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# INVESTIGATION OF POSSIBLE CAUSES FOR HUMAN-PERFORMANCE DEGRADATION DURING MICROGRAVITY FLIGHT

FINAL REPORT

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## Abstract

This report documents the results of the first year of a three-year investigation of the effects of microgravity on human performance. The two general goals of this work were to identify and define the incidence and nature of performance degradation in space and to conduct experiments testing preliminary hypotheses about performance degradation in microgravity. In order to determine the incidence, nature, and promising countermeasures for alleged performance degradation, two approaches were taken. First, a literature search was conducted. The three primary findings of that search were a) there is sufficient evidence to indicate that some types of performance degrade in microgravity, b) there is sufficient evidence to conclude that, to date, such degradation has not interfered with mission success, and c) there is general concern in the scientific space community about the possibility of performance degradation in upcoming longer-duration flights. Potential countermeasures were identified in the literature and others suggested. Second, a structured interview was created to capture the knowledge and experiences of astronauts with regard to performance in microgravity and their opinions about the need for training-based countermeasures. In order to establish an experimental research program, hypotheses were generated and two experiments were conducted to test those hypotheses. The first hypothesis was that the effects of microgravity can be studied indirectly on earth by measuring performance in an altered gravitational field. To test this hypothesis, a group of subjects was tested on a variety of cognitive and motor tasks in one of two positions, normal (erect) and in a reclined position (rotated to a six-degree, head-down position). Results provided support for the hypothesis, suggesting that meaningful and cost-effective research can be conducted to identify tasks likely to be vulnerable to degradation in microgravity. The hypothesis was that an altered gravitational field could disrupt performance on previously automated behaviors if gravity is a critical part of the stimulus complex controlling those behaviors. In addition, it was proposed that performance on secondary cognitive tasks would also degrade, especially if the subject is provided feedback about degradation on the previously automated task. Degradation on the secondary cognitive task is theorized to be due to the subject reallocating attention from the secondary task to the previously automated task. In the initial experimental test of these hypotheses, there was little statistical support. However, when subjects were categorized as high or low in automatized behavior, results for the former group supported the hypotheses. Specifically, the predicted interaction between body orientation and level of workload in their joint effect on performance in the secondary cognitive task was significant for the group high in automatized behavior and receiving feedback, but no such interactions were found for a) the group high in automatized behavior but not receiving feedback, and b) the group low in automatized behavior.

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# I. Introduction

## A. Background

Self-reports of human performance decrements during orbiter reentry procedures prompted this work. Although there are apparently few empirical data to support the claims, they are significant because a) self-reports are likely to be directly or indirectly related to actual performance; b) extremely competent and experienced NASA pilots are not likely to create such reports unless there is a real phenomenon; c) if degradation occurs after relatively short missions, it could be exacerbated in upcoming longer flights; and d) if degradation, its source, and its cause are identified, effective countermeasures can probably be prescribed (e.g., pre-flight training, embedded training, other forms of on-board training, performance aids, etc.).

Degradation of human performance has clearly not been a significant problem in the continuing highly successful space program. However, with upcoming long-duration flights, there is increased concern that more should be known about possible sources and countermeasures. This research was funded in an attempt to identify such sources and, if found, identify countermeasures. For example, while astronaut training has clearly been adequate in relatively short-duration orbiter flights, is there a need for embedded or on-board proficiency training for astronauts on longer flights? Also, can a methodology be developed to investigate potential sources of degradation and countermeasures on earth? The present research was intended to help answer such questions.

If performance degradation occurs in microgravity, it could be due to a variety of sources. The most intuitive explanation is that degradation is a side effect of some physiological change that occurs in microgravity. While the effects of weightlessness on human physiology are continuing to be investigated, less work has been conducted to determine the corresponding effects on human performance. While there are no known direct influences of microgravity on the nervous system and cognitive functioning, there are secondary physiological changes which could indirectly mediate changes in human performance.

In addition to direct/indirect physiologically based causes of performance degradation, there are a number of possible performance-based causes of performance degradation. Following are some possible explanations for performance degradation in microgravity:

* The proprioceptive and kinesthetic cues associated with certain motor performance tasks trained in a simulator under earth's gravitational force might be inappropriate or even create negative transfer in microgravity. This could explain recent reports

by pilot astronauts that psychomotor performance rather than cognitive performance was degraded. If this is found to be the case, then possible countermeasures include changes in the human-machine interface or special training procedures.

* Much of human performance is under automatic control, with little conscious attention paid to the task(s) at hand. If gravitational stimuli are important for guiding behavior, then alteration of such stimuli would lead to performance degradation in the actual task as well as any simultaneous motor or cognitive tasks because attention would be diverted from those tasks to monitor what had been automated performance. The logic of the explanation as it is applies to microgravity follows:

  a) Performance that has been trained to a high degree becomes automated.

  b) Behavior under automatic control is guided by exteroceptive and interoceptive stimuli, but not at a conscious level, as had been the case when the subject was learning the task.

  c) Subsequent changes in the interoceptive or exteroceptive stimuli (e.g., gravitational forces) that guide the automated behavior cause performance degradation and a decrease in human reliability.

  d) The resulting performance degradation could be especially disruptive, because, since the performance had been under automatic control, the subject would have difficulty identifying the source of the disruption, become disoriented and unsure (possibly aggravating the disruption), and have difficulty compensating or correcting their performance because the behavior had been under automatic control.

  e) Degradation in such motor performance could indirectly degrade performance in other simultaneous cognitive or motor tasks because the individual's attentional resources must be reallocated to monitor the previously automated motor performance.

* In earth's gravitational field, there is a relatively constant reference field for spatial orientation; up is up and left is left. In microgravity, astronauts are exposed to situations which, because of the astronaut's changing orientation relative to his/her surroundings, violate those well-established cognitive sets (e.g., left might be up, up might be right, etc.). While a number of experiments have shown that humans can effectively adjust to new spatial reference fields if those fields are held constant (e.g., prism glasses), little is known about the human's adjustment to a constantly changing spatial reference field. Possible effects could include performance degradation (e.g., when manipulating spatially-referenced switches

or monitoring spatially-referenced displays). Possible countermeasures include better astronaut selection based on ability to spatially adjust (e.g., measures of field dependence/ independence), and providing constant spatial, tactile, or auditory cues for switch manipulation or visual monitors.

* There is actually equivalent or greater degradation in cognitive task performance, but the crew is more aware of the subtle motor performance decrement because of the immediate and salient feedback provided during the motor tasks.

* Several authors in the literature have discussed the stressful nature of space flight due, among other things, to the very nature of the potentially hazardous situation and high workload involved (perceived danger, isolation, separation from family/friends, fatigue, changes in wake/sleep patterns, etc.). The negative effects of stress on performance are well-known, especially for difficult tasks and tasks that are not well-trained or established.

* Interference Theory predicts that memory degradation is, in part, a function of the amount of activity between learning and time of recall. It is clear that during missions, astronauts are extremely active in both motor and cognitive tasks (e.g., Lebedev, 1988). Consequently, memory deterioration could be accelerated during space flights. Presumably, comparable deterioration would take much longer on earth, while conducting routine daily tasks.

* Degradation on the secondary cognitive tasks diverts attention and resources from the primary motor task, degrading what was formerly an automatized behavior pattern (Regian, 1989).

Consider the first two explanations, that weightlessness alters proprioceptive and kinesthetic feedback involved in fine motor responding, causing a degradation in motor performance, and that automated behavior involving gravitational cues could be especially vulnerable to such disruption. The results of a number of experiments conducted under weightlessness conditions support this hypothesis. Ross, Schwartz, & Emmerson (1987) reported consistent distortions in using a perceptual-motor task to discriminate masses during the D1 Spacelab Mission; Ross, Brodie, and Benson (1984, 1986) reported similar findings for Spacelab 1; Ross, Schwartz, & Emmerson (1987) reported that subjects tend to overreach in microgravity; Cohen (1970) reported that subjects tend to under-reach in high G; and Ross et al. (1984, 1986) reported that subjects tend to under-reach after returning to earth.

Presumably, reduction of earth's gravitational forces could cause altered proprioceptive, kinesthetic, afferent, or efferent information or the misinterpretation of such information. If so, then during the mission, the astronaut would adjust to the new sensory-motor information. However, the adjustment could cause negative transfer during reentry. When re-introduced to gravitational cues during reentry, the fully or partially adapted pilot is forced to operate under not only the "new" cues of gravity, but also the changing cues of gravity, since G forces are changing during reentry. Unless a veteran shuttle crew member, the pilot has never before performed the task under such stimuli. In addition to possible degradation of the motor task, one might expect degradation of other concurrent tasks because, during training, the motor task had probably come under automatic control, and now, in a novel situation, requires more resource allocation.

This report presents the results of the first year of a three-year effort aimed at identifying different possible sources/countermeasures for performance degradation in microgravity and begin an experimental investigation of possible sources of degradation.

## B. Objectives

The major objective of the overall multi-year effort is:

* To identify sources of performance degradation and corresponding countermeasures that will overcome or minimize such effects (e.g., with training or performance aids).

The objectives for the first year effort were:

Task 1: Establish an expert panel to guide future research.

Task 2: Define the incidence and nature of performance degradation in microgravity.

Subtask 1: Conduct a literature search.

Subtask 2: Create, administer, and analyze the results of an astronaut questionnaire.

Task 3: Create a methodology and conduct an initial experiment to investigate one candidate source of performance degradation in microgravity.

The present research and the research planned for the second and third years provide valuable information for increasing the human reliability, safety, and probability of mission success associated with future long-duration space flights.

## C. General Technical Approach

The overall strategy for the first year was to address the topic of performance degradation in microgravity on several fronts. The first goal was to document the incidence and nature of performance degradation in microgravity. To reach this goal, candidate causes for performance degradation were identified by conducting a literature search and preparing an astronaut questionnaire. A second goal was to establish an expert panel to help coordinate, plan, and critique research in this area. To reach this goal, the results of the literature search were organized into the most promising topics relevant to performance degradation in microgravity, and scientists active in those topics were identified as possible candidates for such an expert panel. The third goal was to create an experimental methodology for investigating possible sources of degradation in microgravity and conduct an initial experiment testing one promising explanation.

In the second and third years, the findings and methodology from the first year will be improved and expanded to test other possible sources/countermeasures with the guidance and consultation of the expert panel. Systematically, candidate causes will be investigated. If a candidate variable is found to be a significant source of degradation, countermeasures will be identified, tested, and implemented. In the following sections, the three primary tasks for the first year effort are described.

# II. Literature Search

A literature search was conducted in an attempt to a) identify sources of performance degradation and countermeasures that have been suggested in the literature or are currently under investigation; b) create a taxonomy of the most important general topic areas for human performance in microgravity that can then be used to guide areas of expertise for the expert panel and topics to be addressed in the astronaut questionnaire; c) identify candidate scientists active in critical areas; and d) identify documented incidence and nature of reported cases of performance degradation in microgravity.

Table 1. Key Words Used in the Literature Search

Group A:

| | | |
|---|---|---|
| Train* | Performance | Error |
| Reliab* | Mistake | Cogniti* |
| Psychomotor | Motor | Psycholog* |
| Behavior | Percepti* | Perceptual-Motor |
| Skill | Learn* | Transfer |
| Memory | Degradation | Automatic* |

Group B:

| | | |
|---|---|---|
| Space | Microgravity | Micro-Gravity |
| Weightless* | Zero Gravity | Flight |
| Reduced Gravity | | |

Computerized literature searches were conducted on three commercially available databases: PSYCHINFO, AEROSPACE, and National Technical Information System (NTIS). The key words used are presented in Table 1. Any documents containing one or more of the key words from Group A and one or more of the key words from Group B satisfied the logical terms of the search. In addition, duplicate articles from different databases were eliminated. The number of reports resulting from the first pass (4109) was much too large to deal with under the current level of effort. Inspection of the number of reports for individual key terms indicated that the two terms "space" and "flight" were contributing substantially to the large numbers. Those two terms generated false alarms (e.g., "space" was associated with irrelevant articles dealing with architecture or interpersonal space and "flight" was associated with less relevant articles dealing with normal aircraft). Consequently, in the second pass, space was combined with flight. This step significantly reduced the number of papers.

A previously published 1989 NTIS search was obtained that provided abstracts for the period January 1972 through August 1989 from the Aerospace Data Base for topics dealing with "Psychological Effects of Space Flight." While that search did not include all reports of interest, it was concluded that there was significant overlap with the present search. Consequently, to save duplicate printing charges, abstracts from August 1989 to present, abstracts prior to January 1972 and abstracts during the 1972-89 period that satisfied our search criteria but not those of the NTIS search were printed.

In total, 331 abstracts in the published Aerospace search, 585 abstracts from the Aerospace database that were not included in the published search, 213 abstracts from the NTIS database, and 21 abstracts from the PsychInfo database were obtained and read. Brief summaries of relevant abstracts are found in Appendix A. Articles dealing with acceleration, simulators, space suits, medical issues, and animal research were not pursued. Following the initial review of abstracts, a total of 111 representative documents were ordered. Both the Southwest Research Institute (SwRI) library and the NASA Technical Library at the Johnson Space Center participated in this collection of materials.

According to Bluth (1982), there are seven factors that relate to human errors in space flight: the environment (especially weightlessness), physiology (particularly altered body functions that affect sensory systems and mental/physical tone), technology (e.g., adequacy of the design of the human interface), personality systems (primarily individual differences in attitude and motivation), social systems (e.g., roles, schedules, communication patterns, authority, etc.), culture systems (e.g., values, beliefs, assumptions), and process (consideration of events in their larger context). However, little is known about the specific influence of these factors or their interactive effects on human error. The present literature search confirmed, extended, and expanded those seven categories.

Table 2 presents the general taxonomy used to classify relevant documents found in the literature. This taxonomy evolved through the course of the search. Summaries of articles presented in Appendix A were assigned to the category judged to be most relevant. The first two general categories address potential independent variables (physiological and psychosocial) that could affect performance. The third general category includes articles that discussed performance variables potentially affected in microgravity. The fourth general category includes articles highly related to performance in microgravity, but which do not imply specific cause-and-effect relationships.

The literature was too large to fully address all the topics identified in Table 2. Presumably, the taxonomy provided in Table 2 will be used by the Expert Panel to help guide their efforts in the second and third years. The independent variables identified in Table 2 can be divided into two major categories. The first category includes those variables usually present in microgravity (specifically, cardiovascular changes, vestibular and inner ear equilibrium changes, vision changes, altered biorhythms, space motion sickness, and psychological effects that are likely to accompany long-duration flights such as stress, crowding, limited social interaction, and confinement. The second category includes variables that could affect performance in space flight, but which are judged to be relatively unimportant or unlikely to become important because of the care taken in designing today's spacecraft. Those variables include excessive vibration, heat/cold, toxins, noise, motion forces, radiation, taste, and medication. While relevant to space flight, the latter group will not be emphasized in the following discussion.

Because the main thrust of this research effort was to address the possible degradation of performance due to microgravity, emphasis in the following literature search was placed on variables judged to be most susceptible to microgravity, notably the cardiovascular, vestibular, and vision systems. Space motion sickness and biorhythm changes were also discussed because of their relatively unique association with space flight and their potential effects on performance. While the other variables in the first category (i.e., stress, crowding, limited social interaction, and confinement) are clearly important determinants of human behavior, and while they are topics that must be considered by the expert panel in future related efforts, they were not emphasized here because there is no known conceptual reason to believe that their effects would be different in microgravity than on Earth (they would be expected to degrade performance in either environment).

The three primary goals of the following literature search were: a) present the evidence that performance degrades in microgravity, b) identify possible cause(s) for degradation, and c) identify promising countermeasures. The next three sections address those three goals.

Table 2. Classification Taxonomy for Characterizing the Literature

I. PHYSIOLOGICAL VARIABLES AFFECTING PERFORMANCE

A. General Physiological Changes in Microgravity
B. Cardiovascular Changes
C. Vestibular and Inner Ear Equilibrium Changes
D. Vision Changes
E. Altered Biorhythms
F. Motion Sickness
G. Physical Variables that Could Affect Performance

1. Vibration
2. Heat/Cold/Climate
3. Carbon Monoxide
4. Carbon Dioxide
5. Other Toxins
6. Sound (Noise)
7. Motion Forces
8. Radiation
9. Changes in Taste:
10. Effects of Medications:

II. PSYCHO-SOCIAL VARIABLES AFFECTING PERFORMANCE

A. Psychology of Long Duration Flight
B. Stress
C. Social Interaction, Isolation and Confinement (also Duration)

III. PERFORMANCE DEPENDENT VARIABLES

A. Human Performance
B. Cognitive Performance
C. Motor Performance
D. Perception in Microgravity
E. Reaction Time in Microgravity
F. General effects on Work Capacity

Table 2. Classification System for Characterizing Literature (Continued)

IV. PROJECT-RELATED LITERATURE

A. Environmental Variables Affecting Performance

1. Human Factors of Space Flight
2. Space Station Design

B. Organizational Variables Affecting Performance

1. Training
2. Astronaut Selection
3. Preadaptation to Weightlessness

C. Water Immersion and Other Techniques for Simulating Microgravity
D. Possible Paradigms, Tasks, Test Beds for Future Phases
E. Related Bibliographies
F. Interesting and Relevant Information

## A. Evidence of Performance Degradation in Microgravity

It is interesting to note that the present effort was not the first to attempt a systematic investigation of possible performance degradation in microgravity. Christensen and Talbot (1985, 1986) described the findings of an ad hoc Working Group that was convened by the Federation of American Societies for Experimental Biology to review the psychological aspects of space flight. This group:

> ". . . focused on: 1) human performance requirements for the long-term (90 d) manned mission; 2) human perceptual, cognitive, and motor capabilities and limitations in space; 3) crew composition, individual competencies, crew competencies, selection criteria, and special training; 4) environmental factors influencing behavior; 5) psychosocial aspects of multi-person spacecrews in long-term missions; 6) career determinants in NASA; 7) investigational methodology and equipment; and 8) psychological support."

The authors cited a number of studies that reported no "overt functional impairment caused by adverse psychological responses" (i.e., Johnston, Dietlein, & Berry, 1975; Johnston, & Dietlein, 1977; Gazenko, Genin, & Egorov, 1981; and Nicogossian & Parker, 1982), as well as several other authors who cited examples of such impairments (presented in the following sections). This was not the first time that such a discrepancy was reported. Parin and Kas'yan (1969) reported that two different views existed at that time. Seven studies were cited in which the authors concluded there was no effect of microgravity on motor performance and a second group of studies was cited in which performance degradation was found for sensory performance (visual perception) and motor performance (accuracy of hits on a target, coordination of movements, muscle strength in hands, speed of motor responses, time to turn off toggle switches, and errors in determining indicator pointers).

These seemingly conflicting conclusions are not necessarily contradictory. It is possible that two different questions are being addressed. The first question involves whether any change in performance has been measured (to which the answer has often been affirmative). The second question involves whether evidence exists that performance would degrade to the point that safety or mission success would be compromised (to which the answer has often been negative). Consequently, the two sets of data might not be as inconsistent as they first appear; minor degradation in certain behaviors might not lead to major overt functional impairments.

One of the ad hoc Working Group's major findings was a lack of scientific research in the area (a finding which was supported in the current literature search):

> "The most serious lack of data pertains to the performance of astronauts and other crew members during training, simulations, and actual space flight."
>
> "The Extremely limited information available on details of spacecrew performance inflight was regarded as a pivotal gap in essential knowledge for identifying clues for improving design, operational procedures, training, and formulation of research plans. The Working Group advocated crew performance assessment in all space flights as well as in ground training and simulations including participation by expert behavioral scientists."

In summary, Christensen and Talbot reported "Documented untoward psychological and psychophysiological responses to space flight" including a) transient disorientation and spatial illusions (Beregovoy, 1979; Leonov & Lebedev, 1973; Yuganov & Kopanev, 1975; b) temporary alterations of visual function (Beregovoy, 1979; Leonov & Lebedev, 1973), c) anomalous myopias (Liebowitz, Hennesy, & Owens, 1975; Liebowitz & Owens, 1975; Roscoe, 1982; and Whiteside, 1965), d) performance degradation and sleep disturbances associated with undue shifts in work, rest, and sleep schedules (Berry, 1970; Leonov, 1979; Leonov & Lebedev, 1973; and Strughold & Hale, 1975); and e) space sickness, which might have a significant psychological/performance effect in some people (Homick, 1979; Homick & Miller, 1975).

There are two types of evidence in the literature relevant to the question of performance degradation in microgravity: a) evidence based on anecdotal reports about astronaut/cosmonaut experiences during space flights and b) evidence based on systematic scientific experimentation. While the latter is obviously preferable, the former information can also be important, especially in an area in which few experimental data exist. In the following two sections, evidence from historical accounts and scientific studies are presented.

### 1. Historical Accounts of Performance Degradation During Space Flights

Many of the anecdotal reports of degradation cited in this section were found in the translated Soviet literature. A number of Soviet review articles by different authors were found, often containing the same findings. Because of differences in reporting style, translation effects, and the fact that many cited papers have not been translated, it was often difficult to identify specific authors associated with specific experiments. Consequently, in this paper, citations are usually associated to the authors of the review articles that contained the information.

According to Khrunov, Khachatur'yants, Popov, and Ivanov (1974), human error represents a substantial portion of total space system reliability:

> "So, Grodesky and Levy in one of their reports devoted to the comparative analysis of existing American rocket systems, noted that mistakes of the human operator make up 20-53% of the system's reliability."

Reports of performance degradation or conditions that could produce degradation go back to the earliest days of space flight. Clark (1963) discussed space illusions and proposed that they could result from the effects of microgravity on the vestibular and visual systems. For example, Clark reported that an oculo-gyral illusion was experienced by Glenn (1962) during orbital flight. This illusion can be created when a subject is rotated in darkness while watching a visual object rotating in the same speed and direction. If, for example, the subject's rotation to the right is first accelerated and then held at a constant velocity, a two-stage illusion occurs. First the object appears to move rapidly to his right; next, the object tends to move to the left. Regarding perception of the vertical and horizontal, Clark reported that the vertical and median plane both shift in a direction opposite to that of rotation. If the subject moves to the right, then the apparent vertical will shift counter-clockwise about two degrees. Also, because of the relative boredom and sensory isolation that could occur on some flights, Clark suggested that astronauts might be vulnerable for the autokinetic illusion (the perception of apparent motion of a stationary object). It was also suggested that such conditions might cause astronauts to direct more attention to otherwise faint vestibular sensations.

Isakov, Popov, and Khachatur'yants (1965) described some evaluations of cosmonaut performance in the Russian space program. While concluding there were no significant problems with the ability of crew members to carry out their assigned operations, they also reported a number of cases in which performance was degraded in microgravity. Time spent carrying out assigned functions was somewhat longer in early flight than on Earth or later in the flight. Also, the time to complete "logic tests" was reported to degrade in early flight.

As an example of degraded performance, Isakov et al. presented data showing that the time for V. Komarov to orient the ship was almost twice as long on the second orbit than in the later orbits or during training on Earth and proposed that the degradation could be due to external inhibition. They reported that a study of the "visual analyzer" did not reveal any marked changes, but that "visual operating proficiency was somewhat reduced in a number of cases, particularly toward the end of flight." In studying the quality of operative memory, they reported a shift in the types of errors, which they interpreted to indicate a weakening of operative memory over flight duration. In an analysis of "the dynamic characteristics of the operator in a model control system," they reported performance degradation of up to 25% when compared to Earth-bound training exercises. In an early argument for on-board training, they argued that "this would not occur if we had the opportunity to train crews in orbiting space stations."

Faulty perception of sensory information could either directly or indirectly lead to performance degradation. For example, according to Alyakrinskiy (1967):

> "P.B. Miller reports that during the attempts to set a mobile light beam horizontally in accordance with the subjective perception of the vertical during the Gemini-5 flight, G. Cooper made an error of 32 degrees."

Gazenko (1983) reported that persons exposed to microgravity often have illusions of falling or flying in a downward direction. Soviet cosmonauts have also reported illusions of visual inversions (feeling that they are upside down), believed to be caused by the effects of microgravity on the vestibular organs. Parin and Kas'yan (1969) reported that several cosmonauts experienced visual inversions which usually dissipated quickly, but, in some cases persisted throughout the flight. Graybiel and Kellogg (1966) supported the vestibular explanation of the inversion illusion. They found that, when subjected to microgravity during parabolic flight, some individuals with a normal vestibular system experienced the illusion but not one of a group of persons with bilateral labyrinthine defects experienced the illusion. Berry (1971) reviewed the biomedical findings for the 54 persons who had been in space at that time. Berry reported that almost all crew members had reported a transient "fullness-of-the-head" sensation similar to hanging upside down.

A major review of the research and observations on the performance of cosmonauts in the Soviet space program was presented by Leonov and Lebedev (1973). Many of the data reported there are similar to the findings reported in other another major translated works (e.g., Parin & Kas'yan, 1969). A variety of psycho-physiological effects are discussed. A series of studies by Kitayev-Smyk are described in which a number of illusions are reported for subjects experiencing microgravity during parabolic flight.

> ". . . images grew, became pale, displaced downward, rocked from side to side . . . the entire figure became distorted: the circle became an ellipse, the square became pear-shaped, and straight lines became curved."

Kopanev and Yuganov (1974) reviewed studies and self reports of astronauts in the Gemini and Apollo programs. Regarding sensory impressions, astronauts experienced sensations of "heaviness" upon entering microgravity. This phenomenon has been attributed by some to the redistribution of blood to the head (as the feeling one experiences when hanging upside down) and by others to the general change in signals sent from the various sensory apparatus sensitive to gravity. Also, Berry (1970) reported that astronauts did not experience hunger as often and attributed it to the "expansion" of their stomach. Three Apollo astronauts suffered illusions of being inverted. Some astronauts observed flashes of light at an interval of every two minutes with eyes open or closed. Gemini 4 astronauts, when approaching a target, "noticed themselves in error in visual evaluation of distance by a factor of 4-5."

Albery and Repperger (1990) reported that astronauts tend to perceive time in microgravity as compressed relative to on Earth, leading to the expression "time compression syndrome" coined by Schmidt and Reid, 1985). Schmidt and Reid also reported that astronauts feel that standard mental activity takes longer in microgravity. Albery and Repperger argued that research in these areas is important because of the possible implications for performance on mission-critical tasks:

> "After the astronauts have adapted to the zero G environment and then re-enter the atmosphere, they may encounter difficulties in making decisions quickly and in controlling the vehicle."

Albery and Repperger also reported that anecdotal self-reports by astronauts indicate that things weigh too little in microgravity and too much upon return to Earth.

Regarding cognitive performance degradation, Khachatur'yants (1975) argued that findings of Soviet experimentation showing degraded performance for operational memory and complex reaction time (data which will be discussed in a later section) can help explain actual incidents in flight. During Gemini-4, astronaut MacDivitt was unsuccessful in an experiment in which he attempted to approach with the second stage of the carrier rocket during his first and second orbits in microgravity. During the second orbit of Gemini-10, astronaut Young successfully docked with the Agena rocket after spending twice as much fuel as planned. Voskhod cosmonaut Komarov spent twice as much time orienting the spacecraft on the first orbit of flight than the second orbit. According to Khachatur'yants "One could cite many such examples." He states:

> ". . . an analysis was made of the prerequisites that could lead to complications of the space flight. It proved that 17% of these prerequisites appeared as the result of erroneous crew actions and that more than half of these occur in the initial period of adaptation."

Concerning motor activity in microgravity, Khrunov, Khachatur'yants, Popov, and Ivanov (1974) concluded that, based on subjective statements made by cosmonauts, "deformation of motor skills in flight occurs both with respect to quality and time of completion." According to Leonov and Lebedev (1973), Popovich emphasized that the novelty of microgravity causes "tension" when performing a task. Similarly, Feoktistov noted that constant vigilance and correction of motor activities quickly led to a feeling of fatigue.

Kas'yan, Kopanevk, and Yuganov (1969) in a general review of the effects of microgravity on motor coordination found evidence for degradation in both experimental findings and anecdotal reports. For example, they state that: "Armstrong (1953) and Gaspa (1953) also indicated the possibility of the arising of disturbances in the coordination of movements . . ." Their review lead them to the conclude that: "the motor activity of people is not disturbed if they are attached to the working area." However, in a free-floating environment, movement can potentially disturb equilibrium.

According to Bluth (1982), human error during spaceflight is a strong concern:

> "In spite of great successes, both the American and Soviet space programs have suffered tragic accidents, near tragic accidents, as well as a varied list of mistakes and human errors."

The author described several incidents of human error in both the American and Soviet space programs. For example, an "exuberance error" was reported by Wolfe (1979). Also, Scott Carpenter used a dangerous amount of his retro fuel in curiosity during the Mercury 7 flight, and then forgot to throw the switch that cut manual control when he went to fly-by-wire. Hence, fuel from both systems was expended. Because of a 9-degree error and because of operating the switch too late, he ended up 250 miles off target.

Bluth reported another incident that occurred during the Apollo Soyuz Test Project. When the American capsule reentered, the crew forgot to set two critical switches (Stafford and Brand both missed it). As a result, the crew began to choke and gag as nitrogen oxide gas (which should have been dumped with switches) filled the cabin. To complicate matters, it took five minutes for Stafford and Slayton to un-stow the oxygen masks:

"The effect of such a toxic mixture on the lungs could be permanent and fatal. It was not, but in evaluating the reasons for this error and the others occurred, Astronaut Walt Cunningham suggested that Stafford and Slayton did not train as much as they should have for the mission and 'the crew did less training together than usual, even for those phases of the mission which require close coordination'" (Cunningham, 1977).

In addition, Bluth reported that some of the problem could be attributed to astronaut scheduling (apparently publicity efforts interfered with flight preparation). On-board scheduling was also cited as a problem for the Skylab IV 84-day mission. Because new experiments were added after the mission started, the crew fell behind and "the harried crew was plagued with errors and mistakes" (Skylab Transcription, 1974). While microgravity is probably not the cause of such performance effects, it is very possible that it could have exacerbated the problems.

According to Bluth, the Soviet program has reported several incidents of human error. In one case of exuberance error, Cosmonaut Romenenko forgot to attach his tether and almost floated away (Oberg, 1981). Vereschetin, deputy chairman of Intercosmos Council told attendees of a news conference that "cosmonauts' efficiency declined during long flights" (Los Angeles Times, 1981). On such long-duration flights, the Soviets have gone through a careful process to make sure the crew is compatible. Yet, there are several incidents of strain, disagreements, and arguments within the crew and between the crew and the mission-control staff. There are also examples of mood swing, difficulty in sleeping, and increased tension. Interestingly, Bluth reported that cosmonauts are reluctant to use games provided for relaxation, preferring to work instead. Cosmonaut Kovalenok reported that in space you want to "load yourself with work so the time will go faster. Otherwise, you feel that the time slows down,"(Kovalenok, 1980).

Bluth argued that, while many difficulties could be due to the microgravity environment, the fact is that similar difficulties have been found on Earth in related environments. There was one report that on an oceanographic research vessel, the crew threw $50,000 in specimens overboard because of a dispute. On submarines, crew members become depressed, irritable, annoyed, disinterested, bored, uncomfortable, and frustrated. Other symptoms include insomnia, headaches, anxiety attacks, a decrement in alertness and reaction time, vulgar language, joking, establishing pecking orders, feuding among small groups, and making errors. On the undersea laboratory Ben Franklin, during a NASA 30-day study, six crew members became withdrawn and needed more privacy and had difficulty sleeping. Also, a major conflict between surface staff and the underwater crew broke out, resulting in performance errors. During the Sealab and Tektite studies, performance degradation was reported and a fatal accident occurred when the crew decided to abandon a buddy system because they preferred to work alone.

Bluth reported that findings from space simulators are mixed. No problems were reported during a McDonnell Douglas 90-day study, with the crew of four maintaining high performance. During the NASA SMD III Spacelab 7-day simulation, some difficulties were reported, but no performance errors. NASA-sponsored work at Johns Hopkins showed that when performance requirements, norms, or group membership were changed, then social interaction, error rate, quality and amount of work, testosterone level, and willingness to work all can be affected.

Reports of crew stationed in the Arctic and Antarctic (usually for six months) have described numerous incidents including one murder, many stabbings, altercations, and alcoholism. The Naval contingent showed a 40% increase in stress related symptoms of anxiety, depression, insomnia, hostility (Gunderson, 1968). Performance degradation attributed to such psychological origins have been reported in the space program. For example, Christensen and Talbot (1985, 1986) cited incidents from space flight:

> "Anecdotal information from space missions of the United States and Soviet Union includes other examples of adverse psychological effects such as hostility between space- and groundcrews, friction between members of spacecrews, and episodes of mental depression," (Bluth, 1981; and Helmreich, 1984 are cited).

Finally, reports of performance degradation are not limited to the microgravity stage of flight. Ratino, Repperger, Goodyear, Potor, and Rodriguez (1988) cited anecdotal information reported by Schmidt and Reid (1985) indicating that after astronauts reenter the Earth's atmosphere:

> "they may encounter difficulties in making decisions quickly and controlling the vehicle. A number of anecdotal comments have been reported from the astronauts during the reentry period. The syndrome is termed the "Time Compression Syndrome."

## 2. Experimental Evidence of Performance Degradation

According to Alyakrinskiy (1967), in an attempt to study the effects of microgravity, subjects have been tested:

> ". . . in small cabins, in special chairs, under the observance of strict bed rest, during submergence of the subjects in water or in various solutions, with the use of the lift effect (in ordinary and express elevators, in falling capsules and containers, during parachute jumps), during the flight of aircraft along a ballistic curve . . ., and under conditions of orbital flights of single- and multi-place spacecraft."

Alykrinskiy stated that among the most scientifically valuable studies are "those which typify the motor activity of man, the features of his motor coordination during a change (in any direction and by any amount) of the gravitational force..." Alykrinskiy concluded that a general performance degradation is usually evident:

> "The disruption of senso-motor coordination in the state of hypodynamia as a rule is combined with a decline in the general mental work capability and by a deterioration in such mental functions as perception, thinking and attention."

A number of reports have summarized findings from experimental investigations of the effects of space flight on human performance (e.g., Parin and Kas'yan, 1969; Leonov and Lebedev, 1973; Khrunov, Khachatur'yants, Popov, and Ivanov, 1974). In one such discussion, Khrunov et al. reported that an earlier analysis (Ivanov, Popov, & Khachatur'yants, 1967), led to the conclusion that "prolonged weightlessness somewhat disturbs visual function, operator memory, and leads to discoordination of purposeful activity." Because human errors usually fall into these three categories (perceptual, cognitive, and motor), experimental findings are presented separately in the following sections. Although it is expeditious to treat the three categories of performance separately, the reader is cautioned that in the real world, these three systems interact in a complex manner. Also, experimental results will be limited here to evidence resulting from actual microgravity (including research conducted under parabolic flight). However, because another popular method of simulating microgravity (neutral buoyancy) produces less than perfect microgravity characteristics, those data will be presented later in this section. Finally, although work capacity is not a direct measure of human performance, because of the relationship between fatigue and human error, research in that area will be presented in this section.

### a. Perceptual Performance Degradation

Clark (1963) reported that humans are very accurate at estimating the vertical and horizontal, unless they are tilted. For large tilts (e.g., 90 degrees), the "A-phenomenon" is likely to occur; specifically, a vertical line is perceived as tilted in the direction opposite to that of the body tilt. For small tilts (e.g., 30 degrees), the "E-phenomenon" is likely to occur; specifically, a vertical line is judged to be tilted in the same direction as the body. In cases of increased gravitational force, the "oculo-graphic illusion" has been reported (e.g, a subject rotating in a counter-clockwise direction and facing in the direction of the rotation reports that a horizontal bar is tilted clockwise or, if facing the center of the rotation, reports that a stationary object tends to move upward). Clark reported the occurrence of an oculo-agravic illusion during parabolic flight. In parabolic flight, periods of increased gravity are followed by periods of reduced gravity. During increased gravity, subjects reported that targets were higher than they actually were and during simulated microgravity, targets were reported as lower than they actually were. It should be noted that this phenomenon might be short-lived or related to the unusual circumstances associated with parabolic flight. Clark cautions against over-generalization: "However, there is no reason to believe that these particular short-lived effects can be generalized to prolonged periods of zero gravity in orbital flights."

Alyakrinskiy (1967) described work conducted by Soviet researchers, in which subjects were classified into three groups characterizing their tolerance for microgravity (indifferent, positive, and negative). Those with a negative tolerance are completely disoriented, lose contact with other people, and develop "the illusion of falling, accompanied by a feeling of horror and high motor activity." Alyakrinskiy gave reports of persons who reported being very comfortable in microgravity and others who reported "disruption of their somatic and neuro-mental well-being."

Alyakrinskiy pointed out that long-duration flights almost certainly create conditions of sensory deprivation, conditions which have been shown in laboratories to: a) illusions and errors in recognition; b) a feeling of the presence of another person; c) dreaming accepted as reality; d) decreased capacity for mental work and interest in the study along with increased self criticism; e) indifference; f) slowed reactions and motor responses; g) degraded ability to perform mental operations; h) sleep disturbances; i) degraded operational memory; j) degraded performance on complex sensorimotor tasks; k) distorted time perception; k) states of excitement; l) altered personality; m) increased sensitivity to the remarks of others; and n) a nonobjective evaluation of the performance of others. While these effects were found in studies involving reduced sensory stimulation or reduced motor behavior, they are possibly relevant to long-duration space flight, and steps must be taken to prevent such occurrences, monitor crew behavior for their occurrence, and provide countermeasures should they occur.

