PREFACE

Why write this book? Of all the intricate components of the human body, the central nervous system is the most responsive to the environment, detecting and responding to changes immediately. Its complexity, however, also means that it is still one of nature's best-kept secrets. Considering that the exploration of space is often thought of as the final frontier in the discovery of our origin and the preparation for our future, ***Neuroscience in Space*** is a book addressing the last, and greatest, scientific frontier.

All living things on Earth have evolved in the presence of gravity and all of their biological systems have anatomical and physiological mechanisms designed to interpret and measure the force of gravity. However, in the near weightlessness of space, the sensory systems that provide basic information regarding linear acceleration no longer function as they did on Earth. As a result, most if not all, physiological systems dependent on the body's central nervous system are in flux until a new microgravity state is realized. This includes adaptation of basic life sustaining functions such as blood pressure control and cardiac function, as well as other critical functions for everyday activities including balance, coordinated movement in three-dimensional space, and the regulation of sleep. Bones that supported body weight on the ground no longer have that load to bear. They begin to lose mass and strength, as do weight-bearing and postural muscles in the legs. Reduced physical activity and a shift of fluids into the upper body combine to reduce cardiovascular capacity. While in space, cardiovascular, bone and muscle deconditioning does not present a serious problem. However, whether returning to Earth or landing on some other planet, the body's adaptation to microgravity increases the risk of bone fractures, reduces work capacity, and can result in severe balance disorders and even blackouts when standing.

Other significant changes take place in the central nervous systems of astronauts during and following exposure to microgravity. Space travelers are transported in vehicles that move in three-dimensional space and generate inertial forces that create environmental factors to which they are not accustomed, either by evolution or experience. The responses of the vestibular organs in the inner ear, as well the kinesthetic, pressure and touch receptors, may be altered by hyper- or hypogravity. These altered responses to inertial stimulation outside their normal physiological range, or, even within this range, signal appropriately for the force environment, but inappropriately for the other sensory systems. These changes can modify situational awareness, induce spatial disorientation, result in illusions of self-motion, trigger dizziness and vertigo, and bring about motion sickness. However, the plasticity of the central nervous system allows individuals to adapt to these altered sensory stimulus conditions, and after a few days in space the symptoms disappear. The price paid for this in-flight adaptation (what has become known as "space normal") is a deconditioning of antigravity responses necessary for effective living following a return to Earth or landing on Mars. The duration of these altered responses is function of the time spent in space. In order to minimize the impact of adaptation to microgravity on crew health and performance following long-duration space flight, effective countermeasures must be developed.

Since the first human space flight in 1961, extensive experimental and operational research has been performed to investigate these adaptive processes by looking at electrophysiological changes in neural activity, behavioral changes including movements of the eye or body segments compensating for head or visual surround, as well as changes in perception and spatial orientation. The results obtained during and after space flight have contributed to a better understanding of the functioning and adaptation of multi-sensory interaction within the central nervous system. It could be said that the microgravity environment of space flight provides the ideal laboratory to study the underlying function and interactions among physiological systems. This environment can only be improved by an ability to switch gravity on and off during flight. New concepts and questions about the functioning and adaptation of the balance system have been raised directly from results of studies conducted in space. For example, new knowledge of neuronal plasticity, the way nerve cells “re-wire” to compensate for disease or injury, has been gained from animal studies during space flight, and will allow insights into treatment of nervous system disorders.

If one were interested in studying space travel, one would have little difficulty finding descriptions of the early developments in the Soviet space activities, as well as of those who helped establish NASA and their efforts. Should one be more serious about studying the development of space programs, one can find libraries of information addressing the bureaucracy of space flight full of tomes written by mission managers and project engineers. A student of space studies can find a plethora of technical books describing the principals of propulsion and rocket development, orbital mechanics and astrodynamics, as well as books detailing the design of spacecraft and the ground stations required to control them and collect their data. Entire museums dedicated to the progression of flight technology, from the first brief aircraft flights to the development and assembly of the International Space Station, have been established world-wide. However, it is truly challenging for anyone to find a comprehensive history of the life sciences experiments that have been performed in space and the role that neuroscience has played in our quest for space flight.

Our intent and purpose of compiling this historical overview of neuroscience and its role in space flight serves two purposes. The first is to equip researchers with a single reference document compiling a representation of those neuroscience experiments that have been flown in space. The second is to highlight the accomplishments of many scientists who have contributed to the history of space neuroscience. It is our hope that insights generated by reading this book will greatly contribute to the future agenda of space neuroscience.

In a sense, this book originated in a small office in Paris, France when the authors were first introduced. From that initial meeting a shared interest for sensorimotor and vestibular function in space flight would come to define a collaboration that has lasted over 25 years.

We are indebted to all of those astronauts and cosmonauts who became the subjects for much of the work detailed in this book. In particular, we would like to acknowledge Patrick Baudry, Sonny Carter, Owen Garriott, Claudie Haigneré, Joe Kerwin, Bob Parker, Rhea Seddon, and William Thornton who have provided both guidance and inspiration.

We also acknowledge our colleagues Drs. Owen Black, Alain Berthoz, Jacob Bloomberg, Bernard Cohen, Fred Guedry, Deborah Harm, Jerry Homick, Makoto Igarashi, Inessa Kozlovskaya, R. John Leigh, Francis Lestienne, William Paloski, Scott Wood, and Larry Young for their counsel and support. We would also like to express our gratitude to Jody Krnavek and Liz Fisher for the early mornings, late nights and missed holidays they gladly sacrificed to collect data at remote landing sites.

We are particularly grateful to Dr. Donald E. Parker for his support and guidance, as well as his contribution to Chapter 7 for the refinement of the otolith tilt-translation reinterpretation hypothesis. We are also grateful to Dr. Robert Welch who gave us permission to use the material from his contribution to the *"Space Human Factors Engineering Gap Analysis Project Final Report"* (Hudy & Woolford 2005). And finally, thanks to Angie Bukley for her time spent editing this book.

Gilles Clément & Millard Reschke

Houston, 24 January 2008

Chapter 2

HISTORY OF SPACE NEUROSCIENCE

This chapter provides a brief history of space flight, with an emphasis on the role of life sciences in the space program. A detailed table including all the neuroscience experiments by all countries from Vostok-3 (August 1962) to the ISS Expedition-15 on board the International Space Station (June-October 2007) completes this overview.

Figure 2-01. The Khilov's swing test was used in Star City (near Moscow, Russia) for selection and training of cosmonauts. Here, a French cosmonaut sat in a chair suspended from the top of a four-post structure. The fore-aft translation of the swing generated linear accelerations that stimulated the otolith organs of his vestibular system. Photo courtesy of CNES.

1 A BRIEF HISTORY OF HUMAN SPACE FLIGHT

To date, astronauts from more than thirty different countries have flown in space and countless more have participated in some capacity with space research. However, only three countries, the United States, Russia, and China, possess the means to launch humans into orbit. The launch of the first living creature on Sputnik-2 on November 3, 1957, marked the beginning of a rich history of unique scientific and technological achievements in space life sciences that has spanned more than fifty years to date.

1.1 The Soviet and Russian Space Program

The Soviet Union initiated the space age with the launch of Sputnik-1 and quickly followed this remarkable achievement by launching a dog, named *Laika,* on board Sputnik-2. The *Sputnik* program (1957-1960) was followed by the *Vostok* program (1961-1963), which after several unmanned sub-orbital and orbital flights launched the first human, Yuri A. Gagarin, into Earth orbit on board Vostok-1 on April 12, 1961. Vostok was followed by the *Voskhod* (1964-1965) flights, an interim program designed to prepare for the more mature *Soyuz* flights (1967-present). The early Soyuz

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flights were designed more with the aspirations of circumlunar and Moon landings, but were quickly adapted to support the Soviet Union's space station programs.

Almaz was the Soviet's first station program scheduled for use in low Earth orbit, and was intended more for military reconnaissance than research. When it became clear that the intended *Proton* launch vehicle could not be man-rated, it was decided to use the *Soyuz* spacecraft as a crew transport vehicle. The modified space station was called *Salyut* (1971-1986). Subsequent Almaz stations were also called Salyut in an attempt to conceal the existence of two separate space station programs. Salyut-1 was launched on April 19, 1971, and became a major step in developing a platform that would help establish a continued human presence in space. Salyut-7 was followed by the *Mir* space station (1986-2001), which was launched on February 19, 1986 (Figure 2-02). Mir was never a static platform, but continued to evolve throughout its lifespan, as a true permanently inhabited space station. Before the Mir station was forced into the Earth's atmosphere, its inhabitants watched the dissolution of the Soviet Union, the formation of the new Russian Republic, and the establishment of cooperative agreements between Russia and the United States, allowing U.S. astronauts to serve as crewmembers along side Russian cosmonauts. The *NASA-Mir* (1994-1995) and *Shuttle-Mir* (1995-1998) programs represented the final scientific endeavors on board Mir, and paved the way for future cooperation on board the *International Space Station* (1998-present).

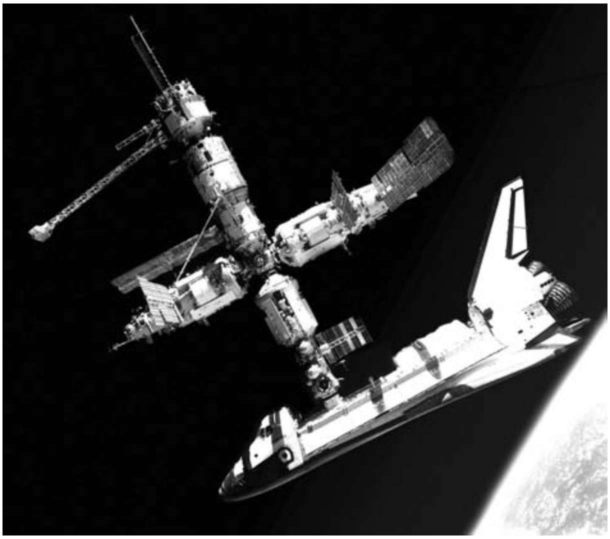

Figure 2-02. This photograph taken from a Soyuz vehicle shows the Space Shuttle docked to the Russian Mir station. The Shuttle-Mir program consisted of seven Space Shuttle missions to Mir and 1000+ days in space for U.S. astronauts on board Mir between 1994 and 1998. Photo courtesy of NASA.

