety, as participants adjust to their new environment;

mid-mission depression and monotony, as activities become routine and participants may experience boredom and homesickness; and terminal anticipation and euphoria, as the end of the mission approaches and participants look forward to returning home. Elements of these three stages have been observed during space missions [Chaikin, 1985; Grigoriev et al., 1987]. The second model is a quarterly model, which has been reported from space simulation environments on Earth and mainly emphasizes the third quarter [Bechtel and Berning, 1991; Gushin et al., 1993, 1997; Palinkas et al., 2000; Sandal, 2000; Sandal et al., 1995; Stuster et al., 2000]. The idea is that people participating in a long-duration isolation and confinement mission arrive at the halfway point somewhat relieved that their experience is half over. But then they realize that they still have another half to go. Consequently, there is an emotional letdown in the subsequent third quarter. The final model is a biphasic model that emphasizes first half versus second half differences, with the notion that degradations occur in emotional state and group cohesion during the second half as the mission wears on. However, not all space analog studies have found these stages uniformly occurring in isolated groups, although individual crewmembers may experience them [Kanas et al., 1996; Steel and Suedfeld, 1991; Wood et al., 1999, 2005]. On-orbit studies also have tested for group stages, and this work is described below.

4.3.2. Problems related to changes in cohesion

Disruptions in cohesion at different stages of the mission have been described during long-duration Russian space missions [Chaikin, 1985; Grigoriev et al., 1987]. Especially problematic is the long monotonous second stage. For example, in his diary Lebedev [1988] described withdrawing more and more from his crewmate as their mission dragged on. Withdrawal also has been observed in space analog environments [Vaernes, 1993; Haythorn and Altman, 1963]. In its extreme, it can result in territorial behavior, where people become overly sensitive to the need for their own personal space and property, and where arguments and fights can result from minor intrusions (e.g., borrowing someone's pen or sitting in "their" chair). Such behavior, which is much more extreme than normal privacy concerns, may seriously destroy the cohesion of a crew and lead to major disruptions in performance.

Another cohesion problem is subgrouping, where crewmembers segregate along social, national, or job-oriented lines. Some subgrouping occurs in all groups, since people like to associate with others based on common interests, hobbies, background, etc. But in its extreme, it may reflect deep divisions in a group of people and destroy their ability to function as a unit. For example, during the 12-man International Biomedical Expedition to the Antarctic [Rivolier et al., 1991; Taylor, 1991], subgroups formed along national lines. This resulted in group conflicts, characterized by irritability, aggressiveness, subgroup competition, and lack of mutual concern. In Biosphere 2 [Walford et al., 1996], the eight-person crew divided into two factions (each composed of two men and two women). One group was loyal to the program management, whereas the other group viewed management more negatively. The resulting personal differences between these

groups were at times intense. Similar subgrouping occurred in the four-person crew involved with the 60-day EXEMSI isolation mission [Vaernes, 1993]. Palinkas et al. [2000] described a pattern of subgrouping in the Antarctic where crewmembers formed cliques based upon where in the station they spent most of their leisure time. They termed these the “biomed”, “library”, and “bar” subgroups. Interestingly, crews characterized by such a clique structure exhibited higher levels of tension-anxiety, depression, and anger-hostility on the Profile of Mood States than crews whose members identified more with the whole group. Subgrouping is a common phenomenon, and if the subgroups do not interact with one another at least part of the time, it sets up the potential for misunderstandings and miscommunication that can negatively affect the mission.

In contrast, cohesion sometimes improves over time as people adjust to one another, and anticipation of the mission can be worse than the mission itself. In a study of seven men and women participating in a 3 week Arctic scientific expedition, Palinkas and his colleagues [1995] reported significantly higher tension levels prior to the start of the mission than during the mission itself, where the crewmembers seemed to adapt to their situation. Similarly, in their 135-day Mir space station simulation study, Kanas and his colleagues [1996] found significantly less tension during the last half of the isolation than during the first half, and there was significantly more tension in the group prior to entering the isolation chamber than after the mission began. What distinguishes groups that do better over time from those that do worse is unclear. In the Mir simulation study, subjects received replacement computer parts, favorite foods, and letters from home during a mid-mission resupply, and perhaps this positive event improved morale and cohesion. In addition, this mission did not involve much danger, and there was the impression that the crew learned to relax over time and enjoy the positive aspects of being isolated away from the cares and woes of everyday life. More research needs to be done in this area of group stages and what makes an isolated and confined experience positive versus negative for the participants.

4.4. Language and dialect variations

4.4.1. Native language versus space terminology

When crewmembers are fluent in different native languages, their perceptions of the interpersonal environment can be grossly affected. For example, astronaut Norm Thagard commented that he felt socially and culturally isolated during his Mir mission and that this was related to the fact that he was the only native English speaker on-board. His fellow cosmonaut crewmembers were Russian, and Thagard sometimes went up to 72 h without speaking to someone in his native language [Benson, 1996]. Astronauts have stated that conversational language training is important in missions involving international crews [Santy et al., 1993].

Language differences also have been found to affect crewmember interactions in space analog environments on Earth. For example, language differences were implicated in some of the group disintegration that was observed during the SFINCSS

project [Gushin and Pustinnikova, 2001]. Although English was the official language, it was not native for some of the participants. The lack of pre-mission language training, along with differences in communication styles, interfered with effective communication between one of the groups and outside monitors [Gushin et al., 2001].

In their survey of 54 astronauts and cosmonauts who had flown in space, Kelly and Kanas [1992] found that all of the respondents acknowledged that it was important for space crewmembers to be fluent in a common language, and 63% believed that it was very important. International astronauts participating in U.S. missions rated the importance of speaking a common dialect significantly lower than their American and Russian counterparts. This may have been due to the fact that most of the internationals were European and may have been exposed to more languages in their lifetime. Crew communication was judged to be enhanced by a sense the respondents had of undergoing a shared common experience during their space missions.

Peeters and Sciacovelli [1996] have pointed out that native language is not the only linguistic issue related to space missions. Astronauts and cosmonauts also must be familiar with the specialized space terminology that is used during a mission. NASA space terminology is derived from basic English and includes a set of synonyms, acronyms, and neologisms related to this language. In contrast, Russian space terminology has a different set of linguistic parameters, and so on for other languages. It is possible that a common, unique space language will evolve over time that will transcend the peculiarities of any single national language, especially as a result of multinational space missions.

4.4.2. Problems related to language and dialect variations

Linguistic differences can lead to crew miscommunication. This may create serious problems during crises and emergencies, where the need for prompt integrated crew response is paramount in an environment producing anxiety and confusion. In their survey of 54 astronauts and cosmonauts who had flown in space, Kelly and Kanas [1992] found that astronauts scored significantly higher than cosmonauts on a scale rating the importance of a common language, and pilots and commanders scored significantly higher than researchers. This last finding may have reflected the concern of pilots and commanders that people communicate clearly while performing tasks of vital operational importance.

But subtle miscommunication can occur among people speaking the same native language as well. During his 175-day Salyut 6 mission, Valeri Ryumin wrote in his diary that comments uttered between him and his fellow Russian crewmember sometimes took on special meaning, and even the tone was important [Chaikin, 1985]. He found it necessary to consider the consequences of his words in case some miscommunication occurred that might have been offensive or unclear to his crewmate. He also found that in space neither he nor his fellow cosmonaut was talkative, and most of their communications related to work.

4.5. Crew size

4.5.1. The impact of size in small groups

Unlike other isolated and confined conditions (e.g., submarines, Antarctic bases), space crews have tended to be small, generally consisting of fewer than eight individuals. This puts a restriction on the number of dyadic contacts available, which over the course of a long period of time may lead to a sense of interpersonal boredom as the same stories get told and responses among crewmembers become predictable. Thus, it is important to consider the impact of size on the behavior of small groups when planning crew composition for a long-duration space mission.

In a classic study, Bales and Borgotta [1966] studied group size and social interactions in a number of small groups consisting of two to seven people. The groups were composed of male students who did not know each other before they became involved with the study. The groups were given a five page presentation of a problem, and they met for four sessions to discuss the issues and develop a plan of action. Interpersonal interactions were analyzed using the Bales Interaction Process Analysis. The intent of the study was to evaluate the impact of group size on group performance and to examine effects associated with subgrouping.

Kanas and Feddersen [1971] carefully reviewed this complicated study and came up with a number of conclusions. As group size increased, the members became more organized and efficient, with a greater tendency for leaders and followers to emerge. Two-man groups showed much tension resulting from an inability to form a majority, and the men tended to differentiate from each other in a complementary manner in order to maintain peace and stability. Three-man groups showed more variety in interactions resulting from shifting majorities, with the odd man out exhibiting either active or passive behavioral strategies to cope with his isolation. Seven-man groups (the largest size studied) showed relative stability, primarily as a result of passive acquiescence by a large number of followers to decisions and courses of action. Even-numbered groups often formed even-numbered subgroups which deadlocked, making decision-making difficult. In general, variability in interactions tended to decrease over time, suggesting that time caused stability of observed patterns.

4.5.2. Problems related to crew size

It should be noted that the above study was done in a student environment where no formal leadership structure was imposed and where groups of males problem-solved for four sessions. Consequently, it is difficult to project how these findings will be applicable to long-duration space crews composed of men and women operating in a structured setting with defined leadership roles and stressful conditions. However, studies like this one point out that group size is another variable that should be considered when composing a crew for a specific mission.

What can such a study tell us about the size of space crews? First, two-person crews might be expected to exhibit tension, difficulties in solving interpersonal problems, and progressive psychological separation and territorial behavior. In fact, indications of these traits were reported during the 211-day Salyut 7 mission, where

in his diary cosmonaut Lebedev described interpersonal strains that he and his fellow cosmonaut experienced as the mission wore on, which resulted in silences and withdrawal [Lebedev, 1988]. Second, three-person crews can be very unstable due to shifting alliances and a tendency of one person to be scapegoated or put in a minority position. Although the three-man Apollo missions generally were successful, they were highly structured and relatively short-term. But during the longer-term three-person Shuttle/Mir missions, some of the American astronauts reported a sense of social isolation, possibly due to the fact that they were a true minority in their crew in many ways: only American, only native English-speaker, only person not in the operational chain of command (Russian mission control was responsible for the Mir, and the commander and engineer for all of the flights were Russian cosmonauts). However, although groups of three seem to have disadvantages, they are to be preferred to groups of two. This is suggested in the results of a study by Smith and Haythorn [1972], which showed that groups consisting of three people work better under conditions of isolation and confinement than two-person groups. Third, the larger the group, the greater the tendency for leader-follower relationships to form, and the greater the stability. In odd-numbered groups, there is less likelihood for deadlocking subgroups to form in situations where non-leader directed activities are involved. Since future ISS or expeditionary class space missions may involve crews consisting of six to eight individuals, one might predict that on the basis of number alone, a crew of seven would be ideal since this would be the largest odd-numbered crew size.

4.6. Leadership roles

4.6.1. Task versus supportive roles

The demands of a work group necessitate different types of leadership roles. During space missions (and in many work groups on Earth), two major leadership roles have been identified: (1) task (or instrumental) leadership, which is oriented toward accomplishing work-related activities and addressing operational needs, and (2) supportive (or expressive) leadership, which is oriented toward accomplishing people-oriented activities and addressing emotional and morale needs. At times one person fulfills both roles, but frequently different people specialize in one or the other. Generally, the mission commander is the task leader, but not always. For example, during the 96-day Salyut 6 mission, the commander was younger and less experienced than his older crewmate in the engineering skills that were needed to repair the space station, and the two men decided to share decision-making in order to successfully accomplish the mission goals [Oberg, 1981].

In their review of leadership characteristics from four space analog environments (aviation, polar bases, submersibles, and expeditions), Nicholas and Penwell [1995] concluded that an effective leader profile included a focus on mission objectives and the ability to take charge during critical situations (which is suggestive of the task role alluded to above), and a sensitivity to the crewmembers' expertise and personal qualities and attention to group harmony and cohesion

(which is suggestive of the supportive role). Additional positive leader characteristics included optimism, hard work, and the ability to gain the respect of others.

Different leadership roles may be especially important at different times. For example, in early Antarctic missions, the task role of the leader was important initially, since setting up the base and organizing work-related activities needed to be accomplished. With the onset of the wintering-over period, however, the supportive role of the leader became more important as morale dropped due to inactivity and the need for structured tasks lessened [Gunderson and Nelson, 1963; Nelson, 1964].

Both task and supportive leadership roles are important for crew functioning at some point in the mission. In the HUBES study of a three-man crew confined in the Mir simulator in Moscow for 135 days, measures of leader control (addressing task-oriented, instrumental characteristics) and leader support (addressing supportive, expressive qualities) each correlated significantly with a measure of crew cohesion [Kanas et al., 1996]. During the Bering Bridge expedition, there was a positive relationship between measures of group cohesiveness and perceptions of the quality of decision-making that emphasized the role of the leaders in promoting group morale [Leon, 1991]. There were conflicts between the more experienced and conciliatory Soviet leader and the more stubborn and task-oriented U.S. leader, and these conflicts upset the overall cohesiveness of the group [Leon et al., 1994].

4.6.2. Problems related to leadership roles

The expression of unclear or inappropriate leadership role at the wrong time can produce role confusion, which can result in group performance problems or in competition between crewmembers. Overt competition occurred during the 60-day EXEMSI hyperbaric study between the designated leader, who continued to emphasize his task role, and another crewmember [Vaernes, 1993]. The lone female crewmember, who was more supportive and sensitive to emotional needs, intervened and was successful in moderating and defusing the dispute.

In the 135-day HUBES study, Kanas and his colleagues [1996] found a significant drop in a measure of the task-oriented, instrumental characteristics of the mission commander over time. This suggested that status leveling was occurring, where the leader assumed a more equal stance in relation to the other crewmembers. Compared with pre-seclusion scores, the leader was seen as being more supportive of his fellow crewmembers during the confinement, and both his task and supportive characteristics were correlated with crew cohesion. Status leveling also has been reported in the Antarctic, where the leader sometimes has been viewed more democratically as a member of the crew during the wintering-over period [Gunderson and Nelson, 1963; Nelson, 1964]. Although morale-enhancing during unstructured or monotonous times, status leveling may lead to inadequate responses during busy periods or in times of danger when a more formal command structure is called for.

4.7. Crew-ground interactions

4.7.1. Ingroup versus outgroup issues

The relationship between crewmembers in space and mission control personnel on the ground is very important, especially during near-Earth missions such as those involving the Space Shuttle or Soyuz spacecraft, the ISS, or even flights to the Moon. People on the ground frequently set the schedules for such missions, and they provide key support in solving problems that occur in space. If they are not sensitive to the specific demands and needs of a space crew, there is a danger that they may overload them with activities or misinterpret their requests.

There also is information that during long-term conditions of isolation and confinement, crewmembers may become more autonomous and want to separate from the influences of outside monitoring personnel. For example, during the 90-day ECOPSY and the 135-day HUBES isolation studies in Moscow, Gushin and his colleagues [1997] analyzed the communication frequencies and patterns between the crewmembers and people on the outside who monitored their activities. The results suggested that the isolated crews were becoming more autonomous over time, a phenomenon that the research team called “psychological closing”. The crewmembers seemed to filter the information they communicated outwardly. In addition, communication patterns varied with different outside teams that were scheduled to be on-duty. The authors concluded that their isolated groups became more self-sufficient and began to rely on their own resources due to the isolated living conditions. Results such as these suggest that space mission planners may need to consider growing crew autonomy as an important factor for long-duration missions (e.g., a trip to Mars).

Positive communications with mission control personnel or family and friends on the ground can be very supportive to crewmembers. In their survey of 54 astronauts and cosmonauts, Kelly and Kanas [1993] found that the respondents rated a shared experience and a mutual excitement for space flight as two factors that significantly helped their communication with mission control personnel. They further acknowledged the value of contact with loved ones on the ground as having a positive influence on mission performance. Also, space travelers who spent 20 or more total days in space endorsed the value of letters and other forms of contact with people on Earth significantly more than their colleagues who spent less time in space [Kelly and Kanas, 1994], which suggests that supportive crew-ground interactions are even more beneficial during long-duration space missions.

4.7.2. Displacement

Sometimes other factors disrupt the relationship between isolated individuals and people on the outside. For example, there have been reports from space analog studies that isolated individuals have become irrationally angry at people monitoring their behavior, especially during tense times when anger is not expressed between the confined crewmembers themselves [Dunlap, 1965; Jackson et al., 1972; McDonnell Douglas, 1968]. This suggests that what is happening is a displacement or transfer of intra-crew tension and negative dysphoric emotions to safer, more remote individuals on the outside, an idea proposed by Kanas and Feddersen [1971]

in their review of space analog environments. Behavior suggestive of displacement also occurred during the 60-day EXEMSI space simulation project [Vaernes, 1993] and during the 135-day Mir simulation study [Kanas et al., 1996].

Evidence of displacement also has been reported from space. For example, during his 211-day mission, cosmonaut Lebedev [1988] reported in his diary that he felt increasing frustration with people on the ground, while at the same time he recorded on-board tension between himself and his fellow cosmonaut that was not overtly expressed or discussed between the two of them. Sometimes this anger with the ground was related to a perceived change in the voice quality of people on Earth. In particular, Lebedev stated that a physician friend of his seemed to become more strident and sharper with him as the mission wore on, which puzzled and annoyed him since there was no rational explanation for this change.

By moving the focus of their on-board problems to the outside, crewmembers may experience temporary relief. However, the source of the problems may not be dealt with, allowing them to fester. So in the long run, displacement may be harmful to crewmembers and their ability to live and work together during the remainder of the mission. The same goes for mission control personnel, who may react to work pressures on the ground by displacing tension and unpleasant dysphoric emotions to management or even to the crewmembers in space.

4.7.3. Problems related to crew-ground interactions

Problems related to lack of empathy, over-scheduling, growing crew autonomy, psychological closing, or displacement can lead to crew-ground miscommunication and perceived lack of support. Information filtration was discussed in Section 4.7.1. In their survey of nine astronauts, Santy and her colleagues [1993] found three reported incidents of miscommunication, misunderstanding, or interpersonal conflict that involved the crewmembers' interactions with people on the ground. Also, during the American 3-month Skylab space station mission, the crewmembers were under pressure to comply with a busy activity schedule, and they perceived members of mission control as being unsupportive. As crew-ground tensions increased, the crewmembers conducted a work stoppage, which was tantamount to a strike in space [Belew, 1977; Cooper, 1976]. After a crew-ground "bull session" to clear the air, the schedule was modified and the mission continued. However, such conflict between crewmembers and mission control could be catastrophic, especially if it occurred during a crisis, and it is important for crewmembers and personnel in mission control to continually monitor their interpersonal interactions.

4.8. Empirical findings from space: ISS operations challenges as seen by junior and senior mission control personnel

Missions to the International Space Station (ISS) are complex from an operational perspective, and the mission control team bears much of the responsibility resulting from this complexity. Currently, personnel located at mission control sites in the United States, Russia, and elsewhere are involved. The team is multi-national and multi-organizational, the members are dispersed across many locations and time

zones, the schedules are demanding, and both junior and senior personnel must interact together with a minimum of psychosocial training. For the safety of the missions and optimal crew-ground interactions, it is important to understand how people on the ground view these operational challenges, especially those with relatively little experience. This was the goal of a study conducted by Clement and his colleagues [Clement and Ritsher, 2005; Clement et al., 2007a, 2007b]. The purpose was to identify and evaluate the major cultural and leadership challenges faced by ISS flight controllers and to highlight the approaches found effective in surmounting these challenges.

4.8.1. Procedures

A semi-structured qualitative interview was conducted on 14 senior and 12 junior flight control personnel who were involved in various aspects of mission planning and day-to-day operations of the ISS at the Johnson Space Center in Houston, Texas. The interview questions addressed various leadership and cultural issues and challenges as well as further training that the subjects felt they needed [Clement and Ritsher, 2005]. The senior sample consisted of 13 men and 1 woman who were mostly in their 40s and had worked as mission controllers in several programs, including early Space Shuttle flights, Shuttle missions to the Mir Space Station, and the ISS program. The junior sample consisted of 6 men and 6 women who were mostly in their 20s and had worked primarily in the ISS program. Written and verbal responses to the study questions were collected and categorized into emergent themes by a consensus of the research team. Significant differences between the senior and junior subjects were looked for in terms of the frequency in types of responses.

4.8.2. Results

Significantly more senior than junior controllers stated that maintaining team morale and motivation in the mission control environment was an important leadership challenge, and they also perceived change as a factor affecting their work. They were more likely than their junior colleagues to be concerned that the current two-country (U.S. and Russian) solutions may not be effective in future multinational situations. Although not statistically significant, there was a stronger trend for junior controllers to see language differences as a major cultural challenge, and to acknowledge the importance of expanding cultural awareness as a solution to operational challenges. Both groups strongly saw cultural differences, organizational differences, and the dispersion of team members across time zones as important challenges. Both groups also viewed effective communications, robust interpersonal relationships (particularly with their Russian counterparts), and open-mindedness as important solutions to the various challenges in their work.

4.8.3. Conclusions

These results suggest that the day-to-day operational tasks involved with managing on-orbit space missions are full of many leadership and cultural challenges. How these challenges are viewed and dealt with depend in part on the experience level of the mission control personnel. Senior controllers who have been involved with

several different space programs are more likely to be sensitive to changes in team morale that result from programmatic changes and complexities. In contrast, their less experienced and younger colleagues, who have primarily worked in one program, tended to be more concerned with language differences and cultural sensitivities, although both groups acknowledged cultural and organizational differences and the need for everyone to communicate effectively as being important.

Certainly, being aware of operational challenges is important, and a way to heighten awareness is through improved training in psychosocial and cultural issues. However, trainers need to be aware of attitudinal differences between senior and junior controllers in order to more effectively meet the needs of both groups. In addition, managers need to pay careful attention to the importance of cultural, language, and organizational differences, and they need to minimize the negative impact of distance and inflexible interpersonal interactions on team morale and communications. Since more countries will be involved with ISS missions in the future, it is important to obtain feedback from their controllers as well and to consider training packages where they can be trained jointly with counterparts from other nations. In this way, many of the challenges cited above can be exposed and dealt with before they can compromise mission safety and success.

4.9. Empirical findings from space: human interactions during the Shuttle/Mir program

4.9.1. Procedures

Many of the above interpersonal issues were examined during a 4½-year NASA-funded study in the late 1990s that evaluated the effects of tension, cohesion, leadership role, and displacement from a series of space missions conducted during the Shuttle/Mir Program.¹ This program was viewed as Phase 1 of the International Space Station (the construction and operation of which were referred to as Phase 2 and 3, respectively). Shuttle/Mir provided an opportunity for American astronauts and Russian cosmonauts to work together in space for long periods of time. Altogether, seven Americans and 17 Russians participated in this program over a span of 4 years [Uri and Lebedev, 2000].

The U.S. and Russian launches to the Mir were staggered in time, but generally there was one American and two Russians on-board. The commander was always a cosmonaut. Operational decisions between the cosmonauts and mission control in Moscow usually were in the Russian language. On-board activities included routine maintenance of the spacecraft, material and life sciences research, observations of the Earth, space walks, and exercise and physical conditioning. The crewmembers

¹The international investigative team was from the University of California and the Veterans Affairs Medical Center in San Francisco (Nick Kanas, M.D., Principal Investigator; Charles Marmar, M.D.; Daniel Weiss, Ph.D.; Alan Bostrom, Ph.D.; Ellen Grund, M.S.; and Philip Petit, M.S.), and the Institute for Biomedical Problems in Moscow (Vyacheslav Salnitskiy, Ph.D.; Vadim Gushin, M.D.; Olga Kozerenko, M.D.; and Alexander Sled, M.S.). The study was supported by NASA Contract #NAS9-19411.

worked the same shift, and time was set aside for them to eat together. Leisure time activities included television downlinks and e-mail with family and friends on Earth. Breakdowns of vital equipment on the Mir (e.g., oxygen generator, coolant system) and two life-threatening accidents (an on-board fire and a collision with a Progress resupply spacecraft) led to stressful periods of time. But these issues were resolved, and mission goals generally were accomplished.

Due to the interest in examining displacement and the crew-ground relationship, both crewmembers and mission control personnel were involved with the study. The formal hypotheses dealt with a number of important interpersonal issues and are listed in Table 4.5. Participation in the study was voluntary, and all enrolled subjects signed informed consent. The final study sample consisted of five U.S. astronauts, eight Russian cosmonauts, and 42 U.S. and 16 Russian mission control personnel (that included flight surgeons, operations leads, engineers, mission scientists, spacecraft communicators, hardware specialists, and psychological support personnel). Crewmembers were on-board the Mir for periods of time ranging from 4 to 7 months.

The emotional state and interpersonal relationships of the subjects were assessed through the completion of a study questionnaire that consisted of items from three well-known and standardized instruments: the seven subscales from the Profile of Mood States (POMS) [McNair et al., 1992], the ten subscales from the Group Environment Scale [Moos, 1994a], and four relevant subscales from the Work Environment Scale [Moos, 1994b]. The subscales that were used in the study are listed in Table 4.6. A Critical Incident Log also was included that asked subjects to describe and rate important events that had occurred in the past week. Four times pre-mission, weekly during the mission, and twice post-mission, subjects completed the study questionnaire, which took 15–20 min. While on the Mir space station, crew subjects completed a computerized version of the questionnaire and saved their data to an optical disk for later return to Earth. The mission control subjects preferred to use hardcopy versions that were mailed to the study center in San Francisco. There were a total of 212 observations from the crewmembers and 1,088 observations from the mission control personnel. Data were analyzed using

Table 4.5. Shuttle/Mir Human Interactions Study Hypotheses.

-
1. Crew cohesion will decrease in the second half of the missions.
 2. Crew tension will increase in the second half of the missions.
 3. Crew perception of crew leader and mission control support will decrease in the second half of the missions.
 4. Mission control perception of mission control leader and management support will decrease in the second half of the missions.
 5. Crew tension and dysphoria will be displaced to mission control personnel.
 6. Mission control tension and dysphoria will be displaced to management.
-

Table 4.6. Subscales Used During the Shuttle/Mir Human Interactions Study.

<i>Profile of Mood States (POMS)</i>	
Tension-Anxiety	Fatigue-Inertia
Depression-Dejection	Confusion-Bewilderment
Anger-Hostility	Total Mood Disturbance
Vigor-Activity	
<i>Group Environment Scale (GES)</i>	
Cohesion	Self Discovery
Leader Support	Anger & Aggression
Expressiveness	Order & Organization
Independence	Leader Control
Task Orientation	Innovation
<i>Work Environment Scale (WES)</i>	
Supervisor Support	Managerial Control
Work Pressure	Physical Comfort

regression, analysis of variance (ANOVA), and t-test procedures. Because there were a total of 21 subscales analyzed, corrections were made to control for possible Type I errors (where significant findings may occur by chance due to the large number of analyses being made) [Benjamini and Hochberg, 1995]. For analyses using regression techniques, normally distributed or transformed subscales were analyzed using a mixed model [Delucchi and Bostrom, 1999; Littell et al., 1996]. Non-normally distributed subscales were dichotomized into high and low scores and were analyzed using a Generalized Estimating Equation [Liang and Zeger, 1986].

4.9.2. Results

Using a piecewise linear regression analysis, none of the subscales used to test for second half score decrements as predicted by hypotheses 1, 2, and 4 resulted in significant findings. However, one of the two subscales used to test hypothesis 3, Leader Support in crewmembers, showed the predicted significant decrease in scores during the second half [Kanas et al., 2001c].

Time effects other than first half/second half also were tested for crewmembers using regression techniques. Neither a high-low-high “U-shaped” pattern nor an overall linear increase or decrease in the scores over time throughout the missions was found on any subscale for all crewmembers or for Russians alone. However, for the Americans alone, the subscale for Order & Organization showed a significant

triphasic U-shaped pattern, indicating higher scores at the beginning and the end of the missions. In addition, for the Americans alone, there was a significant linear decline in Cohesion as the mission progressed, and significant non-linear declines in Task Orientation and Self Discovery during the middle and end of the missions [Kanas et al., 2001b]. These findings suggested that a novelty effect occurred for the Americans, where they exhibited high scores on several measures in the first few weeks that then dropped as the mission progressed and the astronauts became more familiar with their tasks and the on-orbit environment.

Using one-way ANOVAs, scores also were examined for the 21 subscales across the four quarters of the missions to look for the third quarter phenomenon (see above, Section 4.3.1) and to see if any single quarter gave unique scores. There were no significant quarter differences for all crewmembers or for Russians alone [Kanas et al., 2001a, 2001c]. American crewmembers gave significantly higher mean scores in the earlier versus later quarters for Task Orientation and Self Discovery, a pattern reminiscent of the linear trends described above in the regression analysis.

Using one-way ANOVAs, crewmember responses for the 21 subscales during the on-orbit phase of the missions were compared to their pre-launch baseline scores and to their post-return scores. There were no significant differences in the mood subscales among the on-orbit and pre- and post-mission periods for all crewmembers combined or for U.S. and Russian subjects taken separately [Kanas et al., 2001b]. However, the crewmembers reported higher levels of Self Discovery and Innovation prior to launch, and higher levels of Work Pressure during the missions [Ritsher et al., 2007].

Strong support was found for the presence of displacement effects (hypotheses 5 and 6) using a regression analysis [Kanas et al., 2001c]. Based on previous space simulation work [Kanas et al., 1996], displacement was defined operationally as occurring when there were significantly lower levels of perceived support from outside supervisors on the Supervisor Support subscale during periods of higher intra-group tension and dysphoria, as measured by the following six subscales: Tension-Anxiety, Depression-Dejection, Anger-Hostility, Total Mood Disturbance, Anger & Aggression, and Work Pressure. Predicted significant negative relationships were found between all of these subscales and Supervisor Support when all subjects were analyzed together. Table 4.7 shows that there were no differences between crew and ground subjects except for Work Pressure, where the predicted negative relationship reached significance for crewmembers alone but not for the mission control subjects, although there was a non-significant trend in the predicted direction.

Overall differences in response between Americans and Russians and between crew and ground subjects were examined using a two-way ANOVA [Kanas et al., 2000a, 2000b]. In terms of nationality, the U.S. subjects seemed less satisfied with their interpersonal and work environments than the Russians. As seen in Table 4.8 (see Section 4.10.2), Americans reported significantly higher scores on the subscales measuring Work Pressure and Vigor-Activity, and Russians scored higher on measures of Task Orientation, Managerial Control, Leader Support, Self Discovery, and Physical Comfort. In terms of location (Table 4.9, Section 4.10.2),

Table 4.7. Subscales Showing Significant* Negative Relationships with Outside Supervisor Support (Suggesting the Presence of Displacement).

Subscale	Relationship with Supervisor Support Subscale	
	Crewmembers	Mission Control Personnel
Tension-Anxiety	Negative, significant	Negative, significant
Depression-Dejection	Negative, significant	Negative, significant
Anger-Hostility	Negative, significant	Negative, significant
Total Mood Disturbance	Negative, significant	Negative, significant
Anger & Aggression	Negative, significant	Negative, significant
Work Pressure	Negative, significant	Negative, trend (p = .087)

* p-values were less than the adjusted significance level threshold of p = .05 [Benjamini and Hochberg, 1995].

mission control subjects scored significantly higher than crewmembers on four measures of unpleasant dysphoric emotions: Tension-Anxiety, Fatigue-Inertia, Confusion-Bewilderment, and Total Mood Disturbance. However, both crew and ground groups scored significantly lower on these dysphoric subscales than comparable work groups from other studies on Earth [Kanas et al., 2000a, 2000b, 2001b]. In terms of the interaction of nationality and location, for three subscales (Leader Support, Expressiveness, and Independence), Russian crewmembers scored higher than their American counterparts, and Russian ground subjects scored lower than Americans. For all three of these significant subscales, U.S. astronauts scored the lowest.