Lebedev and Chekirda (1968) demonstrated that brief exposure to microgravity in parabolic flight resulted in errors when estimating the angle of rotation in a Barany seat. The errors were typically underestimates of actual rotation and were attributed by the authors to increased sensitivity of the semicircular canals and a subjective sensation of more rapid passage of time. However, subjects were able to decrease errors in subsequent trials, indicating rapid adaptation to the effects of microgravity.

Clement, Berthoz, & Lestienne (1987) presented findings of a study conducted aboard a joint French-American Discovery spaceflight that investigated adaptive mechanisms of postural and oculomotor systems in microgravity. Multisensory integration is the process by which vestibular (especially the otolith organ), tactile, proprioceptive and visual information are integrated to make single unambiguous perception of body orientation with respect to the environment. According to Clement et al., this is a flexible process and has been repeatedly demonstrated to be adaptable to rearranged sensory signals. In microgravity, the central nervous system must make profound changes in the weights associated with different stimulus sources. Based on previous work and on the inconsistent nature of stimulation from the other senses in microgravity, they expected vision to predominate.

Clement et al. described an experiment conducted in space in which subjects were rotated in yaw, pitch and roll with eyes their closed and asked to report the angle they were rotated (up to 360 degrees). They found that reports of change in yaw were accurate and both roll and pitch were over-estimated. This might be explained by the fact that on Earth, yaw is the only movement that is determined by the semicircular canals alone; the other two also involve the otoliths.

In another experiment reported by Clement et al., subjects in orbit were asked to mentally rotate a visual cabin scene until it was no longer recognizable. They found that, over days, subjects were able to increase the amount of rotation. Specifically, on the first day, they could rotate the scene 65 degrees but by the seventh day, they could rotate the scene 180 degrees. Clement et al. concluded that these results indicate the increased flexibility of the visual system to adjust to different orientations in microgravity.

In another experiment, Clement et al. asked subjects to write their name across the page and down page with their eyes closed. They found that length shortened in space and that vertical writing was more shortened than horizontal writing. This effect was short-lived and their writing returned to normal after about five days. They asserted that their results contradict earlier Gemini results indicating no disturbance in the vertical reference.

Regarding time perception in space, Leonov and Lebedev (1973) reported that, in general, those subjects who reacted well to microgravity underestimated time intervals. "They perceived an interval of 35-40 sec as lasting 15-20 sec." On the other hand, subjects who thought microgravity was an unpleasant experience overestimated time intervals (i.e., reported a 24-26 second interval as lasting 60 seconds or more). They also reported that cosmonauts familiar with microgravity were more accurate in their perception of time. However, they went on to describe the findings of isolation studies in which subjects have been found to underestimate time and, to the extent that long-duration flight approximates such an isolation environment, asserted that such underestimation of time can be expected.

In an attempt to empirically test reported changes in time perception during and after microgravity, Ratino, Repperger, Goodyear, Potor, and Rodriguez (1988) used a test battery including simple reaction time, choice reaction time, and a time-perception task to test aboard a 1985 Space Shuttle flight. They reported that perception of the shortest (2-second) time was "progressively overestimated as the mission proceeds." Perception of longer periods of time were less affected, indicating that length of the test interval is a variable that affects the accuracy of estimation.

Similar results were reported by Albery and Repperger (1990), who conducted five experiments to test the effects of microgravity on time and mass perception. Regarding time perception, they reported that performance on both long and short intervals was degraded (long duration tasks were underestimated and shorter duration tasks (e.g., 2 seconds) were overestimated.

Regarding mass-perception, Albery and Repperger found that performance was degraded in microgravity. Difference thresholds for mass discrimination were reported to be 1.9 times greater in microgravity than on Earth. This finding was consistent with earlier reports. For example, Ross, Schwartz, & Emmerson (1987) reported consistent distortions in using a perceptual-motor task to discriminate masses during the D1 Spacelab Mission and Ross, Brodie, and Benson (1984, 1986) reported similar findings.

### b. Cognitive Performance Degradation

Unfortunately, not many reports could be identified which addressed the effects of microgravity on cognitive performance. In one major summary, Parin and Kas'yan (1969) reported the results of a study indicating decreased operative memory when in microgravity (especially early in the flight). However, it was difficult to understand the exact nature of the task, and, from its description, a motor task might have also been involved. As a result, it is difficult to determine whether to attribute the resulting degradation to operating memory or to the possible motor component. In a later account, Khachatur'yants (1975) defined operational memory as the "short-term direct memory which enters the algorithm of accomplishing any particular operation as a component element." Khachatur'yants reinforced the earlier finding of degradation by reporting that operational memory had been found to decrease sharply up until the thirtieth orbit and then recover by about the seventieth orbit.

Khachatur'yants also reported that, while simple and choice reaction time was not degraded, reaction time was impaired for selection and complex reactions of prediction. Because the latter tasks involve more cognitive activity than the former, these results suggest that cognitive activity is more impaired than motor activity (at least on reaction-time tasks). In another account of the same study, Khrunov, Khachatur'yants, Popov, and Ivanov (1974) reported degradation was evident for a reaction-time task involving "more complex associative reaction of extrapolation." They reported that degradation/recovery the complex reaction time task followed approximately the same temporal profile as that of operative memory (increased degradation over the first 30 orbits and then precipitous recovery by the third day).

More recently, Hideg, Bognar, Remes, Kozarenko, Myasnikov, and Ponomareva (1982) presented data on the cognitive performance of cosmonauts on Salyut-6. A small portable device called the "Balaton" was used to measure simple and four-choice reaction time, pulse rate, and galvanic skin response to provide estimates of information processing ability. According to Hideg et al., first-time cosmonauts showed a decrease in information processing speed early in the flight.

### c. Motor Performance Degradation

A rather substantial literature was found for the topic of motor performance degradation in microgravity, but most of it described relatively early research (i.e., 1960's). The presence of a more substantial literature for motor than cognitive performance degradation is partially due to the fact that there is an intuitive mediating mechanism in the case of motor behavior (i.e., changes in proprioceptive and kinesthetic feedback due to changes in gravitational forces), while such a mediating mechanism is not present (or not intuitively present) for cognitive performance. Also, it should be noted that, with the possible exceptions of reflex behaviors, classically-conditioned responses, and some automated behaviors, cognitive behavior is involved to some extent motor behavior. To complicate matters, it could be argued that perceptual behavior is also involved in most cognitive and motor performance. Consequently, if degradation is found in a motor task, it is often difficult to determine whether it should be attributed to the perceptual, cognitive, or motor components.

In one of a number of review articles, Leonov and Lebedev (1973) stated that a number of theorists predicted degradation of motor coordination in microgravity before space flight had been achieved (e.g., Haber, 1951; Armstrong, 1953; and Gaspa, 1953). They reported the results of numerous studies conducted in both short-term microgravity (e.g., during parabolic flight) and in orbital space flight, in which various motor performance measures showed degradation (i.e., aiming, tracking, mission-related tasks, producing a designated muscular force, performing radio-telegraph communications, performing on a coordinograph, pointing, using tools, drawing, and writing). Leonov and Lebedev concluded that "The data which we analyzed indicate that man's motor skill coordinational structure is altered under weightless conditions."

In one experiment reported by Leonov and Lebedev (1973), (analyzed by Ivonov, Popov, and Khachatur'yants), degradation was found in a motor tracking response in microgravity relative to performance on Earth. They also reported a general tendency for most subjects to improve their performance when given extended practice in microgravity environments.

Leonov and Lebedev also reported that in two series of studies by Von Beckh (1954) and Gerathewohl (1954), subjects were asked to aim at targets with their eyes open or closed when on Earth and when in microgravity. Although the tasks were slightly different (Von Beckh had subjects attempt to place "x's" in target squares and Gerathewohl asked subjects to aim a pencil at the center of a target), they both showed more degradation a) when denied visual feedback and b) when in a microgravity environment. In both cases, errors tended to be vertically elevated. This is expected because the subject is compensating for a gravitational force which is absent. In both the Gerathewohl (1954) and Gerathewohl, Strughold, and Stallings (1957) data, there was also a tendency for errors to be to the right of the target. These errors tended to diminish with experience.

Leonov and Lebedev (as well as several other reviewers) reported research conducted by Kitayev-Smyk (1963) indicating that microgravity degraded the accuracy of fire in a target-shooting task and that errors tended to be high and to the right. Interestingly, there was also a tendency for a major orientation error among Von Beckh's subjects. Specifically, in a task in which subjects were instructed to create a diagonal line out of x's, "in most cases the crosses began to deviate after the third cross at a 90-degree angle from the diagonal toward the upper right corner." Parin and Kas'yan (1969) cited two other Von Beckh studies (1953, 1956), which also reported deterioration of orientation/coordination in lower animals and humans.

Leonov and Lebedev reported that Zverev and Kitayev-Smyk (1963) found increased time was required when operating toggle switches and when setting indicator pointers to a given position (in the second task, errors increased by about three to four times). They also reported the findings of a carefully conducted bio-mechanical analysis of the motions and forces involved when subjects were using a tool (hammer) on Earth and in microgravity, and found differences primarily in the vertical components.

In yet another motor-performance task, Leonov and Lebedev described the work of Ivanov, Popov, and Khachatur'yants. Analysis of radio-telegraph communication performance was found to degrade, especially early in flight: "the pause between the symbol elements doubles, the dash becomes somewhat longer, and so on."

Perhaps one of the most sophisticated and developed skills involving motor coordination is handwriting. Mantsvetova, Neumyvakin, Orlova, Trubnikova, and Freidberg (1965) reported that, although several previous authors reported no evidence for degradation of motor coordination in microgravity (e.g., in a task involving hitting a target), they found marked deterioration of writing ability in microgravity by examining cosmonaut log entries and notes. They argued that this is a significant finding because it has been "found that motor coordination is a fairly accurate index of capacity for work and can be effectively used in investigations." They asserted that handwriting is an automated behavior and that it is sensitive to a number of manipulations:

> "In the learning of writing the movements used to make the letters are built up into a system of habits and become relatively constant and characteristic of the writer. In people with a highly developed "hand" the writing becomes automatic to a high degree. At the same time, it has been shown in a number of investigations [references cited] that various external conditions (position of writing instrument, sitting position, quality of paper, ambient temperature, etc.), as well as the general state of the organism (fatigue, emotion, certain nervous diseases, etc.) can upset the elaborated automatic movements and affect motor coordination.
>
> The degree of deviation in motor coordination can be used to assess the state of certain other physiological functions. We think that the degree of change

in motor coordination will provide some information for assessment of the capacity of the cosmonaut for work at different times during the flight."

The present authors agree with this argument and believe that, in addition to assessing physiological functions, degradation of handwriting can serve as a predictor of other forms of human performance including coordinated motor performance and, in certain cases, concurrent cognitive performance. In addition, the present authors argue that the amount of degradation will depend on the extent that the behavior is under automatic control and guided, in part, by gravitational cues. Mantsvetova et al. made an observation that supports this hypothesis:

> "The deterioration in motor coordination judged by the described characteristics was more pronounced in the entries of cosmonauts whose handwriting showed less variation. For instance, the deterioration of motor coordination in the first period of the flight was greater in Nikolaev than in Popovich."

It is argued here that less initial variation indicates that the writing task is under greater initial automaticity. Consequently, more degradation is expected when cues that guide that automatized behavior are altered/removed. These points will be elaborated and the experimental results of tests of these hypotheses will be presented in a later section of this report.

It is important to note that Mantsvetova et al. were addressing the physical characteristics of the writing rather than the contents of what was written. Concerning the content, they emphasized: "We did not find any changes in the characteristics of written speech which could indicate functional disturbances of the central nervous system."

The authors used a "graphological" technique to analyze the handwriting, but, on the basis of the examples presented, there can be little question of the degradation. However, there is not overwhelming evidence that the degradation was due to microgravity per se, rather than other potentially confounding variables like stress, space motion sickness, etc.

Analyses indicated that the deterioration started in first few hours and continued through six days. There was some improvement over time and substantial individual differences were evident. Mantsvetova et al. observed that the best writing occurred just after sleep or when recording observations (in a relaxed state). The worst writing followed difficult performance tasks and tests, and in situations with greatest interference and noise. They note that connectedness (tendency to keep the pen on the paper rather than lifting it) increased in microgravity and that the pressure on the paper increased. They explained the latter two findings in terms of adjusting to microgravity:

"The 'customary' afferent information is replaced by the different information and the efferent impulsation is altered in a corresponding manner. In seeking to restore the former customary sensations the writer strives to preserve the connection between the pencil and paper and to introduce the customary force element into the movement."

In other tests involving handwriting, Yuganov, Kas'yan, Gurovskiy, Yasdovskiy, Konovalov, and Yakubov (1961) and Kas'yan (1963) found no effect during microgravity. They attributed their findings to the "good fixation of the test subjects at the working areas during the flying experiments."

Parin and Kas'yan (1969) reported the results of a study conducted by Volynkin et al., in which handwriting tests were given to Cosmonaut Yegorov. They found more degradation (errors and time) for drawing spirals than writing the number "6" when his eyes were open than when closed. There was a 51% increase of time in making double spirals with eyes open and 17% increase with eyes closed; also, errors were in a ratio of 7:1 (microgravity:Earth) for eyes open but only 5:3 with the eyes closed. While both the "spiral" task and the "6" task degraded relative to measures taken on Earth, there was more degradation for drawing a double spiral than drawing a "6." The authors attributed this finding to the fact that drawing a double spiral is less of a "fixed habit." Similarly, performance was found to be degraded for Komarov on a "coordination-motor habit developed on Earth." The authors also cited another investigation which demonstrated degradation of fine-motor coordination (handwriting), especially early in flight.

Parin and Kas'yan (and other reviewers) summarized analyses conducted on movements of cosmonauts while writing, taking food and water, removing articles from the pocket, and opening containers, and found that the results indicated generally coordinated smooth and clear movements. Consequently, they concluded that there had not been a major problem of psychomotor performance degradation. However, they warned that the early flight data are limited along many dimensions and that conclusions about the effects of microgravity on motor coordination could be premature. They also qualified their conclusion by stating that, based on the reactions of people to microgravity, there is evidence of degradation for some individuals in the following domains: perception, motor behavior, and muscle tone/strength.

In another review of the early literature, Kas'yan, Kopanevk, and Yuganov (1969) asserted:

"If under terrestrial conditions, during any movement man applies effort which is adequate for the action of gravity, then under weightlessness a similar stereotype of movement can become a source of errors."

With regard to evidence of degradation of coordinated motor behavior in microgravity, Kas'yan et al. argued:

"There has already been accumulated material on the fact that conditions of weightlessness somewhat disturb highly coordinated acts."

Kas'yan et al. reported that in one line of research, Lomonaco et al. (1957a or 1957b - not clear which) and Lomonaco (1960) showed that in "Roman Tower" high-speed elevator studies, subjects were less able to consistently place a pencil in 15 cm target during the 1.7 sec of simulated microgravity. Also, the fact that the corresponding performance of deaf-mutes was less disrupted, suggested involvement of the labrynthine network as a contributing variable.

According to Gurfinkel, Isakov, Malkin, and Popov (1959), Yazdovskiy, Bryanov, Kakurin, Krylov, and Cherepakhin (1963) analyzed available data and came to conclusion that microgravity "does not lower the quality of coordination in any concrete form which has a place in actual space flights." However, Kas'yan et al. described the evidence indicating the presence of degraded motor performance. In addition to many of the reports already cited, the authors reported that Grossfield (1951) and Ballinger (1952) found difficulties in hitting a target with their hand. Yuganov, Kas'yan, Gurovskiy, Yasdovskiy, Konovalov, and Yakubov (1961) found 10/14 subjects had "a lessening of reflex times." While recognizing that the evidence for motor degradation was considerable, Kas'yan et al. concluded that degraded performance are not substantial enough to be of major concern:

"Flights under conditions of weightlessness lead to insignificant changes in certain indicators of the movements of man which essentially do not reflect on his efficiency."

They argued that this is especially true if astronauts are adequately attached or tethered to their work areas.

Parin and Kas'yan (1969) described the work of Kitayev-Smyk (1965) as noteworthy because the performance of cosmonauts was analyzed while they conducted a task in microgravity (placing and removing a parachute attachment system). Impaired motor coordination and increased time to perform motor actions were reported.

Seeman, Smith, and Mueller (1966) investigated the effects of microgravity (during parabolic flight) on a common maintenance task (removing and replacing a pre-start solenoid valve) and found that performance was degraded in microgravity.

In an analysis of slow movement in microgravity, Chkhaidze (1970) estimated that when performing coordination skills, muscular effort could be expected to degrade by as much as 50%. The analysis also predicted "a more frequent interference in the coordination structure by the central apparatuses" (central nervous system) "regulating the course of the skill." Chkhaidze described the results of a variety of studies that empirically supported the theoretical analyses. Chkhaidze noted the discrepancy between such findings and both observations of cosmonaut performance and self reports indicating very little degradation. He attributed the apparent absence of performance degradation during space flights as due to the effectiveness of training programs and to the ability of the human to adjust to new situations.

In discussing man's ability to restructure his coordination in microgravity, Chkhaidze cited the work of Chekirda (1967), who described man's adjustment to microgravity as occurring in three stages. First, there is a period of "excessive corrections." Second, a "pseudoreautomation" phase occurs, characterized by a "decrease in the role of the vertical components of efforts," and also by a decrease in the magnitude and number of correction signals. During a third phase, stabilization occurs, characterized by a further reduction in correction signals and resulting in "sufficiently automated skills." Chekirda also asserted that this process does not always occur rapidly, and that its measurement "can serve as a convenient test for checking on the course of man's training for spaceflight."

In an experiment on simple motor coordination conducted by Cherepakhin (reported by Chkhaidze), it was shown that greater degradation of motor performance occurred during transition from Earth's gravity to microgravity and from microgravity back to Earth's gravity than when in microgravity. When in a state of microgravity, the subject's coordination was found to adjust fairly quickly.

Chkhaidze concluded:

"1. Man's presence in a state of weightlessness should not cause serious disorders in the coordination of voluntary movements, provided that he is adequately prepared. A possible initial deterioration in the quality of performed motor skills caused by the transition to unusual conditions is replaced relatively rapidly on a stable performance of the required dynamic components of the coordinated structure of movements.

2. Proper and purposeful training, however, can reduce these discriers to a minimum and bring about a gradual restoration of the coordination of movements even in increased (to a certain limit) gravity fields.

3. When movements are performed in a modified gravity field one must expect definite changes in the magnitude of the dynamic components of the coordination structure of skills (including the key components, direct muscular efforts). During weightlessness the limits of decrease in elements of the structure of movement can attain 50%."

Khachatur'yants (1975) reported that simple and up to three-choice reaction time was not degraded in microgravity, but tracking performance was. He explained degradation in tracking performance as due to two factors: a) changes in motor coordination and b) weakening of the muscles due to microgravity.

Finally, in more recent investigations, Ross, Schwartz, and Emmerson (1987) reported that subjects tended to overreach in microgravity and Ross et al. (1984, 1986) reported that subjects tend to under-reach after returning to microgravity.

### d. Work-Capacity Degradation

While investigations of work-capacity do not typically involve task performance measurement directly, they are obviously relevant to the topic of performance degradation because of the relationship between task performance and fatigue. While the effects of fatigue have apparently remained within tolerable ranges in past flights, it might become a significant factor in planned long-duration flights. Garshnek (1989a) asserted that "after approximately six months in space, fatigue has been identified as a problem resulting in decreased work effectiveness and productivity." Also, Billingham (1987) reported that long-duration Soviet flights found psychological changes over time including decreased motivation, increased irritability, boredom, declined productivity, and shorter work days (sometimes only 2-4 hours). Consequently, discussion of the literature on work-capacity has been included here.

Kakurin (1968) discussed the similarities of microgravity and hypokinesia. In each case, there is reduced muscular load, blood redistribution, and deprivation of usual support for maintaining a vertical posture. Kakurin presented data from studies of hypokinesia (extending up to 20 days) indicating effects on the neuromuscular system as indicated by tolerance for physical load and mental work. In one experiment, physiological and work capacity degradation were reported for six subjects who were confined to bed for 62 days. Exercise proved to be a partially effective countermeasure.

In addition to any direct effects of microgravity on work capacity, research has shown that a decrease in muscle activity (hypokinetic conditions - similar to that possible on space flights) can reduce the functional state of the motor system, cause more rapid exhaustion, and decrease the quality of dynamic work (Taranov and Panferova, 1970).

Wortz (1968, 1969) explained energy expenditure and work capacity during locomotion in microgravity in terms of a continuum of amount of traction. Parin and Kas'yan (1969) discussed the topic of work capacity in microgravity (especially when unsupported), and reported conflicting findings.

According to Berry (1971) "A reduction in work capacity has been noted following all missions in the Gemini and Apollo series." Work capacity was determined by an electronic bicycle ergometer; oxygen consumption is monitored for a workload corresponding to a given elevated heart rate (e.g., 160 or 180).

Kas'yan, Makarov, and Sokolkov (1971) reported that the metabolic effects of working (e.g., tightening a bolt) in parabolic microgravity "lead to a significant rise in the intensity of metabolic processes, both when the person is in a state of relative rest, and when he is engaged in a certain form of activity."

A major effort reported by Norman, Miller, Grohman, and Jones (1971), was "designed to fill a gap in our knowledge of man's capabilities to perform complex tasks in the zero-gravity environment." One of the major goals of the resulting Astronaut Performance Program was to correlate ground-based simulation with in-flight conditions. Also, a "Handbook of Human Engineering Design Data for Reduced Gravity Conditions" was created. Norman et al. presented a detailed task analysis of extravehicular activities and a corresponding human-engineering analysis of those tasks. Results of research are reported that describe the effects of various manipulations on seven generic maintenance task components: restraint installation, gaining access, two-hand eye/hand coordination, precise hand movement, force emission, torque emission, and operational maintenance (handling and manipulating small components and tools). Tests were conducted under 1-g, simulated microgravity (neutral buoyancy), a mechanical six-degrees-of-freedom simulator, and microgravity (parabolic flight).

Results were presented for a very small sample size (N = 2), describing the effects of four major independent variables: simulation mode, space suit type, restraint type, and access type on the seven generic tasks. Unexpectedly, several measures indicated superior performance in simulated microgravity (parabolic flight) than in 1-g (precise hand movement and two-hand task). In other tasks, performance was degraded in microgravity or simulated microgravity relative to a 1-g environment (precise force task and sustained force). In the precise torque task there were no significant differences and in the sustained torque task, there were no differences among the simulations except for the six-degrees-of-freedom simulator, in which inferior performance was found.

Kopanev and Yuganov (1974) reported that, according to Wagner (1971), conducting tasks in microgravity requires 100% more time than on Earth. Nevertheless, Gemini astronauts carried out all of their tasks with a few minor exceptions and during the Apollo program, all tasks were conducted except one. A slight deterioration of physical working capacity was found after prolonged Gemini and Apollo space flights. Within the Apollo program, complaints decreased and work capacity rose as the work schedule was brought more closely in line with the target schedule (8 hours work, 8 hours rest, and 8 hours sleep).

### e. Experimental Evidence from Simulated Microgravity (Neutral Buoyancy)

The two most common methods of simulating microgravity are parabolic flight and immersing individuals in water or a solution. Duddy (1969) summarized the literature related to water immersion (also called "neutral buoyancy"). As pointed out by Brown

(1961) there are three disadvantages of water immersion as a method of simulating microgravity. First, the respiratory device is awkward. Second, the density of the liquid dampens movements too much. Third, the reaction of the vestibular apparatus (the utricular system) might not be the same as it would in actual microgravity.

Brown found that after being rotated at a depth of 18-25 feet subjects had errors of up to 180 degrees when asked to point to the surface, but nodding the head usually corrected these errors. Also, because errors were greatest in some positions (i.e., with head down or back), Brown suggested that these positions be used in the future to more accurately simulate microgravity. In similar work, Nelson (1967) found errors ranging from 15 to 40 degrees when testing subjects' ability to assume different orientations under water.

Hartman, McKenzie and Graveline (1960) reported that a subject exposed to extended (7-day) neutral buoyancy showed small but consistent degradation in performance tasks over the period. Also, there was significant degradation in subsequent (post-immersion) tasks. They attributed the degradation to changes in the musculoskeletal system and disruption in cardiovascular function. Hartman et al. concluded that performance is adequate during long flight, but that it might be impaired during reentry.

Chambers et al. (1961) reported decrements in psychomotor skill performance, memory, judgement, and learning ability. They described uneven performance, irregularity, less precise performance, and increased errors when subjects were tested during prolonged water immersion. They also reported increased irritability and personality deterioration. In a later report, Ferguson and Chambers (1963) concluded that immersion results in significant physiological changes, so it cannot not be determined if the results of immersion-based performance studies are representative of those that would be found in a microgravity environment.

Whiteside (1961) discussed the pointing task, with and without feedback, as a clinical test to discriminate between sensory ataxia (in which visual feedback facilitates pointing performance) and cerebellar ataxia (in which visual feedback does not improve performance). Whiteside used a no-feedback pointing task to assess the effects of microgravity by comparing normal baselines with performance when immersed in water. He found that in the simulated microgravity condition, subjects pointed high and to the left of the target, while in microgravity, subjects pointed low and to the right of the target. Because the only difference between the two conditions was whether the head (the labyrinth) was in a weightless environment, he attributed the findings to the "elevator illusion". Whiteside argued that this illusion is due to a change in the amount of accelerative force and not to a changing direction of resultant acceleration, as in the oculo-graphic illusion (described earlier).

In similar work, Morway et al. (1963) gave subjects two psychomotor tasks before, during and after water immersion. One of the tasks measured the ability to reach and point arm and hand; the second tested their ability to estimate a pre-learned level of force. They found no difference in horizontal aiming but a significant bias upward in vertical aiming as well as a significant difference in force estimation between immersed and other two conditions.

## B. Possible Causes of Performance Degradation in Microgravity

The literature discussed in the previous sections suggests that, although performance degradation has not been a significant factor in space programs to date, it is a potential concern (especially for long-duration flights). There are many possible causes for performance degradation in long-duration space flight. However, such sources are not caused by microgravity, but by other associated factors. These variables are discussed first.

### 1. Possible Sources of Degradation Not Directly Related to Microgravity

Perhaps the most obvious source of performance degradation is simply the passage of time (forgetting). In his early "interference" theory of forgetting, Melton and his colleagues demonstrated that it is not just time per se that causes forgetting, but the amount and kind of mental/physical activity that occurs before the information is learned (proactive interference) and during the retention interval (retroactive interference) that influences the rate that information is forgotten. For example, Melton and Irwin (1940) clearly demonstrated that the more mental activity that occurs between the time of original learning of verbal learning and later recall, the more memory degradation (i.e., retroactive interference interferes with recall). This fact could increase the rate of memory deterioration during space flight because, according to several authors in the literature, astronauts are kept very busy performing tasks (in fact, they prefer to work). To complicate matters, the degree of forgetting is known to be affected by the similarity of interpolated tasks to the original task (e.g., King and Cofer, 1960). Not only the more tasks, but the more similar the intervening tasks, the more forgetting will occur. Also, one would expect substantial interference to occur in the space environment simply because of the limited stimulus set afforded by most spacecraft (i.e., intervening associations have a higher probability of being linked to the same stimulus set). All of these facts point to the possibility that memory could degrade more during space flight than, for example, during the same period of time on Earth.

In addition to memory deficits, a number of situational variables could occur in space flight that, although not due to microgravity per se, could directly or indirectly degrade performance. For example, under certain conditions the following variables, known to affect performance, could occur: heat - Grether, 1972; Curley and Hawkins, 1983; heat and high altitude - Fine and Kobrick, 1978; and noise/vibration - Sommer and Harris, 1972). Also, while exposure to cosmic radiation has always been a concern for both the astronaut's health and performance, Gazenko (1983) reported that exposure to radiation only reached 5.0 rem on 7 month flights, which is well below permissible radiation dose of 15 rem per flight. Finally, Seminara, Shavelson, and Parsons (1967) found degraded performance in an Apollo space suit under reduced pressure (3.7 psi as opposed to 14.7 psi).

Other potential sources of degradation that are likely to occur on long-duration flights, but which are not directly attributable to microgravity include psychosocial reactions due to loneliness, isolation, and crowding; changes in sleep patterns; and effects due to the stress and apprehension associated with exposure to potentially hazardous situations. In discussing the general psychological reactions of astronauts on long-duration space flights, Pierce (1988) suggested that the crew (as well as ground support personnel) might need psychological training/services. Pierce also discussed the interactions among biology, psychology, and sociology in relation to physical illness and identified possible sources of depression include isolation, unforeseen events, injuries, illness, and intra-crew conflict.

For more information about the psychological and sociological effects experienced or expected during long-duration flight, the reader is referred to a number of recent papers which address those topics: Nicogossian, Rambaut, and Pool, 1984; Christensen and Talbot, 1986; Billingham, 1987; Santy, 1987; Lebedev, 1988; Pierce, 1988; Garshnek, 1989a, 1989b; Huntoon, 1989; Hancock, Caird, and Parasuraman, 1990.

While the topics discussed in the above paragraphs are relevant to human performance in space flight, they are not currently believed to directly or indirectly result from microgravity. In contrast, the topics addressed in the next sections could serve as direct or indirect links between microgravity and human performance.

## 2. Sources of Degradation Due to General Physiological Reactions to Microgravity

If degradation in human performance is to be attributed to microgravity, then a mechanism or mechanisms must be identified which could mediate that effect. There are no known direct effects of gravitational forces on the central nervous system. However, researchers have identified a number of other biological systems affected by microgravity, any or all of which could affect performance. A number of excellent reviews of such physiological effects have been reported in the literature (e.g., Bayevskiy and Maksimov, 1968; Vasil'yev, Kas'yan, and Pestov, 1969; Parin and Kas'yan, 1969; Berry, 1971; Khrunov, Khachatur'yants, Popov, and Ivanov, 1974; Dietlein, Rambaut, and Nicogossian, 1983; Gazenko, 1983; Nicogossian, Rambaut, and Pool, 1984; Frey, 1987; Billingham, 1987; Garshnek, 1989a, 1989b; Huntoon, 1989).

Physiological reactions to microgravity could affect performance either directly or indirectly. The most probable mechanism for causing indirect performance degradation is stimulus-generalization decrement or external inhibition, due to an altered stimulus configuration (i.e., performance degradation because the performance environment differs significantly from that in which the astronaut was trained). It is important to note that negative transfer due to a change in the stimulus situation is not limited to exteroceptive stimuli, but can also, and probably more so, be produced by altered interoceptive stimuli (most notably, changes in sensory information caused by the effects of reduced gravity on the vestibular system and changes in proprioceptive and kinesthetic feedback due to the effects of microgravity on the skeletal and muscular systems).

Any effects of microgravity on individual sensory systems which lead to altered sensory information could contribute to performance degradation, especially if the sensory information is relevant to the task being performed. In addition, complex interactions among individual sensory systems could also be a source of performance degradation. For example, Parin and Kas'yan (1969) discussed the effects of microgravity on the "analyzer system" (which consolidates information from proprioceptive, vestibular, visual, cutaneo-mechanical and interoceptive stimuli).

One more feature of the human's response to altered sensory information must be addressed, because of its potential negative effects on performance. The human has an amazing facility to adapt to altered sensory configurations. Adaptation to the new sensory world created by microgravity is similarly impressive. Berry (1971) presented a preliminary model of these adaptive response to microgravity. One aspect of this model is that there is an end-point to the adaptation, and the adjustment would presumably remain stable for extended flights. However, this very impressive quality to adapt to microgravity might be yet another source of performance degradation. Specifically, if the crew adapts to the sensory environment associated with microgravity, then reentering gravity will create a "new" sensory world, to which they must again adapt.

This phenomenon, and its implications for human performance after reentry, has been widely discussed in the literature. For example, Huntoon (1989) described the symptoms following landing (e.g., orthostatic intolerance, fainting, disequilibrium, and syncope - swoon, brief loss of consciousness). Huntoon reported that the Soviets recognize four recovery stages: acute (2-4 days - symptoms occur even when resting); subacute (5-12 days - symptoms occur only when standing); first recovery stage (up to 35 days); and second recovery stage (up to 45 days). Such changes in the stimulus world of the astronaut could disrupt performance during or following reentry. In most cases, this has not been a serious performance consideration, a) because flights have been relatively short, b) because performance demands are low following the termination of a flight, and c) because time and facilities are available on Earth to assist recovery. However, several authors have expressed concern about the implications for long-duration flights to other planets.

Billingham (1987) summarized the expected effects of long-term microgravity (e.g., one-year journey and return from Mars, separated by entry/launch forces and .4 g on Mars) on human physiology and their implications for medical support. On reentering a gravitational field, there could be susceptibility to "vaso-vagal attack" because "there might not be enough blood to 'fill up' the right side of the cardiovascular system and ensure adequate return to the heart." This condition can lead to reduced pulse rate, cardiac output and arterial pressure resulting in fainting. If this were to happen on Mars after landing, then "The ability to perform normal tasks is clearly compromised." Billingham also argued that "It is essential that astronauts do not attempt intensive critical tasks on the Mars surface with weakened, wasted muscle groups." In this regard, Billingham's cautionary statement is interpreted to mean that astronauts might have insufficient strength to complete such tasks. In addition, from a human-performance perspective, it is also possible that weakened muscles would affect the proprioceptive and kinesthetic feedback cues that guide coordinated performance, resulting in a second source of performance degradation. Similarly, Garshnek (1989a) expressed concern about readapting problems following a long-duration flight to Mars, where no time or facilities will exist to aid adaptation.

Because of the singular or joint, direct or indirect, adaptive or re-adaptive effects of altered sensory information on human performance, the following brief review of the known effects of microgravity on different biological systems is presented.

**a. Vestibular Effects**

Because of its known susceptibility to gravitational forces, the sensory system most discussed in the microgravity literature is the vestibular system. Several excellent descriptions of the vestibular system, its response to microgravity, and its interaction with vision to create perceptual illusions are presented in the literature (e.g., Clark, 1963; Graybiel and Kellogg, 1966; Fletcher, 1968; Lebedev and Chekirda, 1968; Parin and Kas'yan, 1969; Simonovic and Simonovic, 1975; Clement, Berthoz, and Lestienne, 1987; Thornton, Moore, Pool, and Vanderploeg, 1987; Watt, 1987; Garshnek, 1989a; Huntoon, 1989). The following discussion of the vestibular sense was extracted from portions of several of those papers.

The two major mechanisms of the vestibular sense are the semicircular canals and the otolith organs. The semicircular canals comprise three generally orthogonal fluid-filled canals, each canal containing an ampulla. Within the ampulla, a cupula is the essential transducer, being physically displaced in proportion to the corresponding angular acceleration of the head. The displacement distorts the crista (base) and neural fibers are stimulated, resulting in neural impulses. Due to elasticity, the cupula returns to a resting position, much like a swinging door with a spring.

It is believed that the otolith organs sense linear velocity (e.g., gravity, rectilinear acceleration of a vehicle, rotation in a centrifuge). The site of the transduction is in the macula, in the utricle of the inner ear. Sensitive hair cells covered with a gelatinous substance rise generally upward and support small calcium carbonate crystals (the otoliths or otochons -- 1-10 microns in size) which have a greater specific weight than the surrounding structure. Forces from linear accelerations are believed to cause the otoliths to bend the hair cells (compression in the case of increased gravity and elongation in the case of decreased gravity). Changes in the hair cells are detected and corresponding neural messages are sent to the brain.

The effects of the reduced gravitational forces on the otoliths has been used to attempt to explain many of the illusions associated with microgravity. However, the most common reference to the vestibular sense in the literature is with regard to its alleged relationship with space motion sickness (SMS). Because several authors have proposed a link between the vestibular system and SMS, and because of the intuitive relationship between SMS and performance degradation, a general discussion of SMS follows.

As early as 1969, Parin and Kas'yan reported that feelings of vertigo in space had been reported to follow sharp movements of the head. According to Thornton, Moore, Pool, and Vanderploeg (1987); Garshnek (1989a); and Huntoon (1989), symptoms of SMS include headache, malaise, disequilibrium, vomiting, lethargy, motion sensitivity, illusions, disorientation, irritability, lack of initiative, and decreased ability to perform tasks. According to most sources, the symptoms subside after few days in space and are moderated by repeated exposure (e.g., Garshnek, 1989a). Parker and Reshke (1988) reported that SMS is easy to spot because astronauts move around craft "like mummies", minimizing head movements.

Estimates of incidence vary. Berry (1971) reported that no crewmembers from the Mercury (n=6), or Gemini (n=20) programs reported motion sickness, but that 11 of 27 crew members from the Apollo program reported stomach awareness, nausea/vomiting, or spatial disorientation. More recent estimates have increased. Thornton, Moore, Pool, and Vanderploeg (1987) reported that, based on informal questioning, the incidence was about 40%. Homick, Reschke, and Vanderploeg (1984); Garshnek (1989a); and Parker and Reshke (1988) all reported an incidence of 50%. Davis, Vanderploeg, Santy, Jennings, and Stewart (1988) reported the incidence to be 67%. There clearly are individual differences in susceptibility to SMS, but according to Watt (1987), to date, there was no test capable of predicting those susceptible to SMS.