1.2 The United States Space Program

The *National Space and Aeronautics Administration* (NASA) was created on October 1, 1958 in response to the Soviet Union's launch of Sputnik-1, and charged by the President of the United States, Dwight Eisenhower, with launching a person into space in an environment that would allow effective performance, and to recover that person safely. Project *Mercury* (1958-1963) was the result of that charge initiated by Eisenhower. All together there were two sub-orbital and four orbital missions, the longest lasted for 22 orbits around the Earth (Swenson *et al.* 1966).

Planning for the *Gemini* program (1961-1966) began in May of 1961 even before the first Mercury flight was complete. One of the primary purposes of the Gemini flights was to demonstrate the feasibility of “long duration” space flight.[2] There were a total of twelve Gemini flights, all leading toward the singular idea of putting a man on the Moon and returning him safely home.

With this goal in mind, the *Apollo* program (1967-1972) was singular and straight forward. The previous Mercury and Gemini programs identified no medical or physiological problems that would prevent missions with durations of two weeks or longer (Link 1965). Nevertheless, Apollo was supported by NASA’s largest biomedical effort to date, and for the first time a number of significant biomedical findings were identified. These included vestibular disturbances, lower than expected food consumption (most likely attributable to the presence of vestibular disturbances), dehydration and weight loss, decreased postflight orthostatic tolerance, decreased exercise tolerance, recording of postflight cardiac arrhythmias, and a decreased red cell mass and plasma volume (Parker & Jones 1975). Unlike the Soviet program where Titov experienced motion sickness on board Vostok-2, no U.S. astronaut had experienced (or perhaps reported) this malady prior to the Apollo flights.

The *Skylab* program (1973-1974) represented a complete departure in direction. It offered the Unites States the first opportunity to explore the problems of habitability and biology associated with exposure to microgravity over extended periods of time. Skylab was comprised of four separate flights. Skylab-1 placed the orbiting laboratory into space (comprised of the S-IVB stage of a Saturn V booster rocket), and was equipped to house three astronauts for an uninterrupted period of at least three months. Skylab flights 2, 3, and 4 kept crews aloft for 28, 59, and 84 days, respectively. The extended duration of these flights meant that scientists could study and evaluate physiological responses, including long-term adaptation, to microgravity. A secondary feature of Skylab was the volume of the orbital workshop. For the first time, astronauts were free to move about unlike any time before (Figure 2-03). This freedom of movement was instrumental in attaining adaptation levels that were well established (Johnston & Dietlein 1977). Skylab was also the first flight that provided for a complex set of vestibular experiments to be flown (Graybiel *et al.* 1974) (see Figure 7-04).

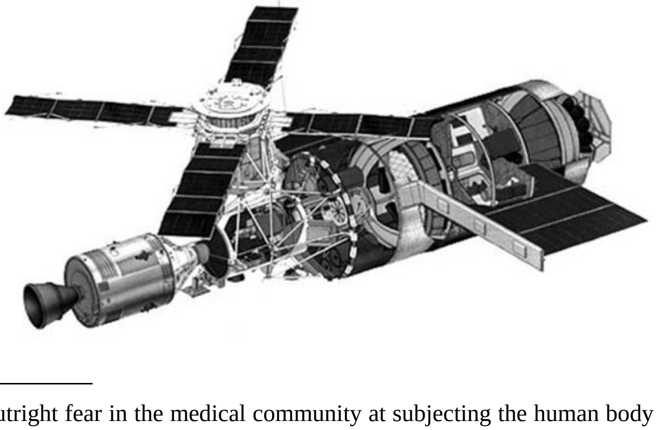

Figure 2-03. Drawing of the Skylab workshop showing the Orbital Module Laboratory *(with the “transparent” walls, right) and the Apollo crew return vehicle (left). Photo courtesy of NASA.*

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[2] “There was concern, even outright fear in the medical community at subjecting the human body to eight days in zero-g. […] Jim McDivitt and Ed White came back from Gemini 4 visibly tired and drawn, and that one was just four days. […] [Scientists feared that] the guys might lose the ability to swallow. Air and pressure problems could lead to ‘space madness’, posed one scientist who feared crew psychosis from oxygen-starved brains. […] Doctors have always been a pilot’s worst enemy.” Conrad & Klausner (2005), p. 141.

After a lengthy hiatus NASA participated in the *Apollo-Soyuz Test Project* (ASTP, 1975). Unlike other flights, ASTP was a joint program between the United States and the Soviet Union, whose objectives were primarily political. For the record, ASTP was to test systems for rendezvous and docking that might be useful should the need for an international space rescue ever be needed. Due to an incorrect valve setting during re-entry, most of ASTP postflight science was lost. During descent of the Apollo command module, after nine days in orbit, the United States crew was exposed to toxic gases (nitrogen tetroxide) that entered the command module through a cabin pressure relief valve that had mistakenly been left open in the landing preparation sequence during an inadvertent firing of the reaction control system. This incident is notable only because it was direct evidence of potential effects of space flight on neurological function (Nicogossian 1977).

ASTP was followed by the *Space Shuttle* (or *Space Transportation System*, STS) program (1981-present). The first launch of the Space Shuttle occurred on April 12, 1981, and was uniquely different than previous programs for several reasons:

a. It employed a reusable Orbiter.
b. Re-entry required the crew to pilot the craft to an un-powered landing.
c. The Space Shuttle was the first U.S. spacecraft having a standard sea-level atmospheric pressure and gas mixture (Mercury, Gemini and Apollo operated at 0.33 atmospheres with 100% oxygen. Skylab also operated at 0.33 atmospheres with 70% oxygen and 30% nitrogen).
d. The Space Shuttle provided the ability to fly dedicated Spacelab modules where significant science investigations could be conducted in microgravity, opening opportunities for investigators around the world to participate in the United States' space flight program (Nicogossian *et al.* 1994).

The Space Shuttle has been instrumental in NASA's transition to the *International Space Station* (ISS). In its infancy, the ISS is a natural progression from the Russian Mir station to a platform, that once completed, will host the space-faring nations of the world in living and working on board the most complex structure ever assembled in orbit (Figure 2-04).

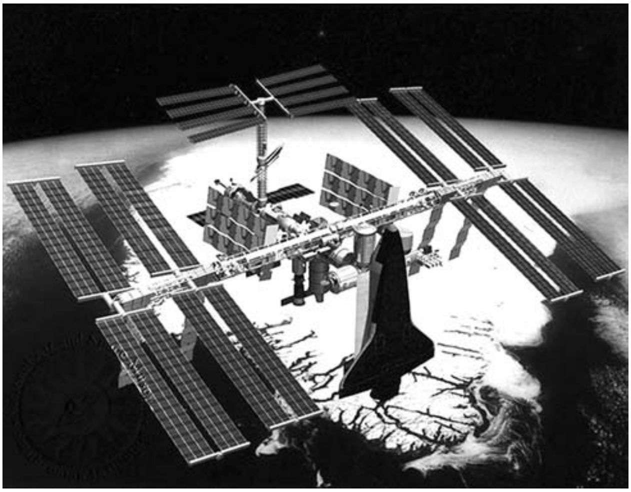

Figure 2-04. In this computer-generated representation, a Space Shuttle is docked to a completed and fully operational International Space Station *(ISS). The ISS will be comprised of scientific modules from the U.S., Europe, Canada, Japan, and Russia. Photo courtesy of NASA.*

1.3 Additional Human Space Programs

While the United States and Russia have dominated space flight, there have been multiple nations from around the world who have participated in various human flight programs primarily through cooperative agreements with either the U.S. or Russia.

Specifically, the *European Space Agency* (ESA), founded in 1975, has been a major contributor to space based research. ESA has participated in multiple flights including *Spacelab* missions 1, 2, and 3, Spacelab D1 and D2 (for *Deutsch*) missions, Spacelab Life Sciences and International Microgravity Laboratory missions, and several missions to the Mir space station. ESA has also developed the *Columbus* research module of the ISS. In addition to those projects sponsored by ESA, individual ESA member states have maintained space flight programs specific to their country. In particular France, Germany, the United Kingdom, Austria, and others have partnered with both the U.S. and Russian flights to fly complex life sciences experiments (see Fitton & Battrick 2001 for review).

The *Japanese Aerospace Exploration Agency* (JAXA), like ESA, has maintained an active flight program, and has undertaken the development of a multipurpose laboratory, *Kibo*, to operate in conjunction with the ISS.

The *Canadian Space Agency* (CSA), established in 1989, has been an active participant in all of the major flight programs, and has developed unique hardware for flight. In addition The CSA, ESA and JAXA have selected and flown astronauts on the Space Shuttle.

China is new to the space age. The Chinese have developed serious launch capabilities and have placed three taikonauts into orbit. They also have plans to develop and build a space station of their own.

2 SPACE FLIGHT: AN ENGINEERING AND SCIENTIFIC MARVEL

Whether the dawn of space flight began with primitive man gazing upon the heavens or with the fatal flight of Icarus, we know that modern man predicted our escape from Earth's atmosphere as early as 1911 when Tsiolkovsky[3] noted in a letter to a friend that "Humanity will not remain on the Earth forever, but in the pursuit of light and space will at first timidly penetrate beyond the limits of the atmosphere, and then will conquer all the space around the Sun." From mythology represented by Daedalus and Icarus, the physics of Archimedes, Newton, Galileo, and Copernicus, the foresight of Leonardo DaVinci, Jules Verne, and H.G. Wells, to the realization of space flight by Tsiolkovsky, Oberth, Von Braun, Korolev, Yuri Gagarin, and Neil Armstrong; the history of modern space travel with its effect on sensory function began in the fifth decade of the twentieth century.