T-test analyses of the on-orbit data for all 21 subscales were conducted that compared crewmember mean scores with published means from similar work groups on Earth [McNair et al., 1992; Moos, 1994a, 1994b]. For six of the seven POMS mood state variables, the crewmembers endorsed significantly less dysphoria than the normative samples. The exception was Vigor-Activity, where there was no difference. The crewmembers also scored lower on measures of group Expressiveness, Independence, Anger & Aggression, and Innovation; and higher on measures of Cohesion, Leader Control, and Managerial Control [Kanas et al., 2001b]. These significant subscale differences were similar for Russian and American crewmembers alone when compared with the normative samples.

In a series of post-hoc analyses, we examined the relationship between both the task and support role of the leader and their effects on group cohesion [Kanas and Ritsher, 2005]. Since both leadership roles have been felt to be important in space analog missions (see Section 4.6), we expected that both would correlate with a measure of cohesion during a series of missions to the Mir space station. Using a mixed model linear regression procedure, we found a significantly positive relationship in crewmembers between Leader Support and Cohesion but not between Leader Control and Cohesion. These findings were true for all

crewmembers, American astronauts alone, and Russian cosmonauts alone. For mission control personnel, there were significantly positive relationships between Leader Support and Cohesion and between Leader Control and Cohesion; these findings held for all mission control subjects, Americans alone, and Russians alone.

A content analysis was made of the Critical Incident Log findings [Kanas et al., 2001a]. Crewmembers contributed 4% of the total number of critical incidents, and mission control subjects contributed 96%. Notably, a few of the more verbal participants contributed over half of the responses. Because of this sample response skewing, and the fact that subjects sometimes gave more than one response per questionnaire, it was not possible to statistically test for critical incident effects. However, a descriptive analysis leads to some suggestive trends. Seven of the 13 incidents reported by the U.S. astronauts concerned interpersonal problems that affected their group (e.g., feeling unsupported by other crewmembers, conflicts with mission control personnel), and the other 6 pertained to negative events on-board the Mir (e.g., accidents, equipment failures). The only two Russian cosmonaut responses were from the same person, who cited two negative events on-board the Mir that threatened the physical environment. For the American mission control respondents, 49 of their 106 reported incidents were related to interpersonal problems that affected their group (e.g., disagreements with each other, the leader, crewmembers, or Russian colleagues), and 16 pertained to negative events on-board the Mir (e.g., accidents, equipment failures). For the Russian mission control respondents, 86 of their total of 273 responses were related to negative events on-board the Mir (e.g., accidents, equipment failures), and 60 pertained to inadequate resources and delays in receiving their salary due to fiscal problems in Russia.

4.10. Empirical findings from space: human interactions during the International Space Station (ISS) program

4.10.1. Procedures

As the Shuttle/Mir Program was winding down, an opportunity presented to replicate this study during the construction of the new International Space Station (ISS). In addition, with plans to expand the crew of the ISS to include participants from countries other than the United States and Russia, it became important to study the impact of language and cultural issues on the performance and well-being of international space crews living and working on-orbit. To accomplish these goals, the members of the Shuttle/Mir investigative team (see footnote to Section 4.9.1) submitted a research proposal to study crew-ground interactions during construction missions involving the ISS. This multi-year proposal was funded by NASA in 1998 (#NAS9-98093 and #NCC-0161).

Many of the hypotheses and procedures for this ISS study were similar to those described in Section 4.9.1, except that based on the Shuttle/Mir findings, it was predicted that there would be no second half changes in crew cohesion and tension and no second half changes in crew and mission control perception of leader and outside supervisor support.

There were a number of differences between the Shuttle/Mir and ISS studies. First, in the former, American and Russian mission control subjects all were located at TsUP in Moscow, but in the latter there were two additional mission control centers in the United States: one at the Johnson Space Center in Houston, Texas (responsible for operations) and one at the Marshall Space Flight Center in Huntsville, Alabama (responsible for science and other payloads). Now, all ground subjects could be studied in their more familiar home countries. Second, the ISS crewmembers in a given mission all launched and returned together rather than being staggered in time, as had been the case in the Shuttle/Mir study. Interpersonal dynamics could now be examined in a closed group of people who were together throughout the mission. Third, the 3-person ISS crews varied in national representation, some having two Russian cosmonauts and one American astronaut, and others having two American astronauts and one Russian cosmonaut. In contrast, the 3-person Shuttle/Mir crews all consisted of two Russians and one American. The impact of nationality versus minority status during on-orbit missions could now be unconfounded, which was not possible in the Shuttle/Mir study. Fourth, some ISS missions had a Russian commander and some had an American commander, whereas in Shuttle/Mir the commander was always a Russian. Fifth, due to the disruption of the Space Shuttle launches stemming from the Columbia accident, the smaller Russian Soyuz was used temporarily to transport crewmembers into orbit. Due to space limitations, only two crewmembers could be launched. Consequently, some of the ISS missions that were studied had only two crewmembers (one American and one Russian), whereas others (prior to the accident) had three crewmembers. Finally, the ISS missions had a major American operational influence, whereas the Shuttle/Mir missions were largely under Russian control. Given these differences between the Shuttle/Mir and ISS mission profiles, if the results were similar across these two studies, then it could be inferred that they would be applicable to future on-orbit missions as well. If the results were different, then the impact of program-specific characteristics needed to be examined more closely.

Like in the Shuttle/Mir study, the ISS missions were 4–7 months in duration and contained crews that included at least one American and one Russian. Due to the Columbia accident and other delays, which impacted on the construction schedule, missions could not be studied that involved non-U.S. and non-Russian participants who were in space for longer than one month duration, which was the minimum time for a crewmember to be included in the study protocol. Eight ISS crews were given an informed consent briefing related to the study, and seven agreed to participate. The final study sample consisted of four missions with 3-person crews and three missions with 2-person crews. One person chose not to participate, but data were collected from the rest of that crew. Crewmembers were in their 30s–50s, as is typical of the population of active astronauts and cosmonauts. In all, the subject sample included 17 crewmembers (8 Americans and 9 Russians; 15 men and 2 women) and 108 American and 20 Russian mission control personnel.

As in the Shuttle/Mir study, the ISS crewmembers and mission control subjects rated their emotional state and social climate weekly using elements from three scales: the Profile of Mood States or POMS [McNair et al., 1992], the Group Environment Scale or GES [Moos, 1994a], and the Work Environment Scale or

WES [Moos, 1994b]. The same subscales were tested as are shown in Table 4.6, with the exception of Physical Comfort, which was deleted in the ISS study due to debriefing opinions expressed from some of the Shuttle/Mir subjects that the questions in this subscale were irrelevant for on-orbit space station environments. Scores on the remaining 20 subscales were used to test ISS study hypotheses. The questionnaire for both crew and ground subjects was completed every Wednesday for 4 weeks prior to launch, during the mission, and 2 weeks after return to Earth. During the missions, the overall compliance rate for completion by the crewmembers was 82%.

Second half time effects, displacement, cultural differences, and leadership role were analyzed using methods similar to those used in the Shuttle/Mir study. None of the ISS variables required transformation because the residuals from mixed model analyses were considered normally distributed. Corrections to reduce the risk of Type I errors were employed using the procedure recommended by Benjamini and Hochberg [1995].

4.10.2. Results

Using a mixed-model linear regression analysis, there were no changes in the slopes of the subscales used to measure crewmember cohesion, tension, or leader support in either the 1st or 2nd halves of the missions; that is to say, none of the slopes showed a significant deviation from a horizontal line with a slope of zero [Kanas et al., 2007]. These results suggested the absence of 2nd half (and 1st half) decrements during the course of the missions. In further analyses using ANOVAs, there were likewise no differences in mean crewmember scores in any of the 20 subscales across the four quarters of the missions. In comparing the 3rd quarter means against the means for the other three quarters pooled together, there again were no significant differences, except for the Independence subscale, which was higher in the 3rd quarter. However, this finding was in the opposite direction from what would be predicted to test for a negative third quarter phenomenon. The failure to find time dependent findings essentially replicated the time results from the Shuttle/Mir study.

Unlike the Shuttle/Mir study, there was no evidence to suggest the presence of a novelty effect in our ISS study for the American (or Russian) crewmembers. They seemed to adapt to the ISS environment and showed no significant subscale differences in the first few weeks versus the rest of the mission.

Also unlike the Shuttle/Mir study, the ISS crewmembers were more positive in their mood states during the mission than before launch (i.e., they had lower scores in Tension-Anxiety, Depression-Dejection, Anger-Hostility, Fatigue-Inertia, Confusion-Bewilderment, and Total Mood Disturbance), and they did not score Work Pressure as being higher during the missions. Like the Shuttle/Mir crewmembers, their Self Discovery and Innovation scores were higher prior to launch, although their levels of Managerial Control were higher during the missions [Ritsher et al., 2007].

Exploratory analyses were conducted to look for a potential relationship between individual mean scale scores and mission duration. Pearson correlations indicated that there was no significant relationship between the length of the

missions (within the 4–7 month range in the study sample) and average scores on the 20 subscale measures. Descriptively, none of the corresponding scatter plots showed signs of any meaningful relationships. Taken together, these analyses suggested that it was unlikely that differential time effects existed between the longer and shorter missions that were included in the study.

As in the Shuttle/Mir study, the ISS results found evidence to support the displacement construct [Kanas et al., 2007]. All six of the relationships between variables measuring tension/negative moods and perceived support from outside supervisors were in the predicted negative direction, after correcting for possible Type I errors. In a secondary set of analyses to evaluate whether these relationships might be different for crewmembers versus mission control personnel, the results showed a statistically significant interaction for four of the six relationships (Tension-Anxiety, Anger-Hostility, Total Mood Disturbance, and Work Pressure), each of which showed a stronger effect among crewmembers than among mission control personnel. Estimates for crew and ground subjects analyzed separately showed that for all of these variables, the effect was in the predicted direction and statistically different from zero, except for the relationship between Tension-Anxiety and Supervisor Support among mission control personnel, which was in the predicted direction but not statistically significant. Taken together, these findings suggest that the displacement effect was present in both crewmembers and mission control personnel, but that it was stronger for the former than the latter.

Using ANOVA methods, Russian-American and crew-ground differences were tested for all of the subscales. In terms of a main effect for Country, there were similarities between the Shuttle/Mir and ISS studies that suggested the presence of cultural differences between the American and Russian subjects. The two-study

Table 4.8. Subscales Showing Significant Mean Score Differences Between American and Russian Subjects. Subscales that showed significant mean score differences in the Shuttle/Mir and ISS studies. **Bold** indicates that the higher pair score is significant, after applying the correction to reduce the possibility of Type I error [Benjamini and Hochberg, 1995]. Adapted from Kanas et al. [2006].

Subscale	Shuttle/Mir Study (Means)		ISS Study (Means)	
	American	Russian	American	Russian
Tension-Anxiety	4.97	7.10	4.11	8.04
Work Pressure	7.75	5.38	6.63	4.06
Task Orientation	7.43	8.41	7.94	8.31
Managerial Control	5.31	6.75	5.90	6.52
Leader Support	5.66	7.51	7.67	6.89
Self Discovery	2.01	4.53	3.79	4.22
Vigor-Activity	19.33	17.41	15.07	15.27
Physical Comfort	1.49	2.86	Not Tested	

comparisons are shown in Table 4.8, where statistically significant Russian-American subscale differences are listed. Although there were seven significant differences in the Shuttle/Mir study and two in the ISS study, all but two of the corresponding non-significant pair comparisons that were tested trended in the same way as those that reached significance (exception: Leader Support and Vigor-Activity in the ISS study). Perhaps if the subject numbers had been greater, some of these trends may have reached significance due to the enhanced statistical power.

Table 4.9 gives the results for the subscales that showed a statistically significant main effect for Location for the Shuttle/Mir and ISS studies. There again are many similarities in findings across the two studies, especially among the dysphoric subscales shown at the top. This suggests that the crewmembers experienced less emotional discomfort than mission control personnel in their work environment. Crewmembers in the ISS study also reported having more vigor, innovative experiences, and support from their leader (the mission commander), although they also perceived having less task-related direction from their leader than people on the ground.

In the Shuttle/Mir study, there were three subscales that showed significant Country by Location interaction effects: Leader Support, Expressiveness, and Independence. These findings were not replicated in the ISS study, since there were no significant interaction effects for any of the subscales evaluated.

Table 4.9. Subscales Showing Significant Mean Score Differences Between Crewmembers and Mission Control (MC) Subjects. Subscales that showed significant mean score differences in the Shuttle/Mir and ISS studies. **Bold** indicates that the higher pair score is significant, after applying the correction to reduce the possibility of Type I error [Benjamini and Hochberg, 1995]. Adapted from Kanas et al. [2006].

Subscale	Shuttle/Mir Study (Means)		ISS Study (Means)	
	Crew	MC	Crew	MC
Tension-Anxiety	4.18	7.89	3.81	8.35
Fatigue-Inertia	2.01	4.83	1.79	6.22
Confusion-Bewilderment	1.87	3.50	1.95	4.92
Total Mood Disturbance	-6.30	10.48	-7.29	17.98
Anger-Hostility	2.54	5.84	2.03	6.26
Anger and Aggression	2.06	3.89	1.12	3.18
Vigor-Activity	18.09	16.32	18.32	14.36
Innovation	3.34	3.98	4.53	3.32
Leader Control	6.77	6.08	5.08	6.27
Leader Support	6.81	6.36	8.12	6.44

The Shuttle/Mir findings were replicated in the ISS study for leadership role. Using mixed-model regression techniques, it was found that for all crewmembers, Leader Support, but not Leader Control, was significantly related to Cohesion. This pattern of results also was found for American astronauts alone and for Russian cosmonauts alone. For all mission control subjects, both Leader Support and Leader Control were significantly related to Cohesion; this was also the case for Americans alone and Russians alone who worked in mission control environments.

Two raters analyzed the log entries from the ISS crewmember subjects and coded their content into any of 17 categories. Eight subjects from both countries provided 37 log entries, with one accounting for 22 entries. The content from the log entries was broken down into a total of 92 ratings coded across all categories. Coded ratings were re-categorized as having a reference to positive/negative/neutral attributes or were related to expected onboard events. From the 92 critical incident ratings, 21% contained positive attributes (e.g., holiday celebrations, actions that bonded the crewmembers closer together), 17% contained reference to expected on-board events (e.g., dockings, EVAs), 55% contained incidents having negative attributes (e.g., interpersonal or psychological problems), and the remaining 7% contained either neutral ratings or not enough information to analyze. Of those logs containing incidents with negative attributes, 47% referred to interpersonal problems (intra-crew, crew-ground, or with management), and 18% dealt with psychological problems (e.g., tension, depression). In response to a question asking how much the incident affected their personal level of tension, the crewmember scores averaged between ratings of “no change” and “increased a little”. The results were similar for a question asking how much the incident affected their group’s level of tension. Because 53% of the subjects did not report a critical incident, and because one subject accounted for 59% of the responses, one must be cautious in interpreting these findings. Nevertheless, the responses suggested that both negative and positive incidents occurred, causing both personal and group tension to fall or rise on-board, and that interpersonal incidents were more common than psychological or other negative incidents.

4.10.3. Culture and Language Questionnaire findings

Unlike the Shuttle/Mir study, the ISS study included a new measure, the Culture and Language Questionnaire, that evaluated the impact of various cultural and language experiences and attitudes. Four of the items were Likert-type questions that asked about the need for a common language and assessed each subject’s tolerance of dialect differences, both in space crewmembers and in mission control personnel. These items were from a previous study by Kelly and Kanas [1992]. Other questions dealt with the number of languages spoken and different countries visited by the respondents, the breadth of their ethnic experiences and interests, and the degree of their knowledge of the people from the countries that were contributing to the ISS program. Unlike the other measures used in this study, which were completed weekly, this questionnaire was only given once, during pre-launch training.

Most of the items from the questionnaire were factor analyzed, and the resulting factor structure produced four subscales that measured the degree to which participants reported having social contact with other cultures, were knowledgeable

about ISS partner countries, had visited other countries, and had foreign language skills. These subscales were summed to produce an overall score measuring “cultural sophistication”. Not included in this score were the responses to the four Kelly and Kanas “language flexibility” questions, which were analyzed separately.

On average, the crewmembers had higher cultural sophistication scores than mission control personnel, with Russians scoring higher than Americans. These differences were mainly due to the lower average score of the American mission control respondents. In examining the associations between cultural sophistication scores and the 20 mood and social climate variables, there was only one significant finding: a negative association between the mean cultural sophistication score and Supervisor Support for crewmembers.

In terms of language flexibility, the results showed that Americans scored significantly higher than Russians on a question about the importance of mission controllers having the same dialect of a common language. They also felt more strongly that the crew should speak the same dialect of a common language.

4.11. Empirical findings from space: conclusions from the Shuttle/Mir and International Space Station human interactions studies

The results from the ISS study generally replicated those from the Shuttle/Mir study. This strengthens confidence in the generalizability of the results for on-orbit missions, despite the small number of crewmember subjects that are typical in space station research. It also suggests that similar psychosocial factors apply to missions near the Earth lasting 4–7 months in duration. We will discuss the findings in terms of several broad categories.

4.11.1. Time effects

Like the Shuttle/Mir study, the ISS study found no general changes in mood or interpersonal environment over time in space, in contrast to some studies from space analog environments on Earth but in support of others [Kanas et al., 1996; Steel and Suedfeld, 1991; Wood et al., 1999, 2005]. This suggests that people who live and work on-orbit do not routinely experience increased tension or decreased cohesion during the 2nd half of the mission, nor do they exhibit the third quarter phenomenon. Perhaps the excitement and potential danger of being on-orbit stimulated the crewmembers in ways that prevented these decrements from developing as general phenomena. This is not to say that an occasional crewmember did not display 2nd half or 3rd quarter effects (which was the case for some individual subjects); rather, these effects were not typical for the space crews that we studied.

Another possible explanation for this absence of time effects may be due to the fact that the crewmembers were supported by space psychologists and flight surgeons in mission control who utilized a variety of countermeasures to help them deal with stress, boredom, and monotony (see Section 6.7). For example, they were encouraged to communicate with family and friends on the ground via audio-video links or e-mail, and gifts and letters were sent up from home during resupply

missions. These activities may have helped to blunt the effects of monotony and homesickness on-orbit. In contrast, this intensity of support has been difficult to maintain during some space analog missions on Earth, such as the winter-over period in the Antarctic where communications and resupply opportunities are limited by the harsh weather.

A final explanation for the lack of time effects during the on-orbit phase of the missions may be related to the stringent selection criteria and intensive training that astronauts and cosmonauts undergo prior to launch. These are people who are used to dealing with stress in an emotionally calm and positive manner, reacting with less lability than other people. In fact, they generally score lower on the negative subscales (and higher on the positive subscales) than normative samples of people in other work settings on Earth [Kanas et al., 2001a]. Furthermore, analyses of their pre-flight versus in-flight emotions showed that for the ISS crewmembers, their moods were more positive during the missions than before launch, where their mood scores were similar to those of mission control personnel [Ritsher et al., 2007]. Thus, it is possible that due to personality and training factors, space crewmembers do not on average experience the extremes of homesickness and other negative emotions during the course of a long mission as compared with participants in space analog environments on the Earth, such as in submarines or polar bases. In fact, they seem to thrive in the space environment.

American crewmembers experienced a novelty effect during the Shuttle/Mir missions, which probably reflected the lack of experience that Americans had at the time with space station missions. This effect was not present during the ISS missions, as both Americans and Russians had by then gained more familiarity in being on-orbit together for long periods of time. In fact, the higher Self Discovery and Innovation scores reported by crewmembers prior to both Shuttle/Mir and ISS missions suggest that more new learning occurred during pre-launch training than during the time on-orbit. Although Work Pressure scores were higher post- rather than pre-launch during Shuttle/Mir, this difference was not found during ISS, perhaps due to the high level of Managerial Control. In addition, there were fewer accidents and equipment breakdowns during the ISS program than during Shuttle/Mir.

4.11.2. Displacement

As with the Shuttle/Mir study, the ISS results found evidence of displacement in both crewmembers and mission control personnel. This effect appeared to be stronger with the more isolated crewmember group. People use displacement to deal with tension and other unpleasant feelings by blaming others for their own problems and perceiving others as feeling negative toward them. Although providing temporary relief, in the long run this strategy can cause additional interpersonal problems with people who are being blamed, and it does not address the source of the original conflict.

It would be better if people involved with space missions could learn to identify the causes of intra-psychic and intra-group stress and learn strategies of coping with these stressors directly. Countermeasures to reduce displacement need to be taught pre-launch in sessions that involve both crewmembers and representatives from

their mission control support team. Each of these groups need time during the course of the mission to self-monitor their emotions and group interactions and clear the air of psychological and interpersonal stressors.

It is possible that crewmembers in space were in fact less supported by people in mission control during the times that they were experiencing tension amongst themselves. However, there was little evidence for this in the critical incident logs that our subjects completed, in the daily reports generated by mission control personnel, or in the post-mission debriefings. Consequently, the predicted negative relationship between measures of tension and negative affect in space and perceived lack of support from the ground was most likely due to the displacement construct than to real events that occurred during the missions.

4.11.3. National and organizational culture

In looking at the results related to differences between Americans and Russians, the findings from both studies suggested that compared with the Americans, the Russians experienced less pressure on the job; more tension during the ISS missions; and more direction, support, and self discovery during the Mir missions. These findings may have been due to national cultural differences between these two groups of people. For example, the American subjects might have felt more pressure to perform than the Russians due to on-the-job expectations rooted in typical American attitudes about competition and achievement.

However, it is also possible that these differences reflected organizational cultures that are characteristic of the two space agencies. For example, it has been suggested that the Russian space program utilizes fewer written procedures and relies more on expert opinion from the ground to deal with problems than the American space program [Clement and Ritsher, 2005; Committee on Space Biology and Medicine, 1998; Ritsher, 2005]. In the Shuttle/Mir program, operations on the Mir space station were Russian-directed and always had a Russian commander. The American astronaut was in the minority in the three-person crew and had less of an operational relevance. In addition, Americans up till then had less experience with extended missions in space as compared with their Russian colleagues. Finally, since most of the space-to-ground communications were in the Russian language, the Americans might have felt a sense of discomfort and isolation. Thus, it is understandable that Russians would have felt more comfortable and supported than the Americans in the Mir program. In contrast, the ISS program had a decidedly American style of operations. These complex missions were largely oriented toward constructing the space station facility, so it would be expected that the Americans would feel a great deal of work pressure to meet the busy construction goals. The tension felt by the Russian crew and ground subjects could have reflected their lack of familiarity with American operational tasks and procedures.

In both the Shuttle/Mir and ISS studies, the crewmembers reported having lower levels of negative dysphoric emotions than mission control personnel, and in the ISS study the crew experienced more vigor and innovation. The mood results may be explained by personality differences between people who become astronauts and cosmonauts and people who work in mission control, with the former acknowledging less emotional distress in response to work stress than the latter. In

addition, people in mission control received less psychological support than the on-orbit crewmembers. Finally, the astronauts and cosmonauts may have experienced more elation and job satisfaction due to the thrill of being on-orbit and fulfilling their dream of being in space, as compared with people on the ground whose work was less novel and exciting by comparison. The opportunity to work on a new space construction project may have accounted for the relatively high vigor and innovation scores among the ISS crewmembers. But despite these differences from one another, crewmembers and mission control personnel still scored lower on most dysphoric subscales than samples of people on Earth who work in non-space related activities.

4.11.4. Cultural and language experiences and attitudes

On the Cultural and Language Questionnaire, the ISS crewmembers scored higher in cultural sophistication than mission control personnel, which might be expected since they trained in various locations and interacted more with people from other countries. American mission control personnel scored lower than the other groups, which was a bit surprising given the diversified nature of American culture, but it might have reflected the relative isolation of people from the United States in comparison to their peers in Russia, whose country is bordered by other European and Asian countries and who are therefore exposed to their cultures (as well as to American culture through television and movies).

Americans scored significantly higher than Russians on the importance of crewmembers and mission controllers both speaking the same dialect of a common language. It is likely that the American subjects were less comfortable themselves with speaking other languages than the Russians, and this might have accounted for their relative discomfort with dialect differences. These findings are reminiscent of those comparing American with international astronauts in the Kelly and Kanas [1992] study (see Section 4.4.1)

4.11.5. Leadership roles

Both Shuttle/Mir and ISS mission control personnel acknowledged a relationship between both the task and support roles of their leader and the cohesion of the group. This was expected, since both of these leadership characteristics have been shown to be important in the performance of other groups of people working together under stressful conditions (see Section 4.6).

Although in both space station studies, the crewmembers perceived a relationship between the support role of the leader and group cohesion, they did not see a link between cohesion and the task role of the leader. Perhaps this was a reflection of crew size. In crews consisting of only two or three people, each person has specialized job skills that make him or her a leader in activities related to these skills. There is less need for the kind of formal work-related leadership structure that is found in larger groups. In addition, in such a small group one's social support system is limited, and it is important to be cordial and flexible to avoid feeling isolated. Thus, group cohesiveness would be expected to be more sensitive to support from the leader than to task-related activities.

4.11.6. Critical incidents

In the Shuttle/Mir study, all subject groups listed negative events taking place on-board the aging Mir Space Station as an important source of critical incidents. American crewmembers and mission control personnel also cited interpersonal problems as being important, perhaps as a result of working in a program that was operationally managed by people from another culture. Russian mission control personnel mentioned resource and salary deficits as important, which reflected real issues related to political changes in Russia and the fact that many of them had delays in receipt of their salaries. These findings support the notion that negative experiences that occur during long-duration space missions may be related more to psychosocial pressures from the stressors related to the mission itself than to individual personality weaknesses, suggesting that they may be prevented through proper training and support or through an improved space capsule environment.

This may be the explanation for the fact that in the ISS study, nearly half of the responses from the crewmembers mentioned neutral or even positive events. Most of the negative events were due to interpersonal or psychological problems. The majority of the critical incidents that reflected operational issues were expected (e.g., dockings, EVAs), and there was a notable lack of emergencies or accidents in comparison to the Shuttle/Mir responses. These differences probably reflected the newer and improved environment on the ISS, in comparison with the aging Mir Space Station. The increased number of total responses might have been due to the higher frequency of positive experiences, or it may have reflected an increased tendency of ISS subjects to respond to the critical incident log in comparison with their Shuttle/Mir colleagues.

4.11.7. Implications for future space missions

These conclusions suggest a number of training countermeasures for future on-orbit space missions. Since crewmembers and mission control personnel are dependent upon each other during such missions, they should receive pre-launch psychosocial education training together. Specific topic areas should include: ways to improve the relationship between crew and ground personnel, dealing with crew tension and displacement, the impact of national and organizational culture differences on mission success, and ways of applying different leadership roles at appropriate times. Computer-based training could be scheduled in space and on the ground during the mission as a reminder and extension of the psychosocial training received pre-launch. Commanders selected for missions should have demonstrated the ability to be both task-oriented and supportive in previous space or space analog environments. Further countermeasures for on-orbit missions are discussed in detail in Chapter 6.

But caution should be used in extrapolating these findings to a future expeditionary mission beyond the Earth's orbit, such as a trip to Mars. Mars is significantly farther away from the Earth, and this radically changes the mission profile. Unique countermeasures for such missions are discussed in Chapter 7.

Interpersonal issues need to be studied further in space, especially in preparation for expeditionary type missions. In addition to space analog settings on Earth (e.g., isolation chambers, polar bases), two off-Earth environments provide good

environments to conduct research related to future missions to Mars and other deep space locations. First, the ISS is an excellent location to study psychological and interpersonal issues with reference to the microgravity outbound and return phases of an interplanetary mission. Second, a lunar base is a good setting to study psychosocial issues with reference to a partial-gravity, ground-based environment, such as a distant planetary surface. Such studies will allow us to further define important psychosocial issues and to develop countermeasures to deal with them before they become problematic during future expeditionary missions to Mars or beyond.

4.12. Empirical findings from space: cultural challenges facing ISS personnel

Some of the cultural issues discussed above were examined in a survey of ISS astronauts, cosmonauts, and mission control personnel by the Canadian Space Agency [Tomi et al., 2007]. The purpose of the survey was to assess intercultural differences among program participants so as to prevent misunderstandings and conflict during the missions and to make recommendations regarding cross-cultural training.

4.12.1. Procedures

A total of 75 astronauts and cosmonauts and 106 ground support personnel were surveyed between 2003 and 2006. All but 20 of the astronaut/cosmonaut sample had flight experience. The study subjects were from a variety of ISS partner agencies and organizations, including the Canadian Space Agency, NASA, the European Space Agency, the Japan Aerospace Exploration Agency, the Russian Institute for Biomedical Problems, the Korolev Rocket and Space Corporation, and the Gagarin Cosmonaut Training Center. The subjects were asked a variety of multiple-choice and open-ended questions concerning their views and ideas on cross-cultural issues and training needs.

4.12.2. Results

Both crew and ground subjects rated coordination problems and/or mistrust among member organizations responsible for operating the missions as the greatest problem, followed by communication difficulties due to misunderstandings. Other common problems related to differences in language and work management styles, and miscommunication or mistrust among ground control and support teams. Astronauts rated cultural isolation experienced by a minority crewmember as a problem, whereas ground subjects rated mistrust of motives and behaviors from team members from other cultures as a major issue. Crewmembers and mission control subjects both considered cross-cultural training of astronauts and mission support personnel to be the most important countermeasure. Over 83% of the respondents thought that crew and key mission control personnel for a given mission should receive some training together, thus encouraging team-building. Highly rated content material included managing conflicts due to intercultural differences, understanding culture-based differences in management and teamwork

activities, building trust among team members, understanding the role of culture and other challenges in working as a part of a small confined multicultural team, and identifying specific communication skills. Learning by evaluating case studies and critical incidents were highly rated training methods. There was surprising unanimity in response among the subjects, although there were also some differences in ratings among members from different agencies.

4.12.3. Conclusions

These results echoed some of the findings from the human interactions studies reported earlier. Both national and organizational cultural differences were identified. Nearly all of the respondents acknowledged that cross-cultural training was important in preparing for multinational space missions. It was felt that both crew and mission control personnel should be trained, and key members of a mission should receive some of this training together. Conflict management and team building were important aspects of this training. The subjects were in agreement about the importance of understanding cultural differences and learning ways of coping with them during the mission.

4.13. Summary

- Psychosocial stressors have more of an impact on long-duration space missions lasting longer than 6 weeks than on short-duration space missions.
- Important interpersonal issues affecting space crews include: crew heterogeneity (due to gender, cultural differences, career motivation and experiences, and personality), changes in cohesion, language and dialect variations, crew size, leadership roles, and crew-ground interactions.
- The interactions between crewmembers and mission control personnel are complex and can result in lack of empathy, over-scheduling, growing crew autonomy, psychological closing, and displacement of tension and unpleasant dysphoric emotions to others.
- Negative sequelae from psychosocial stressors affecting space crews may include: intra-crew tension, scapegoating and the long-eye phenomenon, withdrawal and territorial behavior, subgrouping, minority isolation in small numbered crews, inability to achieve consensus based on crew size, leadership role confusion and inappropriate status leveling, crew-ground miscommunication, perceived lack of support from the ground, failure to deal with intra-crew problems, and information filtration.
- Junior and senior American mission controllers perceive a number of operational and cultural challenges to their work, but not necessary the same ones. Training programs need to take this difference into account.
- The results of two human interactions studies conducted during the Shuttle/Mir and the ISS programs demonstrate that psychosocial research can be done on-orbit during actual space missions. Pertinent findings were:

- In contrast to some space simulation studies conducted on the ground, there was little support for time-related effects (e.g., second half mission decrements, third quarter phenomenon) in both studies, although there was a novelty effect in American crewmembers during Shuttle/Mir (but not ISS) missions.
- In some cases, activities during pre-launch training may be perceived as more stressful by crewmembers than activities during the mission itself. However, higher scores in measures of self discovery and innovation pre-launch suggested that more new learning occurred during training than during the time on-orbit.
- There was strong support for the occurrence of displacement in both crewmembers and mission control personnel during both Shuttle/Mir and ISS missions. This effect was stronger for the isolated crewmembers than for people on the ground.
- In both studies, Americans reported significantly more work pressure; in Shuttle/Mir, they reported less direction and support; and in ISS, they reported less tension than their Russian colleagues. However, cultural differences tended to be similar in both studies and may have reflected organizational as well as national characteristics.
- In both studies, crewmembers were less dysphoric than mission control personnel. However, both groups were happier than people in other work environments on Earth.
- Although the need for a common language during space missions was endorsed by the subjects, Americans were more concerned about the importance of having a common dialect than their Russian counterparts.
- In both studies, mission control personnel acknowledged that both the task and the support role of the leader were important for group cohesion. Crewmembers, however, only saw the support role as contributing to cohesion, perhaps because in the small crews studied, everyone has important task leadership duties.
- Many subjects cited negative interpersonal and psychological issues as reportable critical incidents. During the Mir Space Station study, accidents and equipment failures were mentioned about half of the time on the aging facility, but they were less common on the ISS. In fact, over half of the critical incidents reported from the newer and ergonomically sounder ISS facility were positive or neutral events.
- Further studies need to be done in space to see if these findings generalize to other long-duration space missions, such as an expeditionary mission to Mars.
- The need for cultural training that involves crewmembers and key members of mission control (in some cases together) for a given multinational space mission was suggested by some of the findings from the human interactions studies, as well as from a cultural survey of astronauts, cosmonauts, and mission control personnel conducted by the Canadian Space Agency.