Thornton, Moore, Pool, and Vanderploeg (1987) presented an excellent overview of SMS. They explained the symptoms of SMS and how they differ from more standard forms of motion sickness. In general, if SMS occurs, it is short-lived, usually peaking from 8 hours to two days after exposure to microgravity and then dissipating quickly, usually by the third or fourth day. Estimated implications for performance are that the astronaut's ability to perform tasks during the worst periods range from "able to work with discomfort" to "incapacitated." Although at some level of sickness, it is difficult to imagine that SMS would not degrade performance, there is not much evidence indicating this relationship. Thornton et al. point out that, with the possible exception of two precautionary delays of extravehicular activities, astronauts have performed all assigned tasks. They also reported no degradation for those tested on a neuro-muscular test or a cognitive test (the Sternberg complex reaction time test).

Simonovic and Simonovic (1975) attributed SMS to the absence of gravitational forces on the otoliths and acceleration in the semicircular canals of the vestibular apparatus. They noted that SMS can be exacerbated by the presence of other accelerations. On Earth, sensory information from the vestibular system guides muscle activity to maintain balance, resulting in a constant muscle tone in associated muscles. During microgravity, the system no longer provides appropriate information and the organism soon adjusts to the new state. However, muscle tone that had been present on Earth is now lost, resulting in loss of muscle strength and atrophy.

Based on anecdotal self-reports of astronauts that head movements brought on SMS, Lackner and Graybiel (1987) conducted research and determined that pitch movements produce the most dramatic effects followed by roll and yaw, and that more effect was found with normal vision than when the eyes were occluded.

Thornton et al. (1987) reported individual differences in sensitivity, with some individuals reacting more to changes in pitch and others to changes in yaw. They also summarized the results of their research indicating no support for "the role of altered or disturbed sensory or neurological systems." Rather, they argued that there is theoretical support for the notion that SMS is related to conflicting sensory information. One source of conflict is between the canal signals and the otolith signals. Also, there is a source of conflict between visual cues and the otoliths, but no conflict between visual cues and canal cues. Finally, visual scenes could conflict with scenes experienced on Earth.

Watt (1987) also attempted to link the vestibulo-ocular reflex (VOR) with SMS and demonstrated that torso-based movement could generate problems compared with head-based movement and argued that some tapes have shown some astronauts move from the torso perhaps, ironically, to avoid SMS. Watt discussed studies of the VOR in space and tried to explain the inconsistent findings as possibly resulting from different adaptation rates:

> "It is suggested that VOR gain is reduced initially, but that rapid compensatory mechanisms restore it to normal within minutes of reaching weightlessness. However, even though this process may lead to the rapid return of functionally normal gaze stability, it may not protect against the development of motion sickness."

Even though VOR is quick to adjust, SMS could be a longer-term, related problem. SMS might be due to torso-rotation, causing transient and idiosyncratic decreases in VOR gain.

According to Parker and Reshke (1988), adapting to microgravity involves a complex rearrangement of the relationships among signals from visual, skin, joint and vestibular senses, and SMS can become an unfortunate byproduct of this process:

> "SMS can be viewed as a side effect of adaptation to weightlessness. The adaptation process occurs as the result of sensory compensation and/or sensory reinterpretation. Sensory compensation occurs when the signal from one type of receptor is attenuated and signals from other receptors are augmented. In the absence of an appropriate graviceptor signal in weightlessness, information from other spatial orientation receptors, such as the eyes, the vestibular semicircular canals, and the neck position receptors, can be used by astronauts to maintain spatial orientation and movement control. Alternatively, signals from graviceptors may be reinterpreted by the brain. On Earth, information from graviceptors is interpreted by the brain as linear motion (translation) or tilt with respect to gravity. Because stimulation from gravity is absent during orbital flight, interpretation of the graviceptor signals as tilt is meaningless. Therefore, during adaptation to weightlessness, the brain reinterprets all graviceptor output to indicate translation. This is the otolith tilt-translation reinterpretation (OTTR hypothesis)."

In summary, most accounts of the etiology of SMS have involved conflicting information from the vestibular or from the vestibular and visual systems. However, one author reported a hypothesis that SMS is due to a headward redistribution of body fluids (Huntoon, 1989). Recent support of that hypothesis comes from Simanonok, Charles, Moseley, and Davis (1991), who, in a discriminant function analysis of pre-flight predictor variables and level of SMS as the predicted variable, found that the nine strongest predictor variables suggested a fluid-shift explanation:

> "The nine variables in order of their importance for predicting space sickness severity are sitting systolic blood pressure, serum uric acid, calculated blood volume, serum phosphate, urine osmolality, environmental temperature at the launch site, red cell count, serum chloride, and serum thyroxine. These results suggested the presence of predisposing physiologic factors to space sickness that implicate a fluid shift etiology."

In a personal communication, a NASA expert on SMS indicated that problems with SMS had been over-emphasized because, although it occurs in a substantial portion of the crew, it only lasts a short period of time. Consequently, until the cause and cure can be identified, countermeasures are being employed (specifically, extravehicular activities and other critical tasks are delayed until later in the mission). The expert also pointed out that, because of the short-lived nature of SMS, its possible negative effects on performance will be less and less of a problem as mission durations increase.

### b. Vision Effects

Parin and Kas'yan (1969) pointed out the important role of vision for task performance by citing an analysis conducted by Stevens (1962), which indicated that 75% of all errors committed by a pilot are related to the visual analyzer. Because of findings like this and because of the involvement of vision in most astronaut tasks, the question of the effects of microgravity on vision is highly relevant to this discussion. According to Parin and Kas'yan, three general approaches have been taken to assess the effects of microgravity on vision: a) subjective reports of astronauts, b) results of scientific studies, and c) performance on visual tasks performed during flight. The latter two are stressed in the following discussion.

Using parabolic flight as an environment to study the effects of microgravity on visual acuity, Pigg and Kama (1961), Hammer (1962), and Sasaki (1963) found significant degradation in visual acuity. However, the degradation was not judged to be operationally significant (Moran, 1969). White and Monty (1963) presented data on the effects of microgravity on vision. In general, reported effects were subtle and there was no case in which a change in vision interfered with task performance.

Effects of body orientation on some visual functions have been well-established. Pigg and Kama (1962) found that visual acuity degraded as a function of body orientation (upright is best followed by prone, supine, and inverted). Also, far vision is more affected than near vision. Braunstein and White (1962) demonstrated that brightness discrimination thresholds are approximately 1% degraded when in the supine position relative to a seated position. In another experiment, Pigg and Kama (1961) found that visual acuity degraded by about 6% in parabolic-flight simulated microgravity relative to measurements in Earth's gravity. Whether such effects can directly be attributed to gravitational forces or to physiological changes that accompany such changes in orientation or due to psychological effects of a significantly altered frame of reference (e.g., making sense out of conflicting visual and vestibular information) is not known.

In a review of research on vision in microgravity up to 1968, Parin and Kas'yan (1969) reported mixed findings. One study indicated a general decrease (20% to 40%) in the reliability of the astronauts' visual work (visual acuity). They attributed this degradation to a "discoordination of the oculomotor apparatus." Specifically, in the acuity task used, rapid eye movements must occur and, because gravitational effects are reduced (i.e., the "friction" in the moving tissue caused by gravity is presumed to decrease), the eye muscles tend to miscalculate the force required to move to the next line. Consequently, visual performance on such tasks degrades. They asserted that significant effects on task performance can only be expected in special cases (i.e., where a number of small oculomotor changes are required). Parin and Kas'yan also reported that changes from early flight to late flight showed individual differences, with some cosmonauts improving, others degrading, and others remaining unchanged. They also reported the findings of Monti and Richard indicating that during prolonged exposure to microgravity, vision-related performance degraded (i.e., accuracy of reading instruments).

Parin and Kas'yan reported another study in which the subjective brightness of colors decreased in microgravity. While normal errors usually range from plus to minus 7.8%, they found that corresponding errors for two cosmonauts were 25-26% for the colors purple, dark blue, green, and red. Errors on other colors similarly indicated a decrease in perceived brightness, but those errors did not exceed 10%.

Concerning oculomotor functioning, Parin and Kas'yan concluded:

> "Thus, a definite pattern of oculomotor reactions can be noted in the 4 astronauts during long orbital flights: a considerable increase in the number of eye movements and some impairment of their coordination at the beginning of the flight, a decrease in the number of movements and restoration of their coordination at the end of the 1st day and a secondary increase in oculomotor activity at the end of the flight."

Presumably, these early effects are due to the "unusualness of the circumstances and great emotional tension."

Khrunov, Khachatur'yants, Popov, and Ivanov (1974) reported that analysis of cosmonauts Yegorov and Komarov revealed no change in visual resolution during and after space flight. However, measures of "working visual acuity" revealed that "operative visual efficiency is substantially reduced in space." In a summary of data collected during Voskhod and Soyuz flights, Khrunov et al. reported that degradation profiles differed for visual acuity, contrast sensitivity, and operative visual efficiency. The mean drop in visual acuity was relatively small (5-10%) and remained relatively constant over duration (60 orbits). On the other hand, the drop in contrast sensitivity was initially about 10% and then increased (degraded) over the duration of the flight (maximum of 40% on the 5th day). Operational visual efficiency initially dropped about 20%, climbed to an asymptote of about 27% on the 10th orbit, and then declined over the rest of the flight. When the three measures are combined (i.e., the "generalized visual function"), a double-peaked curve is found with major degradation occurring at about 10 orbits and a second minor peak at about 75 orbits.

Khachatur'yants (1975) summarized the lessons learned from the Soviet program prior to the first international Apollo-Soyuz station. Regarding vision, acuity was not altered but there was a decrease of 14-26% in "visual operational functional capacity," which he defined as "the integral function of vision which permits man to carry out visual action: to recognize objects of observation and distinguish them, etc."

In a recent report, O'Neal, Task, and Genco (1991) summarized the literature dealing with the effects of microgravity on vision and reported generally mixed findings, with some researchers reporting no effects on visual acuity (e.g., Duntley, Austin, Harris, and Taylor, 1969), and others reporting decreased acuity. They cited Lazarev (1979), who reported a decrease of 5-10% in high contrast acuity for 2 Voskhod subjects; a 10% reduction in acuity for high and low contrast targets for three cosmonauts; a 20% increase in high contrast acuity for one cosmonaut on Soyuz-4 and -5; and an 18% drop in high contrast acuity and 4% drop in low contrast acuity for one cosmonaut on the Soyuz-9 flight.

O'Neal et al. reported the findings of their research, in which a small, hand-held device was used to present stimuli at optical infinity. This device (the Visual Function Tester, Model 1 - VFT-1) included a battery of vision tests including visual acuity, flicker fusion, stereopsis, cyclophoria, lateral phoria, vertical phoria, and retinal rivalry. To date, 26 Shuttle astronauts had been tested. With a few exceptions, measures were taken before, during, and after microgravity flight. O'Neal et al. reported no significant differences to date except for stereopsis, which they found to be slightly improved in space and visual acuity, which decreased during the flight. Although statistically significant, O'Neal et al. concluded that the degradation in visual acuity was "not operationally significant." Also, there were substantial individual differences in the data, with individuals varying from 40% loss to 20% gain in acuity. In addition, some individuals varied by as much as 20% within a flight. O'Neal et al. suggested that such substantial differences in individual reactions to microgravity are a possible explanation for the inconsistent findings found in the literature.

### c. Cardiovascular Effects

Billingham (1987) reported that the removal of gravitational forces changes the pressure differentials in veins and capillaries of the lower extremities. Also, there is a shift in blood volume by up to one liter. There are recorded changes in the blood, fluids, and electrolytes (presented in following sections). Berry (1971) reported no unexpected changes in heart rate or in blood pressure. However, arrhythmias and other heartbeat irregularities have been reported (Nicogossian, Huntoon, and Pool, 1989). Berry also reported that heart rate is the most sensitive measure of post-flight orthostatic intolerance.

### d. Hematological Effects

Garshnek (1989a) noted hematological changes in spaceflight including a red cell loss (10-15%), loss of haemoglobin mass (12-33%), and reduction in plasma volume (4-16%). Huntoon (1989) reported a similar red-cell mass decrease (5 to 20%, average = 9.3%) in Skylab astronauts. Huntoon also noted that there is evidence of reduced erythropoietin (the hormone which stimulates the formation of red blood cells). Huntoon points out that the reduction in red blood cells is not anemia, because both red blood cells and plasma decrease. She also suggested that the reduction in plasma volume is a response to increased central blood pressure caused by removal of the gravity-induced hydrostatic gradient.

### e. Body-Fluid Effects

It has been reported that feelings of thirst decline during microgravity flight (Gazenko, 1983). Berry (1971) reported that the majority of the typical weight loss experienced in microgravity could be attributed to fluid and electrolyte loss because most of the lost weight is regained within one day of reentry. Similarly, Garshnek (1989a) reported decreased body fluid (1.5-2.0 liters) and electrolyte level. Berry reported that potassium excretion is depressed, suggesting decrease in total potassium. Sodium and chloride show similar patterns. Also, it has been discovered that more intracellular as opposed to extracellular fluid is lost. However, fluid loss is not proportional to mission duration.

### f. Endocrine System Effects

According to Berry (1971) changes in endocrine responses have been noted (e.g., steroid level) that suggest a reaction to stress. However, such changes are confounded with other potential causes (e.g., vasoconstriction and electrolyte regulation). In addition, hormonal changes have been attributed to in-flight water loss. More recently, Billingham (1987) reported that microgravity is accompanied by changes in circulating hormones and responsiveness to hormones. In summary, there are known changes in endocrine activity, but it is difficult to determine what the causal relationships are and difficult to determine if they affect human performance.

### g. Immune System Effects

Billingham (1987) reported that there is evidence that the immune system weakens in isolated individuals/groups; also there is scattered evidence of decreased white-cell count in the blood. Garshnek (1989a) reported immunological changes due to space flight and noted the most important potential implication, possible increased susceptibility to infection. Huntoon (1989) reported that activation of T-lymphocytes decreased in 36 of 41 astronauts during space flight (average change = -25.7%). Huntoon also reported that the effects on the humoral part of immune system depends on the length of flight; immunoglobulins G and A decreased after two days but increased after 49 days. According to Huntoon, it also has been shown that the number of microorganisms increases with the length of flight.

### h. Skeletal Effects

Berry (1971) reported that loss of bone mass (especially calcium) and general demineralization has been found. However, at that time, there was no evidence that mineral depletion was directly related to space-flight duration. More recently, Billingham (1987) reported that bone mass deterioration had been measured to be 1% per month, but it was not known whether that rate continues indefinitely. Huntoon (1989) reported that there had been a 5% reduction in density of calcaneus mass per month in Skylab and a .9% to -19.8 % change during the 75- to 185-day Salyut missions. Garshnek (1989a) reported that the rate of lost bone mass during Skylab was .5% per month. Huntoon indicated that the Soviets have reported that bone deterioration levels off after three months.

Although recovery occurs after reentry, Huntoon reported that there was still some loss in the spine after six months back on Earth and that development of osteoporosis in cancellous bone might put astronauts at risk for fractures after their return. Also, during microgravity, because serum calcium increases substantially due to bone resorption, and calcium is eliminated through urine and feces, there is a potential risk of renal stone formation, especially when combined with dehydration. Huntoon described two hypotheses for the loss of bone mass. First, it could be due to a lack of gravitational stress. Second, it could be due to hormonal changes (e.g., increased plasma cortisol).

### i. Muscular and Neuromuscular Effects

Berry (1967) reported that a 14-day exposure to microgravity did not result in muscle atrophy or impairment in coordination. However, after an 18-day Soyuz 9 mission, cosmonauts reported difficulty in walking and lifting objects and muscle tone and strength were diminished. Also, when in a prone position, they reported a sensation of being "pressed" into their beds. Berry (1971) reported that backache often accompanied space flight. Billingham (1987) concluded that without corrective measures, "astonishingly rapid" disuse atrophy of skeletal muscles will occur.

Clement, Berthoz, & Lestienne (1987) reported that, when subjects were instructed to attain normal Earth erect posture under normal vision, darkness, and stabilized vision: a) body tilt varied from day to day, b) in all cases, subjects were tilted forward, and c) there was greater tilt in the dark and when vision was stabilized. Also, when asked to do deep knee bends, subjects reported illusions of floor movement. One subject reported preferring socks to shoes because he could use tactile feedback to help guide direction and amplitude of movements.

Describing the physiological changes in muscles that accompany microgravity, Huntoon (1989) reported loss in strength, tone, and endurance. Losses of nitrogen and phosphorus and increases in the urinary excretion of creatinine and amino acids found in actin and myosin indicate muscle atrophy. Similarly, Garshnek (1989a) reported muscle atrophy and loss of strength.

Following landing, both American and Soviet astronauts have complained of weakness and the Soviets have complained of pain (Huntoon, 1989). Similarly, Garshnek (1989a) reported decreased exercise capacity following microgravity flight. Huntoon pointed out that such effects could be a problem if emergency egress is required during landing.

### j. Nervous-System Effects

No documented direct effects of microgravity on the nervous system were found in the literature. However, there could be indirect effects. Billingham (1987) reported that microgravity requires the nervous system to readjust due to new sensory data from otolith organs and from the proprioceptive system due to microgravity. In most of the Soviet reviews, the same general point has been made (e.g., Parin and Kas'yan, 1969; Chkaidze, 1970; Leonov and Lebedev, 1973; Khrunov, Khachatur'yants, Popov, and Ivanov, 1974). According to Friederici and Levelt (1987), there is evidence that in an environment in which ambiguous or conflicting orientation cues are present, the human can relatively quickly adjust by cognitive adjustments of the weights associated with different sensory cues. They argued that on Earth, gravity is the dominant cue but in microgravity, retinal information becomes the dominant cue.

### k. Speech Effects

Regarding studies of man's ability to generate and receive speech communication under microgravity, Parin and Kas'yan (1969) reported that such studies (until recently) "have not been carried out at all." In a reported study that assessed various aspects of the quality of a phrase spoken by subjects before, during, and after temporary microgravity (induced by parabolic flight), Parin and Kas'yan concluded that speech was degraded:

> ". . . the speech formation changed somewhat - the vowel sounds were involuntarily pronounced more loudly. Breathing during speech was freer. The audibility of the standard phrase and the radio messages on the earth proved to be worse than during transmission before and after weightlessness. The principal cause of the deterioration in speech, besides interference, due to the state of the communication channels, lay in the excessive forcing of the speech." (That is, its loudness.)

The authors pointed out that the forced speech could be due to the excitement of experiencing microgravity or to some other attribute of microgravity. Analysis of the associated frequency spectrum indicated elevated amplitude in the frequency range from 100-500 Hz and in the range 1000-2000 Hz, which the authors argued was due to disproportionate louder pronunciation of the vowel sounds. The authors concluded that the change in speech "does not have a noticeable effect on the quality of the reception of vocal ground signals," however, they argued that more research should be conducted in this area.

### l. Taste Effects

As noted in an earlier section, there have been numerous reports of changes in taste preference during microgravity flight. Tennissen, Lesher, and Cardello (1987) provided a brief history of how taste has changed in microgravity for Soviet and American astronauts. Reactions have included a tendency to think food was too salty, a reduced appetite for sweets, and increased desire for pungent and spicy food. On Skylab 4 (1973), a taste threshold study was conducted. It was found that one astronaut increased salt sensitivity while a second increased sweet sensitivity. Another study aboard Shuttle Mission 41G (1984) found no changes in taste or smell for two astronauts. Tennissen et al. hypothesized that taste changes might be limited to those who are susceptible to motion sickness, but found little support for that hypothesis in a reported experiment. Garshnek (1989b) noted that palatable food is psychologically important and that the Soviets use sharp seasonings as appetite stimulators because of taste changes in microgravity.

### m. Tactual Effects

Lackner and Graybiel (1979) demonstrated that the sense of touch, as well as the vestibular sense, vision, and hearing, contribute to the individual's sense of spatial orientation. They reported that subjects who were rotated in the z-axis during simulated microgravity perceived no body motion and lost their orientation, but that touch stimulation could help them regain a sense of orientation. On Earth, such rotation produces an illusion of movement in the opposite direction. If pressure is applied to the skin of a person in such a state, and if the pressure is associated with a given orientation (e.g., lying on the back), then the subject will regain an orientation and interpret that they are in that position.

### n. Biological-Rhythm Effects

No direct links between microgravity and biological rhythms were found in the literature. However, biorhythms will be briefly discussed here for several reasons. First, the mechanisms controlling biological rhythms are not fully understood. Second, although altered biological rhythms in space might not be directly caused by microgravity, they are very likely to be affected by the altered day/night exposures associated with space flight. Third, it is possible that direct effects of microgravity on other physiological systems such as the vestibular, cardiovascular, immune, or endocrine systems could indirectly mediate changes in biological rhythms. Finally, a relationship has been established between altered biorhythms and performance degradation.

There are many studies that substantiate the existence of biological rhythms and describe the performance effects of removing or altering "normal" temporal cues. Schaefer, Clegg, Carey, Dogherty, and Weybrew (1967) monitored physiological and motor-performance changes in two subjects isolated for eight days. Performance measures included hand steadiness, aiming and, two-hand coordination. They found large individual differences, but both subjects performed better in afternoon than morning during isolation (the opposite was true during the 3-day recovery period. They also demonstrated continued improvement over the period. Temporal periodicity was not as evident in the psychomotor measures as it was in the physiological measures.

Dushkov, Zolotukhin, and Kosmolinskiy (1968) described four stages that a subject passed through when subjected to 30 days of isolation. In the first 1-2 days, an "excitement" stage occurs, in which initial adaptation is evident. In the second to eighth days, a stage of "unstable adaptation" occurs. A third period of stable adaptation lasts until the mission is about over. The final "last effort" stage occurs during the last day or two.

Using heart rate and other measures of the cardiac cycle, Halberg, Vallbona, Dietlein, Rummel, Berry, Pitts, and Nunneley (1970) reported evidence for circadian rhythms in astronauts in microgravity (during the Gemini program), in individuals under bedrest conditions without exercise, and in individuals under bedrest conditions with exercise.

Berry (1971) reported that attaining quality sleep was a potential problem because of cyclic noises (e.g., thruster firings), staggered sleep periods, changes in preflight diurnal cycles, the unfamiliar sleep environment, and excitement. However, with the possible exception of sleeping in the Lunar Module, Berry did not interpret sleep as a significant problem for space flight, as long as careful considerations and corrective measures are applied in upcoming long-duration flights. Berry concluded that the effects of sleep and fatigue on human performance in microgravity have not been adequately studied.

A comprehensive discussion of the possible effects on human physiology and performance due to altered biological rhythms was presented by Winget, DeRoshia, Markley, and Holley (1984). They listed possible physical symptoms of desynchronosis as including digestive disturbances, general malaise, irritability, disorientation, confusion, distortion of time and distance, aches of various types, decrements of physical and mental efficiency, disturbances in sleep habits, fatigue, hunger changes, and irregular menstral cycles. Regarding space flight:

> "Rhythmic desynchronization among future Space Shuttle and Space Station crew members has the potential to create major problems for scheduling work and rest within the team. . . imposed 24-h schedules frequently conflict with physiological and psychological rhythms, altering work-rest periods from normal, ground-based sleep and wake cycles."

They described circadian rhythms as autonomous and synchronized by external cues (Zeitgebers or synchronizers) that entrain (bring under environmental control) the temporal position of the peak, establish the period, and influence the amplitude. Examples presented include body temperature, activity, urinary variables, and performance on various tasks. They caution that:

> "In spaceflight and transmeridian flight, there is a phase shift in the rhythms of both the social and the environmental (e.g. daylight) factors."

They presented a discussion of the literature linking shift work to illness, and the literature concerning the performance of flight and cabin crews of airlines flying across multiple time zones. Generally, significant performance degradation follows easterly but not westerly flights and performance returns to normal on simple tasks after three days; on complex tasks, degradation can last up to five days. Various researchers have reported performance degradation in flight simulator performance, psychomotor performance, hand-eye coordination, reaction time, dynamic arm strength, elbow flexor strength, sprint times, lift and carry, logical reasoning, encoding-decoding, calculation, vigilance, short-term-memory performance, visual search, flight-performance errors, and letter cancellation.

Winget et al. cited a Russian study by Litsov (1972) that discussed degradation in cosmonauts due to desynchronosis. In addition, they listed some of the difficulties in the ASSESS II mission (joint NASA and ESA) that might have been due to violations of what is known about biological rhythms. In attempting to explain the relationship between desynchronized biorhythms and performance degradation, they offered the hypothesis that performance degradation is caused by sleep disturbances which, in turn, are caused by altered circadian oscillatory systems. It should be noted that one of the goals of an experiment to be flown on the International Microgravity Laboratory is to determine the effects of fatigue and shifts in work/rest cycles on six cognitive tasks (Schiflett, 1991).

## C. Possible Countermeasures

A number of potential countermeasures were suggested in the literature. Essentially, they fall into two groups, a) those attempting to counter the effects of space flight on the human body and b) those attempting to counter effects of space flight on perceptual, cognitive, and motor performance. Although the latter is more relevant for this investigation, the former will also be discussed because of the often unknown relationship between physiology and performance in space. Consequently, the following two sections address physiological and performance countermeasures found in the literature and suggested by the present authors.

### 1. Physiological Countermeasures from the Literature

A wide variety of countermeasures have been reported in the literature (e.g., see Nicogossian, Rambaut, and Pool, 1984, for a summary of research aimed at finding countermeasures for common physiological reactions to microgravity).

Physical exercise is one countermeasure that has been used to counter different effects of microgravity. According to Berry (1971), calcium supplements and exercise are promising countermeasures to reduce loss of bone mass. Vigorous exercise routines have been used to slow (but not stop) both muscle and skeletal deterioration. Frey (1987) argued that earlier studies were wrong which concluded that aerobic exercises are not beneficial as a countermeasure to help astronauts re-adapting to Earth's gravity. She presented a strong case that aerobic exercise should be used as a countermeasure.

To overcome the possible deleterious effects of desynchronized biological rhythms, Winget, DeRoshia, Markley, and Holley (1984) suggested a number of preventative measures including preadaptation, drugs, diet, and exercise. Also, it should be noted that investigators at the US Air Force Armstrong Laboratory are currently investigating the underlying neurochemical basis of entrainment (e.g., Rea and Lutton, 1991) and the effects of various sources and intensities of man-made light that could conceivably be substituted as a synchronizer (e.g., French, Whitmore, and Schiflett, 1991). The results of their efforts could contribute to our understanding of how to prevent performance degradation in future space flights.

Huntoon (1989) described several countermeasures being tested or used. Several of these attempt to minimize or overcome the physiological changes during and after microgravity flight. For example, to prepare for extravehicular activity, crewmembers breathe pure oxygen to get most of the nitrogen from the blood to lessen the chance of decompression sickness. Also, fluid/electrolyte loading (consuming water and salt prior to reentry) has been found to reduce orthostatic intolerance (negative physiological reactions following reentry). Up to 3.5 hours per day might be spent on exercise and usually involves a variety of equipment. Huntoon reported that pharmacologic agents have been tested and cited Grigoriev, Stepantsov, Tishler, Mikhaylov, Pometov, and Dorokhova (1986) for a good summary of the Soviet research in this area. As an example of such countermeasures, Huntoon stated that scopolamine and dexedrine now are taken by some shuttle astronauts to prevent SMS.

Huntoon also stressed the importance of a nutritious and palatable diet as a countermeasure for both the physiological and psychological stressors associated with microgravity flight. She also emphasized the importance of spacecraft design to insure protection (e.g., controlled environment safely shielded from radiation) and to increase habitability (e.g., windows and private quarters are important for Space Station Freedom).

In two papers that provided a general overview of Soviet space flight from Sputnik to Mir through the eyes of a physician/psychologist, Garshnek (1989a, 1989b) discussed some other "countermeasures to physiological deconditioning" used by the Soviets.

> "Because many physiological changes in space can be medically significant upon return to Earth, the goal of countermeasures is to prevent complete adaptation to microgravity."

Garshnek reported that a number of countermeasures were being used or investigated to overcome some of the physiological changes that accompany microgravity. To counter the musculoskeletal changes, the Soviet "Penguin" suit has been used. This device requires the user to work against suit compression to maintain posture and complete tasks and exercise programs (places axial load of up to 70% body mass on the musculoskeletal system). To counter cardiovascular changes, a number of approaches have been tried including exercise programs, lower body negative pressure devices (e.g., Chibis vacuum suit - used in flight to create downward redistribution of fluids), fluid/salt replacement (prior to landing), and wearing support stockings and anti-g garments after landing. Other countermeasures mentioned include chest expanders, isometric and other exercises, elastic tension straps, electrical stimulation of various muscle groups, pharmacologic agents, and psychological support.

Simanonok, Charles, Moseley, and Davis (1991) reported data suggesting that time in the Weightless Environmental Training Facility may reduce the severity of space motion sickness. They also presented evidence supporting a fluid-shift explanation of space sickness, and argued that such an explanation implied preventative countermeasures such as "preflight blood volume reduction." Simanonok, Charles, and Srinivasan (1991) reported the results of a computer simulation that supported the notion that preflight blood volume reduction by is effective in reducing the responses to fluid shifts and also reducing subsequent fluid loss.

Artificial gravity has also been suggested and is being considered (e.g., see Huntoon, 1989). Centrifugation would eliminate unloading of bones and could help restore the hydrostatic gradient. The idea of two spacecraft connected by a long tether and rotating around a common axis was mentioned by Huntoon. She also argued that serious consideration must be made of any such approach because the introduction of new forces could have negative as well as positive effects (e.g., if not designed correctly, could increase motion sickness).

### 2. Performance Countermeasures

Traditionally, performance has been shown to be maintained or enhanced by improved a) personnel selection, b) original training, c) sustainment training (including simple practice), d) motivation/morale, e) design of the performance environment, and f) performance aids.

#### a. Personnel Selection

Selecting the best possible personnel for a mission is obviously important (e.g., see Parin and Kas'yan, 1969). Garshnek (1989b) discussed how the Soviet cosmonaut selection has been improved and currently includes physical testing; psychological testing; assessing reactions to force, exertion, etc.; and dynamic testing: parachute jumps, parabolic flight, etc.

In general, the selection procedure for astronauts appears to be one of the most successful, refined, and rigorous selection processes in the history of selection. According to most accounts, the program has been successful in selecting the highest quality individuals for space flight. However, there is always room for improvement and two points are suggested here. First, while extremely successful selection has been evident to date, there is a new challenge on the horizon. Specifically, the physical, psychological, and performance demands associated with planned long-duration flights might be different from those of past short-duration flights. Consequently, the selection procedure should be reviewed in light of what is known about individual reactions to long-term missions. The Soviet literature on long-duration flights could provide a useful tool.

The second point deals with research areas which, if addressed, could enhance the current selection procedure. Research should be conducted to determine areas in which substantial individual differences exist in performance. Two such variables identified in the literature are visual acuity and susceptibility to SMS. Once identified and consistently measured, then variables can be sought which predict such individual differences. As described above, work is ongoing in both of those two areas. However, little systematic work was found in the literature in which, for example, perceptual, cognitive, or motor performance degradation was systematically measured in microgravity and then correlated with possible predictor variables. Such an approach requires performance measurement in space, and measurement of actual task performance is often difficult for a number of practical reasons. Consequently, experimental work should first be conducted in which performance samples on different types of behavior should be used instead of performance on actual mission tasks. Such measures are discussed in the following major section. Once "clean" measures of performance change are available, then appropriate predictor variables can be sought and used in the crew selection procedure.

### b. Initial Training

As with selection, the successful history of the space program is testimony to the quality of training delivered to astronauts and other crew members. A number of excellent simulators and numerous training programs are in place. Whether current training procedures require modification for future long-duration missions is a separate issue that should be decided by conducting appropriate training systems analyses, which go far beyond the scope of the present paper. Rather, the following discussion provides suggestions and strategies for learning more about the effects of microgravity on human performance and incorporating that knowledge into original ground-based training.

As noted earlier, there is a deficiency in the amount of rigorous scientific data on the effects of microgravity on performance, especially under long-duration conditions. There are some recent projects aimed to correct that situation (e.g., see the following major section). After such data are available, initial training systems can be modified accordingly. For example, if motor-behavior is found to deteriorate more than cognitive or perceptual behavior in microgravity, then specific training and equipment design countermeasures are indicated. If it is found that the motor coordination portion of operating a stick control degrades in microgravity because the individual has not acquired the altered "feel" for the stick (i.e., has not adjusted to the proprioceptive, kinesthetic and tactual cues that go with microgravity), and operation of the stick is only required in microgravity, then ergonomic studies could determine how the mechanics of the stick in the trainer could be adjusted to simulate the "feel" of the stick in microgravity.

A second approach is to train the astronaut on a wide variety of physical characteristics and environments, so that, to master the task, the crew member must rely on cues likely to be altered or absent in microgravity. Similarly, if manipulating such a control is required for reentry, then similar studies should be conducted to maximize the "feel" of the stick from earth (if it will be performed last during training) or microgravity (if it will be performed last in space) to the conditions associated with reentry. If research determines that little negative transfer (degradation) is associated with moving from Earth's gravitational force to microgravity or, perhaps more important, moving from microgravity back to Earth's gravitational force, then no such adjustments would be required for initial training.

From the very early days of learning theory, it has been known that maximum positive transfer occurs if the eventual performance environment is identical to the training environment. Consequently, it is not surprising that from the very earliest days of space-crew training, substantial efforts have gone into creating high-fidelity training environments that simulate the target performance environment. It is also not surprising that much thought has gone into how to best simulate microgravity in a training environment. The two most common methods are water immersion and parabolic flight (as described above). While useful, the actual similarity of the water immersion environment to that experienced in microgravity has been questioned and parabolic flight does not last long enough and is too expensive to use to train actual mission tasks.

With regard to the adequacy of parabolic and elevator simulations as training vehicles, a number of concerns have been expressed in the literature. Such techniques involve altered states of high and low gravitational forces and the net effect of such a mixture could be different results than either state alone. Moran (1969) described the literature associated with parabolic flight as a technique to simulate microgravity. Moran stated that the main disadvantages of this method are a) the brevity of the simulation period (about 30 sec) which is too short to study many physiological reactions (or train mission tasks), b) the high gravity levels (about 2 g) before and after the simulation phase, c) the requirement for highly trained personnel to fly and maintain the aircraft used, d) the fact that strong wind gusts can effect the quality of the simulation, e) the fact that special aircraft modification is required, and f) the high incidence of motion sickness in personnel operating such aircraft (Loftus - 1963 - reported that 23 of 45 men vomited on one or more of 89 such flights). Moran argued that the principal advantage of parabolic flight is that it is the only technique for simulating the true force field that exists in space, and therefore, for example, the only environment in which meaningful research can be conducted on the effects of microgravity on the vestibular system.

Khrunov, Chekirda, and Kolosov (1971) discussed the training implications for deteriorated motor coordination. They reported the use of parabolic flight as a simulated environment to train cosmonauts in critical tasks that could be affected by degraded coordination, and demonstrated how such training helps reduce inappropriate movements and decrease total task time.

In addition to water immersion and parabolic flight, other techniques have been suggested. Most of them involve simulating some unique features of microgravity in Earth-bound trainers. For example, because of the degradation of fine-motor coordination skills found by Mantsvetova et al. (1965), they argued that training-based countermeasures should be taken:

> "This suggests that in the training of cosmonauts it would be advisable to include special training in movements in the absence, as far as possible, of gravitational forces. Such movement training should facilitate the motor actions of man under various gravitational conditions."

"One of the means of training could be exercises in different movements in equitonometric conditions [15]. Movements in equitonometric conditions are very similar in several cases to movements in weightless conditions and their use in the training of cosmonauts would probably be effective."

Fletcher (1968) discussed the physiological mechanisms related to several types of disorientation (postural, directional, temporal, spatial, vestibular, and clinical - Meniere's disease, vestibular neuronitis, and pressure vertigo). Of those, the first five are most likely to be encountered in microgravity. Fletcher described tumbling as a motion that can cause spatial disorientation and suggested such features could be implemented on existing simulators. The author went on to identify different training and personnel selection tasks for possible use in the space program.

Woodard, Parker, and Von Gierke (1987) and Reschke and Parker (1987) reported early progress in a program intended to investigate preadapting subjects to space by pre-exposing them to conflicting visual-vestibular environment. A later report by Parker and Reschke (1988) updated progress of that program and argued that one implication of their hypothesis linking sensory readaptation to SMS (discussed above) is that individuals could be inoculated to SMS on Earth by training them to disregard vestibular information. They described their effort to build and test the Preflight Adaptation Trainer (PAT), that exposes trainees to stimulus rearrangement on Earth prior to exposure to microgravity. They presented a series of experiments to test the notion that PAT could help train astronauts to reinterpret signals from the otolith organs, specifically, could facilitate a translation interpretation of the signals and suppress a tilt interpretation. Two of the four experiments supported that hypothesis.

Parker and Reschke suggested different kinds of trainers that could help inoculate astronauts to SMS in one of two ways. First, through "graviceptor stabilization" (i.e., keep trainee in fixed position and alter the visual scene to different orientations) sensory compensation is evoked. Second, through "graviceptor-visual rearrangement" (i.e., allow trainee to move head and change visual display accordingly, but maintain the gravitational forces on the otolith organ at a constant level) sensory reinterpretation is evoked.