Those familiar with the initial plans to rocket humans into space will recall that flight surgeons expressed concern that the body organs depended on sustained gravity and would not function in a reduced gravity environment. Others worried over the

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[3] Konstantin Eduardovich Tsiolkovsky (1857-1935) was a Soviet Russian rocket scientist and pioneer of cosmonautics. One of his most famous quotes is usually cited as "Earth is the cradle of humanity, but one cannot live in a cradle forever." However, a more accurate English translation would read "A planet is the cradle of mind, but one cannot live in a cradle forever."

combined effects of acceleration, weightlessness, and the heavy deceleration during atmospheric re-entry. Still other experts were concerned especially about perception and vestibular function. Gauer & Haber (1950) speculated that the brain receives signals on the position, direction, and support of the body from four mechanisms: pressure on the nerves and organs, muscle, posture, and the vestibular organs. Modification of any one of these inputs, they theorized, would disrupt normal functioning of the autonomic nervous system with the ultimate inability to act.

Fortunately the human central nervous system has proven to be enormously plastic. Clearly, humans can adapt to the forces associated with space flight. However, the microgravity environment of space flight does have an impact on the human physiology, and we have recently entered an era where countermeasures must be developed that will not only allow crewmembers to live in space for prolonged periods of time, but also prepare those same crewmembers to encounter the gravitational fields of the Earth and other worlds following flight.

It is interesting to note that soon after NASA began flying humans in space, a series of special symposiums were initiated to address the problems that flight had on astronaut's orientation systems. Addressing the members of the first symposium in 1965 on *The Role of the Vestibular Organs in the Exploration of Space*, Dr. Walton Jones (1968) noted in his opening remarks that "the disturbing symptoms experienced in weightlessness require much detailed study […] Most experts, I believe, are convinced that we will solve these problems; but, we will not be absolutely sure until we have conducted some experiments in orbit under the weightless condition for considerable time." More than 40 years later, we are still addressing many of the original problems.

While it might appear that what we have learned from the past helps us transition smoothly in the resolution of problems, that progression is at best an illusion. Scientific discovery does not progress linearly, but is born out of revolution. Old paradigms are attacked by the formation of new scientific communities that advance new paradigms. Perhaps we are awaiting a new research community to challenge the old paradigms and initiate a much needed revolution.

The initiation of human space flight and the apparent rational movement from one flight program to the next is perhaps an example of the illusion that science and engineering progress in a linear fashion. When it became clear that space travel would become a reality, most believed that we would leave the Earth for space by progressing on logical building blocks. That is, first we would send animals up in rockets before exposing human beings to the feared rigors of space flight (see Clément & Slenzka 2006 for review). Exactly fifty years ago, in 1957, the Soviets launched the first man-made satellite (Sputnik-1) into low Earth orbit. Later that same year, Sputnik-2 was launched carrying a dog, named Laika, the first living creature to be boosted into space. Sputnik-2 was followed two years later with the sub-orbital launch of one Rhesus and one squirrel monkey in the nose cone of a U.S. ballistic missile. The monkeys survived 38 g and 9 minutes of microgravity (Figure 2-05). Although both monkeys survived the landing, one died later under anesthesia during the removal of implanted electrodes.

Between 1959 and 1961 three other U.S. monkeys made successful sub-orbital flights in Mercury capsules. In 1961, the Chimpanzee, Ham, made the first three-orbit flight in a Mercury-Redstone capsule on January 31, 1961. Prior to human flight, twelve other dogs, many mice, rats, and a variety of plants were sent into space for longer and longer periods of time (Clément & Slenzka 2006).

Figure 2-05. Sam, the Rhesus monkey, after his ride in the Little Joe-2 (LJ-2) spacecraft in December 1959. A U.S. Navy destroyer safely recovered Sam after he experienced three minutes of weightlessness during the sub-orbital flight. Photo courtesy of NASA.

Biometric data collected from this menagerie suggested that there were no adverse effects attributable to orbital flight, and on the basis of these results, it was concluded that the physical and mental demands that humans would encounter during space flight would not be a problem. The next steps were obvious. First, a human would be sent into space as a passenger in a capsule (Vostok and Mercury programs). Second, the launch capabilities would increase to include two astronauts, and these crewmembers would be given some control over the capsule (Soyuz and Gemini programs). Third, a reusable space vehicle would be developed to take humans into space and return them (Space Shuttle program). Fourth, a permanent space station would be constructed in low Earth orbit using the reusable vehicle as a transportation system (Mir and ISS programs). Finally, lunar and interplanetary flights could be launched from the station using lower thrust space vehicles. Of course this is not how we have progressed. Scientific, engineering and political revolutions have taken us off course.

By the time of the last Mercury flight in May 1963, the focus of the U.S. space program had already shifted. President John F. Kennedy had announced the goal of reaching the Moon only three weeks after Shepard’s relatively simple 15-minute sub-orbital flight, and by 1963, only 500 of the 2,500 people working at NASA’s Manned Spacecraft Center were still working on project Mercury. The remainders were already busy on Gemini and Apollo.

It is now acknowledged that the first space flights had little or few impacts on the human sensorimotor systems, and although there may have been hints that spatial orientation was somewhat altered in microgravity, NASA’s management had little interest in the life sciences. In a well-written publication on the early history of NASA, Homer Newell (1980) explored the space administration’s view of space biology. He wrote that life sciences were something of an enigma to the highest levels of management within NASA. Maybe this was because no one in the upper levels of management had training in the life sciences, but Newell believed that there was more to it than that. His thesis was that you could sense in the life sciences community within the U.S. a fascination with the novelty of space flight, but that there was a real skepticism within the community regarding the application of space flight to the discipline of life sciences. Interestingly, little has really changed over the years.

NASA's philosophy concerning the life sciences was and remains simple: where science was the objective, make the most of space techniques to advance the disciplines; in other areas do only what was essential to meet the need. According to Newell, a natural outcome of this philosophy was to disperse the different life sciences activities throughout the agency, placing each in the organizational entity it served. Even when life sciences administration was concentrated at NASA headquarters in Washington, little was done to modify this underlying practice (Newell 1980).

Throughout the Apollo and Skylab flights, space medicine and the laboratories associated with the clinical aspects made great strides (Parker & Jones 1975, Johnston & Dietlein 1977). Although space medicine, which in the NASA make-up formed a part of manned space flight organization, achieved extensive results, space biology and exobiology produced only modest returns during the 1960s. This is not a complete negative. There are many who view NASA's life sciences as an operational program. "Pure" biological research can be funded by other federal agencies. This philosophy is as appropriate today as it was in 1960. Regardless of its history, the discipline of life sciences within NASA remains a stepchild with little hope of improving in the next several years. It is interesting to note that Newell (1980) entitled his chapter, within his book on the early years of space science, on life sciences as having "No Place In The Sun."

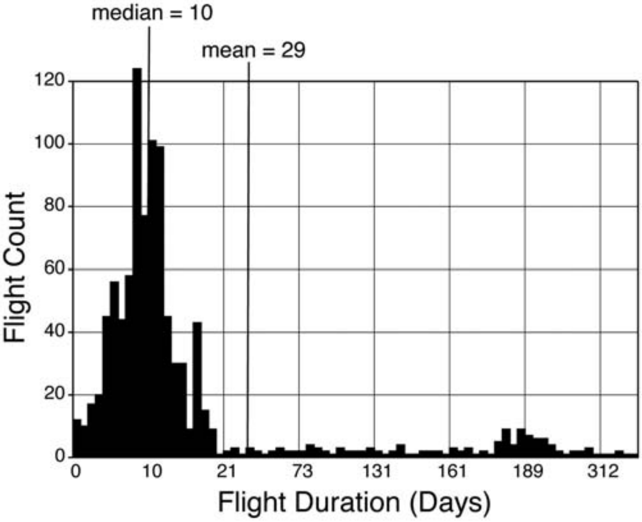

Figure 2-06. Frequency of human space flight as a function of flight duration from 1961 to 2006. Most flights were of short duration with a mean value of 29 days. The median value, however, is in the order of 10 days (Clément 2005).

3 HISTORY OF NEUROSCIENCE RESEARCH DURING SPACE FLIGHT

3.1 Humans in Space

History of manned space flight spans more than forty-five years, beginning with the landmark flight of Yuri Gagarin on April 12,1961 on Vostok 1. Since this first flight there is very little down time when space flight activity did not occur. In fact, activity increased as space flight matured, and since November 2000, there has been a continuous human presence in space on the ISS. It is believed that this trend of continuous human presence in space will progressively persist, as the duration of astronaut time in orbit or in transition between planets and moons becomes common place.

So, how much time have humans spent orbiting the Earth? To get an accurate count, the time must be calculated as man-hours since, at times, there are multiple astronauts flying on the same mission (Clément 2005). Up to ISS Expedition-14, 994 humans (449 not including re-flights) have collectively spent an astounding 707,446 cumulative man-hours, or about 80 man-years in space.

It is interesting to note that, over this period, although the U.S. has launched the most manned vehicles into space (147 for the U.S. as opposed to 103 for Russia) and sent the most humans into space (757 versus 237), the Russians have spent roughly 42% more time in space than the U.S.[4] This is because the majority of the Russian flights were long-duration flights to orbiting laboratories such as the Salyut and Mir stations, while the majority of U.S. flights were short-duration Shuttle missions.