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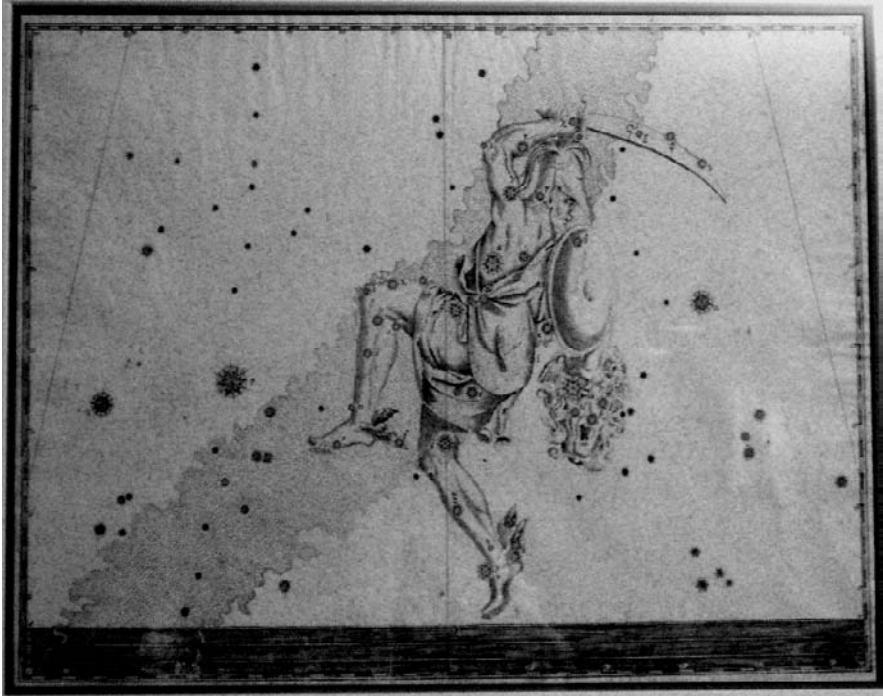
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Space travel can produce a sense of isolation and separation from family and friends. One can feel insignificant in space, with resultant anxiety, depression, and homesickness. This plate is from the first great star atlas, *Uranometria* by Johannes Bayer, which was first published in 1603. It depicts Perseus holding the head of Medusa. The ancient Greeks placed him in the Heavens, and in a sense he became one of the first “astronauts”. (Courtesy of the Nick and Carolyn Kanas collection).

Chapter 5

Psychiatric Issues

5.1. Behavioral health and salutogenesis

Curiosity has inspired human beings to venture forth into space. The psychological risks of this activity may be severe and stem from prolonged isolation from family and friends, confinement in close quarters, and survival in a dangerous and hostile environment under conditions of low gravity and radiation. However, the potential behavioral health benefits of space travel have rarely been discussed and have not been extensively studied, despite some recent work that will be reviewed below.

The concept of salutogenesis, or the health-promoting, growth-enhancing effects of a challenging situation, is a relatively modern one. The term refers to processes by which powerful experiences enhance or bring about well-being and personal growth. Some individuals gain strength and wisdom from successfully coping with personal crises; hence, negative stressors can produce positive change [Cordova et al., 2001; Wilson and Spencer, 1990]. Positive stressors can bring about positive change as well, especially when the positive experience is deliberately sought out.

Isolated and confined environments can be growth enhancing. Both Palinkas [1991] and Suedfeld [1998] have discussed the salutogenic reactions some people have to the adverse conditions found in polar environments, such as increased fortitude, perseverance, independence, self-reliance, ingenuity, comradeship, and decreased tension and depression. Kanas et al. [1996] found that three crewmembers who participated in a 135-day isolation in the Mir space station simulator in Moscow experienced significantly less tension and more expressiveness and self-discovery during their seclusion than during their pre-confinement training period. Some astronauts and cosmonauts in space have reported transcendental experiences, religious insights, or a better sense of the unity of humankind as a result of viewing the Earth below and the cosmos beyond [Connors et al., 1985; Kanas, 1990]. In his diary, cosmonaut Valentin Lebedev [1988] stated that his Earth photography experiences from the Salyut 7 space station were restful and positive, and he hoped that they would help him gain an advanced degree after he returned from his 211-day mission. Thus, involvement in long-duration space missions and related environments can be quite positive for some people. Suedfeld [2005] has argued that we should pay more attention to positive psychology and salutogenesis in the operational planning for future manned space missions.

5.2. Empirical findings from space: positive psychological aspects of space flight

Despite the anecdotal literature, few scientific studies have been done that assessed the positive psychological aspects of being in space. In their questionnaire study, Kelly and Kanas [1992, 1993] reported that a group of 54 astronauts and cosmonauts who had flown in space rated the general excitement related to their mission as being one of the strongest factors enhancing communication within the crew and between the crewmembers and mission control personnel on the ground. This is important, since good communication is essential for crew safety and mission success during long-duration on-orbit missions. Suedfeld and Weiszbeck [2004] reported on a thematic content analysis of the memoirs from four American astronauts and found that the space flight experience had affected their value system. For example, all four reported increases in spirituality, and three had increases in universalism (i.e., a sense of understanding and appreciation for all people and nature).

5.2.1. Procedures

In an attempt to further examine the positive aspects of space flight, Ihle and her colleagues [2006] conducted a questionnaire study involving astronauts and cosmonauts who had participated in at least one space mission. Subjects were recruited anonymously from two sources: the Association of Space Explorers (ASE) and the current NASA astronaut corps at the Johnson Space Center (JSC). The final sample consisted of 39 respondents: 10 from the ASE and 29 from JSC. There were no significant differences in response means between these two groups. Not all of the participants fully completed the demographics section of the questionnaire, but of those who did, most were American (34 of 37 completing this item), male (32 of 37), and had been on more than one mission (24 of 36) but spent less than 30 total days in space (20 of 36).

Respondents completed the Positive Effects of Being in Space (PEBS) questionnaire, which is a 36-item questionnaire developed by the experimenters to assess areas of personal growth that were likely to be positively influenced by being in space. Many of the items were taken with permission from the Post-Traumatic Growth Inventory (PTGI), developed by Tedeschi and Calhoun [1996]. Additional items were added that were specifically related to space travel from themes found in the anecdotal literature. The questionnaire was designed to measure change as a result of being in space, and the items were scored by the subjects using a 6-point Likert scale ranging from 0 ["I did not experience this change"] to 3 ["a moderate degree"] to 5 ["a very great degree"]. Open-ended free-response questions were included at the end to offer participants an opportunity to provide subjective comments about their experiences. The internal validity and reliability of the resultant questionnaire was excellent [see Ihle et al., 2006].

5.2.2. Results

Every respondent reported at least some positive change as a result of flying in space. As shown in Table 5.1, the average amount of change reported by the

Table 5.1. PEBS Subscales and Mean Scores. Adapted from Ihle et al. [2006]

Subscale	Mean Score
Perceptions of Earth	2.94
Perceptions of Space	1.97
New Possibilities	1.84
Appreciation of Life	1.79
Personal Strength	1.69
Changes in Daily Life	1.34
Relating to Others	1.30
Spiritual Change	0.89
Average Subscale Score	1.72

39 respondents was 1.72, or between a “very small” and a “small” degree of change as measured on the 0–5 Likert scale. The greatest change registered among the eight PEBS subscales was in the Perceptions of Earth items (mean change = 2.94, or “moderate”). A general linear model multivariate analysis showed that there was at least one significant difference between the subscale scores shown in Table 5.1, and a set of seven ordered t-tests (with Bonferroni correction) revealed that Perceptions of Earth was the only subscale to be significantly different from the others.

Ten of the respondents indicated that they were reporting no change in at least one item because no further shift was possible (i.e., the described experience was already optimal for them and could not be enhanced by being in space). The item most frequently designated as unchangeable was “I became more excited about space exploration”, followed by “I have a better understanding of spiritual matters” and “I have a stronger religious faith.” Since the last two items were part of the Spiritual Change subscale, this contributed to the relatively low change score for this subscale.

By consensus of the study team, items of the questionnaire were categorized as an “attitude” if they represented an internal experience (thought or feeling state) or as a “behavior” if they represented an external process or activity. This differentiation resulted in 26 “attitude” items and 10 “behavior” items. Prior to the start of the study, the experimenters predicted that five changes in attitude would be associated with five changes in behavior, and four of these predictions came true. Three of these items (“I realized how much I treasure the Earth,” “I learned to appreciate the fragility of the Earth,” and “I gained a stronger appreciation of the Earth’s beauty”) were significantly associated with the behavior item “I increased my involvement in environmental causes”. The fourth item, “I gained a stronger understanding of the unity of humankind,” was also associated with the predicted “My

relationship with my family grew stronger”. However, the last prediction was not borne out: the “unity of humankind” attitude was not associated with the behavior item “I increased my involvement in political activities”.

There were no statistically significant differences in any of the above results between gender, national culture, number of missions flown, or days spent in space. However, a cluster analysis of the scores revealed that the respondents fell into two categories. Using t-tests, a “high change” group scored significantly higher than a “low change” group on the total score, all eight subscale scores, and most of the individual item scores. Furthermore, after the Perceptions of Earth subscale, which was the highest in both groups, the two groups differed in their subscale rankings. For example, the more reactive respondents ranked Perceptions of Space as second, whereas the less reactive respondents ranked Appreciation of Life as second.

5.2.3. Conclusions

The results of this study suggest that space travel is a meaningful experience for the participants. Every respondent had a positive reaction to being in space. The items that were endorsed most frequently, and with the greatest amount of change, were those in the Perceptions of Earth subscale. One of these items, “I gained a stronger appreciation of the Earth’s beauty”, had the highest mean score, with the average rating indicating a “great degree” of change. This implied that people working in space developed a new view of their home planet, gaining a stronger appreciation for its beauty and fragility. This was reinforced by some of the qualitative responses on the questionnaire, which suggested that the view of Earth inspired a sense of awe and wonder rather than a spiritual awakening (which was also reinforced by the low ranking of the Spiritual Change items). Perhaps this reflected an appreciation and longing for the familiar comfort of a natural environment from a space habitat that may have been perceived as confining and sterile. Although respondents endorsed positive changes in all of the seven other subscales, these changes were rated on average as between “very small” and “small” and did not make such a great impression.

Most of the predictions about the relationship between attitudes and behaviors were supported by the findings. Specifically, an enhanced appreciation for the beauty and fragility of the Earth brought with it a greater enthusiasm for environmental causes. Although the study did not track post-return activities to see if the subjects indeed followed through on their intended behaviors, these results still suggested a link between attitude change in space and the subjects’ claims that they acted on these changes after coming home. Perhaps a willingness to enact change brought about by positive experiences could help maintain the morale of long-duration crewmembers and help with their post-flight re-adjustment to society.

Although no statistically significant differences could be found in the respondents along demographic lines, cluster analysis revealed that the subjects segregated into high and low change groups. This difference may be due to differences in personality or cognitive styles and needs to be explored further, since it may affect coping styles and become important in a proposed mission to Mars, when the Earth’s beauty is no longer appreciable (see Chapter 7). Perhaps the more reactive high change group might find more solace from general perceptions of the space

environment than the less reactive low change group, since the former rated changes in this factor as being second in importance to their perceptions of Earth. In contrast, the vastness of the cosmos might not be the same source of inspiration for the less reactive group, who might benefit more from activities that are inner-focused and directed toward appreciating the little things of life. By optimizing and individualizing the positive experiences for crewmembers on long-duration space missions, crew morale can be enhanced, with resulting benefits to their psyche and increased chances for mission success.

5.3. Psychiatric problems in space

Psychiatric problems have occurred during manned space missions. According to Shepanek [2005], from 1981 to 1989, 34 negative behavioral signs and symptoms were reported during medical debriefs following Space Shuttle missions, and two psychiatric events affected the seven American astronauts who flew on the Mir space station from 1995 to 1998. These difficulties ranged from anxiety and depression to memory and problem-solving impairments to interpersonal conflicts and withdrawal. In some cases, productivity was negatively affected.

Some psychiatric disorders seem to occur more often than others during long-duration space missions. Although many of these problems have been reported anecdotally and not studied empirically, it is important to discuss them since crewmembers and operational personnel may then develop strategies of identifying and treating them during future space missions. In addition, an awareness of these problems may promote psychiatric research in space that will focus on further identification and treatment strategies.

A description of these major conditions is given below. The system used is abstracted from the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (or DSM-IV) [American Psychiatric Association, 1994], which is the most common diagnostic system used in the United States. However, in other parts of the world (e.g., Europe, Russia, Asia), the World Health Organization International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (or ICD-10) is used [World Health Organization, 1992]. The DSM-IV provides equivalent codes between these two systems, as shown in Table 5.2.

Table 5.2. Equivalent DSM-IV and ICD-10 Diagnostic Codes.

Disorder	Relevant DSM-IV Codes	Relevant ICD-10 Codes
Adjustment Disorders	309	F43
Somatoform Disorders	300, 307	F44, F45
Mood Disorders	296, 300, 301	F30-34
Schizophrenia and Other Thought Disorders	295, 297, 298	F20, F22-25

5.3.1. Adjustment disorders

Adjusting to the stressors of space can be difficult, and adjustment disorders represent one of the most frequent psychiatric problems experienced by long-duration space travelers. The key clinical elements of this condition as outlined in the *DSM-IV* are summarized in Table 5.3.

There have been anecdotal reports suggesting the occurrence of adjustment disorders in space. For example, cosmonaut Lebedev [1988] cited several problems he had adjusting to the monotonous conditions that occurred during his Salyut 7 mission, which included despondency, withdrawal, and tense relations with his crewmate. Following a series of misfortunes and accidents involving the Mir space station, one cosmonaut commander allegedly experienced tension, fatigue, and cardiac arrhythmias that necessitated a change in his work duties and the prescription of sedatives [Carpenter, 1997]. Adjustment problems also may result from tensions due to differences in crewmember personality, background, and attitudes. In fact, space travelers highly value commonalities they have with their fellow crewmates. In a questionnaire survey of 54 astronauts and cosmonauts who had flown in space, Kelly and Kanas [1992] found that a sense of sharing common experiences and mutual excitement over the mission were two factors that were rated as significantly enhancing crewmember communication in space.

5.3.2. Somatoform disorders

People chosen for space missions may respond to the stressors of space more in somatic than in psychological terms. In the *DSM-IV*, these are subsumed under the category of somatoform disorders, the characteristics of which are summarized in Table 5.4.

For example, in his diary a Salyut 6 cosmonaut vividly expressed a fear of having an appendicitis attack during his mission, and he reported having pain in his tooth after awakening from a dream of a toothache [Chaikin, 1985]. A Salyut 7 cosmonaut allegedly had to be brought back early from his mission for poor work performance due to fatigue, listlessness, and psychosomatic concerns related to perceived prostatitis and fears of impotence [Harris, 1996].

Table 5.3. Clinical Characteristics of Adjustment Disorders. Abstracted from the *DSM-IV* [APA, 1994].

Emotional or behavioral symptoms in response to an identifiable psychosocial stressor or stressors.

Symptoms develop within three months after the onset of the stressor(s).

The resulting distress is in excess of what would normally be expected or it results in significant impairment in social or occupational functioning.

Other disorders are excluded (e.g., anxiety or mood disorder, bereavement).

The symptoms usually resolve within six months of the termination of the stressor(s) or with treatment.

Table 5.4. Clinical Characteristics of Somatoform Disorders. Abstracted from the DSM-IV [APA, 1994].

Physical symptoms that suggest the presence of a medical condition that are not fully explained by a real medical condition.

The symptoms are not explained by the direct effects of a substance or by another mental disorder.

The symptoms may cause significant distress or impairment in social or occupational functioning.

The symptoms are not intentional or under voluntary control (i.e., they are not due to malingering).

Psychosomatic symptoms also have occurred in space analog environments. Tension headaches, fatigue, and other psychophysiological reactions commonly are encountered on submarines and in the Antarctic [Lugg, 1991; Rivolier et al., 1991, Weybrew, 1991]. For example, Lugg [1991] included psychalgia (tension headaches) as one of the most common mental problems reported in research involving Australian Antarctic expeditions over a 25-year period. In a report of submarine experiences, Weybrew [1991] stated that on an average day a quarter of the men on submarine missions experienced headaches. Although in closed environments atmospheric pressure and toxins may contribute to somatic symptoms such as headaches, such factors alone cannot account for the high incidences of psychosomatic problems and preoccupations with physical issues that have been reported in space analog situations.

5.3.3. Mood and thought disorders

Major mood and thought disorders have not been reported as frequent problems during space missions. Table 5.5 lists some of the clinical characteristics of mood

Table 5.5. Clinical Characteristics of Mood Disorders. Abstracted from the DSM-IV [APA, 1994].

The prominent feature is a clinically relevant disturbance in mood.

Depressive syndromes are characterized by symptoms related to depression and at least one major depressive episode lasting for two weeks or more (major depressive disorder) or a history of depressed mood for more days than not lasting for two years or more (dysthymic disorder).

Manic-depressive syndromes are characterized by symptoms related to at least one manic episode and usually major depressive episodes (bipolar I disorder) or at least one major depressive episode and at least one hypomanic episode (bipolar II disorder).

The symptoms may cause significant distress or impairment in social or occupational functioning.

disorders, and Table 5.6 lists some of the features of schizophrenia and other psychotic thought disorders.

The low frequency of such problems in space probably is due to the fact that many of these disorders have genetic and constitutional etiologies and may appear relatively early in adult life. Since astronaut candidates are carefully screened psychiatrically to rule out such problems before they enter the corps, one would not expect to find many people vulnerable for these conditions in the astronaut pool. In the U.S. program, sophisticated psychological testing and psychiatric interviewing techniques are used to select-out individuals who have predispositions or histories of mental health problems that might negatively influence their ability to function in space [Santy, 1994]. Santy [1997] reported that the incidence of psychiatric disorders in a study of 223 astronaut applicants was 9%. Of these 20 affected individuals, five primarily had family problems, four had a personality disorder, three had a life circumstance problem, and two each suffered from bereavement, anxiety disorder, adjustment disorder, or major depression. None of these people had schizophrenia.

Other psychiatric problems that can produce mood alterations or psychotic thinking, such as alcohol or drug abuse, are not present in space due to the unavailability of the offending substance. Psychoses based on an underlying medical illness also are unlikely due to the careful physical screening astronauts and cosmonauts receive pre-launch.

Severe emotional problems have occurred in the less carefully screened populations participating in space analog studies. In a study of men wintering-over at five U.S. Antarctic stations, behavioral problems were related to the length of stay [Rasmussen and Haythorn, 1963]. Findings at one of these stations are shown in Table 5.7. Gunderson [1968] reported that 3% of naval personnel stationed in the

Table 5.6. Clinical Characteristics of Schizophrenia and Other Psychotic Disorders.
Abstracted from the DSM-IV [APA, 1994].

The prominent feature is a clinically relevant disturbance in thought to the point that the ability to test reality is grossly impaired.

Important symptoms include distorted beliefs (delusions), prominent hallucinations, poorly organized speech, disorganized or catatonic behavior, and negative symptoms such as flat affect and avolition.

Depending on the duration of the episode, the presence of concurrent mood disturbances, and other clinical features, categories include schizophrenia, schizophreniform disorder, schizoaffective disorder, delusional disorder, and brief psychotic disorder.

The symptoms may cause significant distress or impairment in social or occupational functioning.

Table 5.7. Emotional Problems During One Year at a U.S. Antarctic Base. Abstracted from Rasmussen and Haythorn [1963].

Problem	Number of Episodes by Trimester		
	0–4 Months	5–8 Months	9–12 Months
Anxious	3	8	19
Suspicious	0	7	16
Uncooperative	1	2	13

Antarctic developed psychiatric problems versus 1% of similar personnel based in other duty locations. Oliver [1991] reported that most of the 31 people at McMurdo station who wintered-over in 1977 adjusted well to the environment, but there was a mid-winter peak in sleeping problems, reports of negative mood, and homesickness. In his review of the Australian Antarctic experience, Lugg [1991] concluded that mental disorders accounted for 4-5% of the total morbidity, with severe psychotic and neurotic illness being much lower than 4%. Mental illness occurred most frequently during the wintering-over period. Rivolier and his colleagues [1991] reported several incidences of severe emotional and group tension that occurred in a group of 12 biomedical scientists who participated in the International Biomedical Expedition to the Antarctic that included a 72-day traverse. One man even had to be evacuated when he experienced severe anxiety, depression, and homesickness.

Finally, recent findings on psychiatric disorders associated with wintering-over in Antarctica have been published by Palinkas and colleagues [Palinkas, 2001; Palinkas et al., 2001]. Their data are based on debriefings with 313 military and civilian personnel who spent an austral winter at South Pole Station or McMurdo Station. In these debriefings, 5.2% of the subjects reported symptoms that met the criteria of a DSM-IV disorder. Most frequently, mood and adjustment disorders were diagnosed (31.6% of all disorders), followed by sleep-related disorders (21%), drug-related disorders (10.5%), and personality disorders (7.9%). None of these conditions were found to depend on age, sex, or prior wintering-over experiences. Interestingly, these disorders developed despite the fact that all subjects had passed a psychiatric and psychological screening prior to their assignment for remote duty in the Antarctic.

Psychiatric difficulties also have occurred during submarine missions. Serxner [1968] reported a 5% incidence of severe psychiatric problems (e.g., anxiety, depression, psychosis) in his report of two cruises of the *Polaris* submarine. In a review of 30 years of research involving nuclear submarines, Weybrew [1991] concluded that the incidence of acute or chronic psychopathology during the longer missions was 1-4%. Anxiety and depressive reactions were most frequent, followed by antisocial and other characterological problems, and psychophysiological reactions. In a review of nuclear submarine missions [Boeing Aerospace Company, 1983], 1.2% of the men suffered from severe psychiatric problems: 50% were related to severe anxiety, 39% to interpersonal difficulties, and 29% to depression.

5.3.4. Post-mission effects: personality changes and marital problems

As mentioned earlier, a number of astronauts and cosmonauts have had transcendent or religious experiences in space or have been humbled by thoughts of their relative insignificance in the vastness of the cosmos. As a result, many space travelers have exhibited personality changes, differences in outlook, or increased sensitivity to human needs on returning to Earth. Others have had more negative experiences, such as neurotic symptoms, depression, and marital problems. These and other difficulties affected Apollo astronaut Buzz Aldrin after his mission to the Moon and necessitated psychiatric intervention [Aldrin, 1973]. Post-seclusion anxiety and suspiciousness also were noted in a crewmember who had participated in a 90-day closed chamber space simulation study [Seeman and MacFarlane, 1972].

Problems have affected the families of individuals who have spent long periods of time away from home. Isay [1968] studied 432 wives living on a submarine base and found that most of them had adjusted to the absence of their husbands. However, nearly two-thirds experienced depression when their spouse returned from sea patrol and tried to reassert his role in the family, thereby disrupting the equilibrium. Isay called this “the submariners’ wives syndrome”. Pearlman [1970] likewise found that serious marital problems occurred in families following the return of the husbands from submarine patrol.

Family difficulties also have been reported following Antarctic expeditions. Oliver [1991] found that 26 of 29 individuals experienced difficulty readjusting to the home environment after they returned from Antarctica. Taylor [1991] reported that at least three of the 12 participants in the International Biomedical Expedition to the Antarctic experienced disruptive relationships with their partners within 16 months of returning. Thus, long duration separations can take their toll on families, even after the members are reunited.

5.4. Asthenia

5.4.1. A common space syndrome?

5.4.1.1. Cultural issues

According to Russian psychologists and flight surgeons, a major problem that affects the emotional state of cosmonauts during long-duration space missions is asthenia (sometimes referred to as “asthenization”) [Kanas, 1991]. This syndrome is defined as a “nervous or mental weakness manifesting itself in tiredness...and quick loss of strength, low sensation threshold, extremely unstable moods, and sleep disturbance. (Asthenia) may be caused by somatic disease as well as by excessive mental or physical strain, prolonged negative emotional experience or conflict.” [Petrovsky and Yaroshevsky, 1987, p. 28]. Asthenia is seen as a milder variant of neurasthenia, a serious mental disorder that appears in the *ICD-10* system of classification and requires treatment. Important clinical elements of neurasthenia are shown in Table 5.8.

Symptoms and signs suggestive of asthenia have been reported anecdotally by American astronauts who have flown in space during long-duration missions

Table 5.8. Clinical Characteristics of Neurasthenia According to the ICD-10. Abstracted from Sadock and Sadock [2000].

Persistent and distressing feelings of exhaustion or fatigue after minor mental or physical activities.
Presence of at least one of the following: muscular aches and pains, dizziness, tension headaches, sleep disturbances, inability to relax, or irritability.
Simple rest or entertainment does not alleviate the symptoms.
Duration of three months or longer.
The above is not due to any other physical or emotional disorder.

[Burrough, 1998; Freeman, 2000; Harris, 1996]. However, neither asthenia nor neurasthenia appear as diagnostic entities in the American Psychiatric Association *DSM-IV*, so American mental health professionals cannot diagnose this syndrome in their patients using this manual. In the United States, many of the symptoms of asthenia are included under such diagnoses as adjustment, dysthymic, or major depressive disorders, or chronic fatigue syndrome.

This is ironic because the roots of neurasthenia can be traced back to an American physician, George Beard, who lived from 1839 to 1883 [Beard, 1905/1971; Kanas et al., 2001b]. He observed that many of his patients complained of vague symptoms, such as exhaustion, morbid fears and anxieties, hopelessness, mental irritability, concentration difficulties, forgetfulness, headaches, insomnia, bad dreams, pains, and sexual problems. He believed that an underlying physiological disorder was responsible for this plethora of symptoms, which he characterized as nervous exhaustion or neurasthenia. He viewed neurasthenia as a peculiarly American disease that especially affected the upper classes. He outlined many treatments for neurasthenia that included diets and herbs, medications, rest, massage, and local applications of electricity. The concept of neurasthenia gradually took hold and spread to Europe, Russia, and Asia [Carlson, 1991]. After World War I, the popularity of this syndrome declined in the United States, although it continued to be identified in other countries, where it persists today.

This creates a dilemma for flight surgeons and psychologists who are involved in supporting crews participating in long-duration space missions. Is there a fatigue-like syndrome that commonly occurs which is conceptualized one way by users of the *DSM-IV* and another way by users of the *ICD-10*? Or are there cultural variations taking place, whereby psychological reactions to being in space are expressed differently by people with different cultural and national backgrounds? The resolution of this issue needs further empirical study (see Section 5.4.3).

5.4.1.2. Russian views of asthenia in space

Russian experts diagnose and monitor asthenia in space by analyzing verbal communication between crewmembers and personnel in mission control; by examining medical information; and by administering clinical scales that assess fatigue, somatic symptoms, sleep quality, and mood. Several of these experts have written about the characteristics of this syndrome in the space environment. For example, Myasnikov and Zamaletdinov [1996] believe that elements of asthenia (e.g., fatigue, emotional lability, sleep disturbances) are seen in cosmonauts participating in space missions lasting more than four months. This has contributed to impaired performance, crewmember conflict, and operational errors. The condition seems to be one of cumulative fatigue that develops over time.

Aleksandrovskiy and Novikov [1996] believe that a mild form of asthenia (i.e., hyposthenia) appears in many cosmonauts after one to two months. They view the hyposthenic state as one in which inhibitory processes predominate and as being characterized by fatigue, decreased work capacity, sleep problems, anxiety, autonomic disturbances (e.g., palpitations, perspiration), attention and concentration difficulties, and heightened sensitivity to bright lights and loud noises. Perceptual changes also have been reported empirically by space travelers. In one questionnaire study of 54 astronauts and cosmonauts who had flown in space, the subjects stated that watching and listening activities significantly increased in space during both work and leisure time periods [Kelly and Kanas, 1992]. This was reminiscent of reports that during Salyut 6 and 7 changes in perceptual sensitivities were noted after three to five months, with some cosmonauts stating that they became increasingly disturbed by loud sounds and the manner of verbal presentations from people in mission control [Grigoriev et al., 1988; Lebedev, 1988].

Aleksandrovskiy [1976] has described three stages of asthenia. In the first stage of hyperesthesia, there is a general increase in sensitivity to external stimuli that results in hyperarousal, increased activity, emotional irritability, impatience, poor attention and concentration, memory problems, tiredness, headaches, perspiration, unstable pulse and blood pressure, and sleep disturbances. In the intermediate stage of irritable weakness, irritability and emotional instability progress into severe fatigue, negative emotional reactions, and somnolence. In the third stage of hyposthenia, there is apathy, constant fatigue, passiveness, and lack of work capability.

More recently, Myasnikov et al. [2000] have contrasted clinical asthenia on Earth with asthenia in space. They believe that the former is a disorder with neurotic features that is treated with medication. However, the latter usually is milder, in part because cosmonauts are carefully screened for psychiatric problems and in part because people in space are monitored and countermeasures are employed at the first sign of psychological difficulty. Consequently, medications usually are not needed. Asthenia in space is viewed as reflecting both the level of psychological stress during space missions and the inadequacy of individual coping strategies. For these reasons, the authors prefer the term “psychic asthenization” when referring to the syndrome in space.

A summary of some of the key points discussed above is shown in Table 5.9.

Table 5.9. Characteristics of Asthenia or Asthenization in Space, Abstracted from various Russian sources. [See text].

Physical or emotional fatigue or weakness
Hypoactivity
Irritability and tension
Emotional lability
Appetite and sleeping problems
Attention and memory deficits
Withdrawal from others and territorial behavior

5.4.2. Empirical findings from space: asthenia and the Shuttle/Mir program

5.4.2.1. Procedures

The above clinical and operational information suggests that asthenia may occur in the space environment. To explore whether or not there was empirical evidence for this syndrome during actual space missions, data from the 4½-year Shuttle/Mir Human Interactions study (described fully in Chapter 4) were retrospectively examined [Kanas et al., 2001b]. This study was not designed to specifically assess asthenia, so to evaluate its presence in space among crewmembers, the data from one of the questionnaire measures, the Profile of Mood States or POMS [McNair et al., 1992], were re-analyzed. Three of the study investigators independently examined the POMS to identify items characteristic of the first stage of asthenia. Since symptoms of this condition in space would trigger a number of countermeasures from psychological support staff on the ground, characteristics of more advance stages of asthenia were not expected to be present. Eight items identified by all three raters were selected as being characteristic of stage 1 asthenia: On Edge and Restless (tension items); Resentful and Annoyed (irritability items); Forgetful and Unable to Concentrate (cognition items); and Weary and Fatigued (low energy items). The weekly on-orbit data from the 13 crewmembers on these eight items were subjected to analysis for asthenia.

Six Russian space experts, who were familiar with the characteristics of asthenia and who had worked directly with cosmonauts for 10 years or more, were instructed to complete a Russian translation of the POMS as if they were cosmonauts suffering from stage 1 asthenia. The POMS results from the astronauts and cosmonauts were compared with the clinically meaningful prototype scores from the experts to examine if this would yield evidence to support the existence of the asthenic syndrome in space.