Although not found in the literature, recent developments in virtual reality technology suggest another approach to this problem. Specifically, individuals could be allowed to "move around" inside a simulated space station environment for which the visual cues do not correspond to the vestibular cues from the otoliths. For example, to see things right-side-up, they might have to cant their head. Such an approach would provide conflicting visual and vestibular cues that could be useful to a) familiarize the crew with the phenomenon, b) be tested/used to identify individuals susceptible to SMS, c) habituate/counter-condition such individuals before the mission begins, or d) as an environment in which to conduct some initial training exercises.

In the research presented later in this paper, a similar, but less expensive approach was taken. Specifically, to determine the effects of altered (not diminished) gravity on several performance tasks, subjects were tested in both a normal (erect) position and in a circle bed rotated to a six-degree head-down orientation. Billingham (1987) reported that such an orientation simulates (imperfectly), the effects of microgravity on the cardiovascular system. The video displays and controls were also rotated, producing conflicting sensory input between vision and the otoliths. Finally, while not removed, the Earth's gravitational vector was altered. Conceivably, such rotation could be added to existing simulators and trainers, or the trainee's orientation could be constantly changed in an attempt to both familiarize the individual to such altered environments and to help train the subject to disregard randomly changing perceptual (otolith) and motor performance (proprioceptive, kinesthetic and tactile) cues. Similar arguments have been taken by other researchers who have noted that microgravity is a special case of a gravitational field (Chkhaidze, 1970; Giovani & Rendel, 1964).

Finally, quantified performance measures should be incorporated into existing and future trainers and simulators. If possible, corresponding measures should be embedded or retrievable from the spacecraft or other performance environment. Until measures of performance are available both during training and in microgravity, the question of performance degradation in space will remain intractable.

### c. Proficiency Training

After initial training is completed, time might pass before an individual is called on to perform the required tasks. Consequently, proficiency training programs are often used to provide practice and to assure high performance if and when the task must be performed. Currently, there are no formal provisions for proficiency training during shuttle flights; however, there are anecdotal reports of individual crew members providing their own training. The addition of formal proficiency training is one question that should definitely be investigated as the length of space flights increases. As highly competent and trained as crew members currently are, it is naively optimistic to presume that they will be able to conduct critical tasks in unusual situations after extended periods of time without some training or practice in the interval.

Presumably, high fidelity and interactive training programs will be embedded in hardware and software on future space vehicles and stations. Such embedded training will allow the crew to practice critical tasks (e.g., reentry). As discussed in the initial training section above, such trainers and simulators should be designed to simulate the conditions under which the task will be performed. As an alternative or as a supplement, it has been suggested that individual hand-held computers could be used to provide proficiency training during long-duration flights (Feng, 1991). Such an approach would allow customized training material, tailored to that person's tasks, duties, and responsibilities. Finally, as argued earlier, information on the types of performance tasks most susceptible to deterioration would help determine which tasks should be targeted for proficiency training.

### d. Motivation/Morale

Bluth (1982) suggested that the physiological effects of stress might be due to psychosocial causes. Therefore, psycho-social countermeasures might improve or sustain performance on long-duration flights. For example, Bluth suggested that relaxation techniques which attempt to restore balance to the autonomic nervous system might be an effective countermeasure. Also, Bluth pointed out that in real life, one belongs to both a supportive friendly group (e.g., family) and a formal working group (work colleagues). In space, there is only one group to provide both functions. Consequently, steps should be taken to change this situation. Bluth also argued that more care should be taken not only in selecting crew members, but in the psycho-social aspects of assembling a team. This will become more important with longer flights.

Santy (1987) provided a discussion of the planning that is currently going into the psychiatric component of Space Station Freedom's health maintenance facility. To prevent depression and other negative psychological reactions to long-duration space flight, Pierce (1988) argues that the crew must be selected and trained to have situational plasticity, that is, to be assertive at times and compliant at others. He also suggested that a buddy system might be useful for monitoring, supporting, and counseling the crew. He suggested that other literatures are relevant and they should be studied to prepare a program of mental health for astronauts on long flights. Other relevant literatures include:

Patient-family-staff in transplant ward
Family therapy theory
Cross-cultural and cross-racial psychology
Migration and translocation dynamics
Compliance with medical and social demands
Propaganda analysis
Effects of clique formation and leadership on athletics
Studies of effects of isolation and countermeasures (e.g., studies of human reaction on submarines and Antarctica stations)

### e. Design of the Performance Environment

Parin and Kas'yan (1969) observed that, in general, there is little or moderate motor coordination degradation in microgravity as long as the individual is immobilized (e.g., attached to the work area). In contrast, they concluded that significant degradation can occur in free-floating conditions. Consequently, one method of maintaining performance is to provide appropriate work stations and environmental features which allow the crew to secure a stable position. Parin and Kas'yan (1969) suggested that the design of the work areas in the space craft must be improved to enhance the crew's performance:

> "During a space flight lasting up to 5 days with the astronauts remaining inside the ship and good attachment to the working places, their working capacity was retained at a high level.
>
> A decrease in the level of efficiency is possible upon complication of working activity, an increase in the length of the flights and during a stay in an unsupported position.
>
> In order to prevent the unfavorable effect of prolonged weightlessness, it is necessary to improve the selection and medical and biological conditioning of astronauts to the effect of this factor."

When discussing Soviet countermeasures, Garshnek (1989b) reviewed the improvements in the design of Soviet space stations over the years. A great deal of effort is currently ongoing to insure that the space station design optimizes human performance and morale. Currently, considerable planning and human-factors considerations are going into the design of Space Station Freedom.

Finally, controls and displays should be designed to reduce discrepancies between the perceptual world associated with microgravity and that of earth. For example, while left/right and up/down can vary considerably in space than on earth, other relationships remain constant (e.g., in or out). Consequently, it could be argued that controls which require in/out relative operation would be preferable to those requiring up/down or left/right manipulation.

#### f. Performance Aids

Performance aids are computer-based, paper-based, or independent physical devices which assist an individual in completing a task. Performance aids can be as simple as a paper-and-pencil check list or as complex as electronic devices to assist the individual to make perceptual judgements. Performance aids are not intended to train persons how to perform the task, nor are they intended to be successfully used to help someone with no prior training perform a task. Rather, they are usually intended to assist a previously trained individual to recall the training and perform the task correctly. Performance aids represent a recognition of the fact that, even in the most highly trained individual, memory is not perfect. They are especially valuable when used to assist highly critical, dangerous, or infrequently performed tasks. In space applications, they also should be considered to supplement any task involving components known to be susceptible to microgravity.

Currently, with the exception of procedural manuals and radio interactions with ground crew, there are no known performance aids. With long-duration flights, it should not be assumed that tasks mastered even to a high degree during initial training will be perfectly performed after extended periods and in altered environments. Consequently, performance aids should be studied as a way of supplementing initial and proficiency training. These aids should probably be embedded in existing hardware/software systems or individual hand-held microcomputers, to allow maximum information storage with little additional weight. To the extent that humans are vulnerable to perceptual illusions in microgravity, performance-aid devices should be developed to assist crew members accurately assess sensory situation. Finally, to the extent that some tasks are found to be more difficult to perform in microgravity, performance-aid devices should be designed and provided.

### D. Performance Assessment in Microgravity

A number of authors have argued that if performance is to be researched, measured, or monitored in microgravity, then methods, apparatus, and software capable of accurately measuring actual task performance or performance on representative critical task components must be developed. In the same vein, some authors have argued that performance tests/measures should be used to test the effects of stress and the general condition of the crew. Such measures might provide early prediction of physiological conditions as well as offering a face-valid index of the astronaut's ability to complete upcoming tasks. Finally, it was suggested by the present authors in an earlier section that collection of performance data on "primitive" task representatives under microgravity conditions could help a) develop better selection instruments, b) improve initial training, c) design proficiency training, and d) prescribe performance aids.

The argument for developing performance tests for use in space was voiced by Hancock, Caird, and Parasuraman (1990), who expressed concern that, while astronauts were expected to put forth "superhuman efforts" in short-duration flights, this is not reasonable for longer duration flights:

> "We have few impoverished models of how the human performance varies in microgravity conditions and have had to rely on the harsh lessons of experience rather than the proactive insights of prediction. Longer duration missions will only serve to set this inadequacy in increasing contrast."

> "Historical concerns in manned space flight have been for physiological support, presuming the general principle that while the environment was sufficient to sustain a stable physiological platform, operator behavioral responses would not be significantly impaired."

Hancock et al. proposed a three-dimensional model of stress. Two dimensions are the physical composition of stress and its temporal duration and the third dimension is the adaptive response. Minor levels of stress can disrupt cognitive efficiency as behavioral adaptive responses compete for limited resources. Higher levels of stress tax the physiological response system which attempts homeostatic processes. Still higher levels of stress can threaten life. They argue that task performance should be used to assess the individual's reaction to stress:

> "It has been shown continually, that conditions which fail to supersede dynamic balance are sufficient to disturb task performance. Our position here, is that it is <u>task performance</u> that is the critical consideration, not the physiological status."

Chiles (1966) argued that if performance-based measures of stress during space flight are to be developed, then a "synthetic task complex" approach is the most reasonable way to study man in the system. In this approach, relevant task components are extracted and combined as they are in the real world. Chiles cited Finan, Finan, and Hartson (1949):

> "Measurement of decrement in isolated reactions throws little light upon deterioration in a complex skill, even though . . . many isolated reactions are sensitive to decrement."

Chiles cited Patton (1953) ". . . while specific and isolated tests of performance may show no decrement under stress, complex performance tasks requiring a patterning of specific responses may suffer greatly," and supported Knowles' (1963) argument for assessing primary and secondary task performance. In summary, this author argued that multiple tasks should be used to best measure the effect of stressors: "In other words, it is the combination of tasks rather than the specific individual tasks that yields stress sensitivity."

Chiles described a "performance battery" comprising tasks that are realistic representatives of real-world task components as well as meaningful measures: probability monitoring, warning lights (reaction time), mental arithmetic, target identification (exposure to spatial pattern followed by decision if pattern occurred in noisy context), and code-lock (team task involving learning the proper sequence of buttons to press). Some example data were presented.

Teichner and Olson (1969) attempted to predict the effects of various flight-related variables on human performance. They described four fundamental tasks:

Searching (orienting, scanning, monitoring, seeking) - measured by probability of detection)

Coding (labeling, naming, categorizing, translating) - measured by percent error

Switching (selecting, dichotomous switching) - measured by reaction time

Tracking (alignment, steering, aiming, walking, tuning, pursuit or compensatory) measured by time on target

Complex tasks comprise combinations of these simpler components. A number of empirical and theoretical relationships are then presented by the authors relating performance on each of the above four tasks to situational conditions (e.g., number of signals presented, transmission lag). These relationships are offered for three general conditions related to space travel: a) normal conditions; b) conditions of degraded atmospheric environments (e.g., contaminants); and c) other environments (temperature, noise, and illumination). Interestingly, no attempt was made to extend this analysis to a microgravity environment.

Alluisi (1970) discussed some computer-based performance measurement equipment and corresponding task batteries, and presented early data on pilot subjects showing subtle effects such as time of the day. Mallory (1971) described the early stages of an attempt funded by NASA to identify a battery of on-orbit tests to quantify the effects of microgravity on human performance. Two methods of performance testing were described, observational performance testing (OPT), in which measures are extracted from standard shuttle task data, and experimental performance testing (EPT), in which special experiments are conducted with special apparatus to determine performance. Mallory stated that OPT was selected for the early Shuttle studies and went on to describe the design characteristics of a hardware system called the Bioengineering Test Administrator (BETA), which had not yet been constructed, but would accommodate both OPT and EPT approaches.

Wortz, Hendrickson, and Ross (1973) reported the results of a large study intended to develop an assessment methodology for using psychological, performance, and psychophysiological variables to monitor and predict crew members feelings of well-being. Attentional flexibility was selected as the domain because it is detectable and is "indicative of a wide variety of factors relevant to the well-being of individuals and groups." In their review of the literature, they concentrated on arousal and selective attention, and did not address attention as a limited central processing capability, as studied in dual-task and mental workload paradigms.

Concerning research in the area of human performance, Dietlein, Rambaut, and Nicogossian (1983) argued that:

"The development of precise tests able to discern subtle decrements in performance, and perhaps changes in behavior, will be necessary in preparation for longer flights, when the ability to predict decrements will be important."

Radkovski and Getzov (1988) described a portable testing device (PLEVEN-87) designed to assess higher cognitive processing. The device was used to test three cosmonauts; however, no data were presented.

Recently, significant steps toward developing such a performance test battery have been made by Essex Corporation under contract to NASA (e.g., Kennedy, Wilkes, Baltzley, & Fowlkes, 1990). NASA funded development of the resulting Automated Performance Test System (APTS) in order "to assess human performance in the presence of toxic elements and environmental stressors." Kennedy et al. provided an overview of the history of computer-based performance tests as well as an excellent review of the psychometric characteristics that such performance tests should demonstrate. For example, one of the advantages of computer-based performance tests is the possibility of almost unlimited parallel forms. That is, a large number of different versions of the same test can be randomly presented. This feature allows repeated-measures to be obtained from the same subject, allowing a baseline to be established before some independent variable (e.g., microgravity) is manipulated. Kennedy et al. argued that attaining stability (i.e., repeatedly administering the test until performance has stabilized) is an important feature of conducting research with such performance-based tests.

Kennedy et al. reported that they have determined four important factors: motor speed (speed of response execution), symbol manipulation/reasoning (ability to reason abstractly), cognitive processing speed (the extent to which defined rules governing generation of response alternatives have been learned and can be used), and response selection speed (speed with which responses can be selected from the generated set of alternatives). They are developing a battery of performance tests that taps these four elements of human performance.

Another recent and promising development is the announcement that a sample of six performance tests from the military-developed "Unified Tri-service Cognitive Performance Assessment Battery" will be flown on the International Microgravity Laboratory to determine the effectiveness of such tests in detecting/measuring the effects of fatigue and shifts in work/rest cycles (Schiflett, 1991).

## E. Conclusions from the Literature Search

In conclusion, there is a great deal of literature available on the effects of microgravity on human physiology, but relatively little information on its effects on human performance. The available evidence is often anecdotal and lacks scientific rigor. There is sufficient evidence to leave little doubt that performance can degrade in microgravity. However, to date, such degradation has been negligible and has not interfered with mission success. The main question that must be addressed soon is whether these subtle effects will remain subtle when the duration of space flight is dramatically increased.

## III. Astronaut Interview Tool

Ideally, performance degradation on critical mission tasks would be objectively determined by comparing performance data from training exercises prior to the mission to corresponding flight data. However, no such data could be located. Consequently, because initial support for the notion of performance degradation in microgravity was limited to a relatively small number of anecdotal self-reports, it was concluded that an attempt should be made to document and quantify the self-reports of a sample of experienced crew members. To accomplish that goal, a structured interview was designed to measure the incidence, nature, and possible sources of alleged degradation.

The first draft of the resulting instrument is found in Appendix B. It was designed to be comprehensive, asking about all the possible sources of degradation identified in the literature search (see Table 2). In general, for each major topic (e.g., near vision), the crew member was asked to rate his/her perception of changes in that dimension early in flight, late in flight, and early after landing on a 7-point semantic differential ranging from "Much poorer than in the week prior to takeoff" to "Much better than in the week prior to takeoff." If changes were reported, they were asked to provide more information about the nature of the changes. In addition to the various performance-related dimensions, questions were posed about the quality of the training they received, whether they felt that on-board training would help them perform their mission tasks, and whether they believed that future long-duration flights would benefit from on-board training options.

The draft questionnaire was circulated within NASA Johnson Space Center and serious questions were raised concerning a) the anonymity of the crew and their willingness to answer many of the questions, b) the length of the questionnaire, and c) the assertion that data already existed that answered many of the questions posed. Currently, answers to these questions are being sought; refinement and administration of the questionnaire, and analysis of the resulting data are being delayed until the second year.

## IV. Formation of Expert Panel

In order to provide the deepest and most comprehensive treatment of this wide topic, the formation of an expert panel was proposed. The strategy was to first use the literature to identify critical areas as well as to identify scientists actively involved in those areas. Also, individuals knowledgeable in both human performance and space-flight issues would be identified and nominated to serve as chairperson of this panel. Once formed, the expert panel would be encouraged to function objectively and independently to a) identify research needs in this area; b) conduct specialized literature searches in their areas of expertise; c) help identify and prioritize possible sources of performance degradation, their causes, and their countermeasures; and d) review and critique ongoing NASA and contractor/grantee research efforts.

From the literature, the primary areas that should be represented by members on the expert panel were human performance (especially someone with aerospace/flight background), cognition, training, social influences, vestibular effects, space physiology, and the psychological aspects of long-duration flight. In addition, several other areas were identified as important and should be represented (to the extent that funds would allow). Those areas included astronaut training and performance requirements, astronaut selection, biorhythms, motor performance, and perception (general). Also, specific nominees representing these areas were provided to the NASA sponsor. However, because there was some question of the availability for funds in years 2 and 3, the decision was made to delay the selection and formation of such a panel until it is certain that funds would be available.

## V. Experimental Approach and Findings

As discussed above, there are a host of possible independent variables that could individually or jointly influence human performance in microgravity. To complicate matters, numerous human performance systems and subsystems have been identified (e.g., see Fleishman and Quaintance, 1985), and manipulations of different individual or combinations of independent variables could effect changes in individual or multiple performance measures. Consequently, only exploratory research was conducted during this effort. Two experiments were conducted to obtain initial data on two general hypotheses.

<u>Hypothesis 1: Changing the Gravitational Orientation of Subjects on Earth Can Help Identify Tasks that Could Degrade in Microgravity</u>. It is too costly and impractical to use realistic simulation of microgravity for training/adaptation purposes. However, it is argued here that meaningful research in this area can be conducted by studying the human's reactions to altered gravitational forces. The absence of gravitational cues is a special case of altered gravitational cues. Using this approach, earth-based research facilities could initially filter the multitude of independent-dependent variable combinations that show sensitivity to gravitational manipulation. Then, more precise experimentation could be conducted in microgravity. Also, after susceptible tasks are identified, cost-effective training equipment (that randomly alters the trainee's orientation with respect to gravity) could be constructed and tested as a countermeasure to inoculate the crew to

the effects of microgravity. In addition, control equipment could be designed/redesigned to provide reference stimuli that are assured to be present in an undistorted form while gravitation and other forces change during flight.

Consequently, the first general hypothesis addressed was that an altered orientation relative to earth's gravity can degrade human performance and that any tasks degraded on earth are candidates for tasks that would be degraded in microgravity. To test Hypothesis 1, a small sample of cognitive, psychomotor, and perceptual tasks were tested under normal, upright posture and tilted (left lateral roll) to a 6-degrees head-down orientation. Details of the methodology are discussed in "Experiment 1" below.

Hypothesis 2: Altering gravitational cues will degrade motor performance tasks which are automated and partially guided by gravitational cues. Also, if performance feedback is provided, then other ongoing cognitive or motor tasks will also degrade because of reduced attentional resources. Based on current knowledge automated behavior and the effects of simultaneous multiple tasks on workload, the second hypothesis was that motor performance that has come under automatic control will degrade in microgravity if gravitational forces or their effects are cues which help guide that behavior. Further, performance on other simultaneous perceptual, cognitive, or motor tasks is also likely to degrade (if the subject is aware of the degradation) because attentional resources usually allocated to their performance must now be shared in order to monitor/adjust the previously automated behavior.

It has been shown that automated performance is so autonomous that an individual can devote most of his/her attentional resources to a second task. For example, one can devote almost full attention to composing a report (non-automated cognitive task) and at the same time enter the letters into a word processor (assuming that typing has been automated). If even subtle changes are introduced, the fragility of the automated performance is demonstrated. For example, if the spring-loadings in the key board are slightly increased or decreased, degradation is very likely to occur in both the "automated" typing performance and the simultaneous cognitive composition performance (the latter because more conscious attention must be diverted to the previously automated motor typing behavior).

It is not suggested here that this is the only possible source of performance degradation that could occur in microgravity. Presumably, over the three year project, several others will be identified and tested. However, it was decided that Hypothesis 2 is a reasonable candidate with which to begin because it could partially explain several anecdotal reports and because it is consistent with many findings in the literature. In addition, it is a hypothesis that can be tested on earth by altering normal gravitational forces. If supporting evidence is found, the hypothesis can eventually can be tested in a microgravity environment. Also, there are candidate countermeasures that can be tested and, if found effective, implemented. To test Hypothesis 2, an experiment was conducted in which automated and non-automated motor tasks were conducted in one of two gravitational orientations, with or without performance feedback, and with or without secondary cognitive tasks. Details of the methodology and results are presented in the section below entitled "Experiment 2."

## A. Experiment 1

### 1. Introduction

The fundamental goal of Experiment 1 was to determine the presence/extent of performance degradation in subjects when their orientation relative to earth's gravity is altered. To test this hypothesis, a sample of cognitive, psychomotor, and perceptual tasks was given to subjects in an upright or laterally rotated (6-degrees head down) orientation. In addition to individual tasks, one dual task served as a pilot for the second experiment.

Based on analysis and the literature findings, changing the subject's orientation with respect to gravity was expected to cause more degradation in some tasks than in others. Degradation was expected to be most apparent for automated psychomotor tasks which could be influenced by altered gravitational forces (e.g., writing). In addition, some degradation was expected for other less automated psychomotor tasks, especially if they resembled tasks conducted occasionally in real life (e.g, fine motor dexterity tasks such as using a tweezers to insert pegs in holes). Perceptual speed tests involving visual scanning were expected to suffer some degradation to the extent that interoceptive feedback stimuli differed due to the change in the gravitational vector.

Finally, cognitive tasks were expected to degrade the least. Because no specific cause could be identified for degradation in cognitive performance due to a change in gravitational frame of reference, it was proposed that any such degradation must be attributed to some other general characteristic(s) of the rotated condition. Possible variables that could contribute to such degradation are a) change in circulation; b) change in alertness or feelings of ambiguity due to the subject being placed in an orientation that usually accompanies resting; c) conflicting visual and vestibular information; d) feelings of stress from being asked to perform tasks in an unusual body orientation; and e) feelings of physical discomfort from being in a tilted position.

### 2. Method

#### a. Subjects

Approval to use human subjects was secured from the University of Texas Health Science Center at San Antonio's Institutional Review Board. Subjects were 10 adult males who a) were between the ages of 21 and 45, b) reported no medical history of hypertension, c) were less than 6 ft. 2 in. tall (due to size limitations of the circle-bed apparatus), d) were right-handed (because the apparatus only allowed rotation in one direction and the subject's preferred hand must be available to perform tasks), and e) whose blood pressure immediately prior to participating in the experiment was below 140/90.

#### b. Apparatus

A special laboratory was constructed for this research. The focal feature of this laboratory was a Stryker Circoelectric bed Model 460. The intended use for this circle bed is to provide care for patients with multiple fractures, extensive burns, quadriplegia, acute arthritis, dermatitis, and others requiring specific treatments. For the present application, it was modified and used as a tool to adjust a subject's body orientation with respect to gravity (see Figures 1-3). In the present experiment, two body orientations were selected: a) upright (standing), and reclined laterally tilted to a 6-degrees head-down orientation. The six-degree, head-down position was selected because other authors have suggested that this orientation partially simulates the effects of microgravity on the cardiovascular system (e.g., Billingham, 1987). Foam cushions were added to support the subject's back and head, and to provide a standard reference for adjusting the subject's position.

A "table" was added to the apparatus because many of the tasks involved reading materials, writing, etc. This table was attached to the bed and kept the same spatial relationship to the subject when the bed was rotated. The height of the table was adjusted to accommodate each subject's stature and preference. Also, the apparatus associated with the dexterity and reaction time tasks were modified so that they could be attached to the table top and remain in the same stable position regardless of orientation. Clamps were used to secure apparatus and tape was used to secure paper to the table top.

Because seven of the selected tasks were computerized, a computer monitor was required to present the task stimuli. Ideally, a single monitor would have been attached to the bed so that, when rotated, the orientation of the monitor with respect to the subject would have remained constant. However, it was not financially possible in the current effort to make such a modification that would insure the safety of the subject, so another approach was taken. Two identical monitors were used, one for the upright condition and one for the rotated position. The heights of the two monitors were standardized relative to the circle bed. The height of the upright monitor was adjusted to the level appropriate for a given subject by raising or lowering a hydraulic jack, which determined the location of the upright monitor within a constructed shaft. The monitor for the reclined position rested on a 6-degree incline (parallel to the orientation of the subject when in the reclined position) and was similarly adjusted to match the position of the upright monitor. The distance from either monitor to the subject's head was approximately 30 inches. Before

Figure 1. Circle bed interior work area.

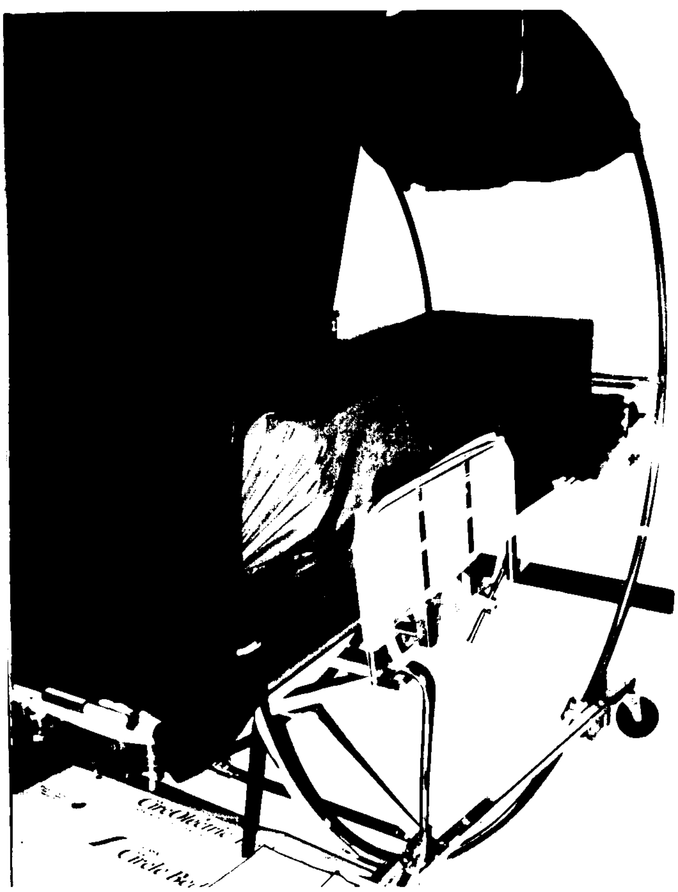


Figure 2. Circle bed in reclined position.

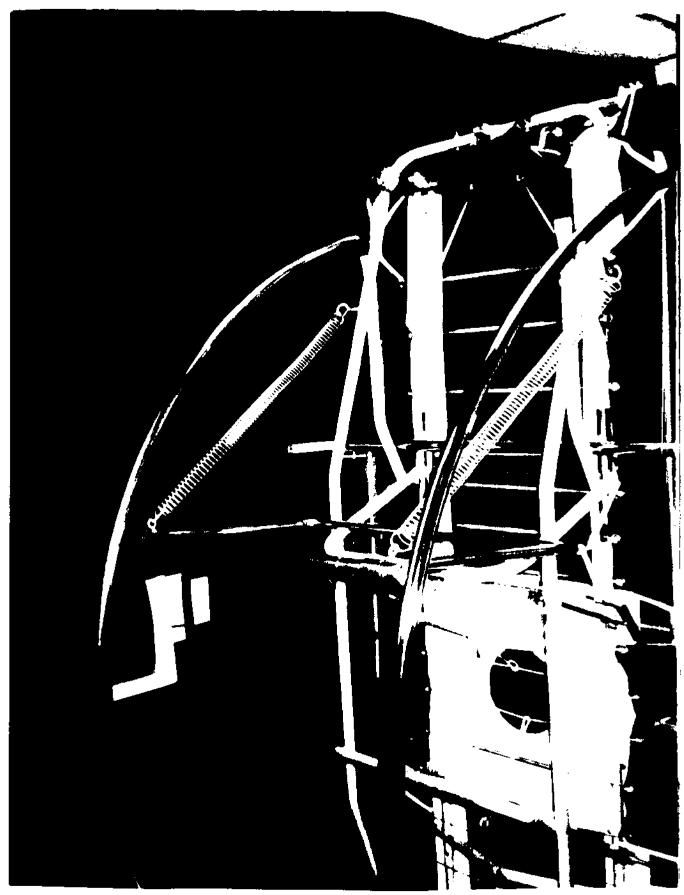


Figure 3. Circle bed in upright position.

the experiment, the brightness for both monitors was set to the same level (by using a Gossen Luna-Pro SBC Light Meter), and the screen adjustment knobs were taped to insure no accidental adjustments occurred.

It was important that the two visual fields corresponding to the upright and reclined positions remained constant. To accomplish this, black cloth was draped over both monitors forming what appeared to be a wall. The material was pulled tight so that visual cues associated with gravity would be minimized (i.e., folds that occur in loose curtains and convey which direction is "vertical"). Similarly, black cloth was secured to the perimeter of the circle bed to obscure the peripheral view of extraneous stimuli. Ceiling lights were turned off to avoid direct or indirect cues of orientation. A small light attached to the circle bed was used to illuminate the table area for tasks requiring light (e.g., reading tasks and dexterity task). This light was positioned to minimize illumination or glare from the monitors. In summary, all attempts were made to keep the visual fields constant for both positions.

A controlling computer and associated equipment were located adjacent to the circle bed and shielded from view by the curtains. The speaker used to present the mathematic problems was located behind the curtain and between the two monitors.

### c. Tests and Tasks

Attempts were made to secure the Automated Performance Test System developed by Essex for NASA, but that test battery was not available. Consequently, the following tasks/tests were selected.

Khachatur'yants (1975) reported that simple and up to three-choice reaction time was not degraded in microgravity

1. <u>Simple Reaction Time</u>. An apparatus and controlling software described in Schroeder & Tuttle (1990) was used to test simple reaction time. Subjects are informed which one of three response keys are to be used prior to each trial. False starts are counted but data from false starts are not included in the resulting statistical analyses. The reaction time apparatus was clamped to the table and individually adjusted for comfortable horizontal and vertical placement. Once adjusted, it was kept in that location for the duration of the reaction time experiment (for both position conditions).

Simple reaction time was included in the performance battery for several reasons. First, although no data were found supporting the contention that simple reaction time degrades in microgravity (e.g., Khachatur'yants, 1975; and Hideg et al., 1982), the procedure used here (see Schroeder and Tuttle, 1990) allows simple reaction time to be analyzed in separate components, which have been found to be more sensitive measures than total reaction time. Second, authors such as Khachatur'yants have reported no effects on simple reaction time but have found effects on reaction times involving more complex analysis and reactions. Consequently, simple reaction time was included to serve as a control for the complex reaction time task described in the following section. Finally, Schroeder (1977, 1990) has argued that relationships between simple and complex reaction time can provide a more sensitive measure to motivational changes (e.g., stress or drug effects) than either task individually. Consequently, combined measures of simple and complex reaction time will be assessed.

2. Complex Reaction Time. The same stimulus display, apparatus, and method for handling false starts are used in the complex reaction time task as described for the simple reaction time task above. The only difference was that the stimulus presented contains information that forces the subject to decide which of three response keys is appropriate. In addition to reaction time, error data are captured. This task was included because Khachatur'yants (1975) reported that reaction times involving more complex cognitive analysis were affected by microgravity while simple reaction time was not. However, it should be noted that Thornton, Moore, Pool, and Vanderploeg (1987) found no degradation for crew members tested on the Sternberg complex reaction time test.

It should be noted that in addition to traditional total reaction time measures of individual simple and complex reaction time measures, several componential and theoretical measures were computed (Schroeder & Tuttle, 1990). These measures have been found to provide more sensitive measures of performance than traditional total reaction-time measures in some applications (e.g., alcohol detection). Most of these measures derive from theoretical relationships within and between simple and complex reaction time (Schroeder, 1977).

3. Stationary Light-Pen Task. This apparatus and controlling software was originally used as a test for detecting alcohol use in human subjects (Schroeder & Tuttle, 1990). In this task, subjects aim a special long-distance light pen at a stationary target presented on a computer monitor. Visual feedback is provided about point-of-aim. In addition, random visual stimuli are presented in the subject's peripheral visual field and, at the end of a trial, the subject is to report if a stimulus (one of a set of digits: 0, 1, 2, 3, or 4) was presented, and if so, what the stimulus was. Measures of accuracy and steadiness in the horizontal and vertical dimensions are the primary measures.

This task was included because it has been shown to be a sensitive and reliable measure of hand-eye motor coordination performance (Schroeder and Tuttle, 1990), and because an altered gravitational vector could affect performance on this task. Such conditions have been reported to result in degraded performance in microgravity (Mantsvetova et al., 1965; Chekirda, 1967; Ivanov, Popov, & Khachatur'yants, 1967; Kas'yan, Kopanevk, and Yuganov, 1969; Chkhaidze, 1970; Leonov and Lebedev, 1973). Also, in a highly analogous target-shooting task, Kitayev-Smyk (1963) found that performance was degraded in microgravity.

4. Light-Pen Tracking Task. The same apparatus as used in the stationary light-pen task is used in this task. The primary differences are a) during a trial, the target constantly moves and randomly changes directions, and b) no peripheral visual stimulus is presented. Scores are based on measures of accuracy in both the horizontal and vertical dimensions. This task was selected because tracking performance has been reported to degrade in microgravity (e.g., Leonov and Lebedev, 1973; Khachatur'yants, 1975).

5. Physical Dexterity Task. A special pegboard apparatus was designed in an attempt to minimize the effects of gravity. The apparatus comprised two perpendicular boards with a line of 20 holes drilled in each board. This wooden frame was clamped to the desk top. At the beginning of the task, metal pins were located in each of the holes on the bottom board (the board parallel to the table top). The subject's task was to use a tweezers to remove each pin from its initial location and insert it in the corresponding hole in the second board (perpendicular to the table top and facing the subject). The subject was to begin at the extreme right and move as many pegs as possible in the time allotted (30 sec). Subject's scores were the number of pins moved and the number of pins dropped during the 30 sec.

This task was included because it represents a classic measure of eye-hand coordination and such performance has been reported to be susceptible to degradation in microgravity (see the justification in the above section discussing the "Stationary Light Pen" task).

6. Perceptual Speed. The Perceptual Speed Test comes from the Guilford-Zimmerman Aptitude Survey published by Sheridan Psychological Services, Inc. This test presents two vertical arrays of four (left) and five (right) pictures. The subject's task is to identify which picture on the right (lettered A through E) corresponds to each test item on the left. Because the test does not come in two parts, the first 12 sets of stimuli were divided into two groups with sets 1, 3, 5, 8, 10, and 12 composing one form of the test and the remaining sets composing the second form. In Experiment 1, subjects were randomly assigned one of the two resulting test forms to be performed in the upright position and the second form in the reclined position. Subjects were allowed 90 sec. to finish each form. If they finished before that, the time to complete the form was recorded.

In the standard test procedure, subjects use a pencil to mark the letter that corresponds to their answer. However, to minimize the motor performance component that could be susceptible to gravitational forces, subjects were instructed to state the number of the test item out loud followed by the letter corresponding to the identical picture. To make this procedure more equivalent to the standard procedure, subjects were given a pencil and allowed to mark any item they might want to skip and return to later. This perceptual/cognitive task was included because it contains a cognitive component as well as a primarily vertical visual scanning component. Scanning performance involving short-duration repetitive eye movements has been suggested to degrade in microgravity (e.g., Parin and Kas'yan, 1969).

7. Identical Pictures Test. The Identical Pictures Test (P-3) comes from the Kit of Factor-Referenced Cognitive Tests published by the Educational Testing Service. This cognitive/perceptual task was included because cognitive as well as horizontal visual scanning behavior is required. To perform this test, the subject must visually scan a horizontal array of five figures to find the one that matches a test figure presented to the left of the array. Because the test comes in two parts, subjects were randomly assigned one of the parts for the upright condition and the second part for the reclined position. Subjects were allowed 90 sec for each part.

In the standard test administration, the subject uses a pencil to mark the identical picture. However, to implement the vocal procedure discussed in the Perceptual Speed Test section above, the letters A through E were typed above each array item and each test item was numbered. Subjects were instructed to state each item number and the letter that corresponded to their answer.

This perceptual/cognitive task was included because it contains a cognitive component as well as a primarily horizontal visual scanning component. Scanning performance involving short-duration repetitive eye movements has been suggested to degrade in microgravity (e.g., Parin and Kas'yan, 1969).

8. Flexibility of Closure Test. The Flexibility of Closure (Cf) Test comes from the Comprehensive Ability Battery (CAB-2) published by the Institute for Personality and Ability Testing, Inc. This perceptual/cognitive task was included because both horizontal and vertical visual scanning are likely to be involved. In this test, a set of five prototype shapes is presented, each identified by a letter A through E. Below the five prototype shapes, 12 test items are presented. The test items are more complicated than the prototype shapes. Each test item contains one and only one of the five prototypes, as well as many other geometric forms. The subject's task is to report which of the five prototype figures is embedded in each test item. Because the test does not come in two parts, the first 12 sets of stimuli were divided into two groups with sets 1, 3, 5, 8, 10, and 12 composing one form of the test and the remaining sets composing the second form. Subjects were randomly assigned one of the two resulting test forms to be performed in the upright position and the second form in the reclined position. Subjects were allowed 90 sec. to finish each form. If they finished before that, the time to complete the form was recorded.