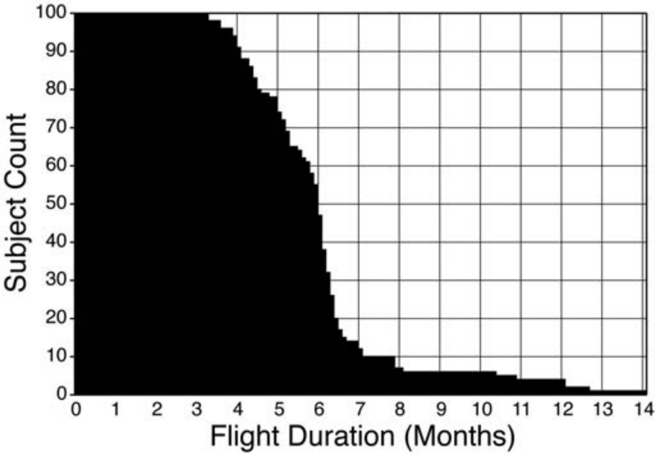

Figure 2-07. Cumulative histogram showing the astronauts count as a function of flight duration. The ordinate axis is truncated at 100 (if not, it would peak at 449). As of today, about 100 human subjects have spent more that three months in space. Among these, less than 50 have spent more than six months in space, and four have flown during continuous missions of one year or more (Clément 2005).

Figure 2-06 is a frequency distribution of flight durations. It shows that the average flight duration is about 29 days and the median flight duration is 10 days, meaning that the majority of life sciences experiments have been performed on crewmembers during short-duration missions. There are only 47 crewmembers with flight durations of six months or greater, and of those, only four have flight durations of one year or greater (Figure 2-07). It is difficult to make conclusions about the effects of long-duration space flight with data from only a handful of subjects, especially when different hardware and protocols were used to collect the data, and the fact that 39 of the 47 long-duration subjects were from Russia, of which we have mostly anecdotal data.

The ISS is currently the only platform available for performing long-duration human physiological experiments. The six-month long ISS flights may not be adequate length for testing the effects of long-duration space flight when, with our current rocket technology, it would take twice this time to reach Mars and return to Earth, plus one and a half year on the surface of the Red Planet (see Figure 1-05).

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[4] China flew two Shenzhou missions, one in 2003 and one in 2005, which total to about six days in duration.

3.2 Life Sciences Experiments

From our research, we have found that a total of 2,340 human and animal life sciences experiments have been conducted on orbit and pre- and postflight by all countries, excluding Russia, through ISS Expedition-14 (Figure 2-08). We did not include Russia in this total due to our unsuccessful attempts at locating experimental records at the time the metrics were calculated. The only records located were those performed during joint ventures between Russia and other countries, such as the Shuttle-Mir, Euro-Mir, and ISS programs. From these joint ventures, Russia has conducted about 175 life sciences experiments from the periods of 1961-1989 and 2002-2005. We realize that these numbers fall short of an accurate representation of the totals achieved by our Soviet and Russian counterparts. One further point needs to be made. It is important to realize that although many reliable sources were used to compile the life sciences database presented in this chapter, these numbers are not exact since we have no way to verify the information in these sources, but they do give us a good estimate to help illustrate the point.

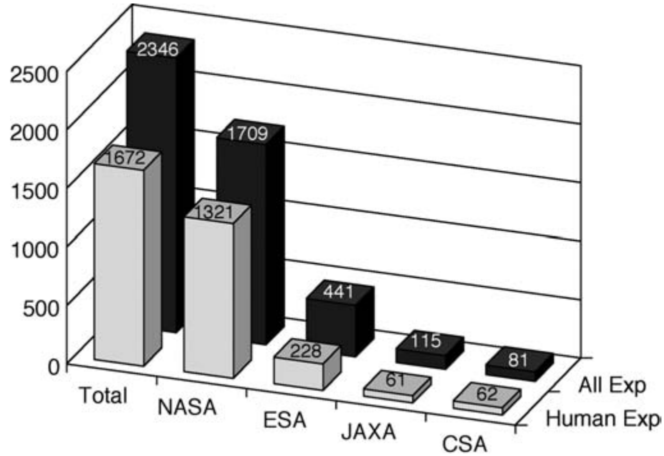

Figure 2-08. Number of space life sciences experiments including both human and animal subjects (All Exp) or just human subjects (Human Exp) for the various space agencies up through ISS Expedition-14.

Although animal studies are a vital aid to understanding space physiology, they are not a perfect analogue to humans. We have detailed these differences in a book published earlier (Clément & Slenzka 2006). Taking only the number of experiments conducted on humans, there is a drop in the number of investigations from 2,346 to 1,672. Even though 1,672 seems like a significant number of human physiological experiments, when it is broken down into the various science disciplines, it is apparent how few experiments have actually been performed (Figure 2-09).

Cardiovascular and neuroscience account for the majority of space life sciences experiments. About 400 space neuroscience experiments have been performed to date. This number is not very encouraging when considering that they were conducted over a 45-year period, i.e., about 8-9 experiments per year on average. In addition, these experiments were performed with different research methods, different hardware, and on mostly short-duration missions. The knowledge attained from these short-duration experiments may not be adequate to predict the physiological changes an astronaut experiences on long-duration missions. Until life sciences and the development of countermeasures become a priority in the space community, astronauts will continue to endure the undesirable neurological and sensorimotor changes brought about by space flight.

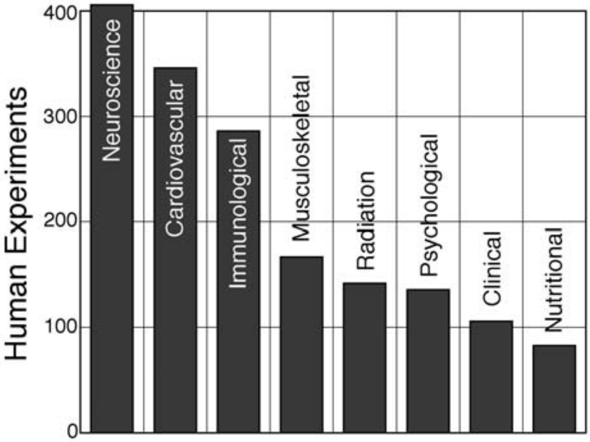

Figure 2-09. Total number of space experiments in human physiology, by disciplines, performed by all countries (except Russia) up through ISS Expedition-14.

4 NEUROSCIENCE EXPERIMENTS CONDUCTED DURING SPACE FLIGHT

To our knowledge, the first documented space neuroscience experiments were performed during the third manned mission on board the Russian Vostok spacecraft. These experiments began after the crew from earlier missions complained from nausea and spatial disorientation in weightlessness. Space neuroscience experiments were typically addressing these operational issues until the Skylab and Salyut space stations were made available for more fundamental research on the effect of gravity (or virtual lack thereof) on central nervous system functions.

The following table lists all the space neuroscience experiments that we have identified between Vostok-3 (1962) and ISS Expedition-15 (2007), sorted by mission launch date.

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
Vostok-3	11-Aug-62	Nikolayev	3:22:25	ElectroEncephaloGraphy (EEG) ElectroOculoGraphy (EOG) Galvanic Skin Response (GSR) Sensory-Motor Coordination Tests
Vostok-4	12-Aug-62	Popovich	2:22:59	Same as Vostok-3
Vostok-5	14-Jun-63	Bykovsky	4:23:06	Same as Vostok-3
Vostok-6	16-Jun-63	Tereshkova	2:22:50	Same as Vostok-3

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
Voskhod-1	12-Oct-64	Komarov Feoktistov Yegorov	1:00:17	ElectroOculoGraphy Eyes-Closed Writing Tests with Galvanic Vestibular Stimulation
Voskhod-2	18-Mar-65	Belyaev Leonov	1:02:02	Neurological Investigations including sensory and stereognostic testing
Gemini-5	21-Aug-65	Cooper Conrad	07:22:55	Human Otolith Function (M009) Visual Acuity in the Space Environment (S008)
Gemini-7	4-Dec-65	Borman Lovell	13:18:35	Human Otolith Function (M009) In-Flight Sleep Analysis (M008) Visual Acuity in the Space Environment (S008)
Apollo-7	11-Oct-68	Schirra Eisele Cunningham	10:20:09	Apollo Flight Crew Vestibular Assessment
Soyuz-3	26-Oct-68	Bergovoy	3:22:51	Investigation of Muscle EMG Activity at Rest and After Exercise
Apollo-8	21-Dec-68	Borman Lovell Anders	06:03:01	Apollo Flight Crew Vestibular Assessment
Soyuz-4	14-Jan-69	Shatalov	2:23:23	Same as Soyuz-3
Soyuz-5	15-Jan-69	Volynov Yeliseyev Khrunov	3:00:56	Same as Soyuz-3
Apollo-9	3-Mar-69	McDivitt Scott Schweickart	10:01:01	Same as Apollo-7
Apollo-10	18-May-69	Cernan Stafford Young	08:0:03	Apollo Flight Crew Vestibular Assessment
Biosatellite III	28-Jun-69	Bonnie (Pig-Tailed Monkey)	8:19:00	Digital Computer Analysis of Neurophysiological Data from Biosatellite III Sleep and Wake Activity Patterns of a Pig-Tailed Monkey During Nine Days of Weightlessness Sleep and Wake States in Biosatellite III Monkey: Visual and Computer Analyses of Telemetered Electro Encephalographic Data

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
Apollo-11	16-Jul-69	Armstrong Aldrin Collins	8:03:09	Apollo Flight Crew Vestibular Assessment
Soyuz-6	11-Oct-69	Shonin Kubasov	4:22:42	Same as Soyuz-3
Soyuz-7	12-Oct-69	Filipchenko Volkov Gorbatko	4:22:41	Same as Soyuz-3
Apollo-12	14-Nov-69	Conrad Gordon Bean	10:4:36	Apollo Flight Crew Vestibular Assessment
Apollo-13	11-Apr-70	Lovell Swigert Haise	5:22:55	Apollo Flight Crew Vestibular Assessment
Soyuz-9	1-Jun-70	Nikolayev Sevastyanov	17:16:59	EEG Monitoring Locomotion Muscle EMG Activity Posture Study Sleep Monitoring
OFO-A (Scout Satellite)	9-Nov-70	Two Bull Frogs	6:00:00	Orbiting Frog Otolith Experiment: Comparison to Control Studies; Preliminary Results; Secondary Spike Analysis
Apollo-14	31-Jan-71	Shepard, Roosa Mitchell	9:00:02	Apollo Flight Crew Vestibular Assessment
Soyuz-11	6-Jun-71	Dobrovolsky Volkov Patsayev	23:18:22	Neurological Testing of Grip Strength, Kinesthetic Sensitivity, Visual Acuity, Color and Contrast Sensitivity, Convergence and Accommodation
Apollo-15	26-Jul-71	Scott Worden Irwin	12:17:12	Apollo Flight Crew Vestibular Assessment
Apollo-16	16-Apr-72	Young Duke Mattingly	11:01:51	Apollo Flight Crew Vestibular Assessment
Apollo-17	7-Dec-72	Cernan Schmitt Evans	12:13:52	Apollo Flight Crew Vestibular Assessment
Skylab-2	25-May-73	Conrad Kerwin Weitz	28:00:50	Human Vestibular Function (M131)
Skylab-3	28-Jul-73	Bean Garriott Lousma	59:12:09	Human Vestibular Function (M131)