For all of the POMS “asthenia” items, t-tests were utilized to assess for differences between the mean scores of crewmembers and Russian experts and to assess for differences between the mean scores of Russian and U.S. crewmembers.

To control for the inflated Type I error rate associated with multiple significance tests, the false discovery rate procedure developed by Benjamini and Hochberg [1995] was utilized in all of the analyses.

5.4.2.2. Results

Table 5.10 shows the mean on-orbit scores for the eight asthenia items from the crewmembers versus the mean scores from the six experts. Using t-tests, crewmember scores were significantly lower than the expert rating scores on seven of the eight items; only Restless yielded a non-significant result. The crewmember mean scores all were less than 1, putting them in the “not at all” to “a little” range of the POMS, while the mean scores for the expert prototype were in the “a little” to “quite a bit” range. T-tests also were used to compare the crewmember scores in space with comparable scores obtained during four weeks of pre-launch training on Earth, and there were no significant differences on any of the eight POMS items. To look for possible time effects, the mean scores for each quarter of the missions were calculated for each subject on each of the eight items. Using an analysis of variance for each item, none of the resulting F-values was found to be significant. Finally, t-tests were used to compare American and Russian crewmember scores for all eight items, and there were no significant differences between these two groups.

5.4.2.3. Conclusions

These findings do not support the presence of asthenia when the crewmember on-orbit scores were compared with scores from a prototype of asthenia constructed by Russian space experts or with the pre-launch scores obtained during training. However, it should be noted that the POMS could only evaluate parts of the

Table 5.10. Mean Crewmember versus Russian Space Expert Scores on POMS “Asthenia” Items. Adapted from Kanas et al. [2001b].

POMS Item	Mean Crewmember Score	Mean Expert Score
On Edge*	0.25	2.50
Restless	0.39	1.00
Resentful*	0.08	2.17
Annoyed*	0.29	2.00
Forgetful*	0.17	2.50
Unable to Concentrate*	0.05	1.83
Weary*	0.42	2.33
Fatigued*	0.59	2.67

*p-value less than the adjusted significance level threshold of $p = .044$ [Benjamini and Hochberg, 1995].

syndrome since it primarily is a measure that assesses emotional states but not physiological status (e.g., blood pressure, heart rate, sleep characteristics) or somatic complaints that are part of the asthenic syndrome. Also, the operational definition of asthenia depended on eight POMS items, and perhaps these were not sensitive enough to identify aspects of the syndrome.

In absolute terms, the crewmembers rated the asthenia items in the “not at all” to “a little” range, suggesting that they were not experiencing the intensity of the asthenia items to any appreciable extent. However, as reported elsewhere [Kanas et al., 2000a, 2000b, 2001a, 2001c], the crewmembers generally scored toward the positive end of the subscales in the measures (including the POMS), and their responses were more adaptive than those from normative samples on Earth. Thus, they seemed to perceive their emotions and their interpersonal environment more optimistically than people in other groups on the ground. For the eight asthenia items, these issues were applicable to both Russian and American crewmembers, since they tended to score in a similar manner.

Despite the negative findings, the concept of asthenia warrants further study. The syndrome should be better defined, and measures specific to asthenia need to be developed and validated in both clinical and astronaut populations. If further study identifies the presence of the asthenic syndrome in space, then pre-launch training programs and in-flight countermeasures to deal with its sequelae should be expanded in order to improve the well-being of space travelers participating in future long-duration space missions.

5.4.3. Empirical findings from space: cultural differences in patterns of mood states on-orbit

Although the above findings did not support the construct of the asthenic syndrome on-orbit, this is not to say that asthenic-like patterns do not exist. The same team that conducted the previous study took a novel approach. After the ISS study was completed, the experimenters wondered if there would be differences in patterns of mood states that were exhibited by U.S. and Russian crewmembers. The reasoning was that in the Russian culture, where asthenia is accepted as a syndrome, there would be an association between depressed mood and fatigue, since these two states should covary according to the asthenia model. In contrast, in the American culture, neurotically-based depression might be expected to covary with anxiety, which would be predicted according to the diagnostic system used in the United States [American Psychiatric Association, 1994].

Using mixed model linear regression, the study team first tested these associations separately for the Shuttle/Mir crewmembers and the ISS crewmembers [Boyd et al., 2007; Ritscher, 2005]. The results were somewhat equivocal. To gain statistical power, the experimenters combined the Shuttle/Mir and ISS data sets, which seemed reasonable since other findings in the two studies were similar (see Chapter 4). In the combined sample (with 13 astronauts and 17 cosmonauts), it was found that as predicted for the Russians, measures of depression and fatigue were significantly related, whereas the relationship between depression and anxiety was not significant [Boyd et al., 2007]. For the Americans, again as predicted, the relationship between depression and anxiety was significant, whereas the relationship

between depression and fatigue was not. In both groups, depression scores were associated with a measure of anger, and for the Americans, it was associated with confusion. No other tested relationships were significant.

These results confirmed the predictions that Russian crewmembers experience depression in the context of fatigue, which is consistent with early asthenization. In contrast, Americans experience depression in the context of anxiety, which supports a culture-bound pattern of mood that is consistent with the American model of neurotic depression. Both groups associated depression with anger, which makes sense since irritability is a common feature of both cultures' models of distress. The covarying of confusion with depression also would make sense since difficulty concentrating is another common feature of both the American and Russian models of distress, but this link was only significant for the American subjects. These findings suggest that patterns of mood states in crewmembers may reflect national cultural norms, and further work in this interesting area needs to be done.

5.5. Treatment considerations

5.5.1. Counseling and psychotherapy

Pre-launch, crewmembers should be briefed on the kinds of psychological stressors and psychiatric problems that can occur during long-duration space missions. During the flight, crewmembers should be monitored for symptoms and signs of developing psychiatric disturbances. In near-Earth missions, counseling sessions, crisis intervention, or brief supportive psychotherapy can occur between individuals in the crew and therapists on the ground using private two-way audiovisual links. In rare occasions, more extended insight-oriented psychotherapy might be indicated. During deeper space missions (such as a trip to Mars), the distance results in communication delays and the inability to send morale-enhancing supplies and gifts up from Earth. As a consequence, therapeutic encounters will depend on the skills of on-board crewmembers who are trained in counseling, psychotherapy, and the use of psychoactive medications. Facilities also need to be available on-board to seclude and restrain a potentially suicidal, violent, or impulsive crewmember.

It is unlikely that a psychiatrist or clinical psychologist would be a member of the crew in early missions involving a space station, a lunar base, or a trip to Mars. However, it is likely that a physician or some other medically trained individual would be present on-board. As described elsewhere [Kanas, 1998], this individual should possess a knowledge of: (1) individual psychopathology and small group behavior; (2) the individual and interpersonal effects of stressors to be expected during the mission; (3) techniques involving crisis intervention, individual psychotherapy, and the facilitation of group awareness and team building; and (4) the appropriate use of tranquilizers and other psychoactive medications, including their usefulness and side effects under conditions of microgravity.

To guard against the negative sequelae that would result if the counselor should become incapacitated by a psychiatric problem, it would be prudent to have another crewmember cross-trained to cover these issues. Also, all crewmembers should be sensitized to important psychiatric and interpersonal problems that might occur

during the course of long-duration space missions as well as to basic interventions for dealing with such difficulties.

5.5.2. Psychoactive medications

Medical kits are available on-board during manned space missions that contain supplies to help the crewmembers cope with space motion sickness, illnesses, and injuries. Medications chosen for these kits have depended on factors such as the duration of the mission, its objectives, and the presence of a physician. Psychoactive medications have been part of the formulary as well. A listing of the categories of these agents appears in Table 5.11. For example, Space Shuttle flights have included antianxiety medications such as oral and injectable diazepam; pain medicines such as codeine and morphine; medications for sleep such as flurazepam and temazepam; stimulants such as dextroamphetamine; medications to counter psychosis such as haloperidol; and intra-muscular promethazine for space motion sickness [Pavy-Le Traon et al., 1997].

Santy and her colleagues [1988] have reported that 78% of Space Shuttle crewmembers have taken medications in space, primarily for space motion sickness (30%), headache (20%), insomnia (15%), and back pain (10%). Psychoactive medications available in Russian flight medical kits have included antianxiety agents such as diazepam and phenazepam; antidepressants such as amitriptyline; stimulants such as “sydnocarb” (N-phenylcarbamoyl-3-b-phenylisopropylsydnominin); antipsychotics such as chlorpromazine and haloperidol; and the GABA analog pyracetam [Aleksandrovskiy and Novikov, 1996]. Newer psychoactive medications also are being incorporated, such as the so-called “atypical” antipsychotics (e.g., olanzapine, risperidone) and the selective serotonin reuptake inhibitor (SSRI) antidepressants (e.g., fluoxetine, sertraline). Physiological changes

Table 5.11. Categories of Psychoactive Medications.

Antianxiety/anxiolytic medications (e.g., diazepam, lorazepam)
Antidepressants (e.g., fluoxetine, imipramine)
Antimanic and mood stabilizers (e.g., lithium, valproic acid)
Antipsychotics (e.g., olanzapine, haloperidol)
Pain medications (e.g., codeine, morphine)
Sleeping pills/hypnotics (e.g., zolpidem, zaleplon) - see also antianxiety/anxiolytic medications, above
Stimulants (e.g., caffeine, dextroamphetamine)
Promethazine for space motion sickness

due to microgravity and other effects of space may change the pharmacokinetic characteristics of psychoactive medications, influencing both their dosage and route of administration [Saivin et al., 1997]. Some of these physiological effects are listed in Table 5.12. In microgravity, blood flow increases in the upper part of the body and decreases in the lower part. Relative disuse of muscle groups can cause atrophic changes as well. As a result of these two effects, the blood available and the amount of atrophy that has taken place at the injection site will influence the bioavailability of medication from an intra-muscular injection. For example, intra-muscular promethazine is usually given in the arm rather than in the hip in space, and it has been found to be useful for space motion sickness, with no appreciable side effects reported (e.g., sedation, dizziness, decrements in psychomotor performance) [Pavy-Le Traon et al., 1997].

Other physiological changes also may affect medication absorption and metabolism. For example, the movement of oral medications out of the stomach may be decreased by the weightlessness of the gastric contents in space. Consequently, the availability of these agents to the intestine may be decreased. Intestinal absorption rates also may be reduced by blood and other fluid shifts to other areas of the body. Medications especially expected to be affected are those observed to be variably absorbed in studies on Earth, such as chlorpromazine, flurazepam, and morphine. Fluid shifts also may affect the bioavailability of medications sensitive to the first pass effect in the liver (where metabolism occurs), such as desipramine, imipramine, morphine, nortriptyline, and propranolol [Saivin et al., 1997]. Protein binding in the blood and renal excretion rates also may be influenced by microgravity. Thus, the effectiveness and side effects of many psychoactive medications may be affected by the conditions of space. More empirical work needs to be done to fully characterize the influences of these physiological effects, both in space and in microgravity simulations on Earth such as bedrest and water immersion [Cintron and Putcha, 1996].

Table 5.12. Physiological Effects of Microgravity That May Influence the Absorption and Pharmacokinetics of Psychoactive Medications.

Blood and fluid shifts to the upper part of the body
Atrophic changes in selected muscle groups
Decreased gastric emptying
Reduced intestinal absorption rates
Decreased first pass effect in the liver
Alterations in protein binding in the blood
Changes in renal excretion rates

In considering future long-duration space missions, Santy [1987] has written that a reasonable psychiatric formulary should consist of several examples from each of the major psychoactive drug classes: antianxiety agents, antidepressants, antipsychotics, sleeping pills, and medications to counter mania and other mood swings. The use of psychoactive medications should be monitored carefully, since a number of them have a potential for abuse and since novel effects may emerge in the space environment. On one Russian space mission, for example, the commander was suffering from insomnia and took too many sleeping pills without informing physicians in mission control. He subsequently developed a number of problems attributable to this action [Aleksandrovskiy and Novikov, 1996]. Thus, supervision of psychoactive drug usage in space by experts on the ground or medically-trained crewmembers in space is important.

5.6. Psychiatric research in space

Many of the issues described above depend on inferences made from space analog studies conducted on Earth. These studies cannot reproduce all of the stressors that are found in space, as was discussed in Chapter 1. In addition, psychiatric reactions to conditions of isolation and confinement depend on the unique characteristics of each analog environment and the psychological meaning of the simulation experience. This also holds for space missions. For example, one's psychological reactions to a Shuttle flight lasting a couple of weeks in near-Earth orbit might be quite different than the reactions of a person undergoing a three-year mission to Mars, where he or she is tens of millions of miles from home. Palinkas and his colleagues [2005] have discussed the importance of taking operational needs into account when conducting space-related behavioral research, and in planning behavioral health countermeasures that are both needs-based and evidence-based.

It is time to conduct more psychosocial research in space, especially in the psychiatric area. Studies could help to determine whether asthenization occurs in space and if so whether its occurrence is dependent upon one's cultural background. Work also needs to be done on the influence of microgravity on the effects and side-effects of psychoactive medications. In addition, studies could be performed on the effectiveness of voice analysis and telemedicine techniques in diagnosing psychiatric conditions and in treating them through counseling and psychotherapy using private two-way audio-visual channels. Long-duration missions to the International Space Station will allow for some of this research to be accomplished, and the results of this research might be expected to help future space travelers cope with the stresses of long duration space missions and work productively with each other as they make their way to the Moon, Mars, and beyond.

5.7. Summary

- Many space travelers find their experiences in space to be rewarding and salutogenic, or growth-enhancing.
- Astronauts and cosmonauts typically have a positive reaction to being in space, especially seeing the Earth and recognizing its beauty and fragility. Changes in attitudes sometime translate into changes in behaviors after the return home. Space travelers appear to cluster into two groups based on the intensity of their reported changes.
- Adjustment and somatoform disorders have been reported to affect crewmembers in space. Mood and thought disorders are comparatively rare.
- Post-mission personality changes and marital problems also have affected returning space travelers and their families.
- Russian space experts view asthenia (a mild form of neurasthenia) as a common problem in space. However, neurasthenia is not recognized in the American psychiatric diagnostic nomenclature as a well-defined syndrome. The question remains open as to whether or not asthenia occurs and if so whether or not its manifestations are affected by cultural factors.
- The results of the Shuttle/Mir study did not support the existence of asthenia in space. However, the measure used (the Profile of Mood States) could only evaluate the emotional aspects of the syndrome, not the physiological and somatic aspects. Also, the crewmembers generally tended to score toward the positive end of the subscales of this measure.
- However, when the Shuttle/Mir and ISS data sets were combined, there was evidence for culture-bound mood patterns, with Russians linking depression with fatigue (predicted by the asthenia model) and Americans linking depression with anxiety (predicted by American diagnostic models of neurotic depression).
- Crewmembers should be prepared to deal with psychiatric problems during long-duration space missions using methods such as counseling, psychotherapy, seclusion and restraint, and psychoactive medications.
- The physiological effects of microgravity may alter the absorption and pharmacokinetics of psychoactive medication.
- Research needs to be done to evaluate psychiatric issues under space conditions, such as during missions to the International Space Station.

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Leisure time activities in space are very important. They help to counter boredom and monotony, and they can serve as a way for the crewmembers to interact around a positive event. “Astronaut Carl E. Walz (lower left), Expedition Four flight engineer, plays host to some crewmates as he performs on a musical keyboard in the Destiny laboratory on the International Space Station (ISS)...” (Photo and quoted description courtesy of NASA)

Chapter 6

Psychological Countermeasures

6.1. General aspects

Psychological countermeasures include all actions and measures that alleviate the effects of the extreme living and working conditions of space flight on crew performance and behavior. Such measures reduce the risks arising from impairments of cognitive performance, well-being, and crew interactions. In principle, two complementary kinds of countermeasures can be distinguished. The first focuses on the accommodation of the environmental conditions during space flight to the specific (psychological) needs and capabilities of humans. One aspect of this approach is related to issues of hard- and software design that are subsumed under the heading of “habitability” or “environmental engineering” [Fitts, 2000]. It also includes organizational factors of work-design and work-rest scheduling during space flight. This approach is not an entirely psychological one but more generally is related to aspects of ergonomics and the human factors of space flight. The human is characterized as a constant element with given strengths and weaknesses, and the environmental conditions are adjusted as well as possible to these characteristics to support optimum human performance.

The second kind of countermeasure assumes an inverted perspective. Its main focus is on adapting humans as best as possible to the given living conditions and work demands of space flight. Thus, the environmental conditions are considered as constant, and activities focus on finding and shaping humans for optimal performance under these conditions. This approach includes specific psychological measures that are applied to select individuals who are best suited for becoming astronauts, to compose crews whose members are compatible, to train individuals and entire crews with respect to the psychological demands of space missions, and to monitor and support astronauts during their mission in order to achieve optimum individual and crew performance in space [Kanas et al., 2002; Manzey et al., 1995]. These measures can be classified according to when they are applied (see Figure 6.1). Whereas selection, crew composition, and training represent countermeasures that are already applied pre-flight on the ground, monitoring and support are provided when a crew is in space. In addition, post-flight support activities assisting with the re-adjustment of astronauts to life on Earth after a space mission can be considered as a psychological countermeasure, since they help to prevent adverse psychological after-effects of space flight.

Whereas the ergonomic aspects of habitability, work-rest scheduling, and basic selection of astronauts represent psychological countermeasures that are important for both short-term and long-term space flight, most of the other psychological countermeasures are most relevant for prolonged space missions with a duration of over 6 weeks, after the first stage of adaptation (see Chapter 2). This is suggested by

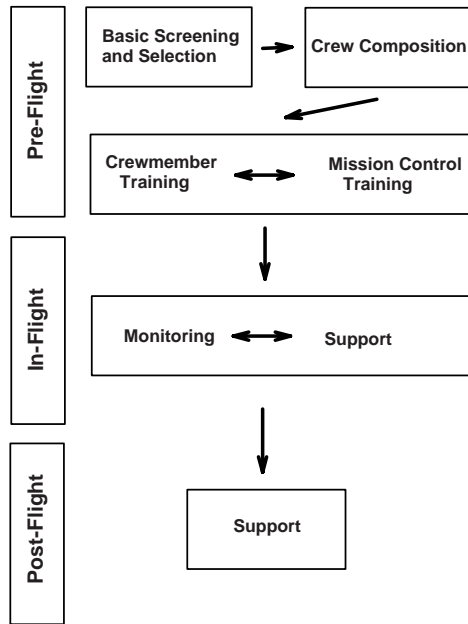


Figure 6.1. Elements of Specific Psychological Countermeasures for Astronauts.

Russian experiences, where psychological countermeasures like in-flight monitoring and support have been applied since the beginning of long-term space missions during the Salyut space station program [Grigoriev et al., 1987; Kanas, 1991]. Even though it is not possible to completely avoid impairments of individual or crew performance by applying these countermeasures, they have been successful in preventing such issues from becoming a threat to mission success and safety.

In what follows, essential elements of both kinds of countermeasures will be addressed. However, since habitability and work design represent broad interdisciplinary fields, a description of countermeasures related to these areas will be limited to the most appropriate aspects; i.e., those directly related to the psychological issues described in the foregoing chapters. The main emphasis of this chapter will be on the specific psychological countermeasures related to selection, crew composition, training, monitoring and support.

6.2. Habitability factors

Habitability is a very broad and vaguely defined concept. According to one definition, it includes all aspects related to the “physical interface between human user and the system/environment”, or to the “usability of the environment” in

general [Novak, 2000, p. A131]. Given this vague definition, it is no surprise that a wide diversity of aspects have been included in this concept. A list of important items that usually are considered to represent important habitability factors of space flight is provided in Table 6.1. Most of these factors are of some psychological importance, and a well-designed living and working environment can promote the performance and well-being of astronauts and entire crews. For example, a good design of workstations may contribute to a reduction of crew errors in operational tasks, reduction of noise can enhance well-being, and a well-designed toilet or shower will considerably increase the living comfort of the crew. In this sense, all of these aspects of design may be regarded as psychological countermeasures during a space flight. However, most of these issues are not entirely psychological ones, nor are they specifically related to space flight. Instead, they represent general issues of ergonomic design and human factors engineering [Wickens et al., 1998]. Take the important issue of workstation and human-machine interface design for space applications as an example. Even though some aspects of this design have to take into account the specific constraints found in space (e.g., the need for restraint systems to stabilize the position of the working astronaut or the fact that fine manual control can be impaired during an early flight phase), a large number of other aspects involve more general issues of human-machine or human-computer interaction that are not really different from those used in Earth applications (e.g., basic principles of compatibility in display design or aspects of software usability).

It is beyond the scope of this book to discuss in sufficient detail all aspects of human factors engineering for space flight. Fortunately, most of them are

Table 6.1. Important Habitability Factors and Examples.

Habitability Factor	Examples
Architecture	Overall layout, translation paths, windows, interior décor, lighting, doors, hatches, location coding, mobility aids and restraints
Living quarter design	Individual crew quarters, wardroom and meeting facilities, recreation facilities
Work station design	Displays, controls, human-computer interfacing, issues of automation, software usability, labeling and coding
Service facilities	Galley, laundry, trash management, stowage
Personal hygiene	Toilet, shower, body waste management
Specific equipment	Tools, racks, specific restraints, crew personal equipment
Environmental factors	Noise, vibration, air quality, radiation, temperature
Health management	Nutrition and food systems, sleep facilities and scheduling, microgravity countermeasure facilities, space medical facility
Facility management	Design of housekeeping tools, inventory control system
Extravehicular activities	Design of suit, tools, and workstation

appropriately addressed in several standardization and requirement documents of different space agencies. The best known are the NASA Man-System Integration Standards (MSIS; NASA-Standards-3000). First defined in 1987, they now are available in a revised version that can be accessed via the World Wide Web [NASA, 1995]. These standards, although currently again under revision, are a valuable source of information and guidance for a large number of human engineering issues related to space flight operation. They also have been adopted by the European Space Agency [ESA, 1994] and provide an important basis for the internationally agreed upon standards for International Space Station habitability design [International Space Station Program, 1995].

In the present section, only a few selected issues of habitability will be addressed which, considering the identified psychological issues in the foregoing chapters, appear to be of general concern. The first issue relates to personal space and the provision and design of individual crew quarters. Lack of privacy and the constant presence of other people are among the most adverse psychosocial stressors of long-term space flight and have been reported to impair individual well-being in other analog environments [Connors et al., 1985]. Given the increased need for privacy and the occurrence of territorial behavior under prolonged isolation and confinement, the provision of sufficient personal space and private quarters represents an important psychological countermeasure. Personal space needs increase with mission duration, but this requirement may be compromised by technical constraints. However, clear information regarding the minimum acceptable habitable volume per person during space flight is lacking, and the most recent studies still date back to the 1960s [Fitts, 2000]. Furthermore, personal space needs can be expected to vary considerably and depend on cultural issues, which make any general recommendation difficult [Raybeck, 1991]. Even more important than considerations about the size of space habitats are having individual quarters for each crewmember. Periodic withdrawal from other crewmates, at least to a certain extent, seems to be a healthy coping strategy for living in confined groups, and this should be supported by the provision of private quarters for each crewmember [Connors et al., 1985; Stuster, 1996]. Important functions and activities to be served by such quarters are summarized in Table 6.2, and minimum size requirements for some of these are located in NASA and ESA documents [ESA, 1994; NASA, 1995].

Perhaps the most important feature of individual crew quarters is efficient visual and acoustical shielding. Whereas visual shielding might be sufficient to fulfill basic privacy needs, acoustical shielding is important with respect to sleep. Given the problem of sleep disturbances in space, individual crew quarters that are efficiently designed to support undisturbed sleep belong to the most important countermeasures related to habitability. Besides acoustical shielding, there also needs to be provision of suitable and comfortable restraint systems for sleeping (e.g., sleeping bags), possibilities to adjust the temperature of the sleeping area, and possibilities to dim the light.

Another issue related to privacy regards the provision of private communication lines that make it possible to communicate not only with family and friends on Earth, but also with other confidants (e.g., crew surgeon or psychologist) without being monitored by third parties (see also below, Section 6.7). Such private

Table 6.2. Important Functions and Activities to be Supported by Individual Crew Quarters (In Priority Order).

Effective visual and acoustic shielding against the outside
Undisturbed sleep
Individual environmental control (e.g., adjustable lighting, temperature)
Private communication via audio/video transmission and e-mail
Donning and doffing of personal clothes
Stowage of personal items
Individual recreation (i.e., availability of compact entertainment devices)
Individually adjustable decor (e.g., paintings/pictures presented on screens, adjustable color of lighting)
View outside the habitat

communication lines can include two-way video- and audio-transmissions as well as e-mail, and they optimally should be accessible from individual crew quarters or at least areas where undisturbed communication is possible.

Finally, individual crew quarters should provide possibilities for donning and doffing clothes, for stowage of personal items, for individual recreation, and for some kind of personalized décor (e.g., family pictures). Windows would be nice to have in individual crew quarters but seem to be a feature that is dispensable when other windows are available and easily accessible in the space habitat.

In addition to private crew quarters, the design of the habitat should provide opportunities for common meetings and leisure activities of the entire crew. This seems to be an important habitability factor with respect to support of crew cohesion. The minimum equipment should include a table with enough room for all crewmembers. Such a table can be used for common games or discussions, and it also would provide a facility for common meals. Eating together has been found to be an important factor in fostering communication between crewmembers, and it can contribute to the prevention of decrements in crew cohesion [Stuster, 1996].

Another habitability factor is the interior décor, which can compensate for the effects of the otherwise decreased range of environmental cues in a space habitat. Even though there is anecdotal evidence that the interior décor (e.g., color, paintings, pictures) can have an impact on individual well-being under prolonged confinement and isolation, only few empirical studies have addressed this topic [Stuster, 1996]. However, there is general agreement that the use of many different colors should be avoided because this may result in visual over-saturation after some time. In addition, the use of dark and highly saturated colors should be restricted to small areas only. The most appropriate use involves a limited variety of colors of medium brightness and saturation. Colors which are recommended include

cinnamon, beige, cream, maize, straw, ivory, white, pale yellow, and blue [NASA, 1995].

An important aspect of the use of colors is for the coding of location. Given the enhanced significance of visual cues for orientation in space, where gravitational cues are lacking, it is useful to provide a clear vertical structure of the habitat by means of color as a countermeasure for problems of spatial orientation and navigation in the habitat. In addition, the different psychological functions of working areas and living quarters may be supported by different coloring. For example, Raybeck [1991] suggests using excitatory colors (e.g., red, orange, yellow) only in working areas and calming colors (e.g., green, blue) in rest areas.

The most detailed research with respect to other aspects of interior décor dates back to a NASA/Ames research program which has become known as “functional esthetics” and which has provided recommendations concerning the topics and layouts of paintings and photographs most preferred under conditions of confinement [Clearwater and Coss, 1991]. For example, it suggests that photographs depicting spacious Earth-bound landscapes might be used to enhance psychological comfort in confined settings. Future research on the preference of specific interior design, and its impact on human behavior and performance, should be conducted under conditions of isolation and confinement and should develop comprehensive design recommendations. With regard to multi-cultural crews, possible cultural differences must be considered in this research.

Windows represent another habitability factor which clearly can be ascribed a psychological countermeasure function. Windows can promote well-being by reducing sensory monotony and feelings of confinement and isolation, and they may prevent the development of claustrophobic reactions [Haines, 1991]. Support for this notion is provided by a number of anecdotal reports. For example, looking outside the space habitat has been appreciated by cosmonauts and astronauts since the first flights into orbit in Vostok or Mercury spacecraft [Haines, 1991], and it is known that the first NASA astronauts spent much effort in convincing the engineers to build a window in the Mercury spacecraft. Even though this request related to the first seven NASA astronauts being pilots who used windows for flying their aircraft [Wolfe, 1980], it turned out that windows also served an important psychological function, particularly during prolonged space missions. This is nicely illustrated by diary entries made by Russian cosmonaut Valentin Lebedev during his 211-day Salyut 6 mission which describe the relaxing function of looking back to Earth through the portholes of the space station [Lebedev, 1988]. After about 2 months in space he wrote: “It’s getting more difficult to fly. Visual observations calm me down” [p. 154]. It is further supported by the findings of Kelly and Kanas [1992] in their survey of 54 cosmonauts and astronauts who had flown in space. They found that “watching” activities were reported to be of increased importance during a space flight. Thus, in a confined environment like a space habitat, windows not only represent a “nice-to-have” feature of the habitat architecture, but they must be regarded as an indispensable element of exceptional psychological significance.

6.3. Work design issues

Three aspects of work design and scheduling serve as effective psychological countermeasures for impairments of individual well-being and performance. The first aspect involves the provision of an *appropriate* daily load of tasks to the astronauts (i.e., avoiding both overloading and underloading the astronauts during their stay in space). Problems of overloading particularly can arise during short-term space flights and the first weeks of long-term missions, which usually are busy due to operational tasks and the interest of experimenters in investigating issues of primary adaptation to space. This is illustrated, for example, by the experiences of the Skylab 4 mission, where the crew felt considerably overloaded during the first three weeks in space [Stuster, 1996]. It further is supported by an entry in the diary of Valentin Lebedev after the first week of his 211-day space flight: “Today the doctor told us that we’ve underslept 7 h and overworked 20 h. We have to compensate for it somehow” [Lebedev, 1988, pp. 39–40]. Such overloading often results from pressure to use the crew time for as many tasks as possible, combined with an underestimation of the demands of adaptation and the time needed for certain tasks in space. As has been shown in several studies, even tasks that have been thoroughly practiced pre-launch on the ground may need more time in space, at least during the first days when sufficient adaptation of the sensorimotor system to microgravity has not yet been achieved [Kubis et al., 1977].

Overloading and prolonged work shifts can result in physical and mental exhaustion and also raise the risk of crew error. This is suggested by studies on Earth that show that the likelihood of making errors increases significantly after 8 h of working [Nachreiner et al., 2000], as well as investigations of crew errors during space flight that point to a relationship between crew errors and workload [Nechaev, 2001]. Thus, appropriate timelining, which takes the specific constraints of adaptation to space into account and which prevents an overloading of astronauts, must be regarded as an important psychological countermeasure with impact on well-being and performance.

After some weeks in space during long-term space mission, when everything has settled into a routine, issues of boredom and monotony may prevail, and meaningful work can be regarded as one of the most effective countermeasures for such feelings. This is suggested by a number of anecdotal reports from astronauts and from people who have lived and worked in analog environments [Stuster, 1996]. These reports suggest that boredom may amplify the adverse effects of confinement and isolation, whereas continuous work can help one to cope with it. As has been stated by the Russian cosmonaut V. Ryumin. “... work is the best cure for anxiety and depression” [Bluth and Helppie, 1986, p. III-22]. According to Norm Thagard, the first NASA astronaut to participate in a long-term Mir mission: “the single most important psychological factor on a long-duration flight is to be meaningfully busy. And, if you are, a lot of the other things sort of take care of themselves” [Herring, 1997, p. 44]. Thus, the psychological significance of work can change considerably during a long-term mission. Whereas daily work hours must be limited and much rest time provided during the early flight phase to reduce the load on the astronaut,

too much rest time and lack of meaningful work might become a psychological problem during the course of a long-term mission.

A second countermeasure related to work in space involves maintenance of a constant 24-h work-rest routine. As has long been known from Russian space flights, stable work-rest schedules (i.e., constant sleeping and waking times) can have a positive impact on crew well-being and performance efficiency. Strict 24-h work-rest scheduling corresponding to conditions on Earth has been reported to promote crew performance, whereas deviations and disturbances of work-rest schedules from a strict 24-h regime have resulted in adverse effects (e.g., increased risks of crew errors) [Litsov and Shevchenko, 1985; Nechaev, 2001]. One reason for this is likely related to the effects of work-rest schedules on the circadian system. As described in Chapter 2, the lack of natural diurnal time-cues (“zeitgebers”) in space may affect the circadian system and contribute to sleep disturbances. However, a free run of rhythms has never been reported, and this may be taken as evidence that the lack of natural time cues can efficiently be compensated for by external zeitgebers that keep the circadian system entrained to a 24-h sleep-wake regime. One of the most efficient external zeitgebers in space is a strict work-rest schedule, and maintaining a constant 24-h work-rest schedule might prevent performance decrements related to disturbances of circadian rhythms and sleep. Yet during Space Shuttle, Soyuz, and International Space Station (ISS) operations, a sleep shift in space may become necessary due to operational constraints (e.g., to align the work-rest schedule of a crew with the expected times of landing, or to align the work-rest schedule of ISS crews with those of visiting crews). In order to avoid detrimental effects on well-being and performance, this sleep shifting must be carefully planned and implemented, depending on the direction of shifting (see Chapter 2 for details).