In the standard test procedure, the subject uses a pencil to mark the letter that corresponds to the answer. However, to minimize the motor component, the vocal procedure described above was used.

This perceptual/cognitive task was included because it contains a cognitive component as well as both horizontal and vertical visual scanning components. Scanning performance involving short-duration repetitive eye movements has been suggested to degrade in microgravity (e.g., Parin and Kas'yan, 1969).

9. Gestalt Completion. The Gestalt Completion Test (CS1) comes from the Kit of Factor-Referenced Cognitive Tests published by the Educational Testing Service. This cognitive/perceptual task was included because a cognitive task with little visual scanning behavior is required (while scanning could occur, it is limited to a small area). In this test, the subject is presented a drawing of a common everyday object (e.g., flag or hammer), however, portions of the drawing are missing. The subject's task is to report what the object is. Because the test comes in two parts, subjects were randomly assigned one of the parts for the upright condition and the second part for the reclined position. Subjects were allowed 2 minutes for each part.

In the standard test administration, the subject uses a pencil to write the name of the object below each test item. However, to implement the vocal procedure discussed above, subjects were asked to state each item number and their answer (e.g., "number 2, hammer"). Also, subjects were given a pencil to mark items they wanted to return to later.

This perceptual/cognitive task was included because it contains a cognitive component with very little horizontal or vertical visual scanning. Consequently, it provided a control condition for the Perceptual Speed, Identical Pictures, and Flexibility of Closure tests described above.

10. Mental Arithmetic (Subtraction). In order to provide a non-visual cognitive task and in order to provide a task that could be presented simultaneously as a secondary task for primary motor-responding tasks, a computerized mental arithmetic (subtraction) task was created. In this task, a computerized voice synthesizer first presented a two-digit starting number, in the range of 30 to 70, and evenly divisible by ten. The subject was instructed to repeat that number out loud (to insure that the subject had heard the starting number). Next, at the rate of one every 4.5 seconds, a single-digit number in the range of two to eight was randomly presented. The subject's task was to subtract each number from the previous total and report the answer aloud. Four such single-digit numbers were presented before a new two-digit starting number was presented. During practice, two such sets were presented; during the test, five such sets were presented.

11. Automated Motor Coordination - Fork Task. Findings in the literature have suggested that motor coordination for tasks involving judgement of the relationship between the arm and the environment is degraded in microgravity (e.g., Ross, Schwartz, and Emmerson, 1987); Ross et al.,1984, 1986). Also, Mantsvetova et al. (1965) as well as the present authors, have suggested that such degradation should be more pronounced in automated behaviors involving gravitational cues. Consequently, in an

attempt to obtain measures of motor coordination tasks that might be influenced by a change in gravitational orientation, three tasks were created. The Fork Task was so-named because subjects were simply asked to lift an eating utensil from a resting position on the table in front of them and aim for the center of their mouth, as if they were taking a bite of food. The utensil held a light-weight marker that recorded point of impact relative to the mouth on a styrofoam plate covering the subjects mouth, chin, and nose. The resulting marks were measured for horizontal (lateral) and vertical (longitudinal) accuracy. It was hypothesized that in the reclined position, lateral errors would tend to be positive (displaced by gravity toward the subjects left arm), and that longitudinal errors would also be positive (toward the forehead) because the arm muscles would overcompensate for the gravitational forces which had been altered.

12. Automated Motor Coordination - Writing Task. Writing was selected as the primary automated motor-performance task. A computer program was created that randomly selected common four-letter words containing one or more letter "l" from a database of 99 such words. The letter "l" was used because it lends itself to computing the slant of the letters (i.e., a baseline is first drawn for each word, a line is drawn that passes through the zenith and the loop at the bottom of the cursive "l", and the angle between the baseline and the letter is measured). The computer presented the words in the center of the screen. Each of five sets of three words was presented according to the following schedule: one word every 4.5 sec followed by a 11.25 sec delay until the next set of three words was presented. Subjects were instructed to write (in cursive) each word presented. A horizontal partition was used to prevent the subjects from receiving feedback about their writing. The experimenter always positioned the subjects hand at a standardized location (top center of the page) for the first word. Subjects were instructed to write each subsequent word below the last, forming a straight "vertical" column. They were told that if they felt they were close to the bottom of the page, they should move up and to the right to form a second column. In a practice condition, subjects wrote two sets of three words. In the test condition, subjects wrote five sets of three words.

13. Automated Motor Coordination - Southwest Task. The third test of automated motor performance also involved writing. This task was included to determine if a shorter form of the writing task would yield the same results. It was also included because it is analogous to a task described by Clement, Berthoz, & Lestienne (1987), in which performance degradation was found in microgravity. In this task, the subject was asked to print a common word "southwest" in one of two ways, either horizontally (from left to right) or vertically (from top to bottom). In two related tasks, subjects were to print an unfamiliar word "tswutoehs" (an anagram that used the same letters found in "southwest") horizontally and vertically. In all cases, a) a partition prevented the subject from observing writing performance, b) the experimenter positioned the starting position to a standardized location, and c) the subject was provided the words to observe while printing. No time limit was imposed. It was hypothesized that printing a familiar word would involve more automated behavior than printing an unfamiliar word, and that printing

a word in a familiar orientation (left-to-right) would be more automated than printing in a less familiar orientation (top-to-bottom). Because automated motor-performance tasks are proposed to be more affected by gravitational manipulation, degradation (or change) should be greatest in the familiar-word/familiar-orientation condition and least degraded (changed) in the unfamiliar-word/unfamiliar-orientation condition; the two other conditions should be intermediate.

14. Dual Task (Subtraction and Writing). In this task, the subtraction and writing tasks described above were combined into a dual-task. The time parameters for each component task remained exactly the same as when presented individually. In the dual task, the two digit number was first presented followed by the first single-digit number, followed 1.5 sec later by the first word presented on the screen, and followed 3 sec later by the second single-digit number. This pattern continued until the first set of four single-digit numbers and three words had been presented. In the practice trial, two such sets of tasks were presented and in the test trials, five such sets were presented. This task was included to determine if any resulting degradation in the motor performance component would cause subjects to reallocate attentional resources from the cognitive (subtraction) task to the writing task, resulting in cognitive performance degradation.

### d. Experimental Design

Each of the above 14 tasks was presented in an upright and a reclined orientation. Two major goals of the design were to a) minimize the time between the two conditions for each task and b) minimize the number of times that the subject had to be moved (because of the time involved in such moves). To meet these goals, the following approach was made. First, tasks were categorized into groups of conceptually similar tasks. The groups as well as the strategy for randomization within a group are shown below:

1. Commercial Paper Tests (order randomized)

   Perceptual Speed
   Identical Pictures
   Gestalt Completion
   Flexibility of Closure

2. Light Pen (always in following order)

   Stationary
   Tracking

3. Reaction Time (always in following order)

    Simple
    Complex

4. Writing Tests (Southwest and Dual Component Tasks randomized)

    Southwest
    Dual Component Tasks (Single tasks randomized, always followed by Dual task)
        Subtraction (Single task)
        Writing (Single task)
        Dual Writing and Subtraction

5. Other Motor Tasks (Randomized)

    Fork
    Dexterity

Overall order of the five groups of tasks was randomized for each pair of subjects. Within that pair, starting position (upright or reclined) was randomly assigned for the first subject and the second subject received the opposite starting position. After the position for the first group of tasks was established, position was then alternated for the remainder of the experiment. Following is a sample run for the first subject in a pair:

| | | |
|---|---|---|
| 1. | Group 4 | Upright |
| 2. | Group 4 | Reclined |
| 3. | Group 1 | Reclined |
| 4. | Group 1 | Upright |
| 5. | Group 5 | Upright |
| 6. | Group 5 | Reclined |
| 7. | Group 2 | Reclined |
| 8. | Group 2 | Upright |
| 9 | Group 3 | Upright |
| 10. | Group 3 | Reclined |

The second subject in that pair would receive the same order of groups, with the positions reversed (i.e., all "upright" change to "reclined" and vise versa). One reason for this approach was to attempt to minimize any differences in performance due to non-specific temporal effects (e.g, warmup or fatigue) by keeping the two position conditions as contiguous as possible. Also, for each pair of subjects, the same order of task conditions was presented for groups of tests (constancy), while contaminating order effects such as learning, practice, and fatigue are counterbalanced for each pair of subjects.

### e. Procedure

Because of the time to complete a test run (average total length was 3 hours), two sessions were scheduled for each subject. These two sessions were scheduled to be as temporally contiguous as possible (usually within 3-4 days). On the first meeting, subjects read and signed an informed consent form. Next, the subject's blood pressure was measured. Subjects whose blood pressure exceeded 140 systolic or 90 diastolic were not allowed to participate in this experiment. Such subjects were informed of their blood pressure reading, encouraged to visit the SwRI clinic, and thanked for volunteering.

Qualifying subjects were then shown the circle-bed apparatus. They were told that the purpose of the study was to determine what effect, if any, body orientation had on the performance of different tasks. They were told that, if at any time they felt uncomfortable for whatever reason, they should inform the experimenter.

Subjects were shown how to enter the circle bed and where to stand for the upright position. The table was individually adjusted to be at a comfortable writing level for each subject. Also, the upright and reclined monitors were adjusted so that the top of the subject's eyes were level with the top of the monitor screen when in either orientation (about -10 degrees to the center of the monitor). The subject was then moved to the assigned position for the first group of tasks.

Each time a new task was presented, appropriate instructions were delivered, and if appropriate, practice was provided. However, because the second exposure to the same task always occurred within minutes of the first, instructions were only paraphrased on the second exposure and subjects were asked if they had any questions.

When in the reclined position, subjects were lying on their left side. Consequently, a small wedge pillow was provided for comfort and to keep the subject's head in line with the rest of his body.

Following completion of the assigned series of task groups (see "Experimental Design" section above), subjects were thanked for their cooperation and excused.

## 3. Results and Discussion of Experiment 1

In order to assess the effects of altered gravitational forces on the selected performance tasks, two-way, repeated-measure analyses of variance were conducted on each performance measure with position (up or down) as one factor and order (up first or up second) as the second factor. In Tables 3-6, mean values for the upright and reclined orientations are presented, along with the corresponding $\underline{F}$ values and probabilities. To assist analysis, asterisks have been added to indicate those comparisons for which the probability was less than .10 (one asterisk), .05 (two asterisks), or .01 (three asterisks). Results of the main effect due to order and the interaction between orientation and order were generally not significant, and are not presented in the tables. However, any significant effects are noted in the text. In the last two columns of Tables 3-6, the results of Wilcoxon nonparametric tests comparing the upright and reclined orientations are presented. These were included because of the relatively small sample size (N = 10).

Results of the four perceptual/cognitive tests are found in Table 3. No significant effects were found for any of the tests and the associated probabilities of being due to chance are relatively high. As discussed above, three of the tests were included not only because they test cognitive performance, but because they involve visual scanning. The absence of significant effects suggests that not only that orientation had no effect on the corresponding cognitive components, but that visual scanning was not affected. This could be due to the fact that altered gravity has no effect on scanning, or that the tasks did not involve enough rapid, short-duration eye movements (Parin and Kas'yan (1969).

Results of the Dexterity task are also shown in Table 3. As shown, fewer pegs were moved and more pegs were dropped in the reclined position. However, only the former effect was statistically significant. It should be noted that, although care was taken to construct the apparatus, some of the resulting effect could be due to artifact. Specifically, it was noted through the course of the study that, if a subject fumbled a peg on when withdrawing it from the hole in the upright position, gravity would pull it back into the hole, while in the reclined orientation, the same event could lead to a dropped peg or a peg hanging precariously half-way out the hole. However, it is unlikely that the entire effect was due to this possible artifact because there was no significant difference in dropped pegs. Also, such changes in the way that physical things "behave" when in a reclined position are also found in microgravity.

A number of authors in the literature have reported degraded coordination performance in microgravity (see discussion above). To the extent that the results of the Dexterity task are due to altered gravity and not due to an apparatus artifact, analogous effects can be reproduced on earth by altering gravitational forces.

The results of the Fork task are shown in the bottom of Table 3. As predicted, there was a general pattern for subjects to aim higher and to the left (in the direction expected due to gravity) when in the reclined position. The only significant effect was for the first lateral placement of the fork. Although the apparatus was designed to minimize feedback resulting from subsequent placements, it is possible that such feedback occurred, and subjects adapted to a more appropriate placement. The tendency for the first fork placement to be high and for the average fork placement to be to the left (toward the earth) both approached significance. Again, this finding provides some evidence that effects reported in microgravity can be reproduced in an altered gravitational field on earth.

Table 3. Results of the Cognitive, Dexterity, and Fork Tasks in Experiment 1.

| TEST | Means | | $\underline{F}$ Value Up/Down | $\underline{p}$ Value | Wil-coxon $\underline{z}$ | $\underline{p}$ Value |
|---|---|---|---|---|---|---|
| | Up | Down | | | | |
| **Cognitive Tests** | | | | | | |
| Gestalt Completion | 67.0 | 69.0 | .21 | .6586 | .42 | .6726*** |
| Guilford-Zimmerman | 74.2 | 68.8 | .40 | .5462 | .71 | .4755 |
| Hidden Figures | 46.7 | 46.6 | 0 | .9910 | .42 | .6744 |
| Identical Pictures | 58.1 | 61.6 | 1.71 | .2275 | 1.24 | .2135 |
| **Dexterity Task** | | | | | | |
| # Pegs | 7.9 | 5.7 | 9.40 | .0155 ** | 2.14 | .0323** |
| # Dropped | 1.3 | 2.0 | .49 | .5038 | .52 | .6002 |
| **Fork Task** | | | | | | |
| First X | -.15 | .6 | 1.28 | .2907 | 2.49 | .0125** |
| First Y | 1.02 | 1.52 | 4.28 | .0724 * | .97 | .3329 |
| Mean X | .14 | .41 | .75 | .4117 | 1.73 | .0831* |
| Mean Y | .54 | 1.05 | 3.12 | .1154 | .66 | .5075 |
| Standard Deviation X | .69 | 1.04 | 2.20 | .1766 | 1.48 | .1394 |
| Standard Deviation Y | .76 | .82 | .16 | .6989 | 1.38 | .1688 |

Table 4 shows the results of the Stationary Light-Pen task. The first two measures represent the average accuracy in the lateral (X) and longitudinal (Y) dimensions. There was essentially no difference in mean lateral aim. There was a significant difference in vertical aim, with subjects aiming higher when in the reclined orientation. In general, one would predict subjects to aim higher and to the left when in the reclined position. In this task, clear and precise feedback about point of aim is provided, so there is little reason to predict differences in average accuracy. However, the second two measures representing variability (steadiness) in the lateral and vertical dimensions should be affected because of the altered proprioceptive and kinesthetic feedback involved in keeping the sight on the target. As predicted, variability in both the lateral and longitudinal dimensions was significantly greater in the reclined position.

The results of the Light-Pen Tracking task are also shown in Table 4. The first two measures indicate the effects of orientation on the mean accuracy in the lateral and longitudinal dimensions respectively. In this task, subjects tended to aim left and low (both non-significant). The last two measures indicate variability around the target in the lateral and vertical dimensions respectively. There was a highly significant effect of orientation on lateral variability. However, there was no significant effect on longitudinal variability.

Because of the feedback provided, the four measures of variability are considered to be the primary measures from the two light-pen tasks. All four showed degradation in the reclined orientation (three of the four showed statistically significant degradation). No analogous performance measures could be found in the literature the Light Pen Stationary task (aiming tasks usually do not involve specific immediate performance feedback). However, authors in the literature have reported degraded tracking performance like that found here for the Light Pen Tracking task. Consequently, there is additional support for the notion that microgravity effects can be reproduced on earth.

The results of the "SOUTHWEST" task are presented in Table 5. This task was included to determine if the effects reported by Clement, Berthoz, & Lestienne (1987) could be duplicated in an altered gravitational field on earth. No significant effects were found among several candidate measures. Table 5 shows the results of an analysis of difference scores (length of the word "southwest" minus the length of the anagram "tswutoehs") for the lateral and longitudinal writing conditions. As shown, subjects tended to take more space writing the anagram than the word, and that discrepancy grew slightly in the reclined orientation; however none of the comparisons was statistically significant.

The results of the reaction time tasks are presented in Table 6. The results of the Simple Reaction Time task indicated no significant effect of altered gravity on total simple reaction time (although it approached significance). This finding is consistent with reports

Table 4. Results of the Light Pen Stationary and Tracking Tasks in Experiment 1.

| TEST | Means | | $\underline{F}$ Value Up/Down | $\underline{p}$ Value | Wil-coxon $\underline{z}$ | $\underline{p}$ Value |
|---|---|---|---|---|---|---|
| | Up | Down | | | | |
| **Light Pen Stationary** | | | | | | |
| Mean X | .20 | .23 | .01 | .9310 | .25 | .7989 |
| Mean Y | -.09 | .48 | 15.23 | .0045 *** | 2.60 | .0093*** |
| Std. Dev. X | 2.28 | 2.70 | 9.22 | .0161 ** | 2.50 | .0125** |
| Std. Dev. Y | 1.69 | 1.90 | 5.49 | .0472 ** | 2.29 | .0218** |
| **Light Pen Moving** | | | | | | |
| Mean X | .42 | -.37 | 2.02 | .1930 | 1.17 | .2411 |
| Mean Y | 1.31 | 1.00 | .90 | .3700 | .61 | .5408 |
| Std. Dev. X | 6.56 | 7.40 | 12.16 | .0082 *** | 2.40 | .0166** |
| Std. Dev. Y | 7.14 | 7.38 | .77 | .4060 | .76 | .4446 |

Table 5. Results of the "SOUTHWEST" Task in Experiment 1.

| TEST | Means | | $\underline{F}$ Value Up/Down | $\underline{p}$ Value | Wil-coxon $\underline{z}$ | $\underline{p}$ Value |
|---|---|---|---|---|---|---|
| | Up | Down | | | | |
| **"SOUTHWEST" Writing Task** | | | | | | |
| Lateral Diff. Score | -.56 | -.60 | 0.00 | .960 | .47 | .6356 |
| Longitud. Diff. Score | -.30 | -.54 | .13 | .729 | .05 | .9594 |

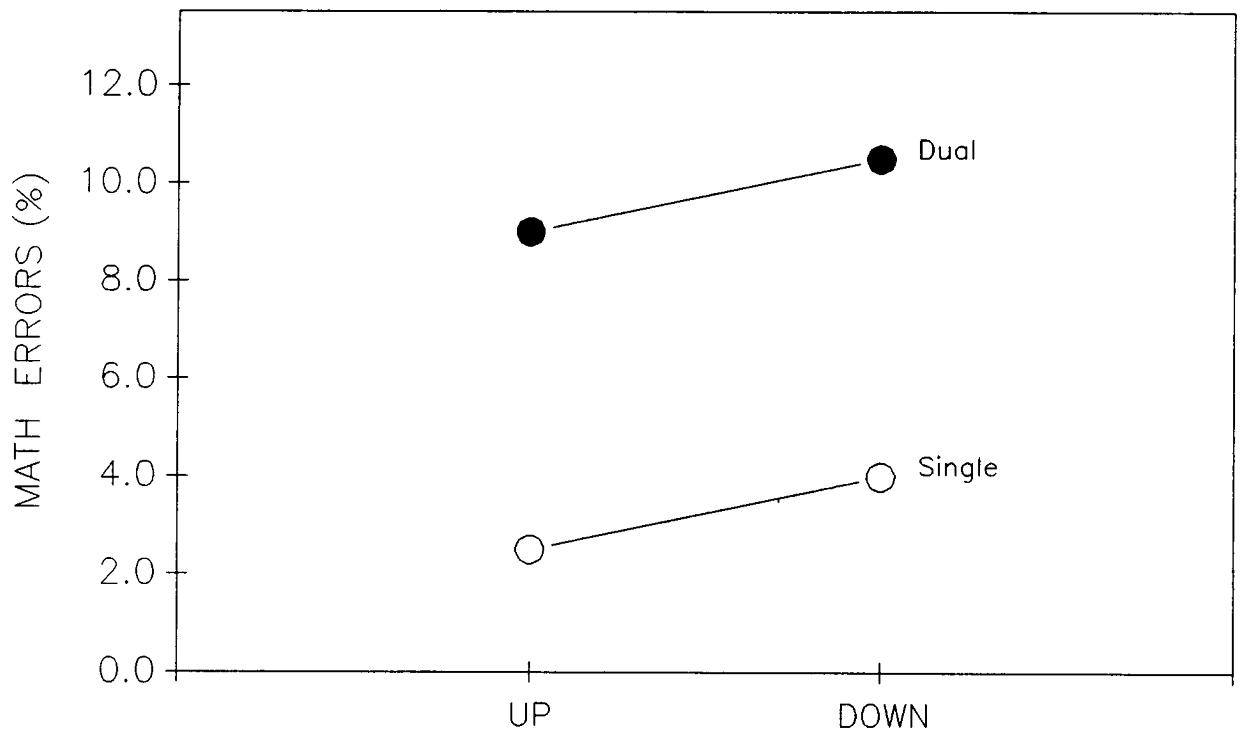



Figure 4. Results of the math task in Experiment 1.

Table 6. Results of the Simple and Complex Reaction Time Tasks in Experiment 1.

| TEST | Means | | *F* Value Up/Down | *p* Value | Wil-coxon *z* | *p* Value |
|---|---|---|---|---|---|---|
| | Up | Down | | | | |
| **Simple Reaction Time** | | | | | | |
| Segment 1A | 303.90 | 322.4 | 1.44 | .2640 | .97 | .3329 |
| Segment 1B | 8.31 | 7.99 | .14 | .7168 | .46 | .6465 |
| Segment 2A | 250.25 | 272.40 | 10.70 | .0113 ** | 2.40 | .0166** |
| Segment 2B | 5.31 | 7.05 | 3.50 | .098 * | 2.09 | .0367** |
| Total Reaction Time | 554.15 | 594.8 | 5.06 | .0546 * | 1.99 | .0469** |
| **Complex Reaction Time** | | | | | | |
| Segment 1A | 934.85 | 911.15 | .66 | .4396 | .76 | .4446 |
| Segment 1B | 13.32 | 12.13 | 1.17 | .3112 | 1.07 | .2845 |
| Segment 2A | 306.3 | 362.65 | 13.11 | .0068 *** | 2.50 | .0125** |
| Segment 2B | 7.32 | 10.39 | 6.06 | .0392 ** | 1.99 | .0469** |
| Total Reaction Time | 1241.15 | 1273.80 | 1.05 | .3356 | .66 | .5076 |
| **Simple and Complex Reaction Time** | | | | | | |
| Variable "A" | 1630.95 | 1588.75 | 2.44 | .1567 | 1.38 | .1688 |
| Variable "B" | 682.20 | 598.50 | 3.40 | .1025 | 1.17 | .2411 |

from the literature. However, previous work (Schroeder and Tuttle, 1990) has found that analysis of two components of simple reaction time can provide a more sensitive measure than total reaction time. In Table 6, there is evidence that the second component was sensitive to altered gravity while the first was not. There are no known analogous data from an actual microgravity environment with which to compare these data from analyses of the second component.

The results of the Complex Reaction Time also indicated no significant effect of orientation on total reaction time. These results are consistent with data from Thornton, Moore, Pool, and Vanderploeg (1987), who found no degradation on the Sternberg complex reaction time test, but inconsistent with statements from Khachatur'yants (1975) indicating that reaction times increased for tasks involving more complex cognitive analysis (if the cognitive demands in the present task are like those alluded to by Khachatur'yants). As in the Simple Reaction Time task, the second component of reaction time was found to be sensitive to the orientation of the subject. Again, there are no comparable data available from a microgravity environment.

Finally, the results of theory-based measures involving the relationship between simple and complex reaction time indicated no significant effect due to altered gravity. These measures were reported by Schroeder and Tuttle (1990) as being highly reliable and sensitive measures of alcohol level. In addition, they are proposed to be sensitive to other altered motivational states such as those induced by stress. There are no comparable data from space or simulated microgravity.

The results of the single and dual subtraction and writing tasks are presented in Tables 7-8. The results of the subtraction (math) task are shown in Table 7 and Figure 4. As indicated, a significant effect was found for type of task (single or dual) with performance degrading in the dual task. However, the predicted effect due to orientation in the dual task (i.e., interaction between orientation and type of task) was not found.

In order to objectively measure writing performance, three general approaches were taken. The first general measure of performance was the accuracy of the written information. This was measured by the variable labeled "Writing Errors" in Table 7, and consisted of the number of errors each subject made in a given condition. Errors included a) omitted words, b) repeated words, and c) words inaccurately containing multiple letters (e.g., balll). As shown in Table 7 and Figure 5, the predicted interaction between type of task and orientation approached significance for this measure of writing performance.

The second general measure of writing performance was called legibility, that is, the effort involved when a naive reviewer attempted to read the written words. To assess legibility, two impartial individuals who knew nothing about this project were asked to read the words on each data sheet. All data sheets were coded on the back to identify subject

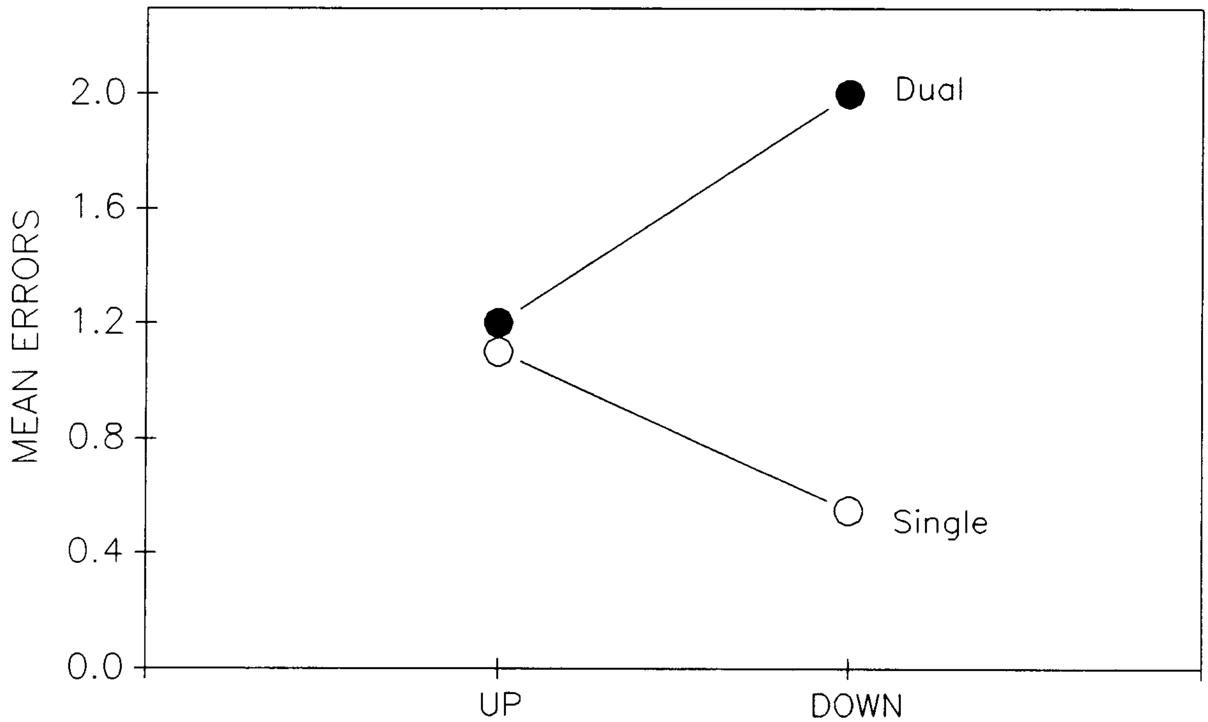



Figure 5. Results of the writing task (errors) in Experiment 1.

Table 7. Results of the math and writing tasks (errors and legibility) in Experiment 1.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | $\underline{F}$ Value | $\underline{p}$ Value |
|---|---|---|---|---|---|---|
| **Math Errors Experiment 1** | .025 | .090 | .040 | .105 | ----- | ----- |
| Up/Down | - | - | - | - | .84 | .3823 |
| Single/Dual | - | - | - | - | 7.76 | .0212 ** |
| Up/Down X Single/Dual | - | - | - | - | 0.00 | 1.0000 |
| **Writing Errors, Experiment 1** | 1.10 | 1.20 | .55 | 2.00 | ----- | ----- |
| Up/Down | - | - | - | - | .18 | .6783 |
| Single/Dual | - | - | - | - | 2.22 | .1701 |
| Up/Down X Single/Dual | - | - | - | - | 4.10 | .0736 * |
| **Legibility (time to read), Experiment 1** | 1.00 | 1.22 | 1.07 | 1.16 | ----- | ----- |
| Up/Down | - | - | - | - | 0.00 | .9774 |
| Single/Dual | - | - | - | - | 8.44 | .0174 ** |
| Up/Down X Single/Dual | - | - | - | - | .93 | .3607 |
| **Legibility (read errors) Experiment 1** | .067 | .184 | .109 | .152 | ----- | ----- |
| Up/Down | - | - | - | - | .07 | .7973 |
| Single/Dual | - | - | - | - | 7.34 | .0240** |
| Up/Down X Single/Dual | - | - | - | - | 1.62 | .2355 |

and condition and then randomly shuffled. The readers were instructed to read each word aloud as quickly as possible. The two scores recorded were the time it took the reader to complete the list (adjusted for the number of words on the list) and the number of miss-read words (e.g., when "held" was read as "hold"). Correlations between the two blind reviewers indicated acceptably high reliability for both measures ($\underline{r}$ = 0.68 for reading time and $\underline{r}$ = 0.84 for reading errors). As Table 7 shows, there were significant effects due to type of task, but not due to orientation or interaction between orientation and type of task.

The third general measure of writing performance addressed the mechanics of writing. Six different objective measures were used in an attempt to determine if the mechanics of writing changed due to different experimental manipulations. The first measure was the main angle of the first letters of the vertical column of words on each data sheet. Specifically, a line was drawn from the first letter of the first word through the last letter of the last word and that angle was measured. No significant effects were found for this measure of writing performance (see Table 8).

The next two mechanical measures of writing performance were the mean and standard deviation of the angles of the baselines for all written words. First, a best-fitting baseline was drawn for each word by an individual who had no knowledge of the corresponding experimental condition. Next, the angles were measured (e.g., an angle of 180 degrees means that the subject wrote the word perfectly laterally across the page). Finally, means and standard deviations were computed for each subject/condition combination. Table 8 shows that there was no significant effect on either of these variables.

The next two measures of writing performance were the mean and standard deviation of all "l's" in the writing sample. As discussed above, the letter "l" was included in all words because it is relatively easy to draw a line through that letter to determine slant. A procedure analogous to that described in the last paragraph was conducted to determine mean and standard deviation of letters. A score of 90 means the letter was perfectly vertical relative to the sheet of paper. Table 8 shows that there was an interaction between task and orientation that approached significance for mean angle. There was no effect for standard deviation of letters (Table 7).

The last measure was labeled "Letter Height," but it actually represents how the words were longitudinally spaced on the page. Specifically, the distance on the main angle (see above) from the first word to the last word was divided by the number of words in that column. As shown in Table 8, there was no effect due to type of task or orientation for this measure.

In general, the results of Experiment 1 supported the contention that some performance degradation effects reported in microgravity can be duplicated and studied

Table 8. Results of the writing task (mechanical) in Experiment 1.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Writing Main Angle, Experiment 1** | 89.8 | 87.5 | 82.6 | 81.0 | ----- | ----- |
| Up/Down | - | - | - | - | 1.83 | .2094 |
| Single/Dual | - | - | - | - | 1.19 | .3030 |
| Up/Down X Single/Dual | - | - | - | - | 0.02 | .8873 |
| **Mean Word Angle, Experiment 1** | 173.9 | 173.2 | 171.60 | 170.7 | ----- | ----- |
| Up/Down | - | - | - | - | .69 | .4261 |
| Single/Dual | - | - | - | - | .81 | .3927 |
| Up/Down X Single/Dual | - | - | - | - | .02 | .8795 |
| **Std. Deviation Word Angles, Experiment 1** | 4.32 | 5.68 | 4.59 | 4.75 | ----- | ----- |
| Up/Down | - | - | - | - | .31 | .5918 |
| Single/Dual | - | - | - | - | 4.70 | .0583 * |
| Up/Down X Single/Dual | - | - | - | - | 2.19 | .1732 |
| **Mean Letter Angle, Experiment 1** | 108.0 | 108.2 | 108.3 | 111.4 | ----- | ----- |
| Up/Down | - | - | - | - | 1.19 | .3028 |
| Single/Dual | - | - | - | - | 2.16 | .1754 |
| Up/Down X Single/Dual | - | - | - | - | 3.69 | .0869 * |

Table 8 (continued). Results of the writing task (mechanical) in Experiment 1.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Std. Deviation Letter Angles, Experiment 1** | 6.45 | 6.55 | 6.91 | 6.73 | ----- | ----- |
| Up/Down | - | - | - | - | .13 | .7308 |
| Single/Dual | - | - | - | - | 0.00 | .9568 |
| Up/Down X Single/Dual | - | - | - | - | .06 | .8081 |
| **Letter Height Experiment 1** | 1.41 | 1.40 | 1.36 | 1.35 | ----- | ----- |
| Up/Down | - | - | - | - | .23 | .6412 |
| Single/Dual | - | - | - | - | .01 | .9320 |
| Up/Down X Single/Dual | - | - | - | - | 0.00 | 1.0000 |

on earth, by altering the gravitational field. However, results of the dual task pilot experiment failed to support the predicted interaction between type of task and physical orientation relative to gravity. Consequently, several modifications were made before conducting Experiment 2. These modifications, and the rationale for pursuing this approach are presented in the following section.

## B. Experiment 2

### 1. Introduction

The purpose of Experiment 2 was to test Hypothesis 2 more thoroughly than in Experiment 1. Hypothesis 2 asserted that degradation in previously automated behavior will occur in microgravity if gravitational forces are an important part of the stimulus complex that guides the automated behavior. Also, unless feedback about the degradation of such automated behavior is provided, the degradation is likely to go unnoticed. It also proposed that feedback of degradation would divert attentional resources from other ongoing motor and cognitive tasks, hence, causing degradation not only in the automated task, but also in other simultaneously performed tasks.

One set of subtests in Experiment 1 provided a pilot test of part of this hypothesis, the combined and individual mental arithmetic and writing tasks. Task selection is very important in this work. Consequently, a discussion of the reasoning that produced the design for Experiment 2 is presented in the following paragraphs.

It is clear that the primary task to be used in the early experiments should be as automated as possible and that it should involve gravitational cues as part of the automated stimulus complex. Such tasks often are difficult to identify because their performance is taken for granted. Ironically, such tasks (i.e., the tasks which are the most automated on earth), could become the most significant problem in microgravity (if gravitational cues are critical for performing that task).

Walking is one such task (think about how much attention is diverted to walking behavior when one is in a slightly different stimulus complex such as wading at the beach, walking through thick snow, or walking on ice). The essence of Hypothesis 2 is that if one were tested on a simultaneous cognitive task while walking under such unusual circumstances, cognitive performance would degrade (because more attentional resources must be diverted from the cognitive task to the previously automated walking task). In addition to specific performance degradation, there also are likely to be more general reactions to such a situation (e.g., confusion, disorientation, stress, a feeling of "what is happening to me?"). Such general reactions could, themselves, become an indirect source for further degradation. Finally, the problem might be exacerbated by the fact that, because the behavior is usually automated, the individual might be relatively unaware of the source of the disruptions; they might just perceive that something is wrong. Consequently, feedback about the performance degradation is an important part of Hypothesis 2. If the individual is unaware of the deterioration in performance, then the corresponding degradation is not likely to occur because no attentional resources are diverted.

Other examples of highly automated tasks which might be affected by gravity are writing, speaking, driving, eating, breathing, and visual scanning. Interestingly, reports were found in the literature search that discussed decrements in three of these behaviors (writing, speaking, and visual scanning). The most relevant is an old (1964) translated Russian paper by Mantsvetova, Neumyvakin, Orlova, Trubnikova, and Freidberg which documents writing degradation in cosmonauts in space. The graphic examples of writing degradation presented are startling. Also, their interpretation is not too distant from Hypothesis 2:

> "The results of these investigations revealed changes in motor coordination throughout the duration of the space flight."

". . . authors found that motor coordination is a fairly accurate index of capacity for work and can be effectively used in investigations."

"In the learning of writing the movements used to make the letters are built up into a system of habits and become relatively constant and characteristic of the writer. In people with a highly developed "hand" the writing becomes automatic to a high degree. At the same time, it has been shown in a number of investigations [6-11] that various external conditions (position of writing instrument, sitting position, quality of paper, ambient temperature, etc.), as well as the general state of the organism (fatigue, emotion, certain nervous diseases, etc.) can upset the elaborated automatic movements and affect motor coordination."

"The deterioration in motor coordination judged by the described characteristics was more pronounced in the entries of cosmonauts whose handwriting showed less variation."

While demonstrating significant writing deterioration, the authors do not present any reasonable confirmation that it is microgravity per se that causes the disruption (e.g., it could be stress, cardiovascular changes, or a host of other variables related to space flight). Also, they do not consider simultaneously performed cognitive or other psychomotor tasks. In summary, while Mantsvetova et al. documented that a highly automated motor task can significantly degrade in microgravity, they did not fully test Hypothesis 2.