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
Skylab-4	16-Nov-73	Carr Gibson Pogue	84:01:16	Human Vestibular Function (M131) Motor Sensory Performance
Soyuz-17 / Salyut-4	10-Jan-75	Gubarev Grechko	29:13:20	Vestibular Monitoring
Soyuz-19 / ASTP	15-Jul-75	Leonov Kubasov	5:22:31	Achilles Tendon Reflex
Apollo-18 / ASTP	15-Jul-75	Stafford Slayton Brand	9:01:28	Achilles Tendon Reflex Electromyographic Analysis of Skeletal Muscle
Soyuz-21 / Salyut-5	6-Jul-76	Volynov Zholobov	49:06:23	Investigation of Sensitivity Threshold of Vestibular System to Galvanic Stimulation Evaluation of Gustatory Sensations in Weightlessness
Soyuz-24 / Salyut-5	7-Feb-77	Gorbatko Glazkov	17:17:26	Same as Soyuz-21
Soyuz-26 / Salyut-6	10-Dec-77	Romanenko Grechko	96:10:00	Attention and Memory Test Color Sensitivity and Visual Acuity Coordination Tests EEG Monitoring Effect of Plantar Stimulation on Space Motion Sickness First Test of the “Cuban Boot” (to simulate Earth loads on foot proprioceptors) Gustometry Investigation of Tactile Sensation Optokinetic Stimulation Posture Tests Reaction Time Space Motion Sickness (SMS) Questionnaire
Soyuz-27 / Salyut-6	10-Jan-78	Dzhanibekov Makarov	5:22:58	Same as Soyuz-26
Soyuz-28 / Salyut-6	2-Mar-78	Gubarev Remek	7:22:15	Same as Soyuz-26
Soyuz-29/ Salyut-6	15-Jun-78	Kovalyonok Ivanchenkov	139:14:47	Same as Soyuz-26
Soyuz-31 / Salyut-6	27-Jun-78	Klimuk Hermaszewski	7:22:02	Same as Soyuz-26
Soyuz-32 / Salyut-6	25-Feb-79	Lyakhov Ryumin	175:00:35	Same as Soyuz-26
Soyuz-33 / Salyut-6	10-Apr-79	Rukavishnikov Ivanov	1:22:23	Same as Soyuz-26

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
Soyuz-35 / Salyut-6	9-Apr-80	Popov Ryumin	184:20:11	Same as Soyuz-26
Soyuz-36 / Salyut-6	26-May-80	Kubasov Farkas	7:20:45	Same as Soyuz-26
Soyuz-T2 / Salyut-6	5-Jun-80	Malyshev Aksenov	3:22:19	Same as Soyuz-26
Soyuz-37 / Salyut-6	23-Jun-80	Gorbatko Pham	7:20:41	Same as Soyuz-26
Soyuz-38 / Salyut-6	18-Sep-80	Romanenko Tamayo	7:20:43	Same as Soyuz-26
Soyuz-T3 / Salyut-6	27-Nov-80	Kizim Grigoryevich Strekalov	12:19:07	Same as Soyuz-26
Soyuz-T4 / Salyut-6	12-Mar-81	Kovalyonok Savinykh	74:17:37	Same as Soyuz-26
Soyuz-39 / Salyut-6	22-Mar-81	Dzhanibekov Gurragcha	7:20:42	Same as Soyuz-26
STS-1 (Columbia)	12-Apr-81	Young Crippen	2:06:20	Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
Soyuz-40/ Salyut-6	14-May-81	Popov Prunariu	7:20:41	Same as Soyuz-26
STS-2 (Columbia)	12-Nov-81	Engle Truly	2:06:13	Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-3 (Columbia)	22-Mar-82	Lousma Fullerton	8:00:04	Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
Soyuz-T5 / Salyut-7	13-May-82	Berezevoi Lebedev	210:09:04	Attention and Memory Tests Audiometry Color Sensitivity and Visual Acuity Coordination Tests EEG Monitoring Effect of Plantar Stimulation on SMS Gustometry Investigation of Tactile Sensation Optokinetic Stimulation Posture Tests SMS Questionnaire
Soyuz-T6 / Salyut-7 French PVH Mission	24-Jun-82	Dzhanibekov Ivanchenkov Chretien	7:21:50	Same as Soyuz-T5 Posture Experiment: Postural Control during Voluntary Arm and Involuntary Body Movements

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
STS-4 (Columbia)	27-Jun-82	Mattingly Hartsfield	7:01:09	Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
Soyuz-T7 / Salyut-7	19-Aug-82	Popov Serebrov Savitskaya	7:21:52	Same as Soyuz-T6
STS-5 (Columbia)	11-Nov-82	Brand Overmyer Allen Lenoir	5:02:14	Acceleration Detection Sensitivity (DSO 405) Head and Eye Motion During Shuttle Launch and Entry (DSO 403) Near Vision Acuity and Contrast Sensitivity (DSO 408) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-6 (Challenger)	4-Apr-83	Weitz Bobko Peterson Musgrave	5:02:14	Acceleration Detection Sensitivity (DSO 405) Extra-Ocular Motion (EOM) Studies, Pre, In and Postflight (DSO 404) Eye Head Motion during Ascent, Entry, and On Orbit (Gyroscopic Head Motion Measurements) (DSO 404) Head and Eye Motion During Shuttle Launch and Entry (DSO 403) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
Soyuz-T8 / Salyut-7	20-Apr-83	Titov Strekalov Serebrov	2:00:17	Same as Soyuz-T5
STS-7 (Challenger)	18-Jun-83	Crippen Hauck Fabian Ride Thagard	6:02:23	Acceleration Detection Sensitivity (DSO 405) Extra-Ocular Motion (EOM) Studies Pre, In and Postflight (Saccadic Tracking) (DSO 404) Head and Eye Motion During Shuttle Launch and Entry (DSO 403) In-Flight Countermeasures for SMS (DSO 417) Near Vision Acuity and Contrast Sensitivity (DSO 408 On-Orbit Head and Eye Tracking Task (Optokinetic Studies) (DSO 404)

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
				Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
Soyuz-T9 / Salyut-7	27-Jun-83	Lyakhov Aleksandrov	149:10:45	Same as Soyuz-T5
STS-8 (Challenger)	30-Aug-83	Truly Brandenstein Gardner Bluford Thornton	6:01:08	Acceleration Detection Sensitivity (DSO 405) Extra-Ocular Motion (EOM) Studies Pre, In and Postflight (Saccadic Tracking) (DSO 404) Eye Head Motion during Ascent, Entry and on Orbit (Gyroscopic Head Motion Measurements) (DSO 404) Head and Eye Motion During Shuttle Launch and Entry (DSO 403) In-Flight Countermeasures for SMS (DSO 417) Near Vision Acuity and Contrast Sensitivity (DSO 408) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-9 (Columbia) First Spacelab Mission (SL-1)	28-Nov-83	Young Shaw Garriott Parker Lichtenberg Merbold	10:07:47	Effects of Rectilinear Acceleration, Optokinetic and Caloric Stimulation on Human Vestibular Reactions and Sensations Eye Movements During Sleep Mass Discrimination During Weightlessness Validation of Predictive Tests and Countermeasures for SMS (DSO 401) Vestibular Experiments Vestibulo-Spinal Reflex Mechanisms using Hoffman Reflex
Soyuz-T10 / Salyut-7	8-Feb-84	Kizim Solovyov Atkov	236:22:49	Same as Soyuz-T5
Soyuz-T11 / Salyut-7	3-Apr-84	Malyshev Strekalov Sharma	7:21:40	Same as Soyuz-T5
STS-41C (Challenger)	6-Apr-84	Crippen Hart Scobee	6:23:40	Near Vision Acuity and Contrast Sensitivity (DSO 408) Validation of Predictive Tests and

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
		Nelson Van Hoften		Countermeasures for SMS (DSO 401)
Soyuz-T12 / Salyut-7	17-Jul-84	Dzhanibekov Savitskaya Volk	11:19:14	Same as Soyuz-T5
STS-41D (Discovery)	30-Aug-84	Hartsfield Coats Resnik Hawley Mullane Walker	6:00:56	Crew Visual Performance (DSO 440) Near Vision Acuity and Contrast Sensitivity (DSO 408) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-41G (Challenger)	5-Oct-84	Crippen McBride Sullivan Ride Leestma Garneau Scully-Power	8:05:23	Crew Visual Performance (DSO 440) Near Vision Acuity and Contrast Sensitivity (DSO 408) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-51A (Discovery)	8-Nov-84	Hauck Walker Fisher Gardner Allen	7:23:44	Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-51C (Discovery)	24-Jan-85	Mattingly Shriver Onizuka Buchli Payton	3:01:33	Crew Visual Performance (DSO 440) Near Vision Acuity and Contrast Sensitivity (DSO 408) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-51D (Discovery)	12-Apr-85	Bobko Williams Seddon Hoffman Griggs Walker Garn	6:23:55	Extra-Ocular Motion (EOM) Studies, Pre, In and Postflight (DSO 404) Validation of Predictive Tests and Countermeasures for SMS (DSO 401)
STS-51B (Challenger) Spacelab-3 Mission	29-Apr-85	Overmyer Gregory Don Lind Thagard Thornton van den Berg G. Wang	7:00:08	Eye-Hand Coordination During SMS (DSO 451)
Soyuz-T13 / Salyut-7	6-Jun-85	Dzhanibekov Savinykh	112:03:12	Same as Soyuz-T5