Finally, a countermeasure for dealing with possible impairments of work satisfaction and motivation in space is to provide the crew with as much freedom as possible to plan and schedule work tasks on their own initiative. Whereas this is not possible during short-term space flights, where the task load is high and tasks need to be strictly scheduled, it is more relevant during long-term space flights. Providing some autonomy to the crew in adapting the scheduling of tasks to their current workload may help to avoid over- or underload, which may be difficult to assess from the ground. Tasks should be classified according to priority, and the crew should have the freedom to decide when to perform “nice-to-have” tasks which are not critical with respect to the time of performance. This has been an important lesson learned from Skylab missions, where such a system helped to increase crew efficiency during the longest flight (Skylab 4) [Douglas, 1991]. Similar experiences have been reported from Russian missions. To refer once more to the Lebedev diary: “Today is a medical day according to our program, but the FCC (*i.e.*, *flight control center* – *added by authors*) decided to give us the day off. Nevertheless we made it a really hard working day by ourselves. We were filled with unhindered versatility and initiative. With our knowledge of the capabilities of our station and equipment, along with our understanding of experimental goals, we were able to schedule our activities efficiently and photograph what we wanted to. Previously when we have had to adhere to rigid schedule formulated on the ground we waste a

lot of time; sometimes our work would be completed ahead the schedule, but we would not be allowed to begin our next jobs until the time specified by the schedule. So we just sat (and) wasted precious time, fuel and resources” [Lebedev, 1988, pp. 279–280].

6.4. Selection and crew composition

6.4.1. General issues

In selecting people to become astronauts, it is important to evaluate individuals not only in terms of absence of negative qualities (e.g., predisposition for mental illness, psychopathological characteristics, difficulties with interpersonal relationships) but also in terms of possessing positive traits (e.g., relevant operational skills and training, maturity, stress tolerance, ability to get along with others). Accordingly, two different aspects of selecting astronauts have been distinguished [Santy, 1994; Santy and Jones, 1994]. The first involves using a psychiatric evaluation and psychological tests that assess for psychopathology, with a focus on selecting-out applicants who possess qualities that might represent a risk for behavioral health in space. The second involves a psychological evaluation aimed at selecting-in the fittest candidates with respect to specific positive psychological criteria.

Although psychiatric interviews and psychological tests are useful screening devices, one’s reactions to space simulations, specific group exercises, and stress testing also are revealing, since these situations can result in experiences that are similar to those in space. These methods traditionally have been used in selecting cosmonauts in the former Soviet Union and Russia, where psychological considerations have played a major role from the very beginning of human space flight [Beregovoy et al., 1987; Bluth and Helppie, 1986; Garshnek, 1989]. A similar process also has been implemented successfully with Japanese candidates [Endo et al., 1994; Sekiguchi et al., 1994] and with candidates selected by the European Space Agency [Fassbender and Goeters, 1994].

In contrast, NASA historically has focused its selection process on select-out procedures that used psychological tests and psychiatric evaluations. Even though some select-in type of psychological testing was done with astronaut candidates during the early Mercury program, this approach was stopped with the beginning of the Shuttle era [Santy, 1994]. In the late 1980s, a NASA in-house working group began to develop psychological select-in criteria for astronaut selection [Santy, 1994]. However, it took several years until an upgraded system of psychological select-in tools for astronauts finally was implemented, mainly with respect to upcoming long-duration space flights [Galarza and Holland, 1999a]. Currently, all space agencies involved with ISS operations recruit their astronauts using psychiatric and psychological selection strategies that combine select-out and select-in approaches that usually occur at the time that individuals are screened in their application to become astronaut candidates.

Another selection issue relates to composing crews of individuals who are most compatible to each other. This is of particular importance for long-term space missions and has been a concern in the Russian (Soviet) space program from the

beginning of long-term flights in the orbital station Salyut 6 [Bluth and Helppie, 1986; Gzenko, 1980]. Since the composition of crews usually is known well in advance, this has allowed the interactions of crewmembers to be observed as they trained together on Earth. However, specific issues might arise if during future missions (e.g., on the ISS) crew composition may be staggered, allowing some crewmembers to remain in space for several months while others are sent up to join them from time to time. This situation creates the potential for interpersonal conflicts to occur which may endanger mission success. Work needs to be done to develop simple, quick methods of assessing potential incompatibilities. Given the availability of such measures, it would be possible to test potential crewmembers before launch, and whenever a major turnover was anticipated, these results could be examined for warnings that suggested possible intrapsychic and interpersonal problems in the proposed new mix of crewmembers.

6.4.2. Select-out: avoiding psychopathology

The emphasis of psychiatric screening is to select-out people who, compared with established psychiatric standards, appear to be disqualified to become astronauts. Typically, this approach includes screening procedures that aim at identifying those few among all applicants who have had psychopathological episodes in their biographical or family history, who have documented psychopathology, or who are likely to decompensate under the conditions characteristic of the space environment. Many of these issues have been considered in Chapter 5.

These psychiatric evaluations usually follow standard medical practices that have been used for decades in aviation and space medicine. Commonly implemented methods involve structured clinical interviews that include detailed psychiatric histories based on the DSM or ICD classification systems of diseases [Endo et al., 1994; Santy et al., 1993]. In addition, specific methods of addressing mental status, as well as clinical psychological tests for detecting psychopathology (e.g., personality questionnaires like the Minnesota Multiphasic Personality Inventory or projective tests like the Rorschach inkblot test) are applied. However, since astronaut applicants usually come from a highly selected pool of the general population where the prevalence rate of psychopathology is low to begin with, only a few candidates are usually disqualified for psychiatric reasons. For example, using structured clinical interviews for the psychiatric screening of 106 NASA astronaut candidates based on the DSM III-R classification of diseases, only 9 (8.5%) applicants met criteria for a psychiatric problem (Table 6.3), and only 2 (1.9%) of them were disqualified on purely psychiatric grounds [Santy et al., 1993]. Similar procedures that were used for selecting Japanese astronaut candidates resulted in the disqualification of only 2 out of 45 (4.4%) applicants [Endo et al., 1994]. Nevertheless, select-out methods of psychiatric evaluation must be regarded as an important and indispensable element of current astronaut selection. They might become even more important with respect to future specialized expedition-type missions (e.g., to Mars or beyond), where potential crewmembers may be under special scrutiny and where the risks of behavioral and mental illness will likely be increased due to the long duration of the mission and the unusual stressors to be expected (see Chapter 7).

Table 6.3. DSM-III-R Diagnoses Among a Sample of 106 NASA Astronaut Applicants.
Adapted from Santy et al. [1993].

DSM III-R-Diagnosis	Number of Applicants
Axis I	
Dream anxiety disorder	1
Major depressive disorder (single episode)	2
Axis II	
Personality disorder, NOS (avoidant and dependent features)	1
V-Code	
Life circumstance problem	2
Bereavement (grief reaction)	1
Marital problem	2
Total	9 (8.5% of group)

6.4.3. Select-in: the “right stuff”

It is more difficult to develop assessment tools to select the best individuals for the astronaut corps from a pool of healthy applicants. Select-in approaches aim at identifying individuals who, concerning their basic capabilities, personality characteristics, and interpersonal skills, can be expected to meet the specific operational and psychosocial demands of (long-duration) space missions. Assessment tools used for this purpose can include performance tests, personality questionnaires, analyses of biographical data, behavioral observations during specific group exercises, and interviews [Beregovoy et al., 1987; Fassbender and Goeters, 1994; Santy, 1994; Sekiguchi et al., 1994]. In addition, analyses of psychophysiological reactions and individual stress resistance assessed by reactions to specific stressors (e.g., parachute jumping, isolation chamber tests) always have been used for select-in purposes in Russia [Beregovoy et al., 1987; Garshnek, 1989]. Comparing the different select-in approaches applied in Russia, Japan, Canada, Europe, and the U.S., there seems to be overall agreement that at least the following aspects need to be considered in evaluating psychological fitness for space flight: motivation, relevant biographical experiences, cognitive and psychomotor capabilities, personality traits related to stress-coping, personality traits related to interpersonal behavior, interpersonal and team-work skills, and, particularly with regard to ISS missions, cross-cultural competence. Yet the weighting of these different aspects may differ according to the specific population of applicants and the professional functions for which the astronaut candidates are being recruited. For example, testing cognitive and psychomotor capabilities might be important if scientists are recruited who later may have to perform operational tasks, but these might be waived if astronauts are recruited from a population of experienced test pilots where such capabilities can be assumed to be already well-developed.

However, most of the currently used select-in systems for astronaut candidates have not been based on systematic research on which individual characteristics best predict efficient work in space [Santy, 1994]. Instead, most of the current attempts to define select-in factors for astronaut selection have been based primarily on expert judgments, which may seem to be plausible and sometimes self-evident but usually lack empirical validation. One of the most recent set of such factors, currently used by NASA, is shown in Table 6.4. It is based on analyses of available research and anecdotal information from analog environments, as well as expert ratings from 20 Russian, European, and American astronauts and mission support experts [Galarza and Holland, 1999a, b]. A comprehensive review of psychological select-in criteria used in Russia, Japan, and Europe is provided by Santy [1994].

Table 6.4. Critical Psychological Factors Required for Long-Duration (LDM) and Short-Duration (SDM) Space Missions. Criticality refers to the expert ranking of the factors with respect to their importance for LDM and SDM, respectively. Adapted from Galarza and Holland [1999b].

Factor	Selected Sample Proficiencies	Criticality for LDM	Criticality for SDM
Mental/emotional stability	Freedom from mental disorder, emotional stability, self-control, self-confidence	1	2
Performance under stressful conditions	Ability to perform under threat to life stress and stressful conditions, flexibility and adaptability, ability to cope with limited personal stress	2	1
Group living skills	Group living and interaction skills, adaptability to crew diversity, multicultural adaptability	3	7
Teamwork skills	Conflict resolution and cooperation, priority of team over personal goals, followership skill	4	4
Family issues	Ability to cope with prolonged separation from family and friends	5	6
Motivation	Achievement motivation, intrinsic work motivation, perseverance, goal orientation	6	8
Judgment/decision making	Exercising sound judgment, situational awareness and vigilance	7	3
Conscientiousness	Responsibility, attention to detail, integrity	8	5
Communication	Interpersonal communication skills	9	9
Leadership capability	Team leadership, effective resource management, accountability	10	10

Longitudinal studies that empirically relate individual characteristics to actual behavior and performance during short-term or long-term space flight are still missing, and it will remain difficult to conduct such studies in the future with a sufficient number of subjects, given the current small number of crew members from the different space agencies during ISS missions. However, what has been done recently, and what may be pursued in the future, is to conduct relevant research in analog settings (i.e., Antarctica, simulation studies) [Palinkas et al., 2000 a, b; Rosnet et al., 2000; Sandal et al., 1996]. Another approach has involved validating possible select-in factors by using criteria of astronaut effectiveness during short-term space missions and training sessions that are derived from peer and supervisor ratings [McFadden et al., 1994; Rose et al., 1994].

The main issue addressed in this research is: what kinds of people have the best personality – the so-called “right stuff” – to undergo the rigors of a long-duration space mission? One way of categorizing personality has been in terms of positive and negative instrumental and expressive traits, respectively. Instrumental traits (I) are related to goal-seeking and achievement motivation. In a positive sense (I+) they include a strong goal-orientation and a high need of achievement. Negative Instrumentality (I-) is reflected in attributes like being arrogant, dictatorial and egoistic in striving for work goals. Expressive traits (E) relate to characteristics of behavior in interpersonal relationships with positive expressivity (E+) including attributes like kindness, warmth and emotionality, and negative expressivity (E-) including aspects of verbal aggressiveness and negative communion (e.g. being servile, submissive, gullible) [Spence et al., 1979].

A methodology has emerged that has clustered people along these traits, and this has been found to be useful in both aviation and space populations [Chidester et al., 1991; McFadden et al., 1994; Musson et al., 2004; Musson and Helmreich, 2005]. Three important personality groupings have emerged. The first one represents a positive instrumental/expressive cluster. Individuals in this group show elevated instrumental and positive expressive traits and can be characterized as people who work hard to achieve their goal but take the needs and desires of others into account at the same time. The second grouping represents a negative instrumental cluster characterized by individuals showing, on the one hand, elevated instrumental traits and a comparatively high level of competitiveness, but on the other hand, low positive expressive traits. Such individuals may strive hard for their goals but are not team-players. The third grouping represents a low motivation cluster, which includes individuals showing generally low levels of positive instrumental and expressive traits.

Studies involving these clusters have shown them to be robust and have related them to aircraft pilot attitudes, command responsibility, stressor recognition, and training [Chidester et al., 1991]. The positive instrumental/expressive cluster was found to be predictive for efficient stress coping in a military context and in situations analogous to short-term space flight [Sandal et al., 1996, 1998]. For example, Sandal et al. [1996] investigated crews participating in confinement studies in hyperbaric chambers lasting between 30 and 60 days. Individuals showing the positive instrumental/expressive profile showed superior coping that was reflected in higher self-reported well-being and lower anxiety during confinement.

More direct evidence that this personality profile might be predictive for astronaut performance has been provided by McFadden et al. [1994]. In their study, they classified a total of 65 NASA astronauts according to the different personality clusters and contrasted them on peer and supervisory ratings of different aspects of astronaut effectiveness (i.e. interpersonal competence, technical competence, leadership competence, overall job performance). The results suggested that positive instrumentality/expressiveness was associated with higher peer evaluations of job and interpersonal competence. They also suggested that whereas technical job competence might not be predicted by personality characteristics alone, peer ratings of interpersonal competence are indeed predictable by expressive traits related to interpersonal sensitivity and concern.

Other analyses involving the same astronaut data have addressed relationships between peer and supervisor ratings of astronaut effectiveness and five global personality traits, referred to as the “Big Five” [Rose et al., 1994]. These include Neuroticism (i.e., being emotionally instable, nervous, anxious, depressive, hostile); Extraversion (i.e., being sociable, talkative, impulsive, assertive); Openness to Experience (i.e., being interested, intellectual, original); Agreeableness (i.e., being cooperative, good-natured, tolerant); and Conscientiousness (i.e., being achievement-oriented, responsible, organized) [Digmann, 1990; McCrea and Costa, 1987]. The results of these analyses are provided in Table 6.5.

The data suggest that Agreeableness is a good predictor of interpersonal competence, as well as the other peer and supervisor competency areas shown in the table. This fits well with the findings of the predictive value of expressive traits, which were described above, as well as with other data from a recent astronaut selection study that showed Agreeableness to be closely related to aspects of positive expressivity [Musson et al., 2004]. However, other relationships are not as straight-forward. For example, the negative relationship between Openness to

Table 6.5. Bivariate Correlations (n = 65) Between the “Big Five” Personality Traits and Different Criteria of Astronaut Effectiveness. Source: Rose et al., [1994].

	Peer-Ratings			Supervisor Rating of Job Performance
	Interpersonal Competence	Technical Competence	Leadership Competence	
Neuroticism	-.119	-.107	-.092	-.205
Extraversion	.124	.040	.033	.147
Openness to Experience	.220	-.376*	-.335*	-.277*
Agreeableness	.408*	.268*	.328*	.286*
Conscientiousness	-.109	-.147	-.133	-.173

* $p < .05$

Experience and supervisor-rated job performance is surprising. In addition, the lack of relationship between Conscientiousness and job performance is in contrast to findings suggesting that this personality trait correlates with the Positive Instrumentality/Expressivity cluster [Musson et al., 2004] and has also been found to be a good predictor of work performance in other work domains [Barrick and Mount, 1991]. These discrepancies might be related to the relatively small sample size in this study. In addition, since all of the astronauts involved with these studies had only experienced short-term space flight, it remains unclear whether the findings can be extrapolated to long-term missions.

Another approach identifying individual characteristics that predict for efficient coping and adaptation during long-term space flight has involved secondary analyses of archival data from 657 men who spent the austral winter in an Antarctic station [Palinkas et al., 2000a]. The predictors used in these analyses involved social/demographic characteristics (e.g., age, marital status), personality characteristics classified according to the Big Five system, and interpersonal characteristics (e.g., interpersonal needs). Individual performance criteria were derived from peer and supervisor ratings, the number of times they were nominated by their fellows as an ideal candidate for wintering-over, and the level of depressive symptoms obtained from self-reports. The results of this study suggested that the ideal candidates for long-duration missions under conditions of confinement and isolation have relatively low levels of neuroticism, extraversion and conscientiousness, and show a low desire of affection of others. These results are partially in line with findings of Rosnet et al. [2000], who found indications that people scoring low in extraversion and assertiveness were better adapted to a wintering-over in Antarctica. Further relationships between personality characteristics and performance during winter-over emerged in another analysis of the Palinkas et al. [2000b] data. Among other findings, the need for order was inversely related to peer and supervisor ratings of emotional stability and leadership, and the need for achievement showed a negative correlation to ratings of social compatibility. However, the predictive power of personality characteristics was weak, with the differences in individual characteristics accounting for only 2–4% of the variance in the different criteria. Again, the conclusiveness of these results for contemporary long-duration space missions might be questioned, given that Antarctica certainly is a good but by no means a perfect analog for space, and given the fact that these results are based on analyses of relatively old data (i.e., from the 1960s and 1970s) of a specific population (i.e. all men from one nation).

Nevertheless, studies like these or like the one by McFadden et al. [1994] and Rose et al. [1994] represent first steps in providing empirical data for defining what might be the “right stuff” for long-term space missions. More work in this area needs to be done during space flight, ground-based simulations, and selected analog environments in order to establish select-in methods for astronaut selection that are grounded on sound empirical evidence.

6.4.4. Crew composition: the problem of interpersonal compatibility

It is recommended that only “psychologically compatible” crews be chosen for long-term space missions in order to ensure good crew performance and smooth

interpersonal interactions under conditions of confinement and isolation. But what does it mean to be psychologically compatible? One important aspect of psychological compatibility refers to the harmony of individual personality characteristics of confined crewmembers; i.e., their needs, traits, attitudes, and capabilities (see Chapter 4). However, this kind of interpersonal compatibility is a very complex issue that has not been fully understood [Kubis, 1972; Manzey et al., 1995; Morgan and Lassiter, 1992].

One influential theoretical approach has been the model of need compatibility proposed by Haythorn and colleagues [Haythorn, 1970; Haythorn et al., 1972]. According to this model, the psychological compatibility of crewmembers is dependent upon congruency in areas that require a similarity for individuals to get their needs mutually satisfied (e.g., need of affiliation or achievement), as well as complementarity in areas where a dissimilar need-structure leads to mutual need satisfaction (e.g., need for dominance versus submissiveness). What has to be avoided, according to this model, are competitive needs that may lead to interpersonal tension and open conflict in small groups. Support for this concept has been provided by a number of simulation studies [e.g., Altman and Haythorn, 1967; Smith and Haythorn, 1972]. For example, one consistent finding of this research relates to negative effects on crew interactions if two or more crewmembers possess a high need for dominance. This has been found to cause interpersonal struggles, subgroup formations, and even isolation of single crewmembers during recent ground-based simulations of space flight [Sandal et al., 1995].

Another facet of psychological compatibility is derived from the results of general group research. Several studies have addressed the question of how the mixture of Big Five personality traits within a work team affects team cohesion and performance [Barrick et al., 1998; Barry and Stewart, 1997; van Vianen and de Dreu, 2001]. Even though the results of this research do not provide a completely conclusive pattern, they suggest that the social cohesion, communication, and performance of a work group are improved if the members all show high levels of Conscientiousness and Agreeableness. In contrast, a good mix of extraverted and introverted members seems to be related to social cohesion, as long as no single member is introverted to an extreme degree. This latter finding has been related to issues of leadership and followership and fits well with considerations about need complementarity, presented above [Barrick et al., 1998; Barry and Stewart, 1997]. Furthermore, the results of this research suggest that individuals who are highly disagreeable and neurotic may be especially disruptive to the group, leading to lower degrees of performance, cohesion, and open communication, and to more conflicts. However, since all of this research has been performed with ordinary work teams, it remains to be seen if the results can be generalized to crewmembers living and working together under conditions of isolation and confinement.

Finally, also common sense considerations might be taken into account for an understanding of psychological compatibility. For example, it can be assumed that factors like shared interests, a shared system of values and norms, or a positive emotional attitude to each other will have positive effects on crew cohesion and performance. And for multi-cultural crews fluency in a common language certainly

represents a basic requirement of interpersonal compatibility [Kelly and Kanas, 1992].

A preliminary but by no means comprehensive list of personality factors and other individual characteristics that may affect psychological compatibility is summarized in Table 6.6.

This list corresponds in part to personality aspects that Russian space psychologists have considered in forming space crews. According to Santy, these aspects include “similarity of crew members’ values; social and motivational attitudes toward performance of work; a combination of complementary personality and character traits, with the commander having predominantly positive personality traits and qualities; complementary objective/productive cognitive styles; complementary job-related skills; positive emotional attitudes of crew members toward each other; crew members who learn rapidly and efficiently” [Santy, 1994, pp. 193–94]. Yet the theoretical and empirical basis for such a list is weak. The main body of western compatibility research dates back to the 1960s and 1970s. Most of this research has addressed mono-cultural dyads and triads confined for relatively short periods of time, and very little systematic research has been conducted since then.

A related problem concerns the *assessment* of psychological compatibility. Based on the findings with respect to personality traits and the need compatibility theory, one approach might be to compose crews according to their answers on

Table 6.6. Important Personality Factors that Affect Compatibility.

Compatibility Factor	Description
Homogeneity of personality traits	Crewmembers have similar (high) levels of Agreeableness and Conscientiousness
Complementary needs	Crewmembers have different needs that complement each other (e.g., dominance versus submissiveness).
Congruent needs	Crewmembers have similar needs that can be mutually satisfied (e.g., affiliation, autonomy, achievement).
Shared interests	The extent to which crewmembers share common interests (e.g. reading, game playing, music, politics, sports).
Shared values and norms	The extent to which crewmembers share a common system of values, beliefs, and behavioral norms.
Emotional attitude to each other	The extent to which crewmembers like and respect each other.
Common language	The extent to which crewmembers are able to express their own feelings and thoughts appropriately in a common language

standardized personality or attitude questionnaires. For example, one questionnaire which has often been used in compatibility research to investigate the similarity of interpersonal needs is the Fundamental Interpersonal Relations Orientation – Behavior (FIRO – B) test [Dunlap, 1965; Ferguson, 1970; Haythorn and Altman, 1963; Palinkas et al., 2000a], and similar psychometric questionnaires are available in many languages for assessing the Big Five personality traits (e.g. NEO-PI-R) [Costa and McCrae, 1992]. However, this approach remains limited to analyses of individual questionnaire data and does not include behavioral aspects of compatibility, like the ability of crewmembers to coordinate their activities efficiently or to communicate with each other in a clear and cooperative manner. For this reason, Russian space psychologists base their compatibility assessments not only on analyses of individual personality profiles but also on observations of the interactions of potential crewmembers during training with compatibility tests like the “Homoestat” test [Gazenko, 1980; Novikov, 1991; Santy, 1994].

Another approach that assesses compatibility using behavioral observations involves techniques derived from assessment center (AC) methods of selection. These methods include behavioral exercises (e.g., group discussions, role plays, presentations) where the performance of an individual or a group of individuals is assessed by a team of experienced judges based on a given set of evaluation criteria. In particular, AC methods often are used to evaluate the interpersonal or teamwork skills of candidates for managerial positions [Thornton and Byham, 1982]. However, they also might be used to assess the psychological compatibility of crews going to live and work in confined and isolated environments. This has been shown by the application of AC methods for selecting the most compatible four crewmembers out of a group of ten candidates for a 60-day confinement study conducted by the European Space Agency [Manzey et al., 1995]. In this approach, a team of judges consisting of two psychologists, one experienced flight surgeon, and the commander of a crew that had participated in a similar simulation study before, observed different constellations of candidates performing different behavioral exercises. These exercises included two different kinds of group discussion, one role-play, one presentation exercise, and one construction exercise where the candidates were assigned a construction problem which they had to work cooperatively to solve. Based on their observations of crew interactions and performance in these exercises and a defined set of evaluation criteria, the judges assessed the compatibility of the candidates with regard to their interpersonal and leadership skills and finally selected four crewmembers who then became the prime crew for the simulation study [Manzey et al., 1995].

However, the compatibility of individual characteristics represents only one aspect of crew composition. Other factors that must be considered include crew size, gender mix, and cultural background, which have been discussed in some detail in Chapter 4. Particular attention also should be given to minority status in crew composition so that an individual does not feel isolated on the basis of national origin, gender, or work role. If small crew size and operational considerations do not allow for a balance in these areas during crew selection, then additional attention needs to be given to discussing issues of diversity and cultural differences during pre-launch training. In any case, potential crews should be observed in

mission simulation and other relevant group activities prior to launch to test for compatibility and performance.

Several factors related to the mission itself can have an impact on the compatibility and cohesion of space crews. In their survey of 54 astronauts and cosmonauts who had flown in space, Kelly and Kanas [1992] looked at issues related to communication that enhanced intra-crew compatibility in space. Of nine factors that were felt to possibly influence crew communication, four were rated as significantly helping: Shared Experience, Excitement of Space Flight, Close Quarters, and Isolation from Earth. Three others were judged to hinder communication: Facial Swelling, Spacecraft Ambient Noise, and Space Sickness. These findings suggest that a bonding experience may occur among space travelers who are physically close to one another, who share common experiences, and who are involved with the same activity in a positive, emotionally exciting manner.

6.5. Training

Training aims at preparing astronaut candidates or crewmembers for the psychological demands of space flight. It complements the crew selection process and focuses on the further development of behavior and performance with respect to the specific job demands of astronauts. However, compared to selection, experiences with psychological training for astronauts are limited. Psychological training has always been provided to Russian cosmonauts in preparation for space missions, but little information has been published about the nature of this training. According to some sources, it has focused on stress management techniques, such as relaxation training and the familiarization with stressful events in field exercises like survival training or parachuting [Garshnek, 1989; Santy, 1994]. American approaches during the Shuttle/Mir program were limited to a few theoretical briefings to crewmembers and their families about psychological and psychiatric issues. In Europe, psychological training has been provided to a group of five German astronauts as part of their basic medical training [Manzey and Schiewe, 1992; Manzey et al., 1995]. The current ISS program has brought more attention to this area. Currently, almost all of the partners involved in ISS operations are engaged in implementing some kind of basic psychological training for their astronauts, and even more advanced training has been provided during specific field exercises (e.g., in the outdoors or in isolation chambers). In what follows, three questions of psychological training for space flight will be addressed: who should be trained, what should be trained and what kind of training can be applied?

6.5.1. Who should be trained?

Most psychological training activities have centered on the astronauts who are potential members of space crews. However, with respect to the efficient co-working of space crews and ground personnel, it seems to be necessary to involve both crewmembers and mission control personnel in pre-mission training, sometimes together, since these two groups are mutually dependent in conducting the activities of a space mission. Consequently, it is important that both groups

understand the mission's goals and communicate clearly with each other. Issues that have to be addressed relate to disturbances of communication between space and ground personnel that might develop during long-duration space missions (see Chapter 4). One issue involves the empathy of people in mission control for specific situations in space. Astronauts have requested more attention from the ground and have complained about a lack of empathy from mission control personnel for the difficulties they face in space [Gushin et al., 1997]. In addition, crewmembers working under conditions of isolation and confinement may experience tension and maladaptive interpersonal relationships that they cannot resolve openly. As a result, they may withdraw from one another and exhibit territorial behavior. They also may displace tension and negative emotions to people in the "outgroup" of mission control who are monitoring their behavior. As mentioned in Chapter 4, this displacement can interfere with the crew-ground relationship and lead to ingroup/outgroup communication problems. Consequently, mission control personnel who interact with space crewmembers need to be sensitized to the different psychological issues likely to arise during the mission. Parts of this sensitization might be achieved in separate training sessions, but to develop a common rapport, consideration should be given to training crewmembers together with key members of their mission control support staff.

6.5.2. Towards a competency model for astronauts

The effective psychological training of astronauts (and mission control personnel) requires that mission-relevant behavioral competencies (and associated knowledge, skills and attitudes) be identified and used in the training curriculum. Ideally, these competencies should be based on both theoretical analyses as well as relevant experiences and lessons learned from actual space missions. A first attempt to define a comprehensive list of behavioral competencies was recently undertaken by the ISS Mission Operations Directorate. In coordination with the International Training Control Board (ITCB) of the ISS program, a working group that included experts and specialists from different disciplines (e.g., astronauts, training engineers, psychologists) and all major ISS international partners was tasked to develop the so-called "ISS Human Behavior and Performance Competency Model" [ISS Mission Operations Directorate ITCB Training Working Group, 2007a]. This model included a total of 25 specific competencies that were classified into seven behavioral categories. Each competency was further defined by different behavioral markers (i.e., described in terms of directly observable and assessable behaviors). In addition, relevant knowledge, skills and attitudes related to these competencies were identified [ISS Mission Operations Directorate ITCB Training Working Group, 2007b]. Although the current model was primarily developed as a basis for developing a training curriculum for astronauts, parts of it are also relevant and easily adaptable to training mission control personnel.

An overview of this model, with the overall structure of competencies and selected behavioral examples, is provided in Table 6.7. The first four categories of competencies considered in this model (Self-care and Management, Team-work and Group Living, Leadership, and Cross-cultural) include categories that are particularly relevant for long-duration space missions involving crewmembers who will

live and work together in a small multinational crew under conditions of isolation and confinement. These categories will now be discussed in detail.

“Self-care and Management” comprises competencies that are needed to cope with the demands and stress of long-duration space flights on an individual level in

Table 6.7. Behavioral Categories and Competencies of the ISS Human Behavior and Performance Competency Model. ISS Mission Operations Directorate ITCB HBP Training Working Group [2007a].

Categories and Competencies	Behavioral Marker (Example)
Self-care and Management	
Refine accuracy of self-image	Seeks formal and informal feedback to understand impact of own behaviors on others
Manage stress	Takes action to prevent and mitigate stress, negative mood, and low morale
Care for one-self	Maintains social relationships
Maintain efficiency	Keeps items organized
Team-work and Group Living	
Active team participation	Acts cooperatively rather than competitively
Interpersonal relationships	Provides emotional support to crewmembers
Group Living	Balances own needs with those of crewmembers
Leadership	
Execution of designated leader’s authority	Adapts leadership style to situation
Mentoring skills	Provides direction, information, feedback, and encouragement and coaching as needed
Followership	Supports leader
Workload management	Plans and prioritizes tasks
Cross-cultural	
Demonstrate respect towards other cultures (national, professional, organizational)	Demonstrates respect and appreciation for team members’ culture(s) and viewpoints
Understand culture and cultural differences (national, organizational, and professional)	Acknowledges the impact of cultural dominance on crew interaction
Builds and maintains social and working relationships	Demonstrates tolerance of cultural differences and ambiguities

(Continued)

Table 6.7. (Continued)

Categories and Competencies	Behavioral Marker (Example)
Intercultural communication and language skills	Makes an effort to use and learn the language of colleagues
Commitment to multi-cultural work	Puts a common "space-faring culture" ahead of one's own national, organizational and professional culture
Communication	
Optimize communication	Communicates information clearly and concisely; provides constructive feedback
Ensure Understanding	Listens "actively"; verifies information
Conflict Management	
Conflict prevention	Prevents disagreements from influencing personal and professional relationships
Conflict resolution	Adapts conflict management strategies to resolve disagreements
Situational Awareness	
Maintenance of an accurate perception of the situation	Monitors people, systems and environment
Processing of information	Identifies and resolves discrepancies between conflicting data or information
Decision-making and problem-solving	
Decision-making and problem-solving methods	Adopts methods that meet situational demands
Preparation of decision	Assembles facts; considers different options; evaluates risks and benefits
Execution of decision	Executes decision; checks results of decision and if necessary, reapplies process

order to ensure that performance efficiency is sustained throughout the mission. Four competencies are identified that include: a realistic self-image with respect to performance capabilities under the impact of specific physical and psychological stressors in space ("refine accuracy of self-image"); diverse skills that help to manage stress in space ("manage stress"); and ability to maintain a good mood and behavioral health ("care for one-self") as well as a high performance efficiency during a space flight ("maintain efficiency"). Specific trainable skills related to this category of competencies include time management techniques as well as techniques related to relaxation, meditation, biofeedback, or autogenic training to calm one-self in situations of high workload or tension and to lower anxious arousal

by controlling autonomic functions. The latter may also obviate the use of medications during stressful periods in space and may even help to control space sickness [Cowings and Toscano, 2000].