Experiment 1 provided a preliminary test of the proposed interactive effects of automaticity of behavior and altered gravitational orientation on motor and cognitive performance. The purpose of Experiment 2 is to expand the test of that hypothesis by replicating a portion of Experiment 1, adding a second, less-automated motor task, and adding a condition in which the subject receives feedback about performance when performing an automated task.

In Experiment 2, performance on a dual cognitive/motor task relative to performance on those tasks performed individually was assessed under two gravitational orientations (upright and reclined) for three major conditions. First, an automated motor task without feedback of performance was combined with a simultaneous cognitive task. Second, an automated motor task with feedback about performance was combined with a simultaneous cognitive task. Finally, a non-automated motor task with feedback about performance was combined with a simultaneous cognitive task. The hypotheses to be tested in Experiment 2 were:

1. Automated motor performance which is guided by gravitational cues will degrade when gravitational cues are altered; degradation will be less when feedback is provided because attentional resources are reallocated to monitor the writing task.

2. Performance on a simultaneous cognitive secondary task will degrade because attentional resources must be allocated to the previously automated motor performance task.

3. Performance on simultaneous cognitive secondary tasks will degrade more if the subject receives feedback about degraded motor performance than if no such feedback is provided.

4. Although affected by gravity and possibly by single/dual task conditions, performance on the nonautomated motor task will not reflect an interaction between gravitational orientation and single/dual task.

5. Performance on simultaneous cognitive secondary tasks associated with non-automated motor performance affected by gravitational cues will not degrade when gravitational cues are altered.

Five assumptions were made, a) the writing task is a relatively automated behavior, b) the light-pen tracking task is a relatively non-automated behavior, c) gravitational forces are important in the selected motor tasks, d) gravitational forces are not important in the selected secondary cognitive task, and e) when given the chance to monitor their hand-writing to obtain feedback, subjects will do so.

The first hypothesis was tested twice. First, the proposed interaction was assessed by measuring writing performance in a dual task combining a writing task without feedback and a cognitive mental arithmetic task; second, in a dual task combining a writing task with feedback and a cognitive mental arithmetic task.

The second hypothesis also was tested twice. First, the proposed interaction was assessed by comparing performance on the secondary cognitive mental arithmetic task when paired with the writing with feedback task, and again when paired with the writing without feedback task.

The third hypothesis predicted a three-way interaction among single/dual task conditions, gravitational orientation, and feedback/no feedback for the writing task. Consequently, this hypothesis was tested by measuring the level of interaction among these three variables in their influence on mental arithmetic performance.

The fourth hypothesis predicted no interaction between single/dual task condition and gravitational orientation condition in their effects on the non-automated motor behavior. Consequently, the interactive effects of those two variables on light-pen tracking performance was assessed.

The fifth hypothesis predicted no interaction between single/dual task condition and gravitational orientation condition for the nonautomated (light-pen tracking task) in their effects on the secondary cognitive mental arithmetic task performance. Consequently, the interaction between those two variables was tested to assess their joint influence on performance in the secondary mental arithmetic task.

## 2. Method

### a. Subjects

Subjects were 18 adult males who a) were between the ages of 21-45, b) reported no medical history of hypertension, c) had not participated in Experiment 1, d) were less than 6 ft. 2 in. tall (due to size limitations of the circle-bed apparatus), e) were right-handed, and f) whose blood pressure immediately prior to participating in the experiment was below 140/90.

### b. Apparatus

The circle-bed apparatus and associated environment described in Experiment 1 was used in Experiment 2. In addition, the apparatus associated with the light-pen tracking task was modified. The reason for using the light-pen tracking task in Experiment 2 was to provide a psychomotor task with feedback that was not highly automated. In Experiment 1, the light pen was held like a pencil in a position and orientation prescribed by the experimenter. Free use of the wrist and arm for the tracking task (as in Experiment 1) was judged to have components that could resemble automated tasks (e.g., writing, painting, etc.). Also, in Experiment 1, although the experimenter instructed the subject about the maintaining a constant distance from the light pen to the computer monitor, the actual distance could have changed during the experiment. Consequently, a modification to the light pen apparatus was made to improve those conditions. To provide a more standardized and non-automated light-pen task, and to help standardize the distance from the light pen to the computer monitor, a lightweight orthopedic wrist brace was added, which held the light pen at a fixed orientation relative to the subject's forearm and minimized motor control of the aim of the light pen by motor components which could be automated (i.e., minimized control of the hand and wrist).

### c. Tests and Tasks

The purpose of Experiment 2 was to assess the effects of gravitational orientation on single and dual tasks involving automated and non-automated behavior. Following are descriptions of the major experimental conditions:

1. Writing with No Feedback. This single task was essentially the same as the writing task used in Experiment 1, with three changes. First, the presentation of words was speeded up so that they occurred every 3.7 sec, with an 11.5 sec pause between sets of three words. This change was included to make all dual tasks more difficult. Second, four instead of five sets of three words were presented to make the tests shorter. Third, an auditory "beep" was added at the moment that each new word was presented on the computer monitor. This feature was added to all writing tasks for constancy, but was directed primarily at the writing with feedback task, so that subjects could watch their handwriting and be signalled when it was time to look at the monitor to read the new word.

2. Writing with Feedback. This task is exactly the same as the writing task with no feedback just discussed, except that the partition used to shield the subject from observing his handwriting was removed and the subject was encouraged to monitor his performance.

3. Light-Pen Tracking. This task was essentially the same as that in Experiment 1 with three primary software changes. First, although conceptually independent, the original tracking task was an integrated part of the overall test which included the stationary task followed by the tracking task. In Experiment 2, the software was modified so that only the tracking task was presented. Second, in the original test, at the conclusion of a trial, a white box was presented in the upper left corner of the screen. The subject was to aim the light pen at the box to start the next trial, consequently, the software essentially waited until the subject responded (this time was measured and used as one of the dependent variables). However, in Experiment 2, precise timing was more important. In a dual-task situation, it is possible that a subject could become so engrossed in the secondary task that he might accidentally or intentionally delay initiating new trials. Consequently, a time limit of 2 sec was placed on the subject to initiate a new trial; if not, the trial started automatically. The third software modification was that the number of trials was changed from four to five in order to equate the light-pen tracking total task time with the mental arithmetic total task time (when in the dual task condition).

There also was an equipment change in the light-pen tracking task that is described in the above "Apparatus" section. Essentially, a light-weight orthopedic brace was used to a) standardize the location/orientation of the light pen and b) to force the subject to use arm and shoulder muscles instead of wrist motion when aiming the light pen (to make the task less similar to other everyday tasks and, therefore presumably, less automated).

4. Mental Arithmetic. This task was similar to the subtraction task in Experiment 1 with three changes. First, the rate of presentation was increased so that after each two-digit number, single digit numbers occurred every 4 sec, with a 4-sec pause between sets of four numbers. This change was made to make the secondary cognitive task more difficult. A second major change was in the very nature of the task. Instead of

subtracting each single-digit number as in Experiment 1, the task was made more difficult by imposing a rule that dictated the mathematical operation to be used. Specifically, if the single-digit number was odd, then the subject was to subtract that digit from the current total; if the digit was even, the digit was to be added to the current total. The third change was that instead of allowing the single digits to randomly vary from two to eight (as in Experiment 1), the digits were allowed to randomly vary from two to seven. This change was made to insure that the probability of receiving an odd number (subtraction) was equal to the probability of receiving an even number (addition).

5. Dual Task - Writing without Feedback and Mental Arithmetic. This dual task was similar to the writing and subtraction dual task conducted in Experiment 1. Any differences are specified by differences in the component tasks described above. The relationship between tasks for each trial was: initial two-digit number, 1.5-sec pause, first one-digit number, 4-sec pause, first word, 1-sec pause, second one-digit number, 2.4-sec pause, second word, 1-sec pause, third one-digit number, 2.4-sec pause, third word, 1-sec pause, fourth word, 2.4-sec pause, and finally, instruction to "start over." The partition used in Experiment 1 to prevent feedback was used in this task. No prior practice was provided for any of the three dual tasks. However, all dual tasks always followed single tasks.

6. Dual Task - Writing with Feedback and Mental Arithmetic. This task was identical to the one just described, except that there was no partition to prevent feedback about writing performance and the subject was encouraged to monitor his hand writing.

7. Dual Task - Light-Pen Tracking and Mental Arithmetic. This task combined the light-pen tracking task and mental-arithmetic tasks described above. Because the two software programs were independent, two computers were used for joint presentation. To make the two tasks similar in total task time, the length of time to complete the mental arithmetic task was determined and then the number of trials for the light-pen tracking task was adjusted. To present the two tasks concurrently, the experimenter started the tracking task on the second computer at the moment that the "get ready" voice command for the mental-arithmetic task was issued by the first computer.

### d. Experimental Design

To test the predicted effects, the following design was employed. Unlike Experiment 1, the tasks were not grouped together except for two major groups, single and dual tasks. Also, all single tasks were conducted under both gravitational orientations before the three critical dual-task conditions were presented. As in Experiment 1, within the two major groups, tasks were randomized for each pair of subjects, with one subject randomly beginning a sequence in the upright position and his counterpart starting the same sequence in the reclined position. Also, to minimize possible contaminating temporal effects, the two gravitational conditions were presented contiguously. First, the four single tasks were presented, with their order randomized for each pair of subjects. An example experimental run follows:

| | | |
|---|---|---|
| 1. | Writing without Feedback | Reclined |
| 2. | Writing without Feedback | Upright |
| 3. | Mental Arithmetic | Upright |
| 4. | Mental Arithmetic | Reclined |
| 5. | Light-Pen Tracking | Reclined |
| 6. | Light-Pen Tracking | Upright |
| 7. | Writing with Feedback | Upright |
| 8. | Writing with Feedback | Reclined |

Next, the three dual tasks were presented, with their order randomized for each pair of subjects:

| | | |
|---|---|---|
| 9. | Dual - Writing with Feedback/Mental Arithmetic | Reclined |
| 10. | Dual - Writing with Feedback/Mental Arithmetic | Upright |
| 11. | Dual - Light-Pen Tracking/Mental Arithmetic | Upright |
| 12. | Dual - Light-Pen Tracking/Mental Arithmetic | Reclined |
| 13. | Dual - Writing without Feedback/Mental Arithmetic | Reclined |
| 14. | Dual - Writing without Feedback/Mental Arithmetic | Upright |

#### e. Procedure

The procedure for the second experiment was exactly the same as that for the first experiment except that fewer tasks were presented. For details, see the "Procedure" section for Experiment 1 and "Design" section immediately above.

### 3. Results and Discussion of Experiment 2

The results of the secondary mathematics task for all three single- and dual-task conditions are shown in Figure 6 and Table 9. The second hypothesis predicted an interaction between Position (up/down) and Workload (single/dual tasks) in their joint effect on performance in the secondary task. As shown in Figure 6, there was a trend toward that interaction for both dual writing tasks (with and without feedback). However, as shown in Table 9, neither effect reached statistical significance.

The third hypothesis stated that performance on the cognitive task would degrade more when feedback about the writing task was provided. The predicted main effect due

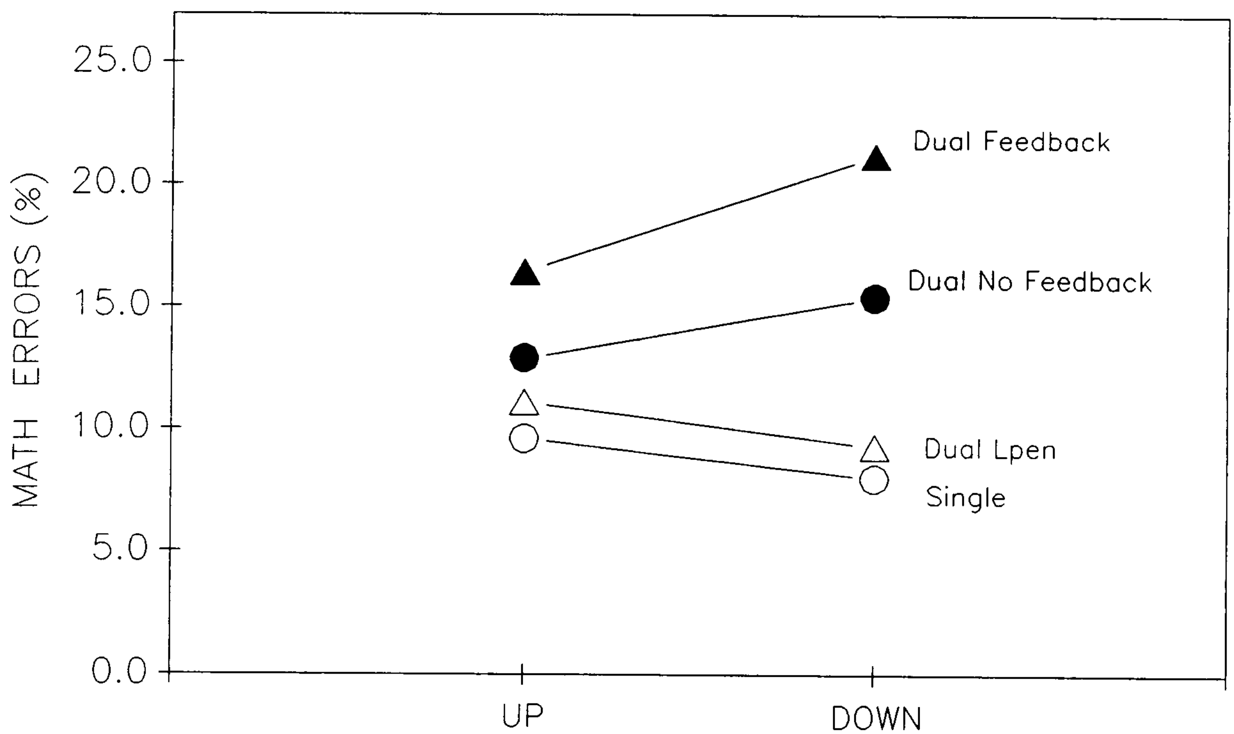



Figure 6. Performance on the mathematics task under different experimental conditions in Experiment 2.

Table 9. Results of statistical analyses on mathematics tasks and writing legibility measures in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | *F* Value | *p* Value |
|---|---|---|---|---|---|---|
| **Math (with Light-Pen Tracking) Experiment 2** | .096 | .111 | .080 | .093 | ----- | ----- |
| Up/Down | - | - | - | - | 1.15 | .2990 |
| Single/Dual | - | - | - | - | .81 | .3798 |
| Up/Down X Single/Dual | - | - | - | - | .01 | .9339 |
| **Math (with Writing-Feedback) Exper. 2** | .096 | .164 | .080 | .212 | ----- | ----- |
| Up/Down | - | - | - | - | .38 | .5448 |
| Single/Dual | - | - | - | - | 14.80 | .0013 *** |
| Up/Down X Single/Dual | - | - | - | - | 2.55 | .1284 |
| **Math (with Writing-No Feedback) Exper. 2** | .096 | .129 | .080 | .154 | ----- | ----- |
| Up/Down | - | - | - | - | .05 | .8236 |
| Single/Dual | - | - | - | - | 6.19 | .0235 ** |
| Up/Down X Single/Dual | - | - | - | - | .88 | .3619 |
| **Legibility (Time to Read) With Feedback, Experiment 2** | .60 | .78 | .61 | .77 | ----- | ----- |
| Up/Down | - | - | - | - | 0.00 | .9550 |
| Single/Dual | - | - | - | - | 8.63 | .0092 *** |
| Up/Down X Single/Dual | - | - | - | - | .15 | .7006 |
| **Legibility (Time to Read) No Feedback, Experiment 2** | .67 | .80 | .74 | .86 | ----- | ----- |
| Up/Down | - | - | - | - | 1.41 | .2516 |
| Single/Dual | - | - | - | - | 6.74 | .0188 ** |
| Up/Down X Single/Dual | - | - | - | - | 0.00 | .9719 |

Table 9 (continued). Results of the writing legibility (reading errors) measures in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Legibility (Reading Errors) With Feedback, Experiment 2** | .06 | .20 | .06 | .21 | ----- | ----- |
| Up/Down | - | - | - | - | .08 | .7785 |
| Single/Dual | - | - | - | - | 10.02 | .0057 *** |
| Up/Down X Single/Dual | - | - | - | - | 0.00 | .9608 |
| **Legibility (Reading Errors) No Feedback, Experiment 2** | .13 | .25 | .16 | .28 | ----- | ----- |
| Up/Down | - | - | - | - | 1.01 | .3293 |
| Single/Dual | - | - | - | - | 11.94 | .0030 *** |
| Up/Down X Single/Dual | - | - | - | - | 0.00 | .9855 |

to feedback condition approached significance [$F(1, 17) = 3.89$, $p = .0651$], offering some support for the prediction that subjects would divert attentional resources from the math task to the writing task when provided feedback about their writing performance. The third hypothesis also predicted a greater interaction between Position (up/down) and Workload (single/dual tasks) when math was performed at the same time as the writing task with feedback than the writing task with no feedback. Figure 6 shows a trend supporting that prediction. No direct test of the latter hypothesis was made because both dual tasks had the same single-task control measures. However, the third hypothesis also predicts an interaction between Position (up/down) and Feedback condition (feedback or no feedback about writing performance) for the dual tasks only. Consequently, an analysis of variance (ANOVA) addressing only dual-task performance was conducted. Results indicated no significant support for the predicted interaction between Position and Feedback [$F(1,17) = 0.28$, $p = .6028$].

The fifth hypothesis predicted that performance on the secondary mathematics task would not degrade when performed with a non-automated motor task (i.e., the light-pen tracking task). Support for this hypothesis is shown in Figure 6 and in Table 9. However, two cautions should be made. First, statistical failure to reject the null hypothesis does not provide strong support for any hypothesis. Second, it is possible the results were not due to a lack of automaticity in the tracking task, but due to the fact that the light-pen tracking task does not contain as many cognitive components that could compete with the mathematics task for resources. Consequently, failure to find a significant interaction is not strong support for the fifth hypothesis. Nevertheless, these results do provide an independent control condition in which no main or interaction effects were found for performance on the secondary cognitive task.

The first hypothesis predicted that altered gravitational forces would degrade the writing task, and that degradation would be greater when subjects received no feedback about writing performance. Presumably, when subjects receive feedback that writing performance is degraded, they allocate more attentional resources to correcting the degraded writing performance (resulting in the degraded mathematics performance discussed above). As in Experiment 1, writing performance was measured in three general dimensions: a) legibility (time and errors when read by a naive person); b) mechanics (letter angle, word angle, etc.); and c) accuracy (omitted words, repeated words, and words with repeated letters).

With regard to legibility, correlation coefficients were computed to determine the inter-reader reliability for time to read and errors. Both correlations indicated satisfactory reliability with the inter-reader reliability for reading time equal to .803 and the correlation for reading errors equal to .815. Results of experimental manipulations on legibility (time to read) are shown in Table 9. As shown, results were similar for both the feedback and no feedback writing conditions. There were no effects due to Position or interaction between Position and Workload, but a significant main effect was found for Workload. A three-way ANOVA to test the predicted main Feedback effect and interactions involving Feedback found significant main effects for Workload [$F(1, 17) = 8.98$, $p = .0081$], and Feedback [$F(1, 17) = 7.57$, $p = .0136$], but no other significant effects.

The results of the legibility (reading errors) conditions are shown in Figure 7 and Table 9. The results of the reading-error data were similar to those of the reading time data. Workload was the only significant effect. Results of a three-way ANOVA of the predicted main effect due to Feedback and interactions involving Feedback indicated significant main effects due to Feedback [$F(1, 17) = 10.34$, $p = .0051$], with more reading errors in the no-feedback condition, and Workload [$F(1, 17) = 14.16$, $p = .0016$], with more errors in the high workload condition. There were no other significant effects.

Before the results of the writing mechanics analyses are presented, one point must be made. The mechanical measures of writing were included in an attempt to derive objective measures of motor-coordination performance. The different measures fall into two categories. While all the changes in any of these measures can be regarded as a change in motor performance, they do not all necessarily constitute degraded performance. Consequently, the mechanical measures of writing performance were divided into two groups depending on whether a meaningful and directional definition of

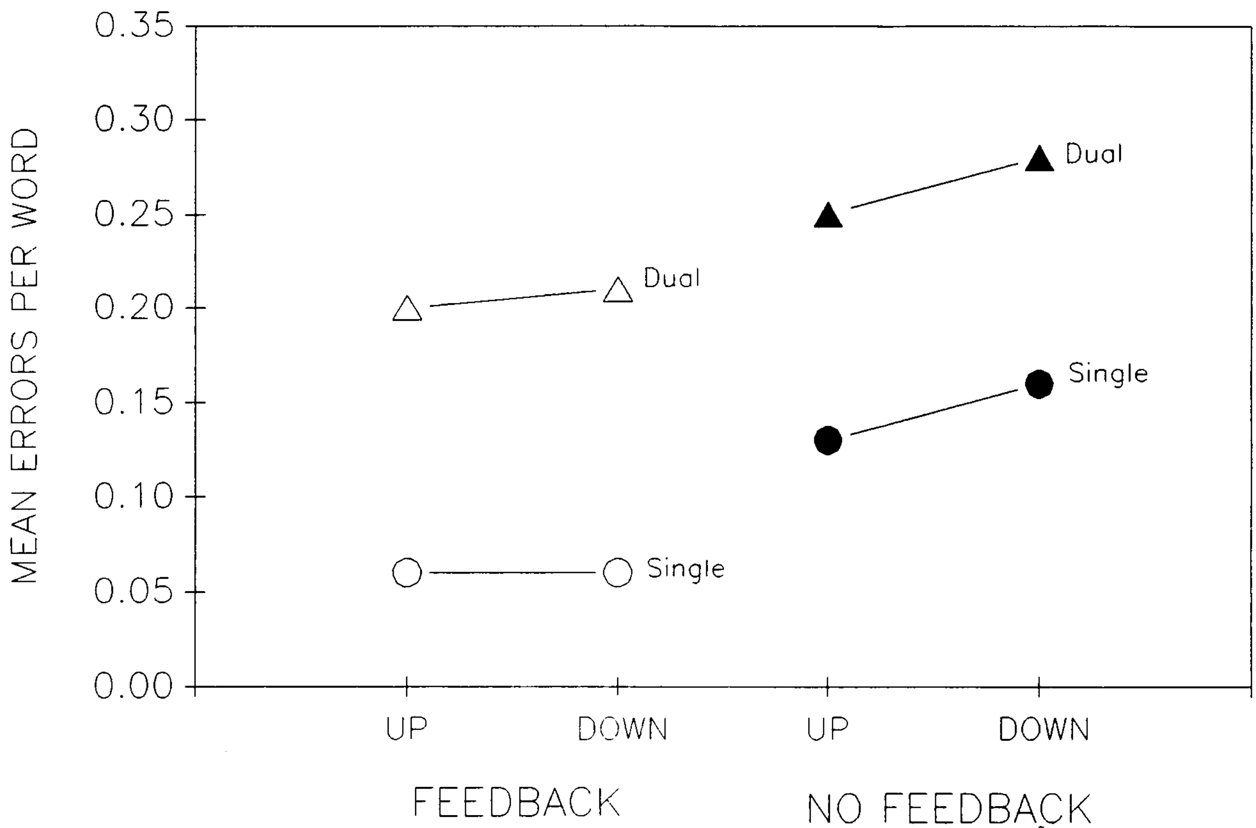



Figure 7. Legibility (reading errors) for the different experimental conditions in Experiment 2.

degradation could be specified. The first category included those measures for which a clear and defendable definition of degradation could be specified. Measures in that category included non-linearity (because subjects were instructed to form a straight column); standard deviation of the word angles (because increased variability is a reasonable measure of degraded writing performance); and standard deviation of letter angles (because increased variability is a reasonable measure of degraded writing performance). Measures in the second group, for which no clear definition of degradation could be specified, included the main angle of the words on the page (e.g., it is not clear that a clockwise tilt is more or less degraded than a counter-clockwise tilt); mean word angle (it is not clear what amount or direction of word angles corresponds to presence or degree of degradation); mean letter angle (direction or amount of change in mean letter angle cannot meaningfully be associated with writing degradation); and height of letters (larger or smaller letters or spaces between letters are not obviously associated with writing quality). Consequently, while all measures are potentially important and, if statistically significant, do reflect changes in writing performance, major emphasis in this report will be placed on those measures which can be reasonably associated with writing degradation.

Results of the analysis of the main longitudinal angle of the words on the page are shown in Table 10. When provided feedback, subjects were able to remain relatively close to the longitudinal axis (90.0 degrees), with the exception of the dual-task condition in the upright condition. In that case, the main angle was shifted counter-clockwise by 4.6 degrees. This single cell probably accounted for the significant interaction and main effects. This finding was not predicted and cannot be explained. However, it was expected that, with feedback, subjects would approximate the longitudinal axis (90.0 degrees), which they did in the other three conditions. In the no-feedback condition, there was a significant interaction between Position and Workload, with mean performance in the dual-task, reclined position representing highest accuracy, and performance in the dual-task upright Position representing the greatest error (8.2 degrees, counter-clockwise). A three-way ANOVA assessing the singular and joint effects of Feedback indicated that a significant main effect for Feedback [$F(1, 17) = 5.35$, $p = .0335$], indicating greater accuracy for subjects receiving feedback.

Figure 8 and Table 10 show the results for degree of non-linearity among the various experimental conditions. This measure is among those which are more defendable as indicating degradation. As shown, there was a significant main effect due to Workload when subjects received feedback. In the no-feedback condition, only the Position main effect approached significance. A three-way ANOVA including Feedback indicated significant main effects due to Feedback [$F(1, 17) = 69.81$, $p = .0001$] and Position [$F(1, 17) = 5.41$, $p = .0326$]. None of the interactions involving Feedback was significant.

Table 10. Results of statistical analyses of writing mechanics (main angle and non-linearity), in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Writing Main Angle, Feedback, Exper. 2** | 89.6 | 85.4 | 89.7 | 89.1 | ----- | ----- |
| Up/Down | - | - | - | - | 5.11 | .0372 ** |
| Single/Dual | - | - | - | - | 5.21 | .0356 ** |
| Up/Down X Single/Dual | - | - | - | - | 16.75 | .0008 **** |
| **Writing Main Angle, No Feedback, Exper. 2** | 85.5 | 81.8 | 84.0 | 89.9 | ----- | ----- |
| Up/Down | - | - | - | - | 2.09 | .1668 |
| Single/Dual | - | - | - | - | .22 | .6442 |
| Up/Down X Single/Dual | - | - | - | - | 6.97 | .0172 ** |
| **Writing Nonlinearity, Feedback, Exper. 2** | .22 | .24 | .22 | .33 | ----- | ----- |
| Up/Down X Single/Dual | - | - | - | - | 2.93 | .1050 |
| Single/Dual | - | - | - | - | 5.33 | .0337 ** |
| Up/Down X Single/Dual | - | - | - | - | 1.68 | .2120 |
| **Writing Nonlinearity, No Feedback, Exper. 2** | .58 | .63 | .72 | .70 | ----- | ----- |
| Up/Down | - | - | - | - | 3.77 | .0690 * |
| Single/Dual | - | - | - | - | .05 | .8205 |
| Up/Down X Single/Dual | - | - | - | - | .27 | .6080 |

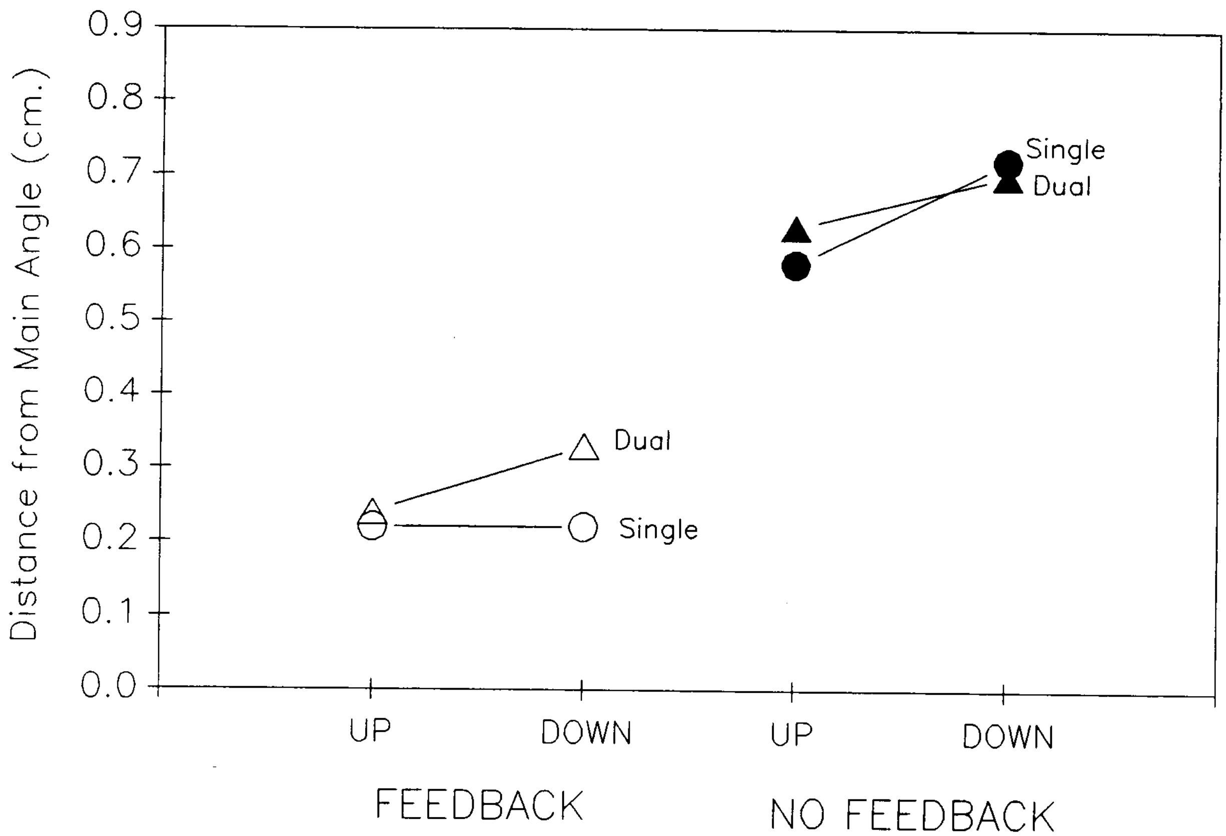



Figure 8. Non-linearity of writing under the different experimental conditions in Experiment 2.

Table 11 presents the results for mean word angle. All means were less than 180.0 degrees, indicating a general tendency for words to be tilted from the lateral axis in the counter-clockwise direction. In the feedback condition, there was a significant main effect due to Position, with subjects more closely approximating the lateral axis in the reclined position. There was also a significant interaction between Position and Workload, with a greater difference between the dual-up and dual-down conditions than between the single-up and single-down conditions. In the no-feedback condition, only the main effect due to Position approached significance. A three-way ANOVA to assess the single and interactive effects of Feedback indicated an effect due to Feedback which approached significance [$F(1, 17) = 4.27$, $p = .0543$]; a significant main effect due to Position [$F(1, 17) = 8.12$, $p = .0111$]; and an interaction among Position, Workload, and Feedback that approached significance [$F(1, 17) = 3.74$, $p = .0699$].

The results for variability of word angles are presented in Figure 9 and Table 11. In the feedback conditions, there was a significant main effect due to Workload, with more word-angle variability in the dual-task conditions. None of the other individual or interactive terms was significant. The three-way ANOVA including Feedback indicated a significant main effect due to Feedback [$F(1, 17) = 9.20$, $p = .0075$]. None of the other effects approached significance.

Results of analyses on the mean letter angles are presented in Table 12. There were significant main effects due to Position in both the feedback and no-feedback conditions. There was a strong tendency for letters to be more tilted in the clockwise direction when in the reclined position. Also, in the no-feedback condition, the interaction between Position and Workload approached significance. An ANOVA including level of feedback found no individual or interactive significant effects due to Feedback.

Figure 10 and Table 12 show the results for variation in letter angles. There were significant main effects for Workload in both the feedback and no-feedback conditions. No other comparisons approached significance. A three-way ANOVA assessing the effects of level of feedback found no significant individual or main effects due to that variable.

The results of analyses addressing letter height are found in Table 13. The only significant effect was for Position in the no-feedback condition. An ANOVA including Feedback as a factor found a significant Feedback by Position interaction [$F(1, 17) = 5.91$, $p = .0264$]; none of the other differences approached significance.

Finally, the results of the analyses of writing errors are shown in Figure 11 and the bottom of Table 13. In the feedback condition, there was a significant main effect due to Workload. In the no-feedback conditions, no significant effects were found. An analysis of variance including all three factors indicated a significant interaction between Feedback and Workload [$F(1, 17) = 5.91$, $p = .0264$].

Table 11. Writing performance (mean and standard deviation word angles) for the various experimental conditions in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Mean Word Angle Feedback, Exp. 2** | 174.3 | 172.7 | 176.3 | 178.3 | ----- | ----- |
| Up/Down | - | - | - | - | 10.17 | .0054 *** |
| Single/Dual | - | - | - | - | .06 | .8026 |
| Up/Down X Single/Dual | - | - | - | - | 7.52 | .0139 ** |
| **Mean Word Angle No Feedback, Exp. 2** | 172.2 | 172.3 | 175.2 | 174.6 | ----- | ----- |
| Up/Down | - | - | - | - | 4.15 | .0574 * |
| Single/Dual | - | - | - | - | 0.07 | .7974 |
| Up/Down X Single/Dual | - | - | - | - | 0.13 | .7262 |
| **Std. Dev. Word Angle Feedback, Exp. 2** | 3.31 | 3.95 | 2.85 | 3.67 | ----- | ----- |
| Up/Down | - | - | - | - | 1.04 | .3227 |
| Single/Dual | - | - | - | - | 4.82 | .0423 ** |
| Up/Down X Single/Dual | - | - | - | - | .03 | .8570 |
| **Std. Dev. Word Angle No Feedback, Exp. 2** | 4.31 | 5.14 | 5.72 | 5.24 | ----- | ----- |
| Up/Down | - | - | - | - | 1.50 | .2375 |
| Single/Dual | - | - | - | - | .06 | .8130 |
| Up/Down X Single/Dual | - | - | - | - | 1.73 | .2053 |

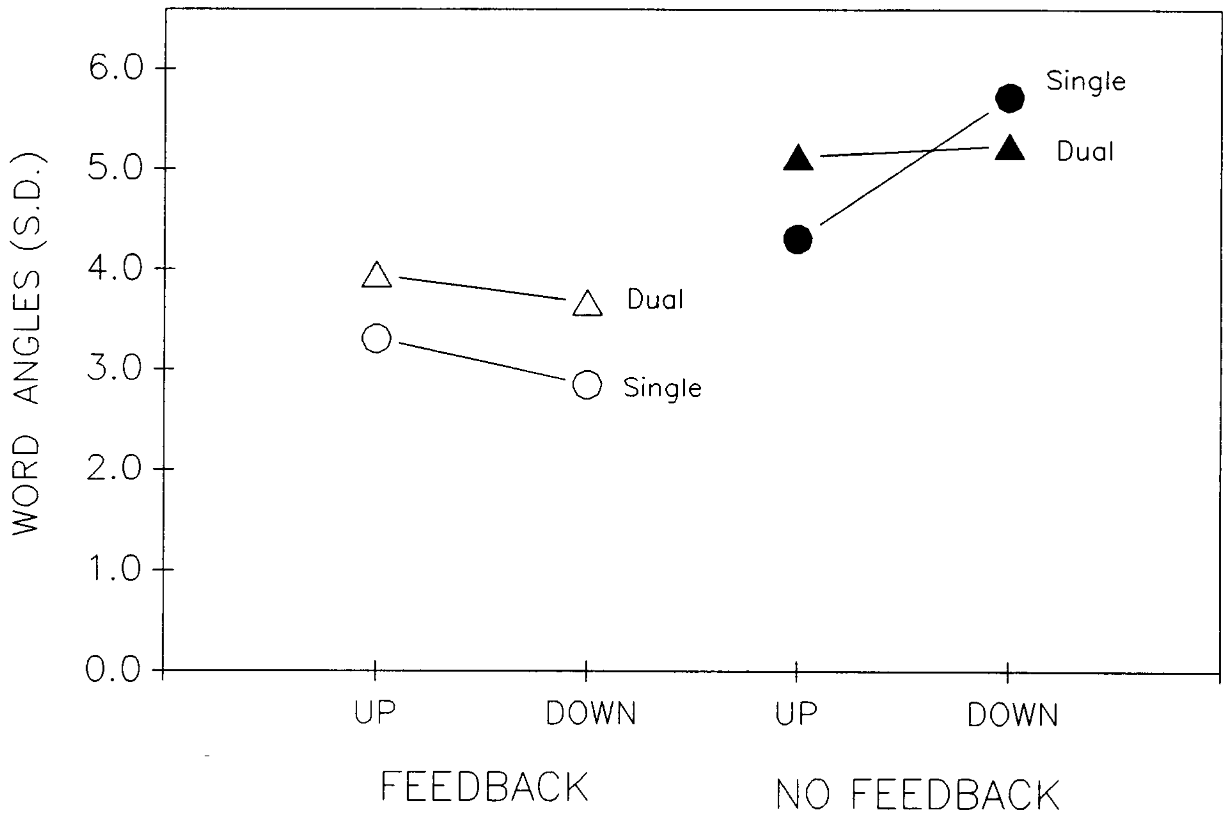



Figure 9. Variability in word angles among the different writing conditions in Experiment 2.