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
STS-51G (Discovery)	17-Jun-85	Brandenstein Creighton Lucid Fabian Nagel Baudry Al-Saud	7:01:38	Clinical Characterization of SMS (DSO 455) Equilibrium and Vertigo: Studies of Postural Control, Vestibulo-ocular Reflex, Optokinetic Nystagmus, and Cognitive Processes Sensory-Motor Adaptation during Visual-Vestibular Interaction
STS-51I (Discovery)	27-Aug-85	Engle Covey van Hoften Lounge Fisher	7:02:17	Clinical Characterization of SMS (DSO 455)
Soyuz-T14 / Salyut-7	17-Sep-85	Vasyutin Grechko Volkov	64:21:52 Vasyutin, Volkov 8:21:13 Grechko	Same as Soyuz-T5
STS-51J (Atlantis)	3-Oct-85	Bobko Grabe Hilmers Stewart Pailes	4:01:44	Eye-Hand Coordination During SMS (DSO 451)
STS-61A (Challenger) German Spacelab Mission (D1)	30-Oct-85	Hartsfiel Nagel Buchli Bluford Dunbar Furrer Messerschmid Ockels	7:00:44	European Experiments on the Vestibular System: Tonometry, Spatial Disorientation, Cognitive Adaptation, Causation of Inversion Illusions, Space Motion Sickness, Mass Discrimination Vestibular Adaptation Using the European Vestibular Sled
STS-61B (Atlantis)	26-Nov-85	Shaw O'Connor Cleave Spring Ross Vela Walker	6:21:04	Clinical Characterization of SMS (DSO 455)
STS-61C (Columbia)	12-Jan-86	Gibson Bolden Chang-Diaz Hawley Nelson Cenker Nelson	6:02:03	Clinical Characterization of SMS (DSO 455) Eye-Hand Coordination During SMS (DSO 451) Otolith Tilt-Translation Reinterpretation (DSO 459) Visual Observations from Space (DSO 204)

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
Kosmos-1887	29-Sep-87	Rhesus Monkeys; Various bugs; Rats	13:00:00	Effect of Microgravity on Metabolic Enzymes of Hippocampus and Spinal Cord in Rat
Soyuz-TM5 / Mir-3	7-Jun-88	Solovyev Savinykh Alexandrov	9:20:10	Psychomotor Studies
STS-26 (Discovery)	29-Sep-88	Hauck Covey Lounge Nelson Hilmers	4:01:00	Otolith Tilt-Translation Reinterpretation (DSO 459) Visual Observations from Space (DSO 204)
Soyuz-TM7 / Mir-4 French Aragatz Mission	26-Nov-88	Volkov Krikalev Chretien	24:18:07	Physalie Experiment: Study of Postural, Oculomotor, and Cognitive Systems
STS-28 (Columbia)	8-Aug-89	Shaw Richards Adamson Leestma Brown	5:01:00	Otolith Tilt-Translation Reinterpretation (DSO 459) Postural Equilibrium Control During Landing/Egress (DSO 605)
Kosmos-2044	15-Sep-89	Rhesus Monkeys; Male specific pathogen free Wistar Rats	14:00:00	Adaptation of Optokinetic Nystagmus to Microgravity Effect of Microgravity on: Metabolic Enzymes, Neurotransmitter Amino Acids, and Neurotransmitter Associated Enzymes in Selected Regions of the Central Nervous System Functional Neuromuscular Adaptation to Space Flight Metabolic and Morphologic Properties of Muscle Fibers and Motor Neurons after Space Flight: II. Ventral Horn Cell Responses to Space Flight and Suspension Studies of Vestibular Primary Afferents in Normal, Hyper- and Hypogravity
STS-33 (Discovery)	22-Nov-89	Gregory Blaha Musgrave Carter Thornton	5:00:06	Preflight Adaptation Training (PAT) (DSO 468)
STS-36 (Atlantis)	28-Feb-90	Creighton Casper Mullane	4:10:18	Postural Equilibrium Control During Landing/Egress (DSO 605)

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
		Hilmers Thout		Preflight Adaptation Training (PAT) (DSO 468)
STS-41 (Discovery)	6-Oct-90	Richards Cabana Shepherd Melnick Akers	4:02:10	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3)
STS-35 (Columbia)	2-Dec-90	Brand Gardner Hoffman Lounge Parker Durrance Parise	8:23:05	Postural Equilibrium Control During Landing/Egress (DSO 605) Preflight Adaptation Training (PAT) (DSO 468)
STS-39 (Discovery)	28-Apr-91	Coats Veach McMonagle Hieb Harbaugh Bluford Hammond	8:07:22	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3)
STS-40 (Columbia) Spacelab Space Life Sciences 1 Mission (SLS-1)	5-Jun-91	O’Connor Gutierrez Bagian Jernigan Seddon Gaffney Hughes Fulford	9:02:14	Postural Equilibrium Control During Landing/Egress (DSO 605) Vestibular Experiments in Spacelab: Smooth Pursuit, Optokinetic Nystagmus, Vestibulo-Ocular Reflex
STS-43 (Atlantis)	2-Aug-91	Blaha Baker Lucid Adamson Low	8:21:21	Head and Gaze Stability During Locomotion (DSO 614) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604 OI-3B)
STS-48 (Discovery)	12-Sep-91	Creighton Reightler, Brown Gemar Buchli	5:08:27	Head and Gaze Stability During Locomotion (DSO 614) Visual-Vestibular Integration as a Function of Adaptation (Perceptual Reporting) (DSO 604OI-1)
Soyuz-TM13 / Mir-10	2-Oct-91	Viehboeck	7:22:12	Directional Hearing in Microgravity Eye-Head-Arm Coordination and

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
AustroMir Mission				Spinal Reflexes in Weightlessness Orientation Effects from Optokinetic Stimulations Sleep Experiment
STS-44 (Atlantis)	24-Nov-91	Gregory Henricks Runco Voss Musgrave Hennen	6:22:50	Head and Gaze Stability During Locomotion (DSO 614) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
STS-42 (Discovery) IML-1 Mission	22-Jan-92	Oswald Thagard Hilmers Readdy Bondar Merbold	8:01:14	Microgravity Vestibular Investigations: Studies of Visual-Vestibular Interactions during Passive Body Rotation in Yaw, Pitch and Roll
Soyuz-TM14 / Mir-11 German ‘92 Mir Mission	17-Mar-92	Flade	7:21:52	Illusions of Verticality Sleep and Circadian Rhythm
STS-45 (Atlantis)	24-Mar-92	Bolden Duffy Sullivan Leestma Foale Lichtenberg Frimout	8:22:09	Head and Gaze Stability During Locomotion (DSO 614) Visual-Vestibular Integration as a Function of Adaptation (Perceptual Reporting) (DSO 604OI-1)
STS-49 (Endeavour)	7-May-92	Brandenstein Chilton Thout Thornton Hieb Akers Melnick	8:21:17	Head and Gaze Stability During Locomotion (DSO 614) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
STS-50 (Columbia) USML-1 Mission	25-Jun-92	Richards Bowersox Dunbar Baker Meade DeLucas Trinh	13:19:30	Head and Gaze Stability During Locomotion (DSO 614) Physiological Evaluation of Astronaut Seat Egress Ability at Wheels Stop (DSO 620) Postural Equilibrium Control

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
				During Landing/Egress (DSO 605)
Soyuz-TM15 / Mir-12 French Antares Mission	27-Jul-92	Tognini	13:18:56	Haptic Perception in Weightlessness Study of Adaptive Process in Human Proprioceptive Functions at Cognitive and Sensory-Motor Levels in Weightlessness Symmetry Detection
STS-46 (Atlantis)	31-Jul-92	Shriver Allen Hoffman Chang-Diaz Nicollier Ivins Malerba	7:23:15	Head and Gaze Stability During Locomotion (DSO 614) Visual-Vestibular Integration as a Function of Adaptation (Perceptual Reporting) (DSO 604OI-1)
STS-47 (Endeavour) Japanese Spacelab-J Mission	12-Sep-92	Gibson Brown Lee Jan Davis Apt Jemison Mohri	7:22:30	Autogenic Feedback Training Exercise (AFTE) as a Preventative Method for Space Adaptation Syndrome Head and Gaze Stability During Locomotion (DSO 614)
STS-52 (Columbia)	22-Oct-92	Wetherbee Baker Veach Shepherd Jernigan MacLean	9:20:56	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
STS-53 (Discovery)	2-Dec-92	Walker Cabana Bluford Voss Clifford	7:07:19	Head and Gaze Stability During Locomotion (DSO 614) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
Kosmos 2229	29-Dec-92	Two Rhesus Monkeys	12:00:00	Adaptation to Microgravity of Oculomotor Reflexes Functional Neuromuscular Adaptation to Space Flight Studies of Vestibular Neurons in Normal, Hyper-, and Hypogravity

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
STS-54 (Endeavour)	13-Jan-93	Casper McMonagle Runco Harbaugh Helms	5:23:38	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
STS-56 (Discovery) German Spacelab Mission (D2)	8-Apr-93	Cameron Stephen Oswald Michael Foale Cockrell Ochoa	9:06:08	Postural Equilibrium Control During Landing/Egress (DSO 605)
STS-57 (Endeavour)	21-Jun-93	Grabe Duffy Low Sherlock Wisoff Voss	9:23:44	Head and Gaze Stability During Locomotion (DSO 614) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
Soyuz-TM17 / Mir-14 French Altair Mission	1-Jul-93	Haignere	21:16:08	Haptic Perception in Weightlessness Mental Rotation Study of Limb/Body Movement in Microgravity Study of Visual-Motor Interactions during Operational Activities Symmetry Detection
STS-51 (Discovery)	12-Sep-93	Culbertson Readdy Newman Bursch Walz	9:20:11	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
STS-58 (Columbia) Space Life Sciences 2 Mission (SLS-2)	18-Oct-93	Blaha Searfoss Seddon McArthur Wolf Lucid Fettman	14:00:12	Head and Gaze Stability During Locomotion (DSO 614) Physiological Evaluation of Astronaut Seat Egress Ability at Wheels Stop (DSO 620) Postural Equilibrium Control During Landing/Egress (DSO 605) Vestibular Experiments in Spacelab