“Team-work and Group Living” include a strong team orientation that is reflected in team-work-related attitudes and skills (“active team participation”), such as the readiness to put common goals above individual needs, a cooperative instead of a competitive work attitude, and skills related to proactively supporting other crew members in their tasks. In addition, diverse skills are needed to establish and maintain positive and trustful relationships with others, and to actively care about the integration of all crew members (“interpersonal relationships”). The “group living” competence mainly involves attitudes and skills necessary for a common life under isolation and confinement. Important factors include the readiness to balance one’s needs with the needs of other’s during co-living in space, as well as skills supporting a positive team spirit and a good team-cohesion within the crew.

“Leadership” competencies are related to the specific demands of commanders of space crews. One important competence addresses the “execution of the designated leader’s authority”. This includes diverse management skills as well as a flexibility to adjust leadership behavior to the specific situational demands. The latter is mainly reflected in a good balancing of task and supportive leadership roles (see Section 4.6), which also constitutes an important lesson learned from previous space missions and analog environments on Earth [Nicholas and Penwell, 1995; Stuster, 1996]. Other competences in this category include “mentoring skills”, such as directing other crewmembers by providing feedback, consultation, and encouragement; “followership”, which mainly involves aspects of subordination and acceptance of authority, but also the support of the crew leader; and “workload management”, which are related to specific skills of effective human resource management, delegation, and balancing of workload within a crew [Helmreich and Foushee, 1993].

“Cross-cultural” competencies have gained particular importance during the last decade due to the construction of the International Space Station. As was described in Section 4.2.2, the “multi-culture” aspect of ISS operations is not limited to the different ethnic or national background of the crewmembers and mission control support personnel. It also involves issues arising from a mix of participants from different space-related organizations and different professional backgrounds. These individuals interact not only during the space missions themselves, but also during pre-launch training, which might involve prolonged stays in other countries and cooperation with other organizations. Some competencies in this category address respect for differences and information that helps in understanding the behavior of people from other cultures, organizations, and professions (“demonstrate respect of other cultures”; “understand culture and cultural differences”). Other competencies include skills based on relating and communicating with members of other cultures (“builds and maintains social and working relationships”, “intercultural communication and language skills”) and an attitude of transcending specific cultural issues for the sake of the group (“commitment to multi-cultural work”).

The remaining four categories in Table 6.7 include competencies that are needed to efficiently cope with the operational demands of a space mission (e.g., piloting,

operating technical systems, conducting experiments, dealing with emergencies). Actually they show considerable overlap with what has been referred as *crew resource management* (CRM) skills in aviation and other operational environments (see Section 6.5.3.3, below)

“Communication” competencies include the application of knowledge and skills in order to ensure a high efficiency of interpersonal communication during common operational work. These include specific skills needed for both sending and receiving communication. Good “sender” competence (“optimize communication”), for example, is characterized by providing important information in a timely and precise manner, providing feedback to others in a constructive way, or actively requesting inputs from others. Competence on the receiver side (“ensure understanding”), is reflected by active listening skills, acknowledgement and verification of received information, and proactive effort to identify and overcome possible sources of misunderstanding.

“Conflict Management” relates to knowledge, skills, and attitudes needed for “conflict prevention” and, if this fails, “conflict resolution” of interpersonal problems during operational activities. These include specific communicational skills, as well as aspects of emotional control. In addition, the “establishment and maintenance of a rational and mutually respectful atmosphere” is essential.

“Situational Awareness” competencies relate to appropriate evaluations and assessments of operational situations. Originally, the term was introduced to describe the way operators interact with dynamic technical systems [Endsley, 1995]. In the competency model, this concept is enlarged to consider not only aspects of relating with technical systems but also with other individuals. Two specific competencies are distinguished. The first includes aspects of appropriately perceiving and monitoring all relevant aspects of a given operational situation (“maintenance of an accurate perception of the situation”); e.g., monitoring all important information sources available on-board a spacecraft, as well as monitoring one’s own performance state and the state of other crewmembers. The second competency includes the capability to understand this information and to initiate appropriate action in case a situation deviates from nominal conditions (“processing of information”).

“Decision-making and Problem-solving” constitute important elements of all kinds of operational work. The two basic competencies and related behavioral skills included in this category are “preparation of decision” and “execution of decision”. These are highly influenced by the FOR-DEC model, a heuristic method for structured decision-making originally developed for application on flight decks [Hoermann, 1995]. According to this model, the preparation for effective decisions involves three steps: the sampling of all facts relevant for the decision, a systematic analysis of the different options available, and an evaluation of the risks and benefits associated with each option. Based on this preparation, further decision-making involves the decision itself, its implementation in terms of concrete actions, and a check on whether or not these actions finally have led to the desired outcome.

It is not possible to address all of the competencies described above in a single training event. Thus, a careful evaluation needs to be made with respect to which kinds of competencies might be taken for granted (e.g., as a result of effective

psychological selection), which may be dealt with on-the-job (e.g., as part of technical training), and which might require specific psychological training events. The last of these is related to another consideration, namely, the kinds of psychological training that are effective for both astronauts and mission control personnel.

6.5.3. Kinds of training

At least three complementary approaches of psychological training can be distinguished which might be used to teach and train relevant competencies and associated knowledge, skills and abilities identified in the competency model: (1) briefings, lectures, and workshops, (2) field exercises, and (3) crew-oriented sensitivity and team-building training.

6.5.3.1. Briefings, lectures, and workshops

Briefings, lectures, and workshops are the most common and easy-to-implement methods of training. Empirical work with military pilots suggests that astronauts and mission control personnel who are operationally-oriented may specifically prefer briefings that are problem-focused and oriented toward direct action, as compared with other forms of information exchange [Picano, 1990]. These methods may in fact be the best choice, particularly for basic and advanced training that addresses general knowledge and attitudes, independent of a specific mission assignment. Therefore, they must be regarded as important training elements for addressing the different competency categories described above. Take, for example, competencies of related to “Self-care and Management”. Specific briefings and workshops could be used to make astronauts aware of their own responsibilities for maintaining mood and performance efficiency in space. In addition, different behavioral techniques can be taught that enhance the competencies of astronauts in this particular area (e.g., techniques of time-management or relaxation). A second example relates to “Cross-cultural” skill training. Briefings and lectures might be used to not only enhance the general awareness of issues that arise from cultural differences, but also to provide relevant knowledge concerning other national, organizational, and professional cultures [Kealey, 2004]. Furthermore, crewmembers and ground personnel can be briefed on behaviors that are perceived as being proper and acceptable by individuals with different national, organizational, or professional backgrounds [Tomi et al., 2001].

Most of the psychological training for astronauts that has been implemented so far has relied on this kind of classroom teaching. Commonly used approaches have included seminars or workshops that involved a mixture of briefings, lectures, and round-table discussions. However, it can be expected that in future computer-based training (CBT) approaches will become more and more important. For example, Carter and his colleagues [2005] are developing a novel, self-guided, interactive multimedia program that is aimed on particular competencies in the areas of communication and conflict-management. Based on taped lectures by experts in the field, and examples and demonstrations provided by audiovideo vignettes, crewmembers are encouraged to develop strategies of preventing, assessing, and managing psychosocial problems that could actually arise on extended space missions.

One of the advantages of this approach is that it might also be provided as a training or refresher tool for astronauts on board a vehicle traveling through space.

The main limitation of these approaches relates to their theoretical nature. Although they may be the method of choice for providing information and for enhancing general awareness of certain issues, they are much less suitable for the establishment and training of specific behavioral skills. This latter training requires more applied approaches like the ones provided by field exercises.

6.5.3.2. *Field exercises*

Field exercises refer to experiential training that is used to provide potential crewmembers with real experiences in self-management, team-work, leadership, multi-cultural issues, and all CRM related competencies in an environment that shares important characteristics and demands with real space flight. Examples include outdoor training (e.g., hiking in the wilderness), specific survival training, short-term stays in underwater habitats (see below), or isolation chamber training. These kinds of activities have played a major role in the education of Russian cosmonauts [Bluth and Helppie, 1986; Garshnek, 1989]. With respect to ISS operations, such training approaches also have been implemented by NASA and other international partners as an important element of advanced training required for possible assignment for a long-duration space flight. One example implemented by NASA includes specific outdoor training provided in the Rocky Mountains or similar areas by the National Outdoor Leadership School. This training involves astronaut crews working and living together for up to 2 weeks in the wilderness who are accompanied by coaches who provide input and feedback on self-management, team-work and leadership under these extreme conditions.

The main advantage of field exercises is that they provide opportunities to train most of the required competencies at the same time and in an integrated manner. In addition, it provides crewmembers the opportunity to encounter their own strengths and weaknesses in a mission-like scenario and to identify individual strategies to cope with extreme demands. For this purpose, it is important that these exercises are combined with some kind of coaching and feedback by experienced trainers and peers. However, most benefit can be expected to arise from these exercises if they are applied as a second step of training after basic knowledge and skills have been provided in all relevant areas by seminars and workshops.

6.5.3.3. *Crew-oriented sensitivity training and team-building*

The training approaches discussed so far can be applied to individual astronauts or mission control personnel independent of a specific mission assignment. Even though this kind of training might be sufficient to prepare astronauts generally for the demands of long-duration space flight, it needs to be complemented by more specific training applied to an entire space crew and key personnel of their ground support staff who are assigned to a certain mission. Nicholas and his colleagues have described important interpersonal issues that can affect crew composition and behavior, and they suggest training the crewmembers together in order to enhance crew functions [Nicholas, 1987, 1989, 1997; Nicholas and Foushee, 1990]. More specifically, Nicholas [1989] suggests that this training should focus on three objectives: improvement of interpersonal skills, improvement of social support

skills, and improvement of crew coordination skills. Specific programs exist to train people on how to work together as a team by observing their interactions, discussing what occurred, and suggesting ways of improving communication and cohesion. Such sensitivity training and team building has been in widespread use for decades in a number of work-related settings [Beckard, 1969; Dyer, 1995; Skopec and Smith, 1997].

A comprehensive program for whole crew training has been described by Manzey et al. [1995]. The main objectives of this training concern: (1) the support of the team building process, (2) the development of effective crew coordination skills, and (3) the identification of strategies for coping with psychological issues that may arise in this specific crew during their common mission. The importance of the team building process for efficient crew functions already has been recognized by the Russian cosmonauts [Leonov and Lebedev, 1975]. With regard to anticipated interplanetary space flight, they have stated "...that the crew of an interplanetary ship should not only be made up on the basis of careful selection, but should go through all the stages of its development long before the flight" [p. 66].

The different stages of team building that need to be mastered by a crew in order to become most efficient have been referred to as *forming*, *storming*, *norming*, and *performing* [Tuckman, 1965, 1977]. The forming stage represents the first stage where team members are introduced to each other and begin working together. The storming stage is the most critical one since the different crewmembers try to clarify their individual roles within the crew. Very often, this stage is characterized by the formation of cliques and by struggles between team members regarding issues of autonomy and control within the team. The central task for the team during this stage is to establish a formal and informal group structure that is accepted by each team member. This represents an important requirement for the next two stages of team performance. During the norming stage, common group norms, goals, and skills have to be defined before team cohesion, efficiency, and task orientation reach their maximum in the performing stage. Only members of crews that have reached this final performing stage can be expected to work efficiently together during a space mission without wasting time and personal energy in interpersonal struggles and conflicts. What is needed for this purpose is the development of a clear and unambiguous crew structure, and the crew should be supported in the development of common group norms and a common commitment to mission goals, which are important pre-conditions for crew cohesion. It is obvious that coaching a crew proceeding through these different stages of team-building provides a good opportunity to train and apply many of the different competencies listed in the competency model described above.

The second objective of the training of whole crews can be seen in the development of effective crew coordination skills that take the specific crew composition into account [Manzey et al., 1995; Nicholas, 1989]. In particular, effective team-working, collaborative decision-making, and workload management skills can be addressed. Such kind of training is similar to concepts of crew resource management training (CRM) or line-oriented flight training (LOFT), such as those used with aircraft crews in simulators [Helmreich and Foushee, 1993; Helmreich et al., 1999]. In these programs, realistic flight scenarios are presented, and the ability

of the crewmembers to respond in a coordinated manner is observed and recorded. Crew actions are later discussed, and better strategies for responding as a group are considered. These programs have been found to be useful [Kanki and Foushee, 1989; Nicholas, 1989; Nicholas et al., 1988; Salas et al., 1999, 2001], and their value for space crews participating in long-duration multi-cultural missions needs to be tested further.

The final aspect of training of whole crews involves enhancing crew efficiency during a mission by what has been referred to as *anticipative problem solving* [Manzey et al., 1995]. Given the knowledge about psychological issues that might adversely affect crew interactions during space flight, crewmembers can benefit from analyzing these issues together in advance of their flight and searching for possible countermeasures under the supervision of a psychologist. Such anticipative problem solving not only improves the awareness of crewmembers for specific problems, but it also can prepare them to cope with such problems during their mission.

The success of such training for space crews has not been evaluated empirically. However, its usefulness is suggested by the first experiences gained from applying such training to crews participating in ground-based simulations. For example, a psychological preparatory training was provided to crewmembers who lived and worked together in a confined chamber for periods of 60 and 90 days, respectively, as part of the NASA Lunar-Mars Life Support Test project [Holland and Curtis, 1998]. Objectives of training, among others, focused on team building, the establishment of a crew identity, and a clarification of the work roles and responsibilities of the different crew members and key members of their support team outside the chamber. Training methods included briefings, group sessions, and (for the 90-day mission) a preparatory field exercise in an underwater station, which was conducted to promote the crew's integration and organization as a team and to provide mission experience. A similar training also was provided to crewmembers and mission control personnel who participated in a 60-day space flight simulation conducted by the European Space Agency [Manzey et al., 1995]. This training included different group sessions that focused on the definition of a set of behavioral rules for the stay in the chamber that all crewmembers committed themselves to, on a clarification of formal and informal crew roles, and on increasing the problem-awareness of crew members by means of anticipative problem solving. Even though no formal evaluation of this training (and other countermeasures) could be performed, its success was suggested by subjective reports of the crewmembers during debriefings conducted after the mission [Manzey et al., 1995].

6.6. Crew monitoring

Crew monitoring is an important countermeasure that includes tracking space crewmembers over time for signs of psychological or interpersonal difficulties. Such monitoring is needed in order to plan for psychological support activities that may help in stabilizing the mood and performance of astronauts and may help in preventing psychological or psychiatric issues from becoming serious threats to

mission success. Aspects needing to be monitored may be derived from a review of psychological issues that affect people during space missions (see Chapters 2–5), and some of these are summarized in Table 6.8.

6.6.1. Remote monitoring from Earth

A variety of methods might be used for remote monitoring of these different areas from Earth (Table 6.8). However, not all of these methods have been applied in real space flight, since some of them are either too invasive (e.g., circadian rhythm monitoring by continuous temperature assessment using rectal thermistors) or too complex (e.g., sleep monitoring by EEG measures) to be applied routinely. To date, monitoring mostly has been limited to an overall evaluation of the psychological state of astronauts derived from self-report data such as questionnaires, observations, or personal interactions between medical or psychological experts on the ground and the crewmembers in space. For example, in past Russian space missions, experts in mission control traditionally have tracked crew-ground audio communications, observed video behavior, analyzed crew errors and work-rest schedules, and held private conferences to assess crewmember well-being [Kanas, 1991]. Of particular importance are the analysis of different structural parameters of verbal behavior (e.g., evaluation of length of talking time, number of words per unit of time) and the analysis of voice characteristics (e.g., rhythmic and structural

Table 6.8. Areas to be Addressed in Psychological Crew Monitoring and Example of Possible Monitoring Methods.

Areas to be Monitored	Examples of Remote Monitoring Methods
Cognitive performance	Performance tests, analyses of crew errors
Workload and fatigue	Questionnaires, analyses of work-rest schedules, private medical and psychological conferences
Sleep	Questionnaires (sleep logs), actigraphy (see text), polysomnography, private medical and psychological conferences
Circadian rhythm	Temperature recordings, analyses of work-rest schedules
Stress and psychological well-being	Questionnaires, private medical and psychological conferences, analyses of crew-ground communication, voice analyses
Interpersonal relationships and crew-cohesion	Questionnaires, private medical and psychological conferences, analyses of crew-ground communication, analyses of videos from crew interactions, sociometry
Behavioral health	Questionnaires, private medical and psychological conferences, analyses of crew-ground communication

properties) by specially trained experts on the ground [Gazenko et al., 1976]. For ISS operations, private psychological conferences between crewmembers and psychological experts on the ground have been implemented (see Section 6.7.3) and represent one of the most important tools currently used by Russian and American support teams to monitor the psychological status of their crewmembers.

However, more specific and objective monitoring methods might be considered. For example, Manzey [2000] has suggested using a set of standardized performance tasks like those used in his research (see Chapter 3) for assessing cognitive performance and fatigue, and others have recommended even more complex approaches combining performance measures with physiological measures in order to not only evaluate the performance level but also assess aspects of stress and workload [e.g. Pattyn, 2007; Salnitskiy et al., 1999]. Other monitoring approaches have involved wrist actigraphy (i.e., recordings of arm movements by means of an electronic device attached to the wrist of the non-dominant arm) as an objective method for differentiating between sleep and wakefulness and for the assessment of sleeping times and sleep efficiency in space [Monk et al., 1999]. Yet all of these methods have only been used for research purposes so far, and their feasibility for operational monitoring still has to be demonstrated. It also has been suggested that the further development of Russian approaches of voice analysis into a more formal standardized monitoring tool would have some appeal, since this technology represents an objective measure that does not require extra effort from the crewmembers but makes use of data that are provided unobtrusively during audio transmissions from space. However, as will be shown below, more work needs to be done before this approach can be used reliably for operational crew monitoring.

6.6.2. Empirical findings from space: monitoring stress through voice analysis

The analysis of formal voice characteristics, such as frequency, amplitude, speech rate, etc., has been advocated as being a useful indicator of the functional state of pilots and astronauts [Lieberman et al., 2005; Ruiz et al., 1990]. Several Russian researchers have reported success in using the analysis of the objective characteristics of speech from recordings of space transmissions as an indicator of cosmonaut stress and emotional state [Gazenko et al., 1976; Khachataryants and Grimak, 1972; Simonov and Frolov, 1973]. In contrast, an analysis by American researchers of the voice frequencies of selected Skylab communications was judged to be insufficiently predictive of crewmember stress to warrant further use [Older and Jenney, 1975]. One study of 17 male subjects in a laboratory found some promising results but did not reveal speech analysis to be as robust a stress indicator as other factors, such as heart rate [Brenner and Shipp, 1987]. The general consensus based on this work was that speech technology did not have enough specificity and sensitivity to be used as a reliable predictor of emotional state in space.

More recently, however, the work of Johannes and his colleagues [1995, 2000] has shown promise in this area. Their work has centered on measurements of the lowest frequency of voice pitch, the so-called fundamental frequency, which results from the vibrating glottis. Since the glottis is innervated by the vagus nerve, this

provides a physiological mechanism for linking the fundamental frequency with the autonomic nervous system, which is itself involved in the body's emotional reactions. And indeed, elevations of the fundamental frequency of the voice have been found to represent the most sensitive voice indicator of workload and emotional stress [Ruiz et al., 1990].

In preliminary studies on the ground, Johannes and his colleagues [2000] provided some support for this general effect. They found that emotional excitation increased the mean level of the fundamental frequency and that voice pitch statistically differentiated people with sensitizing versus repressing personality traits. Unlike other physiological parameters such as heart rate and blood pressure, voice pitch was not systematically related to the increased physical load produced during a bicycle test. Due to individual variation, they found it important to calibrate voice pitch to reflect individual reference values. During a 135-day confinement study involving three men working in the Mir space station simulator in Moscow, they analyzed the speech of the crewmembers while they performed a Mir docking simulation. Drops in the fundamental frequency were found when tasks had to be performed in a state of fatigue after 72 h of sleep deprivation [Johannes et al., 1995, 2000].

Together with Russian colleagues, Johannes also studied voice pitch on the Mir space station itself. Crewmembers were analyzed pre-flight, in-flight, and post-flight while they performed three mental task load tests related to time pressure, tracking, and memory, and a standard physical handgrip test. During all three mission phases, the first test with a manometer induced the highest psychological load and resulted in a rise in the fundamental frequency. There also was an increased level of fundamental frequency for all test and rest periods in space as compared with pre- and post-flight. Johannes and his colleagues concluded that provided calibrations were made to baseline the specific relationship between voice pitch and subjective perceptions of stress in a given individual, the analysis of speech fundamental frequency could be used to monitor the psychophysiological state of people working in the space environment. However, it has not been possible to evaluate the *quality* of workload or stress by means of formal voice analysis so far; i.e., to distinguish whether an elevated fundamental frequency of the voice results from workload or states of positive or negative emotional arousal. This represents a serious limitation of this approach, and Johannes et al. [2000] admit that further work needs to be done on this methodology under different stressors and different environmental circumstances using people with different personality and cultural backgrounds before this method might be applied as an objective evaluation tool in space flight operations.

6.6.3. On-board monitoring

Implementing remote crew monitoring is a sensible way of tracking crew status, but it might be perceived by crewmembers as a control tool instead of a support measure. Consequently, the acceptance by crewmembers can be low, and it can even raise the stress of crewmembers during a mission [Stuster, 1996]. Thus, the extent and quality of monitoring must be planned carefully.

An alternative to remote crew monitoring is the implementation of an on-board monitoring approach (i.e., monitoring relevant areas within the crew without a downlink of information). One method is to have one of the crewmembers be trained to recognize potential problems when they occur and alert mission control only when necessary. It is likely that the mission commander or a physician crewmember will take on this responsibility, and in future exploratory missions with large crews even a psychiatrist or psychologist could serve as an in-flight consultant. However, Nicholas [1989] points out that such a person could not remain completely objective and be unaffected by issues that influence the others, since he or she also is part of the crew and is exposed to the same stressors and group dynamic issues. Nicholas further argues that all of the crewmembers should be trained pre-launch to monitor and evaluate their interpersonal environment in order to be able to recognize early signs of psychosocial problems, and to intervene if necessary. Such an approach would be in line with some of the objectives of psychological training described above. Yet it presupposes that the crewmembers know each other very well. Even though it might be an option for missions where participants have trained and worked together for a long period of time, it is much more difficult on missions where there is a staggered turnover of personnel (e.g., due to visiting crews).

A second approach to on-board monitoring includes the provision of formal self-monitoring tools for each crewmember. This has been pursued in implementing neurocognitive assessment by NASA during the Shuttle/Mir program and on the ISS. For example, a computerized *Spaceflight Cognitive Assessment Tool for Windows* (WinScat) has been developed [Kane et al., 2005; Retzlaff and Vanderploeg, 2000; Retzlaff et al., 1999]. It consists of five well-established and validated neuropsychological tests that probe different cognitive functions, including verbal memory, mental arithmetic, sustained attention, and spatial imagery and memory. Each performance assessment in space needs about 15 min and provides data that can be compared with a self-referenced performance baseline established during pre-flight training. This gives the astronaut a quick overview about his/her actual performance state in space relative to the “normal” level exhibited on Earth. Originally, WinScat was developed as a medical tool for assessing the mental performance of astronauts after a neurocognitive insult (e.g., illness, head injury, exposure to toxic gas, decompression accidents during EVA). But it was realized that it also could be used for repeated self-monitoring of cognitive functions and mental efficiency by astronauts during a space mission. Procedures were established for U.S. crews on the ISS to conduct WinScat performance assessments every 4 weeks during their stay in space. This latter kind of approach might be regarded as equivalent to what has been referred to as readiness-to-perform or fitness-for-duty assessment in the industrial domain.

Another tool that have been proposed for the self-monitoring of cognitive performance in space is the MiniCog Rapid Assessment Battery [MRAB; Lieberman et al., 2005; Shephard and Kosslyn, 2005]. Similar to WinScat, it consists of a set of different cognitive performance tasks that are presented on a personal digital assistant (PDA). It probes nine different cognitive functions and has been developed as an “early warning” tool that can make astronauts aware of

cognitive performance decrement before they lead to decrements in work performance. Although most applications of the MRAB have so far been limited to laboratory research, the first experience of using the MRAB for during a space mission experiment suggests that it may be a generally suitable tool in this novel environment [Pattyn, 2007].

Other standardized test batteries might be used that are not limited to performance assessments alone [Manzey, 2000]. For example, a method of monitoring on-board performance state has been proposed by Cowings et al. [2007]. They suggest combining standardized performance assessments with the assessment of different physiological responses in order to identify and feed back to crewmembers what they call a “stress profile”. This is a very complex assessment strategy, and more research will be needed before such an approach is considered for individual self-assessments of performance state during space missions.

A fundamental problem of all of these approaches to onboard-monitoring relates to the fact that the use of the different tools presupposes high trust in the autonomy, motivation and honesty of each crewmember. Even more important and difficult, it also requires the provision of clear decision criteria and aids in order to assure that appropriate actions will be taken by crewmembers in response to the outcome of such self-assessments (e.g., how much performance decrement would necessitate informing the commander or ground control, or what level of performance is still acceptable for critical mission tasks?). In addition, whereas such an approach might be appropriate for the monitoring of cognitive performance, effects of fatigue, and specific neuro-psychological functions after possible traumatic events such as accidents, it does not appear to be suitable with respect to interpersonal relations and crew cohesion.

To sum up, on-board monitoring might be applied for some selected areas, but it is questionable whether it ever can fully compensate for some kind of remote crew monitoring. Yet remote monitoring is a sensitive issue. The implementation of such monitoring can be expected to be a useful component of psychological support only if it is based on a trusting relationship and cooperation between the crewmembers in space and their support staff in mission control.

6.7. In-flight support

From the very beginning of long-duration space flight, the provision of psychological in-flight support to crewmembers has been an important countermeasure in Russia [Grigoriev et al., 1987; Kanas, 1991]. For this purpose, a psychological support group was established that coordinated different activities in order to counter feelings of monotony, isolation, and behavioral health issues like asthenia. Such activities have included surprise presents and favorite foods delivered via re-supply vehicles, increased on-board music and lighting, increased contact with people on Earth, and ground-crew counseling or psychotherapy [Kanas, 1991, 1998]. In addition, the arrival of visiting astronauts and cosmonauts has helped break the monotony and provided stimulation and assistance in performing mission activities.

Based on this experience, a similar system has been established by NASA for its space station support activities [Flynn, 2005; Sipes and Vander Ark, 2005]. Table 6.9 provides a summary of psychological in-flight support activities for crewmembers as defined in the ISS Medical Operations Requirements Document (ISS MORD) [International Space Station Program, 2000]. The main objectives of these activities are to prevent feelings of monotony, boredom, and isolation, to maintain a close contact between the crewmember in space and family and friends on Earth, and to provide crewmembers opportunities to talk with members of their psychological support group on a regular basis (see Chapter 5 for a separate discussion of in-flight support for psychiatric issues).

6.7.1. Supportive measures for preventing feelings of monotony, boredom, and isolation

An important aspect of psychological in-flight support is to prevent feelings of monotony, boredom, and isolation which might arise during missions with long periods of free time. Consequently, attention should be given to enhancing leisure time activities that take into account changing interests and needs. This is of particular importance after some time in space when primary adaptation has been achieved, initial feelings of excitement of being in space have declined, and mission tasks have settled into routine.

Table 6.9. Psychological Countermeasures for ISS Crewmembers. Adapted from ISS Program [2000].

Personal packages from family and psychological support group delivered by re-supply flights
Uplink of audio news in native language not less than once per week
Uplink of written news summaries not less than every other day
Uplink of video for recreation and leisure purposes (e.g., sports, news, cultural events)
Materials for individually-determined leisure activities, such as videotapes, books, recorded music, and recreational software
Access to an onboard amateur radio for recreational ham radio contacts
Daily uplink of e-mails from family and friends
Private two-way audio-video contacts with family and friends for a minimum duration of 15 min for each crewmember on a weekly basis ("Private Family Conferences")
Private two-way audio-video contacts with members of the psychological support group for a minimum duration of 10 min for each crewmember on a biweekly basis
Psychological intervention if necessary
Family support during the mission as necessary

What kind of leisure activities are preferred by astronauts on long-duration space missions? This question has been addressed in a questionnaire survey by Kelly and Kanas [1994]. It was found that interest areas that were rated as being most helpful for filling free time included international and national events and historical subjects. Topics related to sports, the arts, erotica, economics, and other areas of human activity were ranked lower. This preference for world news and historical issues was endorsed by significantly more cosmonauts than astronauts and significantly more long-duration than short-duration space travelers. This might have been due to the perception by these individuals that their mission was also of international and historical importance, which enhanced their interest in learning more about the adventures of other historic individuals who contributed to society.

These findings suggest that providing informal space-ground contact and news from Earth represent activities that are highly appreciated by crewmembers. The Russian psychological support group has paid attention to keeping cosmonauts informed about important events on Earth (which may be related to their special interest areas) and to organizing audio or video contacts with interesting people on Earth (e.g., artists, politicians, athletes etc.; see Section 6.7.2 for contacts involving family members and friends) [Grigoriev et al., 1987]. With respect to ISS operations, this factor is taken into account by uplinks of audio and written news, or even videos of specific events of interest, and the provision of different space-ground communication tools that may be used for recreational communication with people on the ground (i.e., ham radio, e-mail, internet phone). In addition, a wide variety of supportive material for other leisure time activities is provided to ISS crewmembers. Most of this material is individually defined well in advance of the mission and may consist of music, videos, books, recreational software, variety of food choices, or other similar material that meets defined size and weight requirements. In addition, material might be delivered by crew packages sent with re-supply flights, which offers the possibility of taking into account the changing interests of crewmembers during their stay in space.

6.7.2. Maintaining contact with family and friends

Contact with family members and friends on Earth can be very supportive for crewmembers and their families. In their questionnaire survey of astronauts and cosmonauts, Kelly and Kanas [1993] reported that the respondents rated the value of contact with loved ones on Earth as having a significantly positive influence on mission performance. Cosmonaut ratings were significantly higher than those of astronauts, and long-duration space travelers rated this item higher than those spending less than 20 days in space. Several subjects mentioned the need to have private space-ground audiovisual links available for crewmembers to talk with their family and friends. In addition, cosmonauts and long-duration space travelers felt the absence of letters and other forms of contact with people on Earth significantly more than astronauts and short-duration space travelers [Kelly and Kanas, 1994].

The importance of maintaining close contact between crewmembers and their loved ones on Earth also is supported by findings from Antarctica. In their analyses of data available from 657 men who participated in a winter-over in Antarctica, Palinkas et al. [2000a] found evidence that support provided by contact with family

and friends was more important for stabilizing mood and performance than potential support available from crewmates. Somewhat surprisingly, individuals showed a clear decrease in the tendency to ask other crewmates for advice or support in the course of the winter-over and instead relied on the support provided from family and friends back home. According to Palinkas et al. [2000a], this might have reflected a decreased reliance in support from others facing the same stressors as oneself, and a similar tendency might be expected to occur during long-duration space missions.