Table 12. Writing performance (mean and standard deviation letter angles) for the various experimental conditions in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Mean Letter Angle Feedback, Exp. 2** | 100.8 | 101.3 | 108.3 | 110.1 | ----- | ----- |
| Up/Down | - | - | - | - | 37.23 | .0001 *** |
| Single/Dual | - | - | - | - | 1.63 | .2194 |
| Up/Down X Single/Dual | - | - | - | - | .70 | .4130 |
| **Mean Letter Angle No Feedback, Exp. 2** | 102.4 | 100.4 | 107.9 | 109.1 | ----- | ----- |
| Up/Down | - | - | - | - | 25.12 | .0001 **** |
| Single/Dual | - | - | - | - | .08 | .7861 |
| Up/Down X Single/Dual | - | - | - | - | 3.86 | .0661 * |
| **Std. Dev. Letter Angle Feedback, Exp. 2** | 3.78 | 5.41 | 3.87 | 4.97 | ----- | ----- |
| Up/Down | - | - | - | - | .13 | .7246 |
| Single/Dual | - | - | - | - | 4.72 | .0443 ** |
| Up/Down X Single/Dual | - | - | - | - | .57 | .4595 |
| **Std. Dev. Letter Angle No Feedback, Exp. 2** | 3.52 | 4.59 | 4.00 | 5.32 | ----- | ----- |
| Up/Down | - | - | - | - | .69 | .4174 |
| Single/Dual | - | - | - | - | 6.65 | .0196 ** |
| Up/Down X Single/Dual | - | - | - | - | .08 | .7776 |

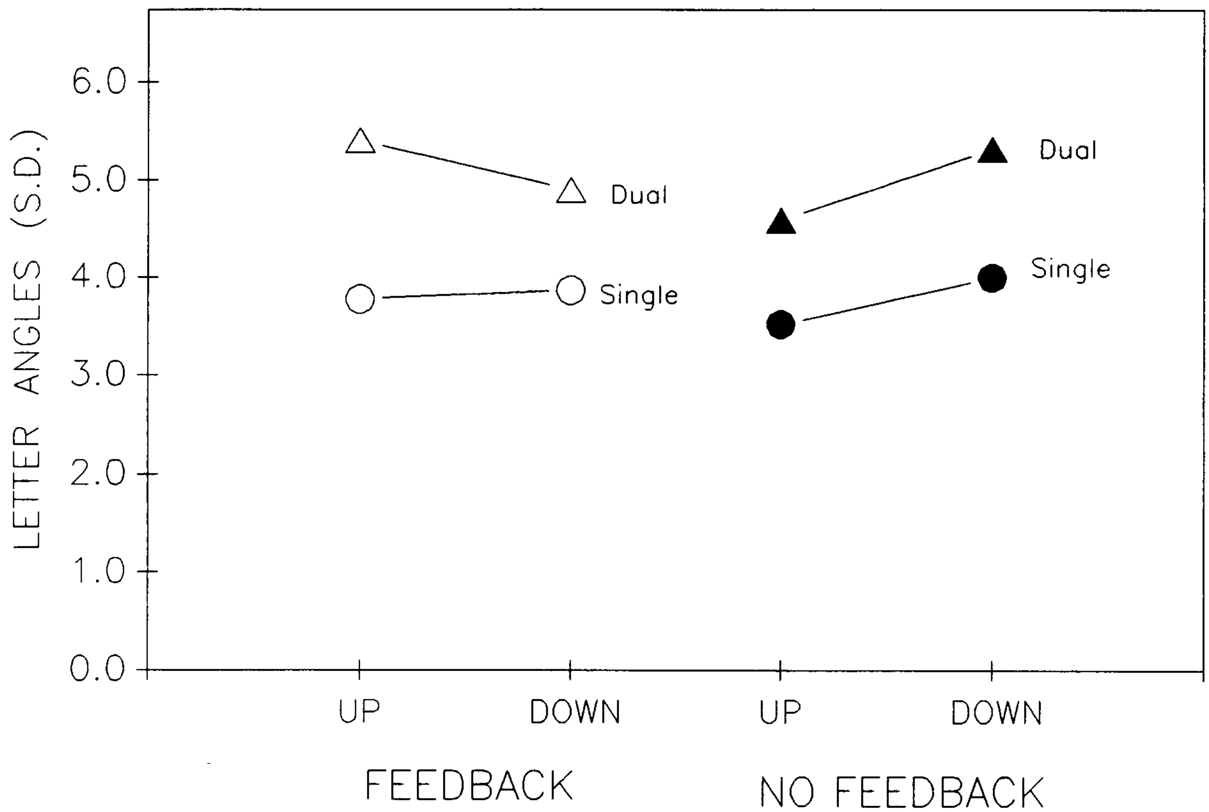



Figure 10. Variability in letter angles among the different writing conditions in Experiment 2.

Table 13. Writing performance (letter height and errors) for the various experimental conditions in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Letter Height Feedback, Exp. 2** | .93 | .99 | .98 | 1.01 | ----- | ----- |
| Up/Down | - | - | - | - | 1.43 | .2484 |
| Single/Dual | - | - | - | - | .98 | .3364 |
| Up/Down X Single/Dual | - | - | - | - | .56 | .4651 |
| **Letter Height No Feeback, Exp. 2** | 1.12 | 1.09 | 1.03 | 1.02 | ----- | ----- |
| Up/Down | - | - | - | - | 4.90 | .0409 ** |
| Single/Dual | - | - | - | - | .11 | .7413 |
| Up/Down X Single/Dual | | | | | .11 | .7395 |
| **Writing Errors Feedback, Exp. 2** | .17 | 1.00 | .11 | .94 | ----- | ----- |
| Up/Down | - | - | - | - | .06 | .8106 |
| Single/Dual | - | - | - | - | 10.37 | .0050 *** |
| Up/Down X Single/Dual | - | - | - | - | 0 | 1.0000 |
| **Writing Errors No Feedback, Exp. 2** | .56 | .72 | .83 | 1.00 | ----- | ----- |
| Up/Down | - | - | - | - | .71 | .4101 |
| Single/Dual | - | - | - | - | .31 | .5821 |
| Up/Down X Single/Dual | - | - | - | - | 0.0 | 1.0000 |

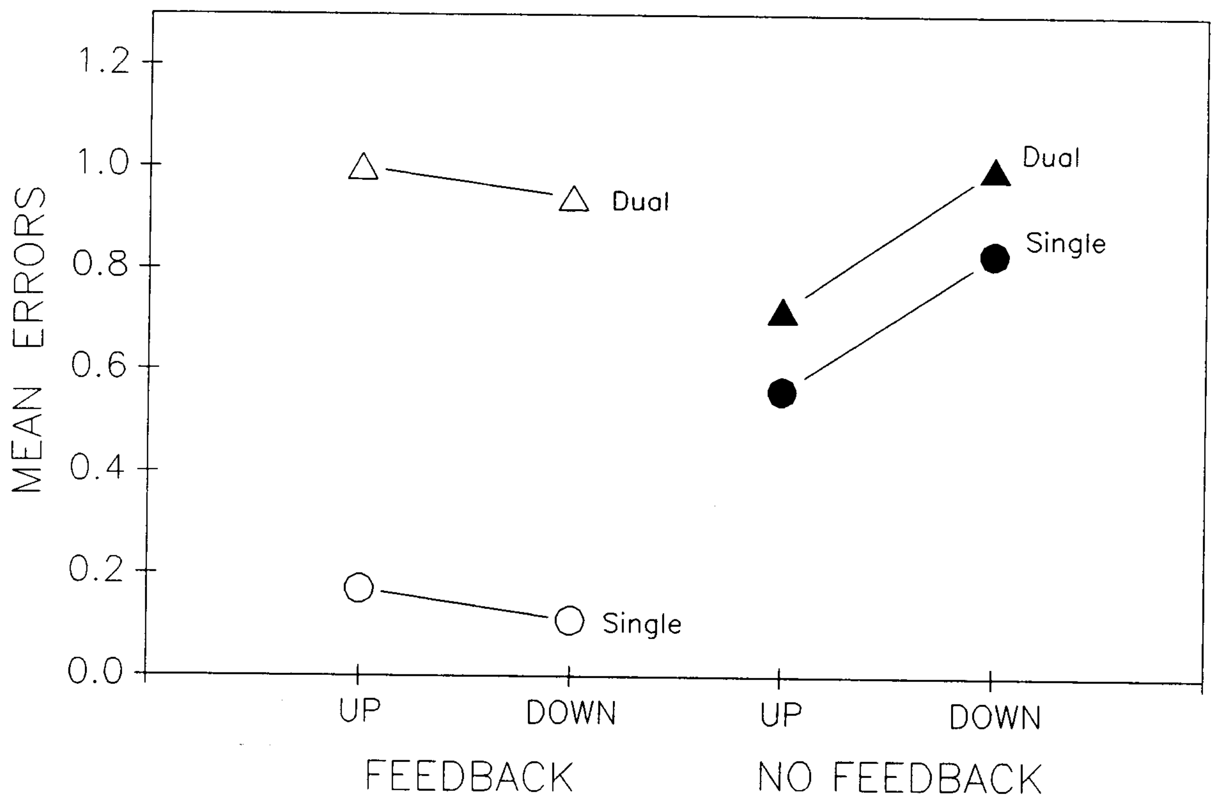



Figure 11. Writing errors among the different writing conditions in Experiment 2.

The first hypothesis predicted degraded performance when no feedback was provided. This prediction was moderately supported, with significantly greater degradation for the no-feedback condition in four of the six more-defendable measures of writing degradation and one of the four less-defendable measures of writing degradation. There was very little support for the predicted interaction between Feedback and Position with none of the six more-defendable measures and one of the four less-defendable measures indicating a significant interaction. There was no statistical support for the predicted triple interaction among Feedback, Workload, and Position.

Summary of Dual-Task Writing Results. Figure 12 presents a visual summary of the effects of Feedback and Position on performance in the mathematics task (top frame) and the five most defendable measures of writing degradation (bottom five frames). Only performance in the dual-task conditions is shown. Time for a naive reader to read the written words was not included here because it was found to be highly correlated with the reading error measure ($r$ = .829 for the first reader and $r$ = .834 for second reader). The predicted pattern of results was a) in the mathematics task, increased degradation when paired with the writing-with-feedback condition and, within that condition, more degradation in the reclined position than the upright position (i.e., a main effect due to Feedback and an interaction between Feedback and Position); and b) in the writing tasks, more degradation in the no-feedback conditions and more degradation due to altered gravity in the reclined position when no feedback was provided relative to when feedback was provided (i.e., a main effect due to Feedback and an interaction between Feedback and Position). Although this general pattern is apparent for some of the measures shown in Figure 12, little statistical support was found (except for the main effects due to Feedback).

In an attempt to assess the overall effect of Position and Feedback on writing performance, a multivariate analysis of variance including the five writing measures shown in Figure 12. Results indicated a significant main effect due to Feedback [$F(5, 13) = 7.75$, $p = .0014$], but no effects due to Position or Feedback by Position interaction ($F$'s < 1.00). These results reinforce those found for the individual measures (i.e., an effect due to Feedback but no effect due to Position or interaction between Position and Feedback).

The fourth hypothesis predicted no significant interaction between Position and Workload for the non-automated, light-pen tracking task. As shown in Table 14, accuracy in the lateral and longitudinal axes, measured by mean locations) were not significantly affected by Position, Workload, or an interaction between Position and Workload. As suggested by the Experiment 1 findings, measures of variability around the target in both the lateral dimension (Figure 12) and longitudinal dimension (Figure 13) revealed significant main effects due to Position. Significant main effects due to Workload were also found. As predicted, the interaction between Position and Workload was not significant. However, the reader is reminded that failure to reject the null hypothesis is not strong support for a theoretical prediction.

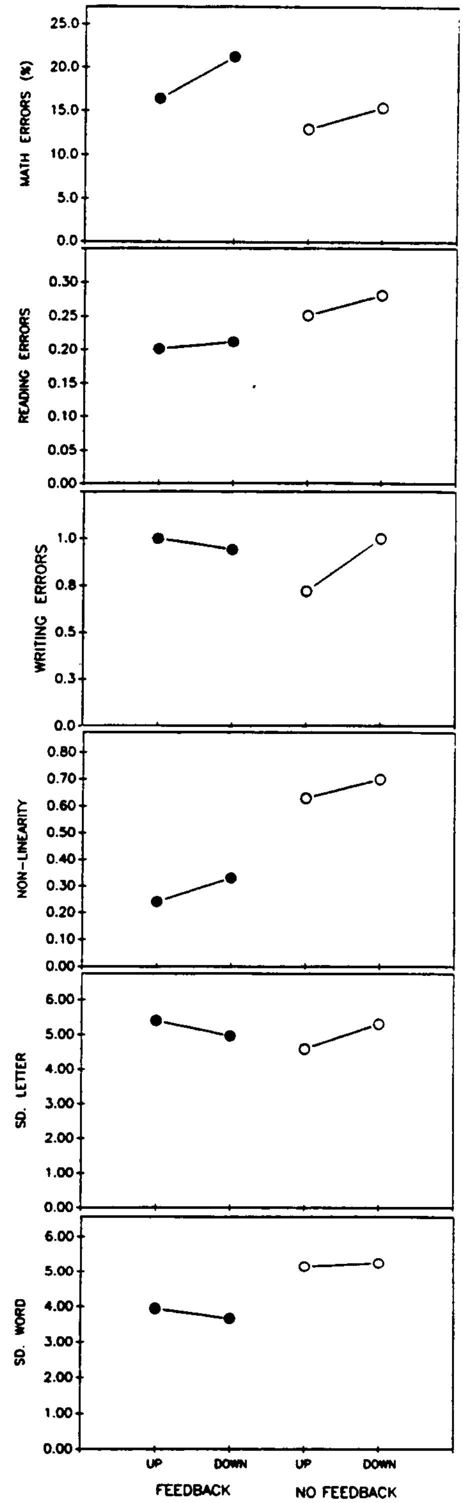



Figure 12. Summary of performance in the dual-task (writing and math) conditions for cognitive performance (top frame) and the five most defendable measures of performance degradation on the writing task (bottom five frames).

Table 14. Performance on the light-pen tracking task under various experimental conditions in Experiment 2.

| MEASURE | Mean Up Single | Mean Up Dual | Mean Down Single | Mean Down Dual | F Value | p Value |
|---|---|---|---|---|---|---|
| **Light Pen (Mean X)** | .21 | .30 | -.30 | -.10 | ----- | ----- |
| Up/Down | - | - | - | - | 3.61 | .0744 * |
| Single/Dual | - | - | - | - | .75 | .3972 |
| Up/Down X Single/Dual | - | - | - | - | .16 | .6902 |
| **Light Pen (Mean Y)** | .65 | .34 | .44 | .43 | ----- | ----- |
| Up/Down | - | - | - | - | .10 | .7592 |
| Single/Dual | - | - | - | - | 1.07 | .3148 |
| Up/Down X Single/Dual | - | - | - | - | 1.02 | .3262 |
| **Light Pen (Std. Dev. X)** | 6.82 | 7.35 | 7.46 | 8.11 | ----- | ----- |
| Up/Down | - | - | - | - | 26.69 | .0001 **** |
| Single/Dual | - | - | - | - | 18.68 | .0005 **** |
| Up/Down X Single/Dual | - | - | - | - | .13 | .7215 |
| **Light Pen (Std. Dev. Y)** | 7.34 | 7.58 | 7.72 | 8.14 | ----- | ----- |
| Up/Down | | | | | 5.69 | .0289 ** |
| Single/Dual | | | | | 5.79 | .0278 ** |
| Up/Down X Single/Dual | | | | | .39 | .5391 |

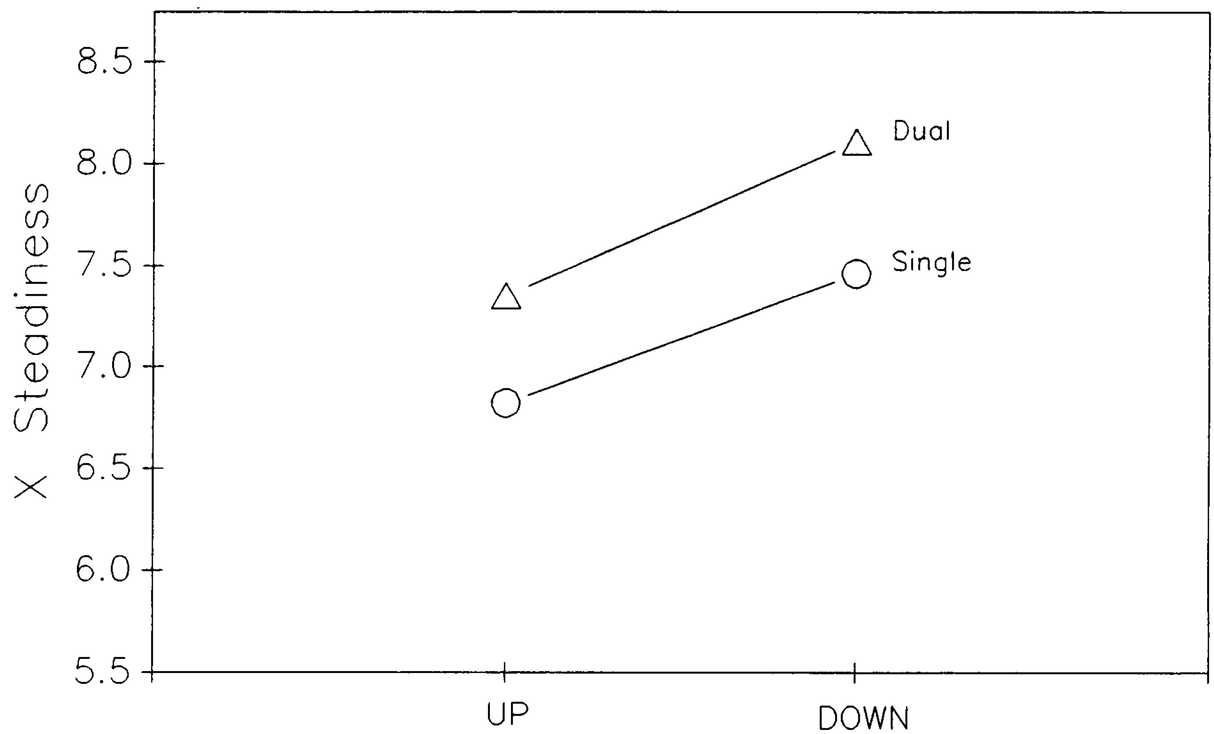
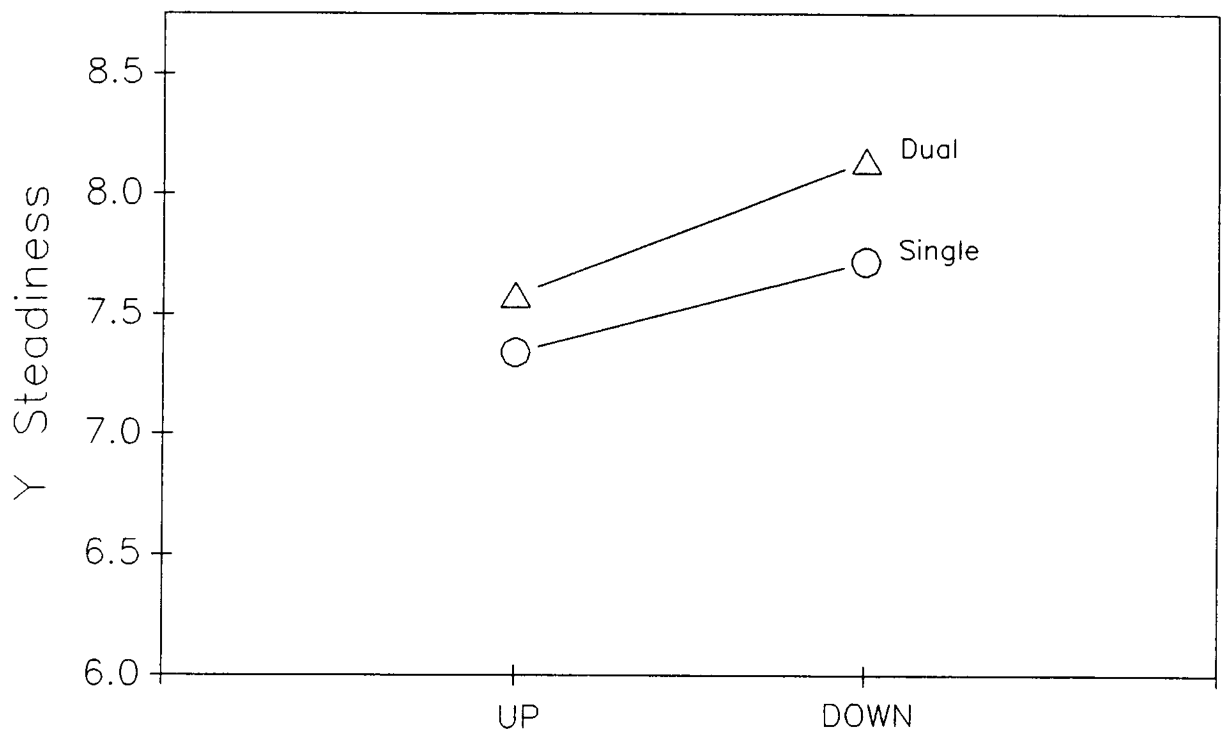



**Figure 13.** **Tracking performance in the lateral dimension under different conditions in Experiment 2.**




<u>Figure 14</u>. Tracking performance in the longitudinal dimension under different conditions in Experiment 2.

Ex Post Facto Analysis of Individual Differences. Because only modest support for the predicted effects was found, a subsequent analysis was conducted in an attempt to explain the lack of empirical support. In this study, several assumptions were made. One of the assumptions was that writing in cursive is an automated behavior. While this is probably true, it is possible that there were individual differences among the subjects with regard to the degree that writing behavior was automated. For example, some might not write as much in their daily jobs as others; or, some might print instead of write.

In the earlier review of the literature, Mantsvetova, Neumyvakin, Orlova, Trubnikova, and Freidberg (1965) observed that the less variable the cosmonaut's handwriting was on earth, the more degradation it suffered in space. In an attempt to follow that observation and obtain an objective measure of automaticity in handwriting, mechanical writing measures were assessed. Of the three measures (non-linearity, variability in word angles, and variability in letter angles) the scores for the last two in the single-task, upright position and with no feedback were summed to serve as a measure of automaticity in handwriting (labeled "Automaticity"). Non-linearity was not included in this index because it showed the most dramatic change when feedback was removed; a trait which is proposed here to contraindicate automaticity (see Figure 10). Also, non-linearity is more related to placement of the words on the page than handwriting per se.

If degree of Automaticity is an important factor in determining degree of subsequent degradation (as suggested here and in the observation made by Mantsvetova et al.), then there should be a negative correlation between the Automaticity measure and subsequent degradation in writing measures (i.e., the less variability in normal writing, the more degradation when subjected to altered gravitational cues). To assess this prediction, degradation scores were computed for mechanical measures for each subject. Specifically, the increase in word and letter variability from the single-task upright condition to the reclined position (single and dual-tasks) were computed and pooled. The correlation between Automaticity and the pooled degradation due to altered gravity was significant ($r = -.71$, $p = .0011$) while correlations computed for control comparison (i.e, correlations computed between Automaticity and comparable "degradation" scores in the upright position were not significant ($r$'s ranged from -.02 to +.04), supporting the notion that normal variability (i.e., in the upright, single-task condition) predicted degradation in the reclined position (lower initial variability predicted greater degradation).

To pursue this approach one step further, the subjects were then divided into two groups based on whether their Automaticity scores were above or below the median. If degree of automaticity is an important factor, then the two groups should perform differently in the dual-task writing condition. The group high in Automaticity should perform as predicted above but the group low in Automaticity should be less likely to conform to those theoretical predictions. Figure 15 shows the results of that analysis for performance on the simultaneous mathematics task. As suggested, subjects categorized as high in Automaticity (left column) produced results supporting the theoretical predictions while the group categorized as low in Automaticity (right column) did not.

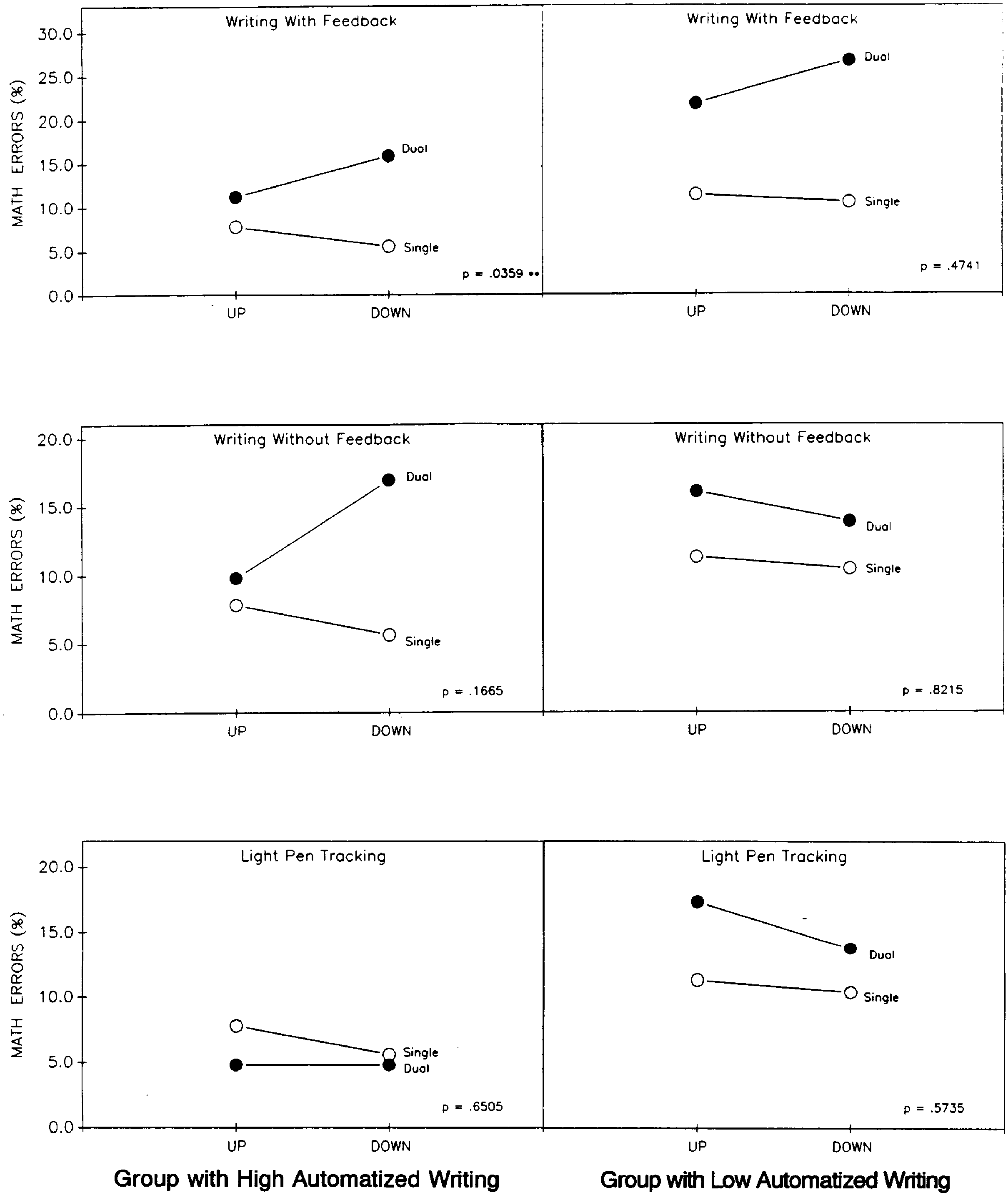



Figure 15. Performance on the mathematics task for groups of subjects categorized as low or high in automaticity under different positions and levels of workload for writing (feedback and no feedback) and tracking tasks.

The "p" value in each frame indicates the level of significance reached for the interaction term (Position by Workload) for that specific set of conditions. As suggested, the predicted interaction between Position and Workload only reached significance for the group high in Automaticity when performing the writing task with feedback.

## VI. General Discussion

The results of Experiment 1 indicated that significant performance degradation could be induced on earth by altering gravitational forces. In addition, the general pattern of results paralleled those reported in analogous tasks performed in a microgravity environment. The findings support the hypothesis that the effects of microgravity on human performance can be studied on earth, if subjects are placed in an altered gravitational field. However, additional research should be conducted in which more direct comparisons among performance measures on earth, in an altered gravitational field on earth, and in microgravity can be made. The findings of Experiment 1 are important, not only because they offer a reasonable and cost-effective approach to investigating the effects of microgravity on human performance, but because they also offer a number of important countermeasures (specifically, incorporating methods designed to train crew members to deal with altered gravitational forces) as well as a methodology for testing the training effectiveness of those methods.

The results of Experiment 2 offered only modest support for the predicted negative effects of altered gravitational forces on automated behavior and simultaneous cognitive performance. However, statistical support was found for one the major hypothesis after subjects were categorized as low or high in automaticity for writing behavior. As expected, subjects categorized high in automaticity displayed the predicted effect while those low in automaticity did not. Consequently, in related future work, measures of automaticity should be incorporated in the experimental design; or novel tasks should be used and automaticity acquired as part of the experimental designed. For example, the light-pen tracking task could be practiced until it reached the desired level of automaticity (as traditionally measured by performance on a secondary task), and then tested for vulnerability to altered gravitational forces.

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## Appendix A: Literature Search: Taxonomy and Abstract Summaries

## Classification Taxonomy for Characterizing the Literature

I. PHYSIOLOGICAL VARIABLES AFFECTING PERFORMANCE

A. General Physiological Changes in Microgravity
B. Cardiovascular Changes
C. Vestibular and Inner Ear Equilibrium Changes
D. Vision Changes
E. Altered Biorhythms
F. Motion Sickness
G. Physical Variables that Could Affect Performance

1. Vibration
2. Heat/Cold/Climate
3. Carbon Monoxide
4. Carbon Dioxide
5. Other Toxins
6. Sound (Noise)
7. Motion Forces
8. Radiation
9. Changes in Taste:
10. Effects of Medications:

II. PSYCHO-SOCIAL VARIABLES AFFECTING PERFORMANCE

A. Psychology of Long Duration Flight
B. Stress
C. Social Interaction, Isolation and Confinement (also Duration)

III. PERFORMANCE DEPENDENT VARIABLES

A. Human Performance
B. Cognitive Performance
C. Motor Performance
D. Perception in Microgravity
E. Reaction Time in Microgravity
F. General effects on Work Capacity

## IV. PROJECT-RELATED LITERATURE

A. Environmental Variables Affecting Performance

1. Human Factors of Space Flight
2. Space Station Design

B. Organizational Variables Affecting Performance

1. Training
2. Astronaut Selection
3. Preadaptation to Weightlessness

C. Water Immersion and Other Techniques for Simulating Microgravity
D. Possible Paradigms, Tasks, Test Beds for Future Phases
E. Related Bibliographies
F. Interesting and Relevant Information

## Summary of Review of Abstracts

**Generally ignored topics:**

Acceleration
Simulators
Space Suits
Medical Issues
Animal Work

**Reference Sources:**

Search A: Summary of important dimensions from Aerospace database -- Large search includes all since 1989, all before 72, and an attempt to get those from Jan 72 -- Aug 89 that were not included in published NTIS search.

Search B: Summary of important dimensions from Aerospace database Published Search Jan 72 -- Aug 89.

Search C: Summary of important dimensions from NTIS database.

Search D: Summary of important dimensions from PsycInfo database.

## TOPICS

### I. PHYSIOLOGICAL VARIABLES POSSIBLY AFFECTING PERFORMANCE

#### A. General Physiological Changes in Microgravity

Search A:

Item 12,13 Exercise as countermeasure for microgravity.
Item 22: Discussion of LBJ Spacelab Life Sciences 1 project to be conducted (includes work on early adaptation to microgravity).
Item 24: Effects of microgravity on microcirculation and theory of why.
Item 28: Relates Apollo 15-day flight physiological (maximal oxygen uptake - 17-21% decrease) and Skylab astronauts (strength of muscle groups - 2-9% elbow and 6-20% knee decrease) and middle-aged men after 21-30 days of bed rest.

Item 30: Describes psychological and physiological problems from over physical conditioning and relates to space.

Item 40: Summary of bone deterioration in microgravity, translated Russian.

*Item 53: Describes changes during long duration microgravity.

*Item 58: General 1989 discussion of effects of microgravity on physiology: lung, kidney, central venous pressure, bones etc.

Item 66: Discussion and theory of muscle atrophy in space.

*Item 70: Effects of space travel on nervous system.

*Item 72: General discussion of body reactions to microgravity and EVA, also, countermeasures for EVA effects.

Item 80: General discussion of human physiological adaptation to microgravity IN GERMAN

Item 138: Discussion of data from Skylab 28, 59, and 85 day missions, also development of cardiovascular model and a model of systemic circulation.

*Item 140: Summary of biological studies from Gemini and Apollo that includes psychosensory reaction and work capacity.

Item 147: 1970 review of biomedical problems of space flight - looks comprehensive, but old and probably superseded.

*Item 164: 1971 Summary of microgravity effects for 54 astronauts.

Item 174: 1971 Discussion of psychophysiological problems in space.

Item 177: 1971 Discussion of psychophysiological problems in space.

Item 199: 1971 Discussion of psychophysiological problems in space IN RUSSIAN

Item 200: 1971 Discussion of psychophysiological responses to space.

Item 205: 1971 Discussion of psychophysiological problems in space. IN RUSSIAN

Item 208: Effects of microgravity on otorhinolaryngological organs during 18-day Soyuz 9 flight IN RUSSIAN

*Item 220: Effect of altered afferentation on astronauts Translated Russian

Item 246: Results of telemetry physiology during Voskhod flight.

Item 251: 1969 Effects of gravity, radiation, and hypodynamics on physiology and human performance.

Item 252: Physiological effects of space flight (AGARD).

Item 254: Physiological and psychological problems in space flight.

Item 262: 1969 Translated Russian article on space physiology.

*Item 267: 1968 Compendium of conversion tables for studies of human responses to space environment (not clear if physiological, psychological, or performance "responses."

Item 270: 1968 Teichner report on: Effects of acceleration and microgravity on humans.

Item 276: Selected Russian articles translated address physiological and psychological testing and stress.

Item 278: 1964 Translated Russian review of literature in physiological reactions of man and animals to microgravity.

Item 289: Effects of microgravity on respiration, gas exchange, and energy expenditure IN RUSSIAN

Item 290: Telemetry of physiological data in Mercury and Gemini.
Item 295: Cardiovascular and respiratory reactions during Voskhod 2 flight IN RUSSIAN.
Item 310: Effects of hypokinesis on human muscle Translated Russian.
Item 327: Reactions of humans to microgravity, acceleration, immobilization, cabin atmospheres, and environmental stress (at SAM).
Item 352: Soviet psychophysiology in 1967 Translated Russian.
Item 373: Polish discussion of physiological effects IN POLISH
Item 378: Data during first minutes following introduction to microgravity IN RUSSIAN.
Item 398: Physiological testing under simulated Martian gravity.
Item 415: Physiological function impairment after extended microgravity - results from Cosmos 110 satellite Translated Russian.
Item 435: Data on effects of microgravity on physiology from Voskhod flights Translated Russian.
Item 439: 1965 Physiological reactions to microgravity IN RUSSIAN.
Item 441: EEG, GSR, and electrooculograms of 4 Cosmonauts in microgravity IN RUSSIAN.
Item 444: Psychological and physiological effects during Mercury project.
Item 458: Autosuggestion experiments and effects of microgravity Translated Russian.
Item 459: Biological, psychological and radiation effects in microgravity Translated Russian.
Item 461: Effect of microgravity on nervous system Translated Russian 1965.
Item 465: Human response to space flight 1964.
Item 495: Physiological effects of radiation, microgravity, and oxygen supply Translated Russian.
Item 512: Psychological and physiological aspects of microgravity flight.
Item 514: Adaptation of humans to microgravity. IN GERMAN
Item 534: Dynamic responses of weightless man 1963.
Item 566: Assessing alertness/consciousness of pilots in microgravity from EEG.