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
				Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3B)
STS-61 (Endeavour)	2-Dec-93	Covey Bowersox Musgrave Thornton Nicollier Hoffman Akers	10:19:58	Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3B)
STS-60 (Discovery)	3-Feb-94	Bolden Reightler Davis Sega Chang-Diaz Krikalev	8:07:09	Alterations in Postural Equilibrium Control Associated with Long Duration Space Flight Autonomic and Gastric Function Associated with SMS Biomechanics of Movement During Locomotion Eye-Head Coordination During Target Acquisition The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion
STS-62 (Columbia)	4-Mar-94	Casper Allen Thuot Gema Ivins	13:23:16	Head and Gaze Stability During Locomotion (DSO 614) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604 OI-3B)
STS-59 (Endeavour)	9-Apr-94	Gutierrez Chilton Godwin Apt Clifford Jones	11:05:49	Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3B)
STS-65 (Columbia) IML-2 Mission	8-Jul-94	Cabana Halsell Hieb Walz Chiao Thomas Mukai	14:17:55	Head and Gaze Stability During Locomotion (DSO 614)
STS-64 (Discovery)	9-Sep-94	Richards Hammond,	10:22:49	Head and Gaze Stability During Locomotion (DSO 614)

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
		Linenger Helms Meade Lee		Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604 OI-3B)
STS-68 (Endeavour)	30-Sep-94	Baker Wilcutt Jones Smith Bursch Wisoff	11:05:46	Head and Gaze Stability During Locomotion (Path Integration) (DSO 614B) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3C)
Soyuz-TM20 / Mir-17 ESA EuroMir '94 Mission	4-Oct-94	Merbold	31:12:35	Adaptation of Basic Vestibulo-Oculomotor Mechanism to Altered Gravity Conditions Circadian Rhythms and Sleep During a 30-Day Space Mission Otolith Adaptation to Different Levels of Microgravity Perception of Figure Symmetry by the Two Cerebral Hemispheres (STAMP) Posture and Movement in Microgravity Spatial Orientation and SMS
STS-66 (Atlantis)	3-Nov-94	McMonagle Brown Ochoa Parazynski Tanner Clervoy	10:22:34	Head and Gaze Stability During Locomotion (Path Integration) (DSO 614B) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3C)
STS-63 (Discovery)	3-Feb-95	Whetherbee Collins Foale Voss Harris Titov	8:06:28	Anticipatory Postural Activity (POSA) Autonomic and Gastric Function Associated with SMS Biomechanics of Movement During Locomotion Eye-Head Coordination During Target Acquisition

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
STS-67 (Endeavour)	2-Mar-95	Oswald Gregory Jernigan Grunsfeld Lawrence Parise Durrance	16:15:08	Head and Gaze Stability During Locomotion (Path Integration) (DSO 614B) Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3C)
Mir-18 NASA-Mir Mission 1	14-Mar-95	Dezhurov Strekalov Thagard	115:08:43	Alterations in Postural Equilibrium Control Associated with Long Duration Space Flight Anticipatory Postural Activity (POSA) Eye-Head Coordination During Target Acquisition The Effectiveness of Manual Control During Simulation of Flight Tasks (PILOT) The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion
STS-71 (Atlantis) Spacelab-Mir Mission (Mir-19)	27-Jun-95	Gibson Precourt Baker Dunbar Harbaugh Solovyev Budarin	9:19:22 STS-71 crew 75:11:20 Mir 19 crew: Solovyev, Budarin	Alterations in Postural Equilibrium Control Associated with Long Duration Space Flight Anticipatory Postural Activity (POSA) Autonomic and Gastric Function Associated with Space Motion Sickness Biomechanics of Movement During Locomotion Eye-Head Coordination During Target Acquisition The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion
STS-70 (Discovery)	13-Jul-95	Henricks Kregel Currie Thomas Weber	8:22:20	Visual-Vestibular Integration as a Function of Adaptation (Perceptual Reporting) (DSO 604OI-1)
Soyuz-TM22 / Mir-20	3-Sep-95	Reiter	179:01:41	Differential Effects of Otolith Input on Ocular Lateropulsion, Cyclorotation,

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
ESA EuroMir '95 Mission				Perceived Visual Vertical, Straight Ahead, and Tonic Neck Reflexes in Man Influence of Gravity on the Preparation and Execution of Voluntary Movements Postural Modifications in Microgravity
STS-69 (Endeavour)	7-Sep-95	Walker Cockrell Voss Newman Gernhardt	10:20:28	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements) (DSO 604OI-3B)
STS-73 (Columbia)	20-Oct-95	Bowersox Rominger Thornton Coleman Lopez-Alegria Leslie Sacco	15:21:53	Postural Equilibrium Control During Landing/Egress (DSO 605) Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
STS-74 (Atlantis)	12-Nov-95	Cameron Halsell Ross McArthur Hadfield	8:04:31	Visual-Vestibular Integration as a Function of Adaptation (Perceptual Reporting) (DSO 604OI-1)
STS-72 (Endeavour)	11-Jan-96	Duffy Jett Chiao Barry Scott Wakata	8:22:01	Visual-Vestibular Integration as a Function of Adaptation (Eye and Head Movements & Perceptual Reporting) (DSO 604)
Soyuz-TM23 / Mir-21	21-Feb-96	Onufrienko Usachev	193:19:07	Anticipatory Postural Activity During Long Duration Space Flight Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) The Effects of Long Duration Space Flight on Gaze Control The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
STS-76 (Atlantis) / Mir-21 Shuttle-Mir Mission 2	22-Mar-96	Lucid	188:04:01	Anticipatory Postural Activity During Long Duration Space Flight The Effects of Long Duration Space Flight on Gaze Control
STS-78 (Columbia) Spacelab LMS Mission	20-Jun-96	Henricks Kregel Helms Linnehan Brady Favier Thirsk	16:21:48	Canal Otolith Integration Studies (COIS) Torso Rotation Experiment (TRE)
Soyuz-TM24 / Mir-22	17-Aug-96	Korzun Kaleri	196:17:26	Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion
STS-79 (Atlantis) / Mir-22 Shuttle-Mir Mission 3	16-Sep-96	Blaha	128:05:29	Recovery of Neurological Function in Long Duration Crewmembers
STS-81 (Atlantis) / Mir-23 Shuttle-Mir Mission 4	12-Jan-97	Linenger	132:04:01	Countermeasures and Correction of Adaptation to Space Syndrome and SMS (Sensory Adaptation) Kinematic and Dynamic Locomotion Characteristics Prior and After Space Flight (Lokomotsi) Microgravity Impact on Induced Muscular Contraction (Tendometria) Recovery of Neurological Function in Long Duration Crewmembers Sleep Investigations Study of Hypo-Gravitational Ataxia Syndrome (Motor Control) Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
				(Ravnovesie) The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion
Soyuz-TM25 / Mir-23 ESA-Mir Mission	10-Feb-97	Lazutkin Tsibliev Ewald	184:22:07 Lazutkin Tsibliev 19:16:34 Ewald	Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Sleep and Vestibular Adaptation Sleep Investigations Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)
STS-84 (Atlantis) / Mir-23 & 24 Shuttle-Mir Mission 5	15-May-97	Foale	144:13:48	Sleep Investigations
Soyuz-TM26 / Mir-24	5-Aug-97	Solovyov Vinogradov	197:17:34	Countermeasures and Correction of Adaptation to Space Syndrome and SMS (Sensory Adaptation) Kinematic and Dynamic Locomotion Characteristics Prior and After Space Flight (Lokomotsi) Microgravity Impact on Induced Muscular Contraction (Tendometria) Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Sleep Investigations Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)
STS-86 (Atlantis)	25-Sep-97	Wetherbee Bloomfield Titov Parazynski Chretien Lawrence	10:19:22	Adaptation to Linear Acceleration After Space Flight (DSO 207)
STS-86 / Mir-24	25-Sep-97	Wolf	127:20:02	Sleep Investigations

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
Shuttle-Mir Mission 6				
STS-89 (Endeavour) / Mir-25 Shuttle-Mir Mission 7	22-Jan-98	Thomas	140:15:13	Recovery of Neurological Function in Long Duration Crewmembers
Soyuz-TM27 / Mir-25	29-Jan-98	Musabayev Budarin	207:12:51	Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)
STS-90 (Columbia) Spacelab Neurolab Mission	17-Apr-98	Searfoss Altman Linnehan Williams Hire Buckey Pawelczyk	15:21:50	Artificial Neural Networks and Cardiovascular Regulation Autonomic Neurophysiology in Microgravity Autonomic Neuroplasticity in Weightlessness Frames of Reference and Internal Models Integration of Neural Cardiovascular Control in Space Role of Visual Cues in Spatial Orientation Spatial Orientation of the Vestibulo-Ocular Reflex Visual-Otolithic Interaction in Microgravity Visuo-Motor Coordination during Space Flight Sleep and Respiration in Microgravity
Soyuz-TM28 / Mir-26	13-Aug-98	Padalka Avdeyev Baturin	379:14:51 Avdeyev 198:16:31 Padalka 11:19:41 Baturin	Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)
STS-95 (Discovery)	29-Oct-98	Brown Lindsey Parazynski Robinson	8:21:44	Postflight Recovery of Postural Equilibrium (DSO 605)