The best way to maintain a close contact between crewmembers in space and their social network on Earth is to provide communication contacts on a regular basis. One important medium for this purpose is e-mail, which has been used frequently by crewmembers on Mir and the ISS for communicating with home. On the ISS, private family conferences have been established as part of the psychological support program. These conferences involve two-way video contacts between a crewmember and his/her family. They are scheduled every week for a minimum duration of 15 min for each crewmember. The communication lines used for these conferences are kept private and cannot be monitored by third parties.

One important issue related to the contact between families on Earth and crewmembers in space is how to inform an astronaut or cosmonaut of bad news from home. During a Salyut 6 mission, authorities delayed telling one cosmonaut about the death of his father until he returned to Earth, fearing that the bad news would negatively affect his performance [Oberg, 1981]. But during a recent Mir mission, the Russian commander was notified of the death of his mother and was able to deal with it with support from his fellow crewmembers. In their survey of 54 astronauts and cosmonauts, Kelly and Kanas [1993] reported that 18 respondents were of the opinion that negative personal information (such as a death in the family) should be withheld until a space traveler completes the mission, whereas another 22 stated that it should not be withheld. Five additional respondents gave no clear opinion but volunteered that information could be withheld on short space flights but perhaps should be disclosed during long-term missions. A reasonable compromise is for mission support personnel to discuss this issue with each astronaut or cosmonaut before launch in order to assess his or her personal preference regarding disclosure. When disclosed, bad news from home should be tempered with support and should probably be delayed until after the completion of a critical mission activity.

6.7.3. Private psychological conferences

Specific psychological counseling or guidance to crewmembers during their stay in space can help prevent behavior and performance issues from adversely affecting individual or crew efficiency. One approach is to conduct "private psychological conferences (PPC)". These conferences involve two-way communicational contacts between individual crewmembers and their psychological support staff on Earth on a regular basis during a space mission. Beyond their significance for crew monitoring, which has been discussed above, the main purpose of these conferences is to maintain a continuous contact with the crewmember in space and to offer him or her the opportunity to talk about his or her actual experiences during the mission,

including individual adjustment problems or difficulties in the relationship with other crewmates or mission control. Besides providing a concrete opportunity for individual counseling and guidance, these conferences also can be regarded as support for coping with the experience of being in space and an opportunity for dealing with negative feelings and complaints about crewmates or people in mission control.

For ISS crewmembers, PPCs have been implemented as a medical requirement, and they are considered to be a key countermeasure in the in-flight monitoring and maintenance of crewmember behavioral health and performance. According to the ISS Multi-lateral Medical Operations Requirement Document [International Space Station Program, 2000], PPCs must be scheduled for each crewmember participating in an expedition to ISS. Scheduling regulations prescribe PPCs every other week, with a minimum duration of 10 min per crewmember. A first survey of the experiences with this kind of support during the first 7 years of ISS operation (Expedition 1-13) has been provided by Manzey et al. [2007]. During this period, a total of 287 PPCs were conducted that involved 16 U.S. crewmembers, 15 Russian crewmembers, and one crewmember from Europe who participated in space missions of varying duration (129–196 days). Analyses of the data revealed that only a few PPCs (< 15%) were waived due to operational reasons or crewmember requests. The average duration of PPCs was considerably longer (16.9 min) than the minimum allotted time of 10 min, with the longest single PPC lasting up to 45 min. These data may be taken as an indication of the high acceptance of this support tool by astronauts, which also is reflected in generally positive feedback during debriefing sessions.

6.7.4. Support of families on Earth

Family members on Earth should be supported while their loved ones are in space. This can include family briefings, support during launch and landing, family conferences, or even individual counseling sessions as needed that are sponsored by the space agencies. In addition, informal support groups led by trained counselors or the family members themselves could be established. Of utmost importance is to provide family members a clearly defined point of contact where they can get information about the progress of the mission, where they can send items that will be transported via re-supply vehicles (e.g., letters, gifts, photos), and where they can ask for support for issues that arise while their family member is in space. Such support can help to maintain the crewmembers' concentration on the mission tasks by relieving them from excessive worry about problems at home and feelings of abandoning their families during crises. This is suggested by often-heard comments from astronauts that they are more concerned for the well-being of their family members on Earth than for their own well-being in space.

6.8. Post-flight readjustment support

Post-flight issues include psychological after-effects of space missions. Even though this is an important area, little has been written about these issues or ways to deal with them, and even anecdotal reports have rarely addressed them. Investigations of

individuals returning from polar expeditions suggest that long-term stays in confined and isolated environments are not necessarily associated with adverse long-term effects on subsequent health and performance [Palinkas, 1986]. However, problems of readjustment after return from a long-duration space mission can arise and might require psychological support.

6.8.1. Individual issues

Readjustment to life on Earth after a mission can be assisted through debriefings at both the individual and the crew level. Some crewmembers may have had unpleasant psychosocial experiences in space that need to be addressed. For example, a crewmember who was scapegoated during a mission may have angry feelings post-flight that may affect future interactions with his or her former crewmates. Some returning space travelers may have experienced psychological problems or personality changes as a result of being in space, in some cases becoming more humanistic, religious, or spiritual after observing the oneness of people on Earth or the infinity of the Cosmos [Kanas, 1990]. Other returning individuals have experienced difficulty dealing with the resulting fame and glory of their mission, especially during a first-of-its-kind mission like the flights to the Moon during the Apollo program. This especially may be problematic for more private individuals who suddenly find themselves thrust into the spotlight and required to go on the road to make appearances for the media or interest groups.

6.8.2. Family issues

Family reentry also may be difficult. For example, studies have shown that many wives of male submariners learned to adjust to the absence of their sailor husband when he was on sea patrol, but over half experienced depression and marital strife after he returned and tried to reinsert himself back into the family dynamics. This has led to the expression: "submariners' wives syndrome" [Isay, 1968; Pearlman, 1970]. Thus, care should be taken that similar developments do not occur in an astronaut's family after the return from a long-term space mission. As a consequence, support activities for family members should not only be provided during the mission but also should be offered in the post-mission period. Support might include joint debriefings of crewmembers and their families by counselors who are trained in the effects of separation on family life. Also, schedules should be arranged to allow crewmembers to reintegrate back into their social networks free from the public scrutiny that can add additional stress to the return home. Despite the fame and glory that accompanies some space missions, involved individuals need private time to readjust both psychologically and physically to their family life on Earth.

6.9. Summary

- A number of habitability factors can be expected to have a psychological impact on the behavior and performance of crewmembers under confinement and isolation. Important factors that are of general psychological concern include the volume of personal space, the provision and design of private crew quarters and meeting facilities, the kind of interior décor, and the provision of windows.
- Countermeasures related to work design include an appropriate daily task load and a stable work-rest schedule according to a 24-h work-rest routine. In addition, abrupt sleep shifting should be avoided, and some degree of freedom for autonomous scheduling of work tasks should be provided.
- Specific psychological countermeasures involve selection, crew composition, training, monitoring, support, and post-mission readjustment.
- Two different aspects of the selection of astronauts can be distinguished. Psychiatric selection focuses on *selecting-out* individuals who possess qualities that indicate an increased risk for developing mental or behavioral illness. Psychological selection focuses on *selecting-in* individuals who, with respect to their capabilities and personality, seem to be best suited for becoming astronauts or working together on a space mission.
- Optimally, space crews should consist of crewmembers who are psychologically compatible to each other. However, interpersonal compatibility is a complex concept that has not yet been fully understood. Important determinants include homogeneity of personality traits, congruent and complementary needs; shared interests, values and norms; a positive emotional attitude to each other; and fluency in a common language. Specific methods to assess the psychological compatibility of individuals still need to be developed.
- Several methods of training can be used to prepare crewmembers psychologically for a long-duration space mission, including briefings, lectures and workshops; field exercises; and specific sensitivity and team building training addressing the whole crew. Important areas of competencies to be addressed include strategies of self-care and management, teamwork and group living, leadership and followership, and cross-cultural issues in crews consisting of individuals with different national, organizational and professional backgrounds. In addition competencies specifically related to operational work should be trained, including communication, decision-making and problem-solving, situation awareness, and conflict management.
- Pre-flight training should be provided to both astronauts and key personnel of their ground control staff, because both groups are mutually dependent in conducting the activities of a space mission, and mission success is directly related to the efficiency of co-working between these groups. Topics specifically relevant for mission control members include a sensitization to issues of living under confinement and isolation in order to enhance their empathy for space crewmembers, and a preparation for typical conflicts between space and ground crews that might arise during the mission.

- It is important to monitor crewmembers with respect to cognitive performance, workload and fatigue, sleep, circadian rhythm, stress, and psychological well-being, interpersonal relationships, and behavioral health, because these areas are critical for efficient behavior and performance. Depending on such crew monitoring, effective in-flight support measures can be provided as necessary.
- Psychological support groups have been established for long-duration space missions to monitor and coordinate supportive activities for crewmembers during their mission.
- Supportive measures to prevent feelings of monotony, boredom, and isolation in space include the provision of a wide variety of material for leisure activities (e.g., music, movies, books, recreational software), regular uplink of news and other relevant information from Earth, personal packages from family and the psychological support group delivered via re-supply flights, and informal contacts with people on the ground.
- Contacts with family and friends on Earth on a regular basis using audiovisual and other available communication links (e.g., e-mail, internet phone) are among the most important psychological countermeasures for space travelers and are also supportive for their families.
- For maintaining continuous contact between astronauts and the psychological support group, private psychological conferences can be conducted on a regular basis using two-way audio or video transmission. These conferences represent an important element for crew monitoring and providing counseling and guidance if necessary.
- After the return from a long-duration space mission, readjustment problems may arise on an individual or family level that require supportive interventions.

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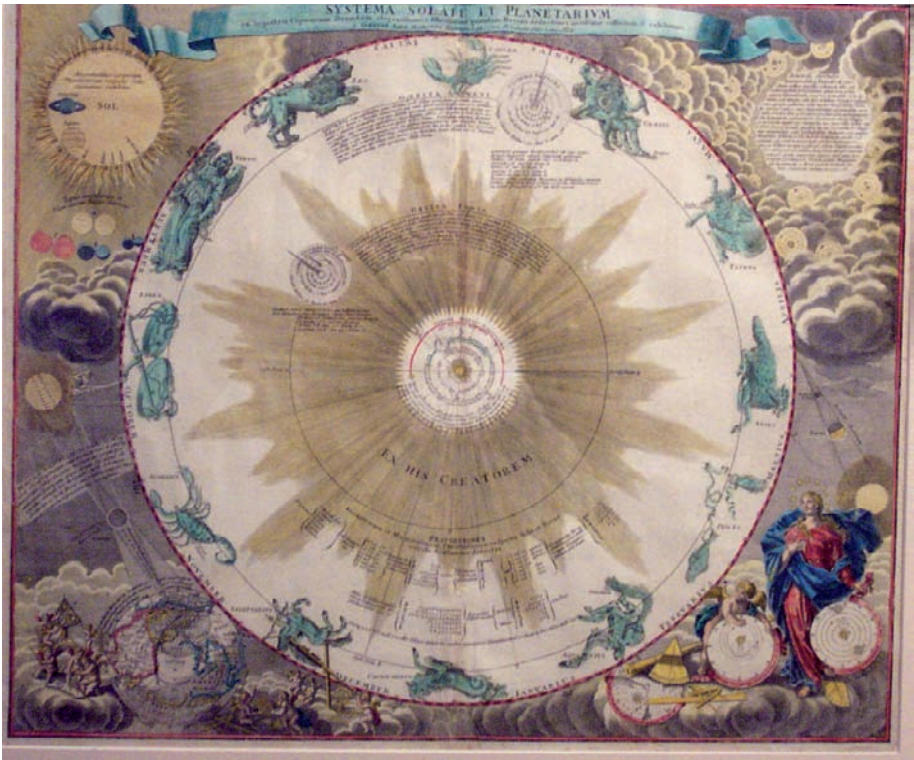
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Following the construction of the International Space Station, the next goal will be to conduct expeditionary type missions throughout the solar system and beyond. The psychological impact of such long-duration and isolated missions has yet to be determined. This plate by Johann Doppelmayr, which appeared in Johann Homann's *Atlas Coelestis* in 1742, features the Copernican view of the solar system in the center rimmed by the rest of the Cosmos, which is represented by the signs of the Zodiac. (Courtesy of the Nick and Carolyn Kanas collection).

Chapter 7

Future Challenges

For nearly 50 years, human space flight has shown an impressive evolution. Since the first flight of Yuri Gagarin into Earth orbit in 1961, which lasted for 1 h and 48 min, numerous human space missions have been carried out. These have lasted for a few days in small capsules or the American Space Shuttle, and up to several weeks and months in orbital stations such as Skylab, Salyut, Mir, and the International Space Station (ISS). In addition, the American Apollo program has given us our first experience with sending humans beyond Earth's orbit to the Moon. To date, five Russian cosmonauts have lived and worked in space for continuous periods of 1 year or longer, with a maximum duration of over 14 months (438 days). The ISS, representing a global partnership of 16 nations, marks the current culmination of long-duration stays in space. But this certainly will not be the end of space activities. An example of further progress has been provided by China becoming another space-faring nation with independent access to space. Other countries will likely follow this example in the future.

Three other and perhaps even bigger challenges have become realistic options and less a science fiction fantasy. The first is the notion that the average person can travel into space as a tourist. The second relates to a return to the Moon and colonizing our closest heavenly body. The final involves leaving Earth's neighborhood and traveling to Mars as our first expeditionary mission to another planet. These three issues are the focus of this concluding chapter.

7.1. Space tourism

Two recent developments have suggested that public space travel, or space tourism, may soon become a reality for more and more people. First, since American businessman Dennis Tito's eight-day flight to the International Space Station aboard the Russian Soyuz spacecraft in April, 2001, a number of people who could afford the asking price have flown orbital missions into space. Although the price of such missions is around \$20 million and is beyond the reach of most people, these individuals still are real space tourists, since they paid for their experience out of their own pockets. Second, following Burt Rutan's successful winning of the X-Prize in 2004 in SpaceShipOne, and Bob Bigelow's subsequent launch of his Genesis 1 orbiting hotel prototype, several private companies have been formed to explore the possibility of developing affordable launch vehicles for sub-orbital and orbital flight. Two of these, Virgin Galactic and Rocketplane, have made plans to begin suborbital operations by 2009, with the hope that such missions will be able to bring the price down to about \$100,000 per trip [Webber, 2004].

In October 2002, a survey was published by the Futron Corporation, a company specializing in forecasting space-related markets [Beard and Starzyk, 2002]. The respondents were millionaires and were interested in and willing to pay for either suborbital flights (72% male, average age 55) or orbital flights (89% male, average age 53). Rating highest in attractiveness of the flight (63% of respondents) was the chance to view the Earth from space (see Section 5.2 for similar results from an astronaut survey). Over half of the respondents said that their desire to fly suborbitally was not affected by the choice of vehicle (government or private) or, for orbital missions, physical discomforts experienced upon return to Earth. In their report, Futron projected that by 2021, the suborbital market could reach over 15,000 passengers per year, and the orbital market could reach 60 passengers per year; together, this could translate into annual revenues of over \$1 billion.

According to Webber [2004], these numbers will multiply due to the tumbling of per person costs once the industry develops passenger modules capable of carrying 20+ people at a time into space. In fact, in their survey of people biased toward adventurous activities such as mountain climbing and skydiving (91% male, 94% under age 60), which included only 14% millionaires, Webber and Reifert [2006] found that price clearly was an issue. Only 7% said they would undertake a suborbital flight at the current price of \$100,000 or above, and this number increased to 36% if the price dropped to under \$50,000. Similarly, only 4% would pay \$10–20 million for an orbital flight, whereas about a third would take such a flight for \$5 million or below.

But vehicles and price are not the only obstacles to space tourism. One must also consider the medical and psychological challenges [Wichman, 2005]. Since many space tourists may not be as healthy or young as a typical astronaut, may have ongoing health problems that are being treated, and may prefer certain accommodations not typical in government-sponsored space activities (e.g., gourmet food, alcoholic beverages), one needs to create realistic guidelines that allow paying customers their preferences, while at the same time do not compromise their safety as well as the safety of other crewmembers. In 2006, medical screening guidelines were published by the U.S. Federal Aviation Administration to assist operators of manned commercial aerospace flights in assessing prospective passengers [Artunano et al., 2006]. This document defines two categories of passengers: suborbital and orbital, describes a number of medical risks associated with acceleration, and lists a number of possible medical contraindications for participation in such flights (e.g., active cancer, severe acute infection, previous overexposure to radiation, current pregnancy). In terms of potential psychiatric contraindications, the guidelines list: “Any psychiatric, psychological, mental, or behavioral disorder that would cause an individual to become a potential hazard to him/herself or to others” [Artunano et al., 2006, p. 3]. Similar guidelines have been developed for “Space Flight Participants” (i.e. space tourists) who would be paying to visit the ISS for less than 30 days [Bogomolov et al., 2007].

However, the guidelines also state that people with medical contraindications may still be certified for space flight on a case-by-case basis pending further evaluation and treatment. Such an example was described by Jennings and colleagues [2006], who presented a case study of a 57-year-old man with several

medical conditions involving his heart and lungs. Through prophylactic treatment and evaluation in space analog conditions, he was finally certified for flight and successfully completed a 10-day mission to the ISS, demonstrating that with proper precautions, a person with medical problems can still be accepted for flight into space. Clearly, more work needs to be done in this area, as the number of people willing and able to be space tourists increases and as we gain more experience with the vicissitudes of manned space flight for the general public.

7.2. Going beyond the Earth's orbit

Although the ISS probably will represent the major basis for human presence in space for the next 10–15 years, this achievement must only be regarded as just one step towards a much bigger endeavor: human exploratory missions into outer space and the establishment of human outposts on other celestial bodies of the Solar System. This will include a return to the Moon and the establishment of a lunar station for permanent occupation, as well as flights of humans to our neighbor planet Mars. These goals already were defined in 1989 in an address by United States President George H. Bush at a celebration of the 20th anniversary of the first landing of humans on the Moon [Arnold, 1993]. And similar sentiments by other space-faring nations already have led to several investigations which have been conducted during the last decade in order to assess the possibilities of human expeditions beyond Earth orbit. For example, the European Space Agency established a Lunar Study Steering Group in 1992 to investigate Europe's priorities for the scientific exploration and utilization of the Moon [European Space Agency, 1992], and NASA has conducted numerous studies on human Moon and Mars explorations, including a feasibility study for a mission to Mars [Weaver and Duke, 1993] that has since been updated [Hoffmann and Kaplan, 1997]. More recent analyses of the possibilities and constraints of human Mars missions have been the focus of studies in Europe and Russia [Horneck et al., 2003; International Science and Technology Center, 2000].

Thus, there can be no doubt that the future of human space flight will involve missions that go beyond the Earth's orbit. Encouraged by President George W. Bush, NASA currently intends to operate the Space Shuttle in order to complete the construction of the ISS, then focus its energies and resources on lunar colonization and expeditions to Mars. The fundamental technologies needed for missions to the Moon and Mars are available already, and the only question currently seem to be *when* these missions will take place. However, technology is just one important aspect of such missions. Beyond that are new medical and psychological challenges that need to be considered, which might become a limiting factor for human expeditions into outer space. This holds particularly true for human missions to Mars, which will add a new dimension to the history of human expeditions into *terrae incognitae* with respect to the distance and duration of travel. Before we discuss the specific psychological challenges of such exploratory space missions, let us first consider what these missions will be like and to what extent our current knowledge might be applied to this new dimension of space flight.

7.3. Future human missions to the Moon and Mars

7.3.1. Missions to the Moon and the establishment of a lunar base

The Moon is our closest neighbor in the Solar System (average distance to the Earth is about 380,000 km). Numerous automated space missions have been conducted to explore this celestial body, and the Apollo missions from 1969 to 1972 have already proven that it is possible for humans to land and work on the lunar surface and to return safely to Earth. Nevertheless, the Moon remains an attractive target for human space explorations. In the first place, there are scientific interests that include: the investigation of the Moon itself, the use of the Moon as a platform for observations of outer space (due to its clear atmosphere-free sky), the study of human functioning in hypogravity (the Moon's gravity is about 1/6 g), and the development of an artificial ecological system beyond Earth [European Space Agency, 1992]. In the second place, lunar missions and the establishment of a lunar base are regarded as an important test bed for technologies that can be applied to more far-reaching expeditions, such as a mission to Mars or beyond.

A big advantage of lunar missions is that the Moon can be reached within 3–5 days, depending on the selected launch window and the consumption of propellant. Thus, launches can be planned flexibly, and the duration of such missions mainly is determined by the planned stay on the surface. Furthermore, crews in a lunar outpost can return to Earth in case of an emergency in a relatively short time, which reduces the risks to a degree that is comparable to or even less than the risk of expeditions into some analog environments on Earth, such as the Antarctic during wintering-over.

Typically, mission scenarios for a return to the Moon envision a crew of four to six crewmembers who stay in a lunar base for 6–12 months [Stuster, 1996]. One such scenario recently has been defined by ESA and may serve as an example [Horneck et al., 2003]. In this scenario, it is proposed to establish a permanently crewed lunar base at the south pole of the Moon. Compared to other locations, this area is characterized by constant sunlight, which provides advantages for the design of electrical power systems and contributes to significant mass and cost savings compared to other places (where periods of sunlight and absolute darkness alternate). In addition, it has been stated that if any water exists on the Moon, it would be available in some form at this location in permanently shaded craters as a relic of cometary impacts [Horneck et al., 2003]. Such a find would certainly present tremendous advantages with respect to in-situ resource utilization and life-support. The lunar base initially is envisioned to consist of one habitation module, one laboratory module with infrastructure needed for the scientific work, and one crew rescue vehicle, but it might be enlarged on a step-by-step basis over time. For transporting crews back and forth between the Earth and the Moon, it is proposed to use the same basic approach that was used for flights during the Apollo program. The recommended crew size includes four crewmembers, which is regarded as the best compromise between mission complexity and costs on the one hand, and possible scientific and technological output on the other. During their stay on the Moon, the crewmembers are expected to work in the laboratory module. However, in contrast to orbital space missions where extra-vehicular activities are limited to

specific construction or repair tasks, extra-habitat activities (EHA) outside of the lunar base are envisaged to occur on a regular basis in order to support geological, biological, or chemical studies on the lunar surface. A crew rotation in this scenario is planned for every 6 months via re-supply flights from the Earth, which will result in an overall mission duration of about 190 days per crew.

7.3.2. Exploratory missions to Mars

The “red planet” Mars has always been fascinating for humans. Of all of the planets in the Solar System, Mars is the most similar to Earth. Like our planet, there are different seasons on Mars, the martian day is only slightly longer (24 h 37 min), and there is a significant gravitational force that equals about 1/3 g. However, the martian environment is harsh and uninhabitable. It consists of a crustal surface with large volcanoes and rifts, and a very thin atmosphere consisting largely of carbon dioxide. The air pressure on the surface is low (about 0.01 of the Earth’s atmosphere), and the average temperature is cold (far below 0°C), with large variations between day and night. No liquid water can exist on Mars under these environmental circumstances, but there is clear evidence that liquid water once was present and may still be available in the form of subsurface permafrost and ice at the polar caps. Thus, the Martian atmosphere must have been denser in former times, and this provides support for the exciting idea that life could have existed on this planet and might still exist there in some microscopic form below the martian surface. As a consequence, two motivations for sending humans to Mars are the scientific investigation of the planet and its atmosphere, and the search for life. Such investigations will not only advance planetary science, but they also may enhance our understanding of the evolution of life and the environmental processes occurring on Earth [Hoffmann and Kaplan, 1997; Zorpette, 2000]. Furthermore, the similarities of Mars and the Earth and the assumption that life might be possible on the red planet has led to visionary ideas of a permanent human settlement there. Admittedly, such ideas are far from reality today. But Mars is the only planet in the Solar System that can be reached by humans in a reasonable time given current propulsion systems, and its environmental conditions make a landing of humans on its surface possible. Thus, Mars is the best planetary choice for exploration by a human expedition, and this fact also contributes to its high attraction as a possible target of future space missions.

However, getting to Mars is a complex undertaking. The distance between the Earth and Mars is enormous, with Mars never getting closer than about 60 million kilometers. The first serious suitability study of a human mission to Mars dates back to 1952, when Wernher von Braun published his book “Marsprojekt” [von Braun, 1952, 1953]. According to this plan, an armada of ten spacecraft was envisioned to travel to Mars, with three “landing boats” for transporting 50 people from the martian orbit to the surface for a stay of 400 days. Since this early publication, several scenarios have been developed on how missions to Mars could be conducted.

Basically, two different approaches are suggested, with a trade-off being made between mission duration and energy consumption [Hoffman and Kaplan, 1997]. The first includes a high energy transfer flight to Mars that lasts between 160 and

250 days; a stay on the martian surface of about 10–60 days; and the flight back (again, 160–250 days). The main disadvantages of this scenario are the high costs of energy (i.e., propellant consumption) and the comparatively short stay on the martian surface, which is determined by constraints for the flight back that are related to the optimal relative positions of the Earth and Mars in their orbits. The more likely concept, therefore, is a second approach that envisions a round-trip to Mars lasting about 1,000 days. This mission scenario involves a transfer flight to Mars on a low energy trajectory, which will take about 200–300 days. However, once on Mars the crew has to stay there for 400–500 days without any possibility for re-supply before another launch window opens for a low energy transfer flight back, which again will take 200–300 days. In this scenario, transfer times might become considerably reduced by investing modest amounts of extra energy, but this would only prolong the required stay on the martian surface. Such a concept has been chosen as the reference mission developed by NASA [Hoffman and Kaplan, 1997]. It largely is based on ideas published by Robert Zubrin and his colleagues and is referred to as “The Mars Direct Plan” [Zubrin, 2000; Zubrin et al., 1991]. It also has been considered in a recent study by ESA [Horneck et al., 2003]. Possible launch windows for such a mission open every 26 months (one martian year) and last for several weeks.

All of the different 1,000-day scenarios currently available envision that a spacecraft carrying a crew of probably six astronauts will either be launched directly to Mars by a heavy booster rocket comparable to that used for the Apollo missions to the Moon, or from some kind of orbital platform, respectively. During the transfer flight in microgravity, the crew will stay in a habitat on-board that is similar to or identical with the habitat to be used for the stay on the martian surface. The overall volume of such a habitat is a matter of speculation, but it might not be expected to be larger than about 300–400 m³. However, on Mars this volume could be considerably enlarged using components sent via independent cargo flights or by inflatable components. Such an option, for example, is envisioned in the NASA reference mission. The work of the crew on Mars will include a diversity of different tasks that include the maintenance of technical systems; the operation of equipment for in-situ resource utilization (e.g., production of propellant for the flight back); and the scientific work, which will include numerous extra-habitat activities and which will be supported by complex automated systems, including telerobotic devices or specific rovers for cross-country explorations on the surface of Mars.

7.4. Applicability of current psychological knowledge to space missions beyond the Earth’s orbit

A number of psychological and psychiatric issues that are related to long-duration space missions have been discussed in the preceding chapters of this book, and countermeasures have been described that might help to ameliorate any adverse effects arising from these issues. Current knowledge has been based on anecdotal information from astronauts and cosmonauts, studies conducted in space analog and

simulation environments, and experiments performed in near-Earth orbits in space. Will this knowledge also apply to exploratory space missions that go beyond the Earth’s orbit, and is our current knowledge sufficient to assess the psychological risks associated with such missions? Yes and no. In principle, exploratory space missions to the Moon and Mars can be expected to involve the same range of psychological issues and risks that have been reported from the above sources. However, missions to Mars in particular will present some new challenges that can seriously raise the risks associated with psychosocial issues. This becomes evident from a comparison of psychologically relevant features of exploratory missions to the Moon and Mars with those of space analog environments (e.g., Antarctica) or orbital space flight, as presented in Table 7.1.

Let us first consider missions to the Moon. The general features of lunar mission scenarios do not differ much from those of orbital flights or expeditions to Antarctica. For example, the expected duration of such missions equals the duration

Table 7.1. Comparison of Psychologically-Relevant Factors for Different Space Mission Scenarios and Winter-Over in Antarctica.

	Orbital ISS Missions	Winter-Over in Antarctica	Lunar Mission	Mars Mission
Duration (in months)	4–6	9–12	6	16–36
Distance to Earth (km)	300–400	–	350–400 thou.	60–400 million
Crew size	3–6	15–100	4	6
Degree of isolation and social monotony	Low to high	Medium	High	Extremely High
Crew Autonomy	Low	High	Medium	Extremely High
Evacuation in case of emergency	Yes	No	Yes	No
Availability of in-flight support measures				
Outside monitoring	Yes	Yes	Yes	Very Restricted
2-way communication	Yes	Yes	Yes	Very Restricted
E-mail up/down-link	Yes	Yes	Yes	Yes
Internet access	Yes	Yes	Yes	No
Entertainment	Yes	Yes	Yes	Yes
Re-supply	Yes	No	Restricted	No
Visitors	Yes	No	No	No
Visual link to Earth	Yes	Yes	Yes	No

of long-duration orbital missions and is even less than a wintering-over in Antarctica; the crew size is comparable to the size of orbital space crews; and there is a possibility of evacuating crewmembers in case of life-threatening emergencies or serious mental or physical illness. With respect to the latter feature, missions to the Moon may be less risky than wintering-over in Antarctica, where such evacuations are not possible. Furthermore, experiences with human space missions to the lunar surface already exist from the Apollo program, although these earlier missions were limited to short-term flights and did not involve a permanent lunar base. Consequently, most risks arising from psychological issues during lunar missions may not exceed those that are already known from long-duration orbital space missions or expeditions to Antarctica. In addition, most of the countermeasures currently being applied during orbital space flights to maintain crew performance, psychological well-being, and crew cohesiveness can be applied to lunar missions as well, even though the availability of re-supply flights likely will be restricted due to cost considerations. But there are also some specific challenges associated with lunar missions that distinguish them psychologically from orbital space missions or expeditions on Earth. Perhaps the most important is the comparatively high level of social monotony resulting from the small crew size, which distinguishes lunar missions from a wintering-over in Antarctica. However, the general availability of two-way video and audio communication lines between the Moon and the Earth and the stimulation of modern communication tools (e.g., the Internet) will compensate for this monotony to a certain degree and might be expected to prevent serious decrements in the mood, behavior, and performance of crewmembers. A second specific challenge is the long distance to Earth, which might considerably raise feelings of autonomy and isolation as compared to missions in low-Earth orbit or on the planet itself. Yet a close visual link to Earth will always be present (unless a lunar base is placed on the back side of the moon), and this might contribute to the reduction of adverse effects due to this factor.

In contrast to lunar missions, missions to Mars will not be psychologically comparable to any other undertaking humans have ever attempted. Even though some aspects of these missions are shared by other settings (e.g., long-duration stays on orbital space stations, historical expeditions to unknown parts of the Earth, wintering-over in Antarctica, long-term submergence in submarines), there are major differences. These include: the physical and psychological demands of Mars missions due to the extremely long distance of travel; the duration of permanent living under the dependence of automated life-support systems; the degree of isolation, confinement and social monotony; and the impossibility of any short-term rescue in case of emergencies. Of course, the Russian space program has shown that a stay in space of 438 days is possible, but this evidence is based on just one cosmonaut who never experienced a period of extreme social monotony that lasted longer than a few months (due to crew exchange and visiting crews), and who received a large amount of ground-based support. During a voyage to Mars and a stay on the martian surface, crewmembers are expected to endure extraordinary long periods of extreme confinement and isolation that may last from 500 to 1,000 days. Depending on the distance between the Earth and Mars due to their relative orbital

positions, audio, video, or other data transmissions between these two planets will need transmission times of 5–22 min. Communication may even be blocked for periods of time should the planets be on opposite sides of the Sun. As a consequence, communications between the Earth and Mars will be delayed, and no real time two-way communication will be possible. Furthermore, there will be no possibility for any re-supply or short-term rescue flights. Consequently, most strategies of ground-based support that currently are used to foster crew morale and psychological well-being during long-duration orbital space missions will be ineffective. So in summary, the risks for mission success and safety associated with psychological and interpersonal issues may be increased during Mars missions.

7.5 Empirical findings from space: cosmonaut survey regarding a mission to Mars

7.5.1. Goals and procedures

In order to gain information regarding the human aspects of a trip to Mars, Nechaev and his colleagues [2007] decided to solicit the opinions of a group of Russian cosmonauts. The goals were to assess their views about issues related to Martian crew size, professional specialization of crewmembers, duration and type of training, important psychological issues to be expected (especially sources of potential tensions and problems), and possible countermeasures. A total of 11 cosmonauts were surveyed using a special questionnaire developed for this purpose.

7.5.2. Results

According to Nechaev et al. [2007], the respondents said that the crew would have 5 or 6 persons. Nine said that it should be international. Six respondents thought it should consist only of men, and 5 said there should be both men and women. To perform the tasks of the mission, the consensus was that the Mars crew should include an engineer, physician, biologist, physicist/astrophysicist, and geologist, and that individuals should be cross-trained to provide redundancy in case a member became unable to perform his or her functions. Piloting skills were not specifically mentioned but were probably assumed. In decreasing order of importance, the consensus was that crewmembers should be professional, sociable, responsible, have self-control and a sense of humor, and be tolerant of others.

The respondents felt that the training for such a mission would last 1.5–2 years. It should include helping to design and test on-board systems and scientific equipment, cross-training duties with other crewmembers, learning skills related to self- and mutual-aid, understanding ways to optimize interpersonal relationships, defining leisure and rest activities, training to work under simulated Martian gravitation, and coordinating interactions with mission control personnel under conditions of communication delays due to the long distance from the Earth.

The major factors that were seen as causing psychological tension and conflict were isolation and monotony, communication delays with the Earth, and insufficient water and nutrition reserves. Other factors mentioned included leadership problems, differences in management style, role redistribution, and cultural problems. In terms of on-board psychological support, the following activities and

percentages were listed: music (35%), personal information about families and friends (22%), movies (21%), literature (14%), and art projects (8%). Keeping up the information link with the Earth was endorsed by a number of respondents, despite the communication delays. Eight subjects endorsed a fixed work-rest schedule, whereas the remaining 3 preferred to regulate their own schedule depending on the mission profile. Interestingly, 7 respondents thought that periodically changing the color scheme of the interior would increase the comfort of the crewmembers. To ensure crew safety, the respondents highlighted issues related to the careful selection of crewmembers, medical and psychological support in-flight, proper radiation protection, and meeting fluid and nutritional needs.

Several subjects endorsed using the ISS to test important operational aspects of the Martian mission (e.g., artificial gravity, radiation protection), study crew and crew-ground interactions under simulated communication delays, and experiment with biological life support systems. It was felt important to assess the crewmembers' post-flight work capacity under conditions that reproduced the Martian gravity. The value of isolation studies on Earth and in space that simulated the Martian mission was also endorsed.

7.5.3. Conclusions

Despite the small sample size, the results from this cosmonaut survey agree well with some of the surveys and studies reported in Chapters 4 and 5. The need for proper selection, training, inflight-monitoring and support, and ability to work under partial gravity conditions were endorsed by the subjects. Attention was paid to a variety of operational, safety, and medical/psychological issues. Clearly, this group of cosmonauts appreciated the realistic challenges of an expedition to the Red Planet. In the next section, we will examine some of these challenges, with special attention paid to those related to psychological, interpersonal, and psychiatric issues, as well as to appropriate countermeasures.

7.6. Human missions to Mars: new psychological challenges

7.6.1. Individual adaptation and human performance

Missions to Mars will be much longer than current orbital space missions and also longer than expeditions to Antarctica. Together with other characteristics (e.g., small crew size, greater crew autonomy, less possibility for in-flight psychological support from people on the Earth), this long mission duration will present a new psychological challenge for maintaining crew motivation, morale, and individual well-being [Kanas, 2005]. What we know from long-duration space missions in low Earth orbit is that psychological problems become increasingly more likely with duration of the mission, but they can be managed efficiently if appropriate psychological ground-based support is provided [Grigoriev et al., 1987; Kanas, 1991; Myasnikov and Zamaletdinov, 1996]. However, empirical knowledge based on psychological and interpersonal research has been limited to mission durations of 4–6 months, which have been typical for crews staying on-board the Mir or the ISS. Little is known for missions lasting over 1 year.

Transfer flights between the Earth and Mars will last about 150–300 days for each direction, depending on the selected trajectory and propellant consumption. Thus, crews traveling to Mars will engage in space flights comparable in duration to a complete ISS mission before they finally reach the surface of the red planet, where major scientific work will be done. And they will have to perform another similar long-duration flight back to Earth after their work on Mars has been finished. These long flight times likely will be accompanied by a number of stressors that may affect crewmember mood, well-being, and performance.

One issue concerns maintaining motivation and morale, since the transit times will involve long periods of decreased workload, monotony, and boredom. In addition, due to the limited size of the spaceship, privacy will be harder to achieve than during a stay on-board an orbital space station. Will it be possible to maintain adequate crew motivation, morale, and mood during these transfer flights to and from Mars? This certainly will depend on the habitability of the spaceship and the meaningfulness of work the crewmembers have to perform during these mission phases. Work activities may be less of a problem on the outbound flight to Mars, when the crewmembers have much to do in preparation for their arrival on the planet, than during the flight back after the most important and interesting tasks have been accomplished on the red planet. Nevertheless, it will be of great significance for overall mission success that the crewmembers remain alert and motivated during this return. A decline of motivation and activity during this mission phase can be a serious hazard, not only for the crew's efficiency in dealing with nominal and off-nominal situations, but also for maintaining the degree of on-board exercise that is needed for re-entering the Earth's gravity after a long period of exposure to low gravity conditions.

A second issue associated with the long transfer flight to Mars is related to the retention of performance skills that have been acquired during pre-flight training but will only be needed after arrival on Mars. Such skills include critical operational activities (e.g., skills needed for landing on the martian surface or the operation of complex technical equipment for Mars exploration) and all kinds of cognitive activities needed to conduct the scientific work on the Martian surface. Even though issues of skill retention have been investigated in several laboratory and field settings [Patrick, 1992], it is unclear to what extent the findings of this research can be transferred to the extreme conditions of space missions. In any case, training methods will need to be developed, which on the one hand allow for the on-board training of critical performance skills during the transfer flight to Mars, but which on the other hand do not require much space and mass. For this purpose, new technological developments (e.g., virtual reality) might be considered, and their potential application for support of on-board training of perceptual-motor and cognitive skills need to be investigated.

One particular issue of skill maintenance during a mission to Mars that will be difficult to investigate in advance will be related to the different gravity conditions that will occur during different mission phases. For example, perceptual-motor skills that are acquired pre-flight under 1 g conditions have to be maintained during the transfer flight to Mars under microgravity conditions (if options of artificial gravity are not available), but they also must be applied on the surface of Mars in a 0.38 g

environment. This will involve the re-learning of skills under different gravitational forces during the mission. And beyond that, learning and acquiring completely new skills while in space might become necessary. This will be the case if skills needed for work on Mars cannot be learned during pre-mission training. Whereas mission control experts can provide effective support and even on-line coaching to crewmembers if issues of new learning arise during orbital space flight, crews traveling to Mars will have to rely much more on their own capabilities. But is learning under conditions of space flight as effective as under the usual learning conditions on Earth? Or are special approaches and tools of training needed to support the acquisition of new skills during a flight to Mars? So far, we do not know much about learning capabilities under the conditions of space missions. Although current experiences from orbital space flight suggest that performance skills acquired on Earth can be applied efficiently in a different gravitational environment after some time of adaptation (see Chapter 3), more systematic research will be needed to increase our understanding of space-based learning.

Beyond the issues arising from the duration of transfer flights and overall mission length, another new psychological challenge for individual adaptation and performance during Mars missions will involve automation and the human-machine interaction. People traveling to Mars will have to interact with complex human-machine systems, including automated life support systems, rovers, robots, and other operational hardware that will be needed for Mars exploration. In addition, human-machine systems on Mars will include interactions with a number of intelligent software agents that make the operation of systems possible without 24-h coverage of ground-based monitoring and support. The design of these systems will determine the quality of life and work during the mission. In order to minimize the workload and stress resulting from interactions with these systems and to optimize overall system performance, a strict human-centered approach of design will have to be applied. On the one hand, this relates to the design of human-machine interfaces, which must guarantee a high level of usability of the different systems given the specific constraints on Mars. However, even more importantly, it will require careful psychological considerations concerning the level of automation to be attained, including an optimum allocation of functions to both humans and machines [Parasuraman et al., 2000]. These considerations must ensure that the obvious advantages of automation do not lead to negative side effects that might impact the well-being and performance of the crew. One of these side effects includes the boredom that can arise if too many tasks become automated, thus reducing the responsibility of crewmembers to monotonous monitoring tasks. Another issue regards the loss of situational awareness and a degradation of skills needed to manually control the different systems if automation fails. This can result from too much automation, leaving the operator "out of the loop" most of the time [Endsley and Kiris, 1995; Lorenz et al., 2002; Parasuraman et al., 2000]. Furthermore, even if today's technology guarantees a sufficient reliability of automated systems, they can break down and might need repair to return to normal functioning. Will the technological levels chosen to implement the systems allow the crew to fix them in case of a severe breakdown? How must systems be designed to optimally support the diagnosis of failures and on-site repair on Mars? What kind

of skills are needed for efficient system-monitoring and trouble-shooting if ground-based support can only be provided to limited degrees or cannot be provided at all? These questions not only require careful technical considerations, but they also require knowledge about human performance constraints in interacting with automated systems under the specific conditions of a long-duration space mission.

These issues will be of particular importance for the design of autonomous life-support systems. During the long flight to Mars and the stay on the Martian surface, the life of crewmembers will depend on the efficient functioning of these systems. In contrast to orbital space flight, there will be no escape possibilities in case of technical failures, and ground-based monitoring and support will only be available to a limited extent due to delays and even temporary blocks of data transmission between Mars and Earth. Independent of the actual reliability of the life-support systems, there will be a constant threat which can lead to anxiety and, in the worst case, the development of manifest anxiety disorders (see Section 7.4.3). In order to reduce the stress, autonomous life-support systems will have to be designed, not only with regard to optimising automation and minimizing the load of crewmembers, but also to provide a maximum level of external controllability and support for on-site trouble-shooting and repair. This is suggested by stress research, which shows that the degree of perceived controllability of a stressor represents one of the most important moderators of the strength of its effect [Ursin, 1988]. One promising approach is to design these systems in accordance with current concepts of adjustable autonomy that allow for a flexible adjustment of levels of automation depending on the situational demands [Dorais et al., 1998]. Thus, different technological and technical options in designing automated systems for use during Mars missions must be considered from a psychological point of view, and more psychological research about human interactions with automated systems will be needed to provide guidelines for optimum human-machine system designs for Mars missions.

7.6.2. Interpersonal issues

Missions to Mars will involve many of the interpersonal issues that already have been observed during orbital space flight and in analog environments; these have been discussed in some detail in Chapter 4. However, whereas in other settings risks associated with interpersonal tension and conflicts can be reduced by effective support measures like visiting crews and real-time communication with the ground, these options will not be available during missions to Mars. Thus, the level of social monotony and feelings of isolation may be higher in crews participating in interplanetary missions, and the risks and hazards for mission success arising from interpersonal tensions, conflicts, and a breakdown of crew cohesion may be considerably increased compared to what is known from other environments.

A distinguishing factor that separates a mission to Mars from other endeavors is the high level of crew autonomy. Due to the restricted opportunities for psychological ground-based support and the impossibility of short-term rescue in case of emergency, the crewmembers cannot rely much on external help but have to solve conflicts and problems on their own. In the first place, this involves autonomous management of external crises related to technical failures or

environmental hazards (e.g., solar particle events). In the second place, it involves internal crises that might arise not only from interpersonal conflicts but also from a serious medical illness of a crewmember, injuries that might require surgical treatment, or incidents of mental and behavioral illness that result in a crewmember losing control. How can a crew on Mars deal with such events? What kinds of skills are needed to cope with them? Will the crew be able to maintain its cohesion and morale in the face of such crises? Of course, some of these issues can be dealt with in pre-mission training or by including an expert in the crew. For example, at least one physician undoubtedly will be part of a Mars crew who will be trained to provide medical (including psychiatric) support and even to conduct surgery if necessary. At least one additional crewmember will be trained as a back-up to provide medical treatment under the direction of experts on the ground [Hoffman and Kaplan, 1997; see also Section 5.4]. With regard to psychological issues, Nicholas [1989] has proposed training all crewmembers in general social support skills.

But incidents may occur during a 3-year mission to Mars that will be more difficult to prepare for. Take, for example, a worst case scenario where the physician dies of an accident, illness, or even a suicidal act during the mission. Will the rest of the crew be able to cope with such a horrible experience without decremental effects on the mission? What if a crewmember murders another? How will the rest of the crew react? Admittedly, these are extreme examples of incidents that hopefully will never happen. But since they cannot be excluded given the general risks of a trip to Mars, crews going on such space missions must be prepared to cope with them in some way. However, our current experiences with such situations generally are limited to military operations, which seem hardly comparable to a civilian expedition to Mars. Thus, the answers to some of these questions cannot be given in advance.

Another issue that might arise in a crew traveling to Mars is what has been referred to as "groupthink" [Janis, 1982]. This phenomenon has been shown to develop in highly autonomous and cohesive groups that work under stressful conditions, and it is characterized by a number of features that can seriously degrade crew performance, especially the quality of decision-making. Important characteristics of groupthink include: delusions of invulnerability (i.e., members think that they are incapable of making wrong decisions and show an unreal confidence in their own competence); reluctance of crewmembers to express concerns and disagreements about decisions and ways of acting in order to maintain harmony (i.e., there is group pressure on deviating individuals to conform); and stereotyped views of people outside the group (e.g., mission control personnel). Observed effects on decision-making include an incomplete survey of decision alternatives, a failure to examine risks of preferred choices, a failure to reappraise initially rejected alternatives, and a failure to work out contingency plans. Thus, the development of groupthink attitudes represents a serious hazard for the performance of crews acting in a high-risk environment. In addition, it can contribute to individuals feeling uncomfortable in the crew (especially those who disagree with important decisions), and it can lead to an erosion of crew cohesion. Finally, there is

a negative impact on the relationship with people on Earth that puts additional pressure on an interaction that already may be strained (see Section 4.7).

7.6.3. Psychiatric issues

As has been described in some detail in Chapter 5, psychiatric issues during a long-duration space mission can include adjustment disorders, somatoform disorders, mood and thought disorders, and specific syndromes like (neur)asthenia. Even though only a few incidents of psychiatric problems have been reported from orbital space flight so far, the risk of developing symptoms of serious mental or behavioral illness will significantly increase during missions as long and extreme as a mission to Mars. This is suggested by Russian observations that the risk for developing severe asthenic reactions is directly related to the duration of a space flight and can be assumed to rise significantly for missions lasting longer than four months [Myasnikov and Zamaletdinov, 1996]. And it is further suggested by a number of anecdotal reports from expeditions to Antarctica, which currently represent the best Earth-bound analog to Mars. The incidents documented by these reports include diverse psychiatric reactions, including psychoses and severe episodes of depression and anxiety [Connors et al., 1985; Stuster, 1996]. Accordingly, incidence rates of psychiatric disorders in the Antarctic vary from 1 to 5%, and they are higher in wintering-over personnel than in personnel who are present only during non-winter months (see Chapter 5 for details).

Specific stressors might lead to the development of mental and behavioral disorders during a flight to Mars. One particular stressor that might contribute to the development of emotional problems is the dependence on technical life-support systems due to the extreme duration of the mission combined with the lack of rescue possibilities in case of technical failures. Experiences with such situations are lacking, and it is difficult to predict how this might impact on crewmember psyche. Another issue that has been discussed in the previous section but may also be of concern from a psychiatric point of view is the reaction of crewmembers to high stress events like accidents, environmental disasters, or the death of a crewmate. Such traumatic events can lead to what is referred to as post-traumatic stress disorder. This syndrome typically occurs with some latency after the traumatic event and can be associated with repeated flashbacks, intrusive thoughts, feelings of emotional emptiness, social withdrawal, anxiety, nightmares, sleep disturbances, and depression.

An important peculiarity of a mission to Mars is that crewmembers will have to deal with psychiatric issues on their own, with only minimum support from people in mission control. This will provide new challenges for the on-board treatment of mental diseases. Training approaches must be developed to prepare crewmembers for dealing with mental disorders of crewmates (see Chapter 5). This requires that relevant skills be identified that are needed to support and treat others in case of severe mental or behavioral disturbances. Also, basic requirements for a psychiatric health facility on-board the spacecraft and the habitat on the martian surface must be defined. Some of these requirements already have been described by Santy [1987] but need to be explored further with respect to the specifics of a Mars mission. For example, more research will be needed to define what kinds of psychoactive

medications for different disorders are most appropriate to use during space missions. Furthermore, with regard to missions to Mars, specific knowledge will be needed about how the different gravitational conditions astronauts will be exposed to (e.g., microgravity during transfer flights, 0.38 g on the martian surface) will affect the pharmacodynamics and kinetics of different psychoactive drugs. Finally, restraint systems need to be developed that can be used to protect agitated, psychotic, or suicidal crewmembers and others from harm. These restraint systems must be designed for application under different levels of gravity.

7.6.4. Psychological countermeasures

In addition to psychiatric countermeasures, the more general concept of psychological countermeasures will have to be re-considered with respect to Mars missions. The factors that will present new challenges in this area are the restrictions of space-ground communication and the inability to support the crews via re-supply flights.

During current orbital space missions, the methods used most often for monitoring and assisting people in space rely on immediate two-way audio or video interactions between crewmembers and mission control personnel. For example, monitoring measures for the ISS include private medical and psychological conferences that are conducted on a regular basis, and Russian support personnel still use their methods of communication (speech) analysis to assess mental and emotional state in real time. In addition, important ground-based countermeasures for the social monotony and isolation that affect crewmembers are based on two-way communications, such as private family conferences or the provision of Internet phone facilities. Finally, remote psychological counseling may be provided by such communication.

However, during a mission to Mars, it will no longer be possible to use these methods, and new strategies of communication between crewmembers and mission control personnel on Earth will have to be developed [Caldwell, 2005]. For example, real-time two-way conversations will not be possible, and communication will be limited to one-way audio, video, and other data transmissions, and even these channels will not be available continuously based on the relative orientations of Mars, the Earth, and the Sun. Protocols will need to be developed to assist time-delayed communications. For example, questions that the crew wants to ask advisors on Earth will need to list possible responses and include additional follow-up questions in the same message so that the mission control can respond efficiently and deal with several issues in their return message.

How will this affect in-flight monitoring and support? It seems most likely that a major communication channel between people on Earth and the crew traveling to Mars will consist of e-mail exchange, which is a commonly used communication tool but does not involve direct two-way interactions. As a consequence, new approaches of in-flight monitoring and support will be needed that take the specifics of this communication channel into account. First studies of the use of e-mail for in-flight monitoring purposes have been conducted during Russian ground-based simulations. These studies have focused on the identification of key characteristics of e-mail communication (e.g., length, content) that might be used to assess the

emotional state of the sender, and they have shown some promising results. For example, analyses of the content of e-mails sent by confined crews reveal that the number of emotional statements and complaints increased significantly after 2–4 months of confinement, which probably reflected issues of adaptation involving the crewmembers [Gushin et al., 1997]. But other important issues related to e-mail communication as an in-flight support tool have never been addressed by systematic research. This include, for example, the advantages and disadvantages of this kind of communication as the sole tool for maintaining social contacts between confined crewmembers and outside personnel, and the suitability of e-mail to serve as the main communication tool for psychological counseling and guidance of a confined crew.

Having only restricted channels for communication that may be blocked for certain periods of time makes it clear that the quantity and quality of in-flight support will suffer considerably. At least to some extent the lack of ground-support might be compensated by the provision of specific on-board training and coaching tools for different psychological issues. Recent developments of training tools like those suggested by Carter et al. [2005, see Section 6.5.3.1] seem to be promising approaches in this area. But other kinds of support tools might include even more sophisticated expert systems and monitoring tools suitable for self-monitoring of different behavioural functions (see also Section 6.6.3). However, the possibilities of such autonomous support tools certainly will be limited. This will affect the relative importance of other psychological countermeasures, particularly those that can be applied in advance of a mission. That is, given that less in-flight support can be provided, crew selection and training will become even more important for mission success and safety than they are already for orbital space flights. The biggest challenge in this respect will be to find the right crew for a mission to Mars. This will include the selection of suitable individuals for the mission as well as the composition of a “psychologically compatible” crew whose members can be expected to work and live together under the extreme conditions that they will encounter. But what kind of personality will be most suitable for a mission to Mars? And what kind of crew mixture will work best? Several attempts have been made to describe the ideal psychological profile for crewmembers traveling together on an long-term expeditionary-type space mission [Ursin et al., 1992]. However, most of these attempts are based on anecdotal information or common sense considerations, and the empirical basis for the definition of crewmember profiles still is weak. Clearly, more research is needed during orbital space missions or in analog environments on Earth in order to identify critical individual characteristics that predict optimum adaptation to long-duration isolation and confinement before valid select-in criteria for Mars crewmembers can be defined. However, even more important for an interplanetary space mission will be a psychologically-guided method of composing the crew. This already has been ascribed some significance for orbital space missions [Gazenko, 1980; Manzey et al., 1995], but it will become a pivotal element for missions involving high levels of crew autonomy, such as a mission to Mars. Important aspects that will have to be considered include the age-mix and gender-mix of the crewmembers, their cultural background, and the compatibility of their personalities. Several of these issues already have been

discussed in earlier chapters of this book (see Sections 4.2 and 6.4.4), but our current knowledge about the ideal composition of confined crews is limited at best.

After selecting the crew for a Mars mission, it will become necessary to prepare them for the specific psychological demands of such an enterprise. Currently used methods will have to be revised, and new methods may have to be developed. Crews leaving for Mars will need more training and preparation than currently is provided to ISS crews, particularly with regard to working under autonomous conditions, building an efficient team and supporting themselves psychologically and interpersonally. They will need to self-monitor and self-correct individual and interpersonal problems that arise and be able to deal with medical and psychological emergencies, such as trauma, accidents, suicide, or psychoses. Orasanu [2005] has argued that naturalistic decision-making models may be of value for space crews on exploration missions. In addition, specific training facilities will need to be defined, where crews can be trained for prolonged periods of time under conditions similar to those in a Mars mission. The ISS provides such an option since it replicates many of these conditions (e.g., microgravity, isolation and confinement, potential danger). But experimental ground-based facilities (e.g., confinement chambers) or human outposts in extreme environments on Earth (e.g., Antarctica) also might be considered.

7.6.5. The Earth-out-of-view phenomenon

Missions to Mars will be associated with a new psychological challenge that has never before been experienced by human beings. Due to the enormous distance of Mars from the Earth, our home planet will progressively shrink in size until it becomes just another dot in space. In the history of human beings, no one has ever been in a situation where Mother Earth, and all of her associated nurturing and comforting aspects (e.g., gravity, atmosphere, food, flora and fauna, collected history of our species) has been reduced to insignificance in the sky. Partially, this lack of direct visual link to our beautiful globe might be compensated by films or e-mail images of the Earth, or even by the provision of a telescope that will allow the crew to scan their home planet in real time when they get homesick. But probably none of these measures can be considered as a sufficient substitute.

The human response to this situation is not known, but it seems almost certain that it will impact on the psyche of space travelers. This is suggested by numerous reports from astronauts who have been in orbit or have traveled to the Moon and have commented on the psychological importance of seeing the Earth in all its glory in space through the windows. But what will the lack of a direct visual link to Earth be like? How will humans respond to such an experience? At a minimum, this experience will add to the feelings of isolation and loneliness within the crew. Beyond that, it seems possible that it will induce some state of internal uncoupling from the Earth. Such a state might be associated with a broad range of individual maladaptive responses, including anxiety and depressive reactions, suicidal intention, or even psychotic symptoms such as hallucinations or delusions. In addition, a partial or complete loss of commitment to the usual (Earth-bound) system of values and behavioral norms may occur. This can result in unforeseeable changes in individual behavior and crew interactions, and it might make any

external guidance of the crew impossible. The main problem related to this issue is that it cannot be studied before the first crew has been sent out, and it will need to be monitored and dealt with in-flight should psychological, interpersonal, or psychiatric problems occur.

7.7. Research directions

As becomes evident from the foregoing considerations, future interplanetary missions to Mars and beyond will provide a number of new challenges in almost all of the different areas discussed in Chapters 2–6 of this book. Before such missions can be considered seriously, preparatory research will be needed in order to better assess the possible risks associated with these new challenges and to develop effective psychological countermeasures that might help to mitigate the associated risks. Four complementary research directions are possible: (1) a re-analysis of databases from previously conducted space or Earth-bound studies in order to clarify issues and stimulate hypotheses for new empirical work; (2) naturalistic experiments during orbital space missions; (3) studies in analog environments that have features similar to those found in space flight (e.g., polar regions, submarines, closed land-based habitats such as hyperbaric chambers, off-shore oil platforms); and (4) research during ground-based simulations of space missions.

Conducting psychological and psychiatric research during actual space flight represents the most direct and probably best approach of investigating psychological issues of relevance to long-duration expeditionary-type space missions. In particular, this kind of research represents the best way to study issues related to prolonged exposure to micro- or hypogravity. However, the opportunities for this research are affected by the number of flights and crew time constraints, and the range of issues that can be addressed is limited to those that do not conflict with the operational demands of the missions. In addition, psychological research during actual space missions suffers from several methodological and technical constraints (e.g., small number of subjects, difficulties in controlling experimental conditions). Thus, space flight studies alone will not be sufficient to accumulate the knowledge needed for extrapolating psychological issues that might arise during long-term interplanetary flights.

Naturalistic research in analog environments on Earth offers important complementary features that will help us prepare for future interplanetary space missions [Kanas, 1997]. In particular, such Earth-bound research can be used to investigate the behavioral effects of prolonged co-living and co-working in small groups under conditions of confinement and isolation. As a matter of fact, a good deal of our present knowledge concerning human behavior and performance under long-term confinement and isolation in hostile environments has been derived from research in polar regions [Palinkas et al., 1998, 2000; Stuster, 1996] and in submarines [Weybrew, 1991]. Yet the analogy between these exotic environments and space flight is far from perfect with regard to crew size, crew selection, and crew tasks [Suedfeld, 1991], and little of the research in these environments has been dedicated explicitly to its applications for space missions. Therefore, even though the experiences and observations derived from these analog environments

provide a useful database from which possible psychological issues of future missions to the planets may be extrapolated, the applicability of this knowledge is somewhat limited.

An alternative approach in investigating psychological issues involving exploratory space mission is through specific simulations of prolonged space flight. In contrast to other approaches, this offers a relatively high degree of control and flexibility, and it provides the opportunity of investigating a sufficient number of subjects under standardized environmental conditions. Examples of this approach reach back to the 1960s and 1970s [Rockwell et al., 1976] and have been pursued in recent years in Russia, America and Europe [Baranov, 2001; Collet and Vaernes, 1996; Holland and Curtis, 1998]. In order to prepare for crewed exploratory missions to Mars and beyond, this approach needs to be continued and expanded. For this purpose, ground-based facilities are needed that represent the best possible analog to space habits as well as opportunities for controlled psychological research in the different psychological areas that have been identified as relevant.

What are the basic characteristics of such ground-based facilities? For one thing, they should be as physically similar as possible to the habitat that likely will be used for interplanetary missions. Based on current ideas involving a trip to Mars, both a transit and a surface habitat will be involved. According to the concepts of the NASA reference mission, both of these habitats will be identical and “will consist of a structural cylinder 7.5 m in diameter and 4.6 m long with two elliptical end caps (overall length of 7.5 m). The internal volume will be divided into two levels oriented so that each ‘floor’ will be a cylinder 7.5 m in diameter and approximately 3 m in height” [Hoffman and Kaplan, 1997, p. 3-78–3.79]. Consequently, one approach would be to plan for a ground-based facility that closely matches these features.

However, physical similarity alone does not guarantee equivalence in a psychological sense. Even more important is that the experiences and feelings of humans living and working in such a ground-test facility should be similar to those experienced during an exploratory mission [Suedfeld, 1991]. This can be achieved if the ground-based research facility meets two requirements: functional similarity and organizational similarity [Manzey, 2002]. “Functional similarity” means that the ground-test facility should provide the same possibilities and constraints that can be expected to characterize a planetary or interplanetary space habitat. That is, it should provide a psychological environment that is as similar as possible to the situation in a real planetary space habitat. This includes realistic environmental control and life support systems and appropriate working and living facilities for at least six crewmembers. Other important functional constraints that should be implemented include restrictions of outside communications (i.e., simulating the communication delays expected on a mission to Mars), restrictions of privacy and personal space, restrictions of environmental cues, and restrictions in variety of food. Most aspects of functional similarity can be met by the appropriate structural and functional design features of a ground-based facility and its placement in an appropriate external environment (e.g., placing it in a remote polar region or in a desert environment that has geological features similar to Mars) [Manzey, 2002].

“Organizational similarity” expands the concept of a ground-test facility beyond considerations of purely environmental, architectural, and functional characteristics. This requirement means that the operational planning around a ground-based facility should resemble that of a “real” mission in important aspects, such as psychological impact. It has been known for some time that stress effects arising in a particular environment do not depend exclusively on its physical and social characteristics but also on its psychological meaning [Suedfeld, 1991]. Lazarus and Folkman [1984] wrote that the amount of perceived stress largely is due to the subjective appraisal of a stressor by an individual. This appraisal has been shown to depend on both personality characteristics and competencies (i.e., how the individual perceives the quality of a stressor – threatening versus challenging – and whether he or she has efficient strategies available to cope with it). Consequently, operational features that affect the way an astronaut perceives and copes with the challenges of an exploratory space mission should be taken into account in running a ground-test facility. This aspect rarely has been addressed in evaluating results from so-called analog environments, and discussions of what makes an environment or ground-test facility an analog of space flight all too often have remained limited to comparisons of different environments on a functional level. But organizational similarity represents another important condition for extrapolating findings from any ground-test facility into space. From a psychological point of view, the most relevant organizational features in this respect include: the provision of meaningful work for the crew, the promotion of a mission mentality, and the provision of psychological countermeasures (i.e., selection, training, and support) [Holland and Curtis, 1998]. For example, it is questionable whether results from a ground-based confinement study using subjects who have not been specifically selected, trained, or supported psychologically during their “mission” can be extrapolated to real space missions with highly motivated, qualified, trained, and supported astronauts.

Provided that the requirements of functional and organisational similarity are made, ground-based research can complement research from actual space missions. Together, they further enhance our understanding of psychological and psychiatric issues during long-duration space missions, and this will help us prepare for the challenges of future missions beyond the Earth’s orbit.

7.8. Summary

- Space tourism is a growing industry, and careful attention need to be paid to establishing realistic medical and psychiatric guidelines to protect the safety of paying passengers and other crewmembers involved with the flight, both suborbital and orbital.
- The future of human space flight will involve missions that go beyond the Earth’s orbit. These include the establishment of a permanent presence on the Moon as well as human expeditions to Mars and beyond.
- Missions to the Moon and the planets will involve many of the same psychological risks and issues that have been reported from orbital space missions or expeditions to extreme environments on Earth.

- However, a number of new psychological issues will arise during a Mars mission due to the long distances and times involved (e.g., a total mission duration of up to 3 years). Such issues include: the dependence of the crew on technical life-support systems without the possibility for rescue and evacuation during a crisis; the negative effects of long-term social monotony on the morale of the crewmembers; the long time delays expected in communicating with people on Earth; the lack of re-supply flights, which will restrict the possibilities for in-flight support and which will lead to an extreme degree of crew autonomy; and the psychological impact of perceiving Mother Earth as an insignificant dot in space.
- Given the restricted possibilities for re-supply and Earth-based support, the significance of other psychological countermeasures like crew selection and training will become particularly important in determining the success of a Mars mission.
- Much preparatory research in the field of psychology and psychiatry is needed before missions to Mars can be considered. The International Space Station will provide an important platform for such research. But specific facilities that might be used for analog and simulation research on the ground also will be needed.

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