Mission	Launch Date	Crew-Members	Duration (D:H:M)	Neuroscience Experiments
		Duque Mukai Glenn		
Soyuz-TM29 / Mir-27 ESA Mir Mission	20-Feb-99	Afanasyev Haignere Bella	188:20:16 Afanasye Haignere 7:21:56 Bella	Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)
Soyuz-TM30 / Mir-28	4-Apr-00	Zalyotin Kaleri	72:19:42	Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)
STS-106 (Atlantis)	8-Sep-00	Wilcutt Altman Burban Lu Mastracchio Malenchenko Morukov	11:19:12	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499)
Soyuz-TM31 / ISS Expedition-1	31-Oct-00	Shepherd Gidzendko Krikalev	140:23:28	Countermeasures and Correction of Adaptation to Space Syndrome and SMS (Sensory Adaptation) Functional Neurological Assessment (Posture) Kinematic and Dynamic Locomotion Characteristics Prior and After Space Flight (Lokomotsi) Microgravity Impact on Induced Muscular Contraction (Tendometria) Sensory and Motor Mechanisms in Vertical Posture Control After Long Duration Exposure to Microgravity (Ravnovesie) Study of Hypo-Gravitational Ataxia Syndrome (Motor Control)

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
STS-102 (Discovery)	8-Mar-01	Wetherbee McNeal Thomas Richards	12:19:50	Effects of Altered Gravity on Spinal Cord Excitability (H-Reflex)
STS-102 / ISS Expedition-2	8-Mar-01	Usachev Helms Voss	167:06:41	Same as Expedition-1
STS-100 (Discovery)	19-Apr-01	Rominger Ashby Hadfield Parazynski Phillips Guidoni Lonchakov	10:19:58	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499)
STS-104 (Atlantis)	12-Jul-01	Lindsey Hobaugh Gernhardt Reilly Kavandi	12:18:36	Spatial Reorientation Following Space Flight (DSO 635)
STS-105 (Discovery)	10-Aug-01	Horowitz. Sturckow Barry Forrester	11:21:13	Spatial Reorientation Following Space Flight (DSO 635)
STS-105 / ISS Expedition-3	10-Aug-01	Culbertson Dezhurov Tyurin	128:20:45	Same as Expedition-1
Soyuz-TM33 / ISS ESA Andromede Mission	21-Oct-01	Afansyev Andre-Deshays Kozeyev	8:59:35	Cognitive Process for 3D Orientation Perception and Navigation in Weightlessness (COGNI)
STS-108 (Endeavour) / ISS Expedition-4	5-Dec-01	Onufrienko Bursch Walz	195:19:39	Same as Expedition-1
STS-109 (Columbia)	1-Mar-02	Altman Carey Grunsfeld Currie Newman Linnehan Massimino	10:22:11	Spatial Reorientation Following Space Flight (DSO 635)
Soyuz-TM34 / ISS Italian Marco Polo Mission	25-Apr-02	Gidzenko Vittori Shuttleworth	9:21:25	An Investigation of Space Radiation Effects on the Functional State of the Central Nervous System and an Operator's Working Capacity (ALTEINO)

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
STS-111 (Endeavour)	5-Jun-02	Cockrell Lockhart Chang-Diaz Perrin	13:20:36	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499) Spatial Reorientation Following Space flight (DSO 635)
STS-111 (Endeavour) / ISS Expedition-5	5-Jun-02	Korzun Whitson Treschev	184:22:14	Same as Expedition-1 Promoting Sensory-Motor Response Generalizability: A Countermeasure to Mitigate Locomotor Dysfunction After Long-duration Space Flight (Mobility)
STS-112 (Atlantis)	7-Oct-02	Ashby Melroy Wolf Sellers Magnus Yurchikhin	10:19:58	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499) Spatial Reorientation Following Space flight (DSO 635)
Soyuz-TMA1 / ISS Belgian Odissea Mission	30-Oct-02	Zalyotin De Winne Lonchakov	10:20:53	Directed Attention Brain Potentials in Virtual 3D Space in Weightlessness (NEUROCOG) Sleep-Wake Actigraphy and Light Exposure During Space Flight (SLEEP) (DSO 634) Stress, Cognition and Physiological Response During Space Flight (COGNISPACE) Sympathoadrenal Activity in Humans During Space Flight (SYMPATHO)
STS-113 (Endeavour)	24-Nov-02	Wetherbee Lockhart Lopez-Alegria Herrington Bowersox	13:18:48	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499)
STS-113 / ISS Expedition-6	24-Nov-02	Bowersox Pettit Budarin	161:01:17	Same as Expedition-1 Promoting Sensory-Motor Response Generalizability: A Countermeasure to Mitigate Locomotor Dysfunction After Long-duration Space

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
				Flight (Mobility) Study of the Action Mechanism and Efficacy of Various Countermeasures Aimed at Preventing Locomotor System Disorders in Weightlessness (Profilaktika)
STS-107 (Columbia)	16-Jan-03	Husband McCool Clark Chawla Brown Anderson Ramon	15:22:20	Sleep-Wake Actigraphy and Light Exposure During Space Flight
Soyuz-TMA2 / ISS Expedition-7	26-Apr-03	Lu Malenchen-ko	13:18:48	Same as Expedition-6
Soyuz-TMA3 / ISS Expedition-8	18-Oct-03	Foale Kaleri Duque	194:18:35 Foale, Kaleri 09:21:02 Duque	Same as Expedition-6 Directed Attention Brain Potentials in Virtual 3D Space in Weightlessness (NEUROCOG)
Soyuz-TMA4 / ISS Expedition-9	19-Apr-04	Padalka Fincke Kuipers	187:21:17 Padalka, Fincke 10:20:52 Kuipers	Same as Expedition-8 Effects of Weightlessness on Eye Movements, Body Coordination, and Posture Effects of Weightlessness on Motion Perception and Susceptibility to Space Sickness (MOP)
Soyuz-TMA5 / ISS Expedition-10	14-Oct-04	Chiao Sharipov Shargin	192:19:2 Chiao, Salizhan 9:21:29 Shargin	Same as Expedition-9
Soyuz-TMA6 / ISS Expedition-11	14-Apr-05	Krikaliev Phillips	179:00:23	Bioavailability and Performance Effects of Promethazine During Space Flight Foot/Ground Reaction Forces During Space Flight Hand Posture Analyzer Promoting Sensorimotor Response Generalizability: A Countermeasure to Mitigate Locomotor Dysfunction After Long-Duration Space Flight (Mobility)

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
STS-114 (Discovery)	26-Jul-05	Collins Kelly Camarda Lawrence Noguchi Robinson Thomas	13:21:32	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499) Spatial Reorientation Following Space flight (DSO 635)
Soyuz-TMA7 / ISS Expedition-12	3-Oct-05	McArthur Tokarev Olsen	189:19:53 McArthur Tokarev 9:21:21 Olsen	Bioavailability and Performance Effects of Promethazine During Space Flight (PMZ) Cognitive Cardiovascular Experiment (CARDIOCOG-2) Sleep-Wake Actigraphy and Light Exposure During Space Flight
Soyuz-TMA8 / ISS Expedition-13	29-Mar-06	Vinogradov Williams Reiter	182:23:44 Vinogrod Williams	Same as Expedition-12 Cultural Determinations of Co-working, Performance and Error Management in Space Operations (CULT)
STS-121 (Discovery)	4-Jul-06	Fossum. Kelly Wilson Lindsey Sellers Reiter Nowak	12:18:37	Eye Movements and Motion Perception Induced by Off-Vertical Axis Rotation (OVAR) at Small Angles of Tilt After Space Flight (DSO 499) Spatial Reorientation Following Space flight (DSO 635)
STS-115 (Atlantis)	9-Sep-06	Jett Ferguson Stefanyshyn-Piper Tanner Burbank MacLean	12:02:34	Perceptual Motor Deficits in Space (PMDIS) Spatial Reorientation Following Space Flight (DSO 635)
Soyuz-TMA9 / ISS Expedition-14	18-Sep-06	Lopez-Alegria Tyurin Reiter Ansari	215:08:23 Lopez-Alegria, Tyurin 10:21:04 Ansari	Same as Expedition-13 Anomalous Long Term Effects in Astronauts’ Central Nervous System (ALTEA) Countermeasures for Space Adaptation Syndrome and Space Motion Sickness Functional Neurological Assessment (Posture) (MR042L) Kinematic and Dynamic Locomotion Characteristics Prior and After Space Flight

Mission	**Launch Date**	**Crew-Members**	**Duration (D:H:M)**	**Neuroscience Experiments**
				(Lokomotsi) Microgravity Impact on Induced Muscular Contraction (Tendometria) Researching for Individual Features of State Psychophysiological Regulation and Crewmembers Professional Activities during Long Space Flights (Pilot) Sensory and Motor Mechanisms in Vertical Posture Control after Long Duration Exposure to Microgravity (Ravnovesie) Studies of Listing's Plane under Different Gravity Conditions (ETD) Study of Hypo-Gravitational Ataxia Syndrome (Motor Control) Study of the Action Mechanism and Efficacy of Various Countermeasures Aimed at Preventing Locomotor System Disorders in Weightlessness (Profilaktika) Test of Reaction and Adaptation Capabilities (TRAC)
STS-116 (Discovery) / ISS Expedition-14	9-Dec-06	Polansky Oefelein Curbeam Higginbotham Patrick Fuglesang Williams	12:20:45 (STS-116) 194:18:03 Williams	Functional Neurological Assessment (Posture) (MR042L) Perceptual Motor Deficits in Space (PMDIS) Spatial Reorientation of Sensorimotor Balance Control in Altered Gravity (DSO 635)
Soyuz-TMA10 / ISS Expedition-15	7-Apr-07	Yurchikhin Kotov Simonyi	173:06:28 Yurchikin, Kotov 13:19:00 Simonyi	Same as Expedition-14 Elaboratore Imagini Televisive - Space 2 (ELITE-S2)
STS-117 (Atlantis) / ISS Expedition-15	8-Jun-07	Sturckow Archambault Forrester Swanson Olivas Reilly Anderson	13:20:12 (STS-117) 111:00:21 Anderson	Perceptual Motor Deficits in Space (PMDIS) Functional Neurological Assessment (Posture) (MR042L)