<u>Search B:</u>

Items 5 & 6: Conference proceedings. including section on gravitational physiology - human health requires countermeasures to microgravity
*Item 27: General effects of long duration microgravity 1987
*Item 36: Physiological and psychological effects of space (small part of proceedings)
Item 37: Effects of space on physiology, psychology, environment, social and operations.
Item 63: "Space Adaptation Syndrome" is physiological reaction to space.
*Item 69: USSR translated, effects of radiation and microwaves on physiology including afferent nervous system.
*Item 73: Summary of over 30 adverse effects, worst: cardiovascular, vestibular, hematological, bone and muscle changes.
Item 178: General effects of weightlessness 1977 IN RUSSIAN

| | |
|---|---|
| Item 225: | ECG change with venepuncture during prolonged hypokinesia indicates person becomes less tolerant to emotional stimuli. |
| Item 229: | Gemini & Apollo summary of effects of microgravity on body - shifts in organs, weight, blood circ., hematological indices, etc. |
| Item 237: | 1974 account of physiological changes following microgravity flight. |
| Item 268: | General physiological and psychological reactions to space. 1974 USSR translation. |
| Item 297: | 1973 Index of Russian and other foreign medical-biological literature including physiological and psychophysiological work. |
| Item 303: | 1972 Russian findings of adaptation and readaptation during and after Soyuz-9 18-day flight -- "readaptation is a more difficult process." |
| *Item 311: | 1972 discussion of kickoff of large NASA program to study man in weightless environment. |
| *Item 318: | 1971 General summary of effects of weightlessness on astronauts. |
| *Item 319: | 1971 Account of physiological problems encountered by cosmonauts on and after Soyuz-9 flight. |

Search C:

| | |
|---|---|
| Item 24: | Looks good but try to find comparable English. IN GERMAN |
| Item 39: | Dutch work in apparatus for testing cardiovascular, pulmonary, and hormonal changes in Spacelab. |
| Item 48: | French treatment of physiological adaptation to microgravity. |
| Item 102: | Hungarian (in English I think) general effects of microgravity. |
| Item 129: | Russian translated. |
| Item 149: | ". . . human energy expenditures on the performance of the same tasks were 22-42 percent higher than were under ordinary conditions on the ground . . ." |
| Item 166: | 1969 USSR general discussion of effects of weightlessness (Borrow copy). |
| Item 167: | Effects of motion on physiology and on disorientation. |
| Item 176: | Early (1968) USSR physiology in microgravity. |
| Item 185: | Using bed rest to simulate space flight - effects on fluids, etc. |
| Item 197: | Early (1965) USSR psychological/perceptual effects of microgravity. |

Search D:

| | |
|---|---|
| *Item 1: | The human in space. Translated Russian |
| Item 13: | Influence of prolonged space flight on human. IN RUSSIAN |
| *Item 18: | Effect of reduced pressure on human performance. |

### B. Cardiovascular Changes

## B. Cardiovascular Changes

Search A:

Item 123: Use of head up or down (5 deg) bedrest and head out of water immersion were investigated as simulation of microgravity.
*Item 119: Using tilt table at -30 deg to simulate blood distribution of microgravity - then looked at spatial position illusions - similar to those in horizontal positions.
Item 138: Discussion of data from Skylab 28, 59, and 85 day missions, also development of cardiovascular model and a model of systemic circulation.
Item 166: 1971 evaluation of cardiovascular system.
*Item 229: Circadian circulatory rhythms in microgravity or bedrest.
Item 282: Myocardial repolarization changes in persons with restricted motor activity.
Item 299: Problems of predicting cosmonaut cardiac reactions in flight from orthostatic tests IN RUSSIAN.
Item 346: Soviet book on space cardiology IN RUSSIAN.
Item 374: Gravity effects on blood distribution - relates astronauts to bed rest patients.
Item 384: Prevention of hypokinesia adverse effects on cardiovascular system by exercise, rhythmic compression of limbs, drugs, and moderate hypoxia Translated Russian.
Item 411: Heat, noise, vibration and acceleration simulation to determine stress effects.
Item 446: Correlational analysis of cardiovascular system during Voskhod flight IN RUSSIAN

Search B:

Item 70: Fluid and electrolyte loss occur during space flight but conversation of these substances is begun almost immediately when back down.

Search C:

Item 27: Instrument development, apparently little data.
Item 97: German abstract - under microgravity, parabolic flight, circ. reactions follow an "individual pattern."
Item 100: comments on physiological effects of spaceflight on circulatory system - done at Brooks AFB.
Item 178: Effects of space tumbling on cardiovascular deconditioning (see quote linking to water emersion and bed ridden).

## C. Vestibular and Inner Ear Equilibrium Changes

Search A:

Item 31: Theory of space posture that says peripheral vision replaces vestibular cues.

Item 101: Discussion of work with vestibular sled.

Item 122: Measurement of vestibular functions by using vestibular reflexes such as response to acceleration which stimulates the otolith organs.

Item 135: 1974 paper describing the otolith function.

Item 141: Simulation of the oculogyral illusion and the semicircular canal.

Item 152: Describes research conducted on Gemini 5 and 7 to determine otolith function - a coordinate space sense exists but "it was noted that the apparent location of the horizontal within the spacecraft may not agree necessarily with its physical correlate in the spacecraft.

Item 276: Vestibular training program to increase tolerance for Coriolis effects.

Item 307: Vestibular microgravity research: effect of changing from geocentric to heliocentric orientation on otolithic apparatus.

Item 391: Vestibular and motor functioning after space conditions Translated Russian.

Item 418: Otolith function experiment results from Gemini.

Item 490: Functions of otolith organs and semicircular canal in microgravity.

Search B:

Item 64: Combination of vestib and vision on space orientation

Item 195: Equation for prediction.

*Item 227: microgravity can lead to physiological and psychological disturbances since gravity is required by the organ of balance - relates it to SMS.

Item 253: Effects of microgravity on vestib., especially with other accelerations, can lead to "a number of vegetative and psychic disturbances in astronauts..." IN SERBO-CROATIAN

Search C:

Item 48 - IN FRENCH

Item 101: Small part of 1977 larger report.

Search D:

Item 12: Interaction of the vestibular analyzer with other analyzer systems. IN RUSSIAN

## D. Vision Changes

Search A:

Item 31: Theory of space posture says peripheral vision replaces vestibular cues.
Item 170: 1971 Visual perception in space.
Item 248: 1968 Vision in space.
Item 273: Effect of visible and ultraviolet light on human performance and safety in space flight.
Item 281: Physiological experiments to investigate flight stress effects on oculomotor equilibrium.
Item 311: Selection standards for vision.
Item 326: Optical illusions in astronauts during microgravity.
Item 332: 1967 Review of visual problems in microgravity.
Item 399: Vision research in extended flight.
Item 472: Survey of research in vision in microgravity 1964.
Item 475: Experiments on vision planned for Gemini and Apollo.
Item 476: Increased and microgravity effects on vision.
Item 502: Effect of transient microgravity on brightness discrimination.
Item 522: Visual potential of man in space 1964.
Item 527: Effects of microgravity on vision 1963.
Item 556: Visual vertical judgements under 4 levels of gravity.

Search B:

Item 102: USSR special case of visual detection.

Search C:

Item 99: Attempts to replicate and explain visual flashes experienced by astronauts when eyes closed and dark adapted.
Item 102: Hungarian (in English I think) work.
Item 104: Vision research in space - looks good - borrow copy.
Item 188: 1967 review of visual problems likely to occur in space.
Item 190: Visual acuity in space - Experiment S-81D-13 showed no significant change in acuity in space.
Item 197: Vision effects of microgravity (early USSR overview).
Item 203: 1964 knowledge of vision in space flight.
Item 161: Vision and vibration.
Item 209: 1965 USSR overview of findings on vision in space.

Search D:

*Item 17: Human frequency response as a function of visual feedback delay.

## E. Altered Biorhythms

Search A:

Item 160: Biorhythms and circadian and space flight.
Item 192: 1970 USSR sleep in space.
Item 219: Effects of altered daily regimen on motor functions.
*Item 229: Circadian circulatory rhythms in microgravity or bedrest.
Item 237: Wake sleep cycles in space.
Item 239: Biorhythm changes in space.
Item 255: 1968 Sleep and performance in space.
Item 261: Sleep limitations in space flight.
Item 350: Fatigue prevention in space (includes circadian effects).
Item 356: Biological clock.
Item 422: Role of circadian rhythms during extended space flight.
Item 489: Effect of diurnal circadian rhythm on sensory and motor performance in space Translated German.

Search B:

*Item 58: Review of human performance associated with changed biorhythms
Item 248: Chronobiology - study of biorhythms and space.
Item 277: Role of social synchronizers in inverting diurnal cycles of life functions.
Item 305: 1972 Russian hypothesis that predicts man cannot adjust to days shorter than 12 or longer than 52 hours.
Item 309: 1972 discussion of diurnal cycle IN RUSSIAN
Item 313: 1972 discussion of problems of sleep in space IN RUSSIAN
Item 315: Psychology of "active rest" IN RUSSIAN
Item 328: Russian active rest paper.

Search C:

Item 162: 1964 paper on biorhythms.

## F. Motion Sickness

Search A:

Item 113: Medication for SMS (scopolamine) can affect performance (e.g., mass discrimination).
Item 533: Motion sickness in microgravity 1963.
Item 568: Vostok II data showed that SMS was aggravated by head turning, ameliorated by sleep, and eliminated by 1g Translated Russian.

Search B:

Item 31: Evaluation of methods of overcoming visually induced MS
Item 33: Physiological reactions to MS
Item 76: USSR summary of SMS, countermeasures tried= antihistamine, pneumatic cuffs on thigh, applied lower body negative pressure, head cap that restricted head movement while providing force stimulus to cervical antigravity muscles, added pressure to sole of foot.

### G. Physical Variables that Could Affect Performance

#### 1. Vibration

Search A:

Item 269: Human responses to vibration in space.
Item 271: Compendium of human responses Vol 2: acceleration, vibration, sound, and noise.
Item 474: Effects of vibration on vision in space flight.
Item 520: Effects of transient noise and vibration in space.

Search C:

Item 161: Vision and vibration.
Item 204: Performance under 5 cycle/sec whole body vibration - different double amplitudes -- only effect at 2 largest, no after effects.

#### 2. Heat/Cold/Climate

Search A:

Item 266: Use of high temperature as a functional diagnostic tool during Soviet training.
Item 468: Hypothermia during flight.

Search C:

Item 169: Heat (1962).

#### 3. Carbon Monoxide

Search C:

Item 155: Effects of CO on animal performance.
Item 156: Effects of CO on human performance.

### 4. Carbon Dioxide

Search A:

Item 344: Effects of hypoxia and hypercapnia on tracking activity Translated Russian.
Item 384: Prevention of hypokinesia adverse effects on cardiovascular system by exercise, rhythmic compression of limbs, drugs, and moderate hypoxia Translated Russian.

Search C:

Item 113: Summary of physiologic, mental, and physical parameters in man as an aid to evaluation.
Item 159: Early 1969 study of CO2 effects.

### 5. Other Toxins

Search C:

Item 157: Ethylene Glycol (heat exchanger).
Item 158: Bromotrifluoromthane (fire extinguisher).
Item 179: Trace contaminants in sealed cabin atmosphere.

### 6. Sound (Noise)

Search A:

Item 198: 1970 Adverse effects of intense noise in space IN RUSSIAN
Item 232: Setting noise limits in space flight.
Item 253: Noise levels on long flights.
Item 271: Compendium of human responses Vol 2: acceleration, vibration, sound, and noise.
Items 303 & 333: Differential and threshold sensitivity of humans in space Translated Russian. (same author, 333=1968 and 303=1967)
Item 348: Human auditory analyzer found stable during prolonged exposure to altered gas medium IN RUSSIAN
Item 520: Effects of transient noise and vibration in space.

Search B:

Item 78: USSR audition (I think)

Search C:

Item 163: 1969 effects of broad-band noise on sleep.

## 7. Motion Forces

Search A:

Item 195: 1970 Discussion of coriolis and gyroscopic effects in centrifuges and other simulators.
Item 276: Vestibular training program to increase tolerance for Coriolis effects.

Search C:

Item 102: Hungarian (translated to English - I think) work.

## 8. Radiation

Search A:

Item 1: Protection from space radiation.
Item 69: General effects of exposure to a variety of electromagnetic fields (EMF's) on behavior in space.
Item 272: Effect of high and low gradient magnetic fields on human performance in space.
Item 315: Effects of irradiation and star magnitude on sextant sighting performance.
Item 459: Biological, psychological and radiation effects in microgravity Translated Russian.
Item 495: Physiological effects of radiation, microgravity, and oxygen supply Translated Russian.
Item 585: Ionizing radiation in space and its physiological effects.

Search B:

*Item 69: USSR translated article
Item 80: USSR effects of radiation on cosmonaut performance = small unless large dose.
Item 116: Radiation effects unpredictable because solar flares are unpredictable - no stated direct effects other than stress induced.

Search C:

Item 50: Cancer and longevity.

**9. Changes in Taste:**

Search A:

Item 196: 1970 USSR translation of olfactory discrimination in space and improvement with repeated exposures.

Search C:

Item 31: They try to relate bland taste in space to motion - 1 of 3 report it (but could simply be nausea).

**10. Effects of Medications:**

Search B:

Item 240: Effect of artificial gravity and drug countermeasures on cognitive/motor tasks.

## II. PSYCHO-SOCIAL VARIABLES AFFECTING PERFORMANCE

### A. Psychology of Long Duration Flight

Search A:

Item 3: Recent account of JSC program to address mental health in SSF.
Item 7: Summary of psychological, psychiatric and interpersonal problems that can go with and after space flight
Item 149: 1971 Summary of behavioral, psychiatric and sociological problems of long flights.
Item 193: 1970 USSR accounts of long-term reactions during Soyuz 9.
Item 233: 1970 Psychological and physiological response to microgravity IN GERMAN FROM RUSSIAN
Item 254: Physiological and psychological problems in space flight.
Item 276: Selected Russian articles translated address physiological and psychological testing and stress.
Item 313: 1968 Psychoneurology for studying behavior and personality changes in space.
Item 345: Psychological reaction to space: weightlessness, immobility, confinement Translated Russian.

Item 363: 1967 Psychology of space including selection, training, and behavior.
Item 364: Psychological and neuromuscular problems arising from prolonged inactivity.
Item 403: Psychology and space flight IN GERMAN.
Item 444: Psychological and physiological effects during Mercury project.
Item 459: Biological, psychological and radiation effects in microgravity Translated Russian.
Item 500: Psychological problems of disorientation in microgravity.
Item 510: Psychological effects of extended space flight - Christensen, might be a repeat.
Item 512: Psychological and physiological aspects of microgravity flight.
Item 524: Psychological problems of space flight and isolation IN GERMAN.
Item 528: Psychological aspects of space flight 1963.
Item 555: Psychological activity of people in space Translated Russian.
Item 561: Space psychology 1962.

Search B:

Item 1C: Bibliography on Neurological and psychological testing: Computer applications Jan 75 - Jan 87.
Item 39: Article from USSR about psychosocial problems in space -- this is similar to the article that sponsor sent.
Items 47 & 48: Social psychology of long duration flights.
Item 49: Strategies for selection and training
Item 56: Some tests given to astronauts - no criterion??
Item 57: Review of 60 flights psychological and social (ordered)
*Item 59: Small subset of whole medical paper
Item 79: USSR social psychology of long flights.
Item 91: USSR summary of psychological and social problems in isolation, confinement - no evaluations predicted problems
*Item 115: Forecast - based on history - of many variables in long duration flight - stress, selection, training, social interaction, prevention etc. Looks good, but 1979.
Item 120: 1980 discussion of psychosocial effects of long flights - probably more recent info.
Items 122-146: USSR review of space psychology (1979). IN RUSSIAN - this is a book. Topics include: General Psychology of space flight, Human factors, changes while adapting to microgravity, crew activity, modeling human activity, increasing crew effectiveness, stress, speech indicators of stress, work capacity, cognitive behavioral style, retention of skills (training facilities are considered, and a technique for maintaining fully developed control skills during extended flight by . . is proposed #134), training (136-141), engineering psychology (the inadequacies of airborne, underwater, and model simulations of

maneuvering in the space environment are indicated and the utility of space-borne testing is pointed out #142), visual work, verbal interaction with automated systems (crews must be psychologically trained to deal with AI systems #144), speech and stress, AND using psychological approach for problem solving.

*Item 202: Effects of stress, isolation, weightlessness, etc. on psychological processes.
Item 210: Psychologically and physiologically adapting to microgravity.
Item 230: Psychological effects of microgravity - 1975
Item 279: East German paper discussing psychology of EVA.
*Item 295: Early (1973) translated USSR misc. effects of spaceflight: training, space/time perception, weightlessness, isolation, stress, "man's motor activity under weightlessness", orientation training for cosmonauts, and work-rest periods.

Search D:

*Item 5: Review of psychology of space flight.
*Item 19: Psychological aspects of space flight.

### B. Stress

Search A:

*Item 20: Effects of stress due to microgravity on performance.
Item 63: Discussion of possible sources of stress on future missions.
*Item 76: Discussion of Polish research in stress, adapting to extreme situations, and decision making
Item 240 284: Effect of hypokinesia on resistance to stress.
Item 276: Selected Russian articles translated address physiological and psychological testing and stress.
Item 314: Stress tolerance in space Translated Russian.
Item 353: EEG as a measure of fatigue in non-microgravity space simulation.

Search B:

Item 17: USSR account of stress development on long duration flights.
Item 42: Physiological and information processing markers of stress
Item 51: East German visual stress test method of testing operational reliability of pilots
Item 66: USSR untranslated: "specific verbal and nonverbal behaviors are indicative of psychosomatic manifestations in conditions of weightlessness
Item 109: Flight duration and stress due to microgravity - looks good but IN RUSSIAN

| | |
|---|---|
| Item 148: | 1980 review of methods to measure stress and recommendation of optimal method. |
| Item 157: | Like earlier, USSR use of parachutes to train stress performance. |
| Item 203: | Skylab I-II evidence of adaptability to stress IN GERMAN |
| Item 214: | Predicting stress and resistance to stress - medical approach. |
| Item 278: | Russian discussion of Simonov's 1970 information theory of emotions and stress. |
| Item 284: | USSR discussion of stress in space flight. |
| Item 287: | USSR examination of stress during Voskhod-2, Soyuz-4, and Soyuz-5 missions. |
| Item 316: | 1972 Effects of stress on task performance IN POLISH |

Search C:

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|---|---|
| Item 141: | Stress effects on performance in space - (1972). |
| Item 192: | Measuring stress through auditory evoked potentials SAM 1965. |
| Item 193: | Workload - time sharing tasks as index to stress. |

## C. Social Interaction, Isolation and Confinement (also Duration)

Search A:

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|---|---|
| Item 5: | Recent account of lessons learned from Antarctica work. Addresses selection, training, conflict, etc. |
| Item 6: | Problems of intergroup behavior in space. |
| Item 8: | Social interactions in isolation: implications for selection and training. |
| Item 11: | Countermeasure for group conflict. |
| Item 17: | Leadership and group dynamics in space. |
| Item 74: | General prophesy of what space living will be like including selection, training, etc. |
| Item 182: | 1971 Long duration confinement effects on crew behavior during flight simulation. |
| Item 190: | 1970 USSR Translation: sleep as indicator of ability to adapt to isolation. |
| Item 213: | Effects of assigning unexpected tasks to isolated operators Russian translation |
| Item 275: | Unidirectional change in oxygen balance after bed confinement and isolation chamber. |
| Item 279: | Human reaction to space-like stress and isolation IN POLISH. |
| Item 282: | Myocardial repolarization changes in persons with restricted motor activity. |
| Item 300: | Effects of isolation on higher nervous activity, motor and vegetative reactions, muscular strength, and emotional state IN RUSSIAN. |
| Item 338: | Sensory deprivation in space flight Translated Russian. |
| Item 349: | Reactions to sensory deprivation IN RUSSIAN. |

Item 364: Psychological and neuromuscular problems arising from prolonged inactivity.
Item 367: Effects of prolonged confinement on functioning.
Item 384: Prevention of hypokinesia adverse effects on cardiovascular system by exercise, rhythmic compression of limbs, drugs, and moderate hypoxia Translated Russian.
Item 416: Psychophysiological effects of confinement, isolation, and sensory deprivation in space.
Item 417: Model for social interaction during long space flights.
Item 469: Group space flight psychology.
Item 470: Effects of immobility on mental state and physical functions Translated Russian.
Item 501: Duration of human's ability to tolerate microgravity Translated Russian.

Search B:

Item 1B: Bibliography on Effects of remote, isolated, or confined areas on humans Jan 70 - Apr 89.
Item 3: From 1970-1980 60% of all fatal accidents resulted from poor crew management.
Item 4: Intergroup conflict in teleconferencing - implications for space
Item 13: Providing balance between social and private time.
Item 16: Problems that evolve in isolation:
"... aggressive behavior during isolation is a behavioral pattern that is adopted by some individuals as a form of personal stimulation during prolonged periods devoid of external stimuli."
*Item 24: Summary of effects of isolation.
Item 46: Initial reflex muscle hypotonia helped by yoga exercises
Item 47 & 48: Social psychology of long duration flights.
Item 54: Cross-cultural psychology
Item 57: Review of 60 flights psychological and social (ordered)
Item 83: Summary of related area studies of isolation (1982)
Item 88: Isolation and confinement environment (ICE) symptoms are like stress
Item 94: Notes on social interaction in space
Item 99: Personality tests did not predict problems in isolation.
Item 112: Projected effects of confinement and isolation on long duration flights.
Item 174: Effects of three types of isolation (sensory/perceptual, temporal, and social) and confinement on space colonization
Item 187: Multi-language crews (RUSTON = Russian & Houston)
Item 193: 1975 paper on space colonization.
Item 215: 1975 review of literature in social dynamics in isolation.
Item 219: Bibliography of isolation studies in cold habitats.

Item 238: Taxonomy of variables related to isolation effects by S.B. Sells. Three clusters: situation, social system, and individual personality. This is the article recommended by NAS in Aerospace Medicine, 1966 A Model for the ...

Item 286: 1973 USSR article on crew compatibility

Item 288: Long-term mission confinement - space and undersea.

Item 291: Use of NIPA (non-interference performance assessment) which uses number and +-or neutral social interactions as measure of adjustment and morale.

Item 310: 1972 Need for work to maximize relationship between flight crew and mission control.

Item 312: 1972 Isolation, confinement and group dynamics (personal space) in long duration flight.

Search C:

Item 164: Effects of isolation on physiology.

Item 187: Effects of confinement on spreading germs.

## III. PERFORMANCE DEPENDENT VARIABLES

### A. Human Performance

Search A:

Item 1: Human behavior in extraterrestrial environment.

Item 19: Relationship between performance and crew size; determines that 4 is optimum for Mars flight.

Item 32: Relates movement and posture from videotapes to general orientation - theorizes that retinal vertical is frame of reference and new cognitive image of body is formed with peripheral vision of lower body replacing vestibular cues.

*Item 34: Development of the Automated Performance Test System (APTS) for toxicology etc. in space.

Item 62: Use of fuzzy set theory to model crew behavior.

*Item 67: General discussion of factors in extended microgravity flight.

Item 112: Argument for more human performance data to be collected in microgravity: estimating numerosity, length and time intervals and reproducing force.

Item 113: Medication for SMS (scopolamine) can affect performance (e.g., mass discrimination).

*Item 136: Results of performance tests in Skylab Orbital Workshop to investigate control techniques for the Astronaut Maneuvering Research Vehicle (AMRV)

Item 153: Studies of energy expenditure during task performance under 1g, microgravity parabolic flight, and microgravity buoyancy indicated that 22-44% higher than 1g. However, metabolic shifts seemed to adapt following initial general reaction "causing a disturbance of motion coordination."

Item 169: 1971 Man in operational aspects of space.

Item 172: 1971 Manned simulation of crew performance for assessing space mission reliability.

*Item 180: 1971 Astronaut microgravity performance evaluation program.

Item 181: 1971 Crew activity analysis for long duration space flight.

*Item 202: 1971 Describes experiments done to determine effects of artificial and microgravity on human performance.

Item 207: 1971 Crew performance as information input factor (done at SAM).

*Item 215: 1970 Astronaut microgravity performance evaluation program. Apparently earlier version of Item 180.

*Item 218: Effects of psychological factors on astronaut performance.

*Item 222 & 223: Effects of microgravity on human performance.

Item 251: 1969 Effects of gravity, radiation, and hypodynamics on physiology and human performance.

Item 301: Effect of lunar gravity simulation on human performance in a maintenance task.

Item 343: Descriptive model for determining optimal human performance.

Item 355: Effect of reduced gravity on human performance - especially work efficiency when traction reduced.

Item 382: Scanning performance in simulated microgravity Translated Russian.

Item 393: Procedure to measure energy expended in parabolic flight.

Item 394: Predicted versus actual astronaut performance.

Item 401: Lowered "psychic tone", absentmindedness and vigilance decline over extended microgravity flight IN FRENCH.

*Item 405: Human performance in space including depth perception, visual acuity, walking ability, reaction time, etc.

Item 408: Human operator in tracking system under microgravity conditions in Voskhod II Translated Russian.

*Item 419: Astronaut performance and response during Gemini flights.

*Item 421: Human performance testing during prolonged flight.

Items 428 & 430: Performance decrements when wearing pressurized suits.

Item 431: A collection of papers on effects of spacesuits on human performance.

Item 432: 1964 Research techniques used to measure human performance in microgravity.

*Item 434: Soviet methods and problems in evaluating human performance Translated Russian.

*Item 447: Monitoring human performance during microgravity with the purpose of assessing central nervous system function.

Item 450: 1965 US and USSR experience with weightlessness.

Item 478: Human adaptability to weightlessness.

*Item 494: Human performance under extended microgravity in Vostok II flight.
*Item 497: Human behavior in microgravity.
*Items 503 & 504: Self reports of human performance during Vostok III and IV.
Item 537: Sensations and performance of orbital workers 1963.
Item 547: Human performance in microgravity - self rotation method.
Item 551: Chimpanzee performance during simulated space.
Item 557: Chimpanzee performance during Mercury flights.
Item 568: Analysis of crew performance indicated that performance improved the longer the duration of flight.
Item 570: Human reliability in space systems 1963.
Item 577: Review of human tolerance to acceleration, vibration and noise.
Item 582: Human performance in short coplanar transfers between orbiting vehicles.

Search B:

*Item 8: 1988 overview of USSR performance measures including attention etc.
*Item 81: Astronauts and Cosmonauts who lived in space for months "lost equipment, ruined experiments, and lost data while displaying symptoms of fatigue, anxiety, mood fluctuation, hostility, social withdrawal, boredom, tension, lowered efficiency, and vacillating motivation."
*Item 82: Human reliability in space, types of errors, sources,etc.
Item 101: Human reliability and algorithms for predict. errors BUT in Russian
Item 103: Enhancing astronaut activity IN RUSSIAN
Item 104: astronaut psychic state and performance IN RUSSIAN
Item 106: Simulated ??affect on stress and performance IN RUSSIAN
Items 161-170: 1976 USSR report (161) that contains 162-170 articles that cover variety of topics: initial adaptation, pilot training, work-rest cycles, using hypnosis for simulating microgravity (there is a fairly large USSR lit. on that), suggestibility, radio telegraphy, sleep deprivation. IN RUSSIAN
Item 178-183: Methods for predicting the reliability of work performed by cosmonauts are analyzed. several papers: sensory-motor & mental activity; work/rest; isolation countermeasures; small groups; and EEG as an analysis of adaptation. IN RUSSIAN
Item 188: Behavior under weightlessness. IN POLISH
*Item 209: Effects of microgravity on task performance "Studies have shown that prolonged weightlessness affects the lability of memory and, thus, the astronauts' operational memory."
Item 211: Results of tests in space including operational memory IN RUSSIAN
*Item 228: Effects of microgravity on various measures.
*Item 234: Translated Russian account of problems encountered in microgravity including visual signalling, contrast sensitivity, and motor reactions.

| | |
|---|---|
| *Item 259: | Medical accounts of Gemini and Apollo showed some astronauts had decreased work capacity during flights. |
| Item 272: | Effects of psychological and psychophysiological factors on human performance: environmental, adaptation, emotion, drugs, selection of crew, crew relations, and man-machine interface. 1972 IN POLISH |
| *Item 280: | 1973 study of tracking performance over 90 days in SIMULATED space station. |
| *Item 300: | 1973 performance measures and psychophysiological variables and attention necessary to engage in functions for studying man in isolation. |

Search C:

| | |
|---|---|
| Item 52: | 11th issue of NASA's USSR Space Life Sciences Digest. |
| Item 193: | Workload, time sharing tasks as index to stress. |
| Item 207: | 1964 AMD review of what was known. |

Search D:

| | |
|---|---|
| *Item 4: | Human engineering and space flight. |
| *Item 10: | Final data for Skylab experiment M516: Crew Activities/Maintenance study. |
| Item 11: | Assessing human performance in space. IN RUSSIAN |

**B. Cognitive Performance**

Search A:

| | |
|---|---|
| *Item 94: | Spatial representations of space in microgravity. |
| *Item 224: | Decision making, memory models, signal detection, and pilot performance in flight. |
| Item 360: | Adaptability of sensory system to space for information processing IN RUSSIAN. |
| Item 578: | Examination of sensory, cognitive, and emotional aspects of space flight 1963. |

Search B:

| | |
|---|---|
| *Item 32: | Perception of body position and mental rotation and memorizing writing. |
| *Item 67: | Hungarian paper on information processing ability in orthostatic and antiorthostatic positions. |
| Item 113: | In midst of other stuff: modeling of astronaut's decision making" BUT IN RUSSIAN |
| Item 199: | Modeling behavioral and mental states of cosmonauts IN RUSSIAN |

| | |
|---|---|
| *Item 200: | Subjects of the objective-Productive type of cognitive behavior exhibit the most rapid and adequate adaptation to weightlessness. Individuals of the subjective and nonproductive types of cognitive activity showed great difficulties in adapting to weightlessness, . . ." "Anticipation of weightlessness on the basis of previous objective information is shown to facilitate orientation and self-control of man under weightlessness conditions." IN RUSSIAN |
| Item 208: | Performance on tests did not differ significantly from before flight to one month after return (there was slight deterioration. IN RUSSIAN |

Search C:

| | |
|---|---|
| Item 47: | German Spacelab D1 mission - part is to assess cognitive functioning. - check to see if any later data |
| Item 129: | Deals with cognition and most other issues (not repeated throughout except physiology). Translated Russian |

Search D:

| | |
|---|---|
| Item 21: | Effects of increased and decreased sensory input on the human. |

### C. Motor Performance

Search A:

| | |
|---|---|
| Item 109: | 1985 discussion of 3-d anthropometry motion analysis. |
| Item 111: | Model and experiments for simulating microgravity in motor control of teleoperator arms. |
| Item 121: | Use of 3-d anthropometry to measure activity in 1g and neutral buoyancy settings. |
| Item 143: | Astronaut maneuvering research on Skylab. |
| Item 176: | 1971 Human movements under lunar gravity. |
| *Item 188: | 1970 USSR translation discusses coordination of human voluntary movements in space. (also 263 below) |
| Item 205: | Human motion under lunar gravity IN RUSSIAN |
| *Item 217: | Human motor activity in microgravity. |
| Item 227: | Effects of hypokinesia - Translated Russian |
| *Item 231: | Biomechanics of man in microgravity Translated Russian |
| Item 263: | Coordination of voluntary movements in Keplerian (parabolic) flight. |
| Items 240 & 284: | Effect of hypokinesia on resistance to stress. |
| Item 293: | Motor reactions during microgravity in parabolic flight IN RUSSIAN |
| Item 294: | Sensory and motor reactions to parabolic flight IN RUSSIAN |
| Item 318: | Effects of sinusoidal motion on physiologic and perceptual-motor function. |
| Item 322: | 1967 Conference in behavioral problems in medicine. |

Item 330: Ability of man to orient and move about in reduced gravity.
Item 337: Motor coordination during parabolic flight - like others above - Translated Russian.
Item 342: Predicting 4-hr level of psychomotor performance from first half hour (Hartman).
Item 361: Human locomotion in reduced gravity Translated Italian.
Item 380: Behavior problems in space Great Britain.
*Item 389: Summary of chimpanzee space performance data.
Item 391: Vestibular and motor functioning after space conditions Translated Russian.
Item 425: Motor coordination analysis of voluntary movements in space flight Translated Russian.
*Item 462: Writing in microgravity Translated Russian.
*Item 473: Motor reactions in weightlessness Translated Russian.
Item 482: Orientation and rotation of human body in microgravity IN RUSSIAN.
Item 543: Locomotive performance in microgravity - new shoe type 1963.

Search B:

Item 276: Work movement performance of the astronaut in flight. translated USSR
Item 281: Work capacity in space and telemetry of medical information.
Item 317: 1972 Motor activity while performing command and control operations IN RUSSIAN

Search C:

Item 49: JSC study of space suit in 1g, water, and KC135 - performance was measured in foot pounds of torque.
Item 143: Times, forces etc. for manual labor tasks on Skylab.
Item 194: Effects of microgravity and space suit pressure on a maintenance task.
Item 208: 1964 study of effects of reduced g on walking.

Search D:

Item 14: Human motor activity in hermetic chamber and space. IN RUSSIAN.

**D. Perception in Microgravity**

Search A:

*Item 9: Time and mass perception are distorted in microgravity.
Item 103: Tests of human reactions indicated hierarchy of spatial perception cues was restructured, with retinal cues given most weight.
Item 194: 1970 USSR translation of role of proprioception in microgravity.
Item 257: 1969 USSR translation, perception of time and space in microgravity.

Item 291: Perception in space based on optic, kinesthetic, vestibular and other input Translated Russian. Item 370 is the Russian version.
Item 294: Sensory and motor reactions to parabolic flight IN RUSSIAN
Item 304: Interactions among sensory systems in microgravity Translated Russian.
Item 338: Sensory deprivation in space flight Translated Russian.
Item 349: Reactions to sensory deprivation IN RUSSIAN.
Item 360: Adaptability of sensory system to space for information processing IN RUSSIAN.
Item 483: Sensory, perceptual, and physiological aspects of sensory deprivation in space.
Item 519: Sensory and perceptual problems in space 1964.
Item 521: Psychological and physiological impact of lack of visual, auditory, and tactile stimulation in space IN JAPANESE.
Item 525: Perception of motion, equilibrium and orientation in microgravity IN ITALIAN.
Item 539: Perceptual phenomena in space theories 1961.
Items 540 & 541: Visual perception problem in space - Mercury.
*Item 477: Visual capability in space - special HF volume.

<u>Search B:</u>

Item 1A: Published bibliography on visual perception and performance: Effects of external stimuli Jan 72 - Dec 88.
*Item 32: Perception of body position and mental rotation and memorizing writing
Item 189: Psychophysical and Psychokinetic effect from stress and corresponding astronaut training. IN POLISH
Item 304: 1972 unofficial exploratory test of ESP by Mitchell during Apollo 14.
Item 323: Time perception in flight - relates time percept. to stress and brain centers.(flight in general, not just microgravity)

<u>Search C:</u>

Item 33: Time perception - short time (2s) is overestimated - longer times less affected.
Item 52: Russian digest.

<u>Search D:</u>

*Item 7: Parabolic flight and sense of orientation.

## E. Reaction Time in Microgravity

<u>Search B:</u>

*Item 67: See cognitive performance section.

*Item 84: Hungarian: "The sensory-motor reaction time and the four-choice reaction time notably lengthen and the information processing ability decreases at the beginning of the postflight period." (I think they mean the beginning of microgravity)

Search C:

Item 33: Reaction-time data during shuttle mission.

## F. General effects on Work Capacity

Search A:

Item 47: Estimates of construction capability of man in space = 180 days at 20% less effectiveness than on earth
*Item 140: 1971 Summary of biological studies from Gemini and Apollo that includes psychosensory reaction and work capacity
Item 204: Human energy requirements in microgravity - data from Gemini and Apollo missions.
Item 243: Work in reduced gravity.
Item 316: Simulation to assess work performance in space.
Item 325: Effects of work-rest cycles and sleep deprivation on performance in microgravity (Hartman).
Item 350: Fatigue prevention in space.
Item 455: Capacity for work in microgravity Translated Russian.

Search B:

*Item 8: 1988 overview of USSR performance measures including attention etc.
Item 105: Work capacity, activity, & dreams in simulation.

Search C:

Item 45: Application of methodology to predict human energy expenditure and physical workload in reduced gravity - underestimated at heavier tasks.
Item 123: Study of work/leisure activities: at least 5 hrs/day of meaningful work is required for satisfactory enjoyment.
Item 153: Soviet 1970 report of reduction in work cap that goes with reduced activity that goes with microgravity.
Item 165: EVA work capabilities (1969).
Item 170: 1968 review of effects of microgravity on work.
Item 182: Visual work capacity in space.

Search D:

*Item 15: Work in microgravity.

## IV. PROJECT-RELATED LITERATURE

### A. Environmental Variables Affecting Performance

#### 1. Human Factors of Space Flight

Search A:

Item 4: Recent human factors of space station design document - looks general.
Item 21: Antarctic as test bed for human factors in space.
Item 25: General discussion of space station HF variables.
Item 26: Human factors of the Hermes spaceplane.
Item 48: Human factors associated with conducting life-sciences experiments on SSF (major chance of problems).
Item 127: Human factors and space station design.
*Item 136: Results of performance tests in Skylab Orbital Workshop to investigate control techniques for the Astronaut Maneuvering Research Vehicle (AMRV)
Item 167: 1971 Model of man operator in space manual control.
*Item 241: Human factors research in parabolic flight.
Item 268: Anthropometry and workspace analysis, psychological effects, and work-rest cycle.
Item 371: Design of spacecraft with human factors input.
Item 448: Man-machine relationship in space flight IN RUSSIAN
Item 451: Problem areas and human factors challenges in long duration flight.
Item 530: Human factor in space flight 1963.

Search B:

*Item 121: Cognitive style, human factors etc. Looks good but IN RUSSIAN.
Item 150: 1979 review of human factors.
Items 190-93: Design, architect., and human factors of colonization.
Item 296: Translated USSR 1973 ergonomics and design.

#### 2. Space Station Design

Search A:

Item 18: Review of habitability lessons learned.
Item 24: Human factors of space station design for European Manned Space Infrastructure (EMSI).

Item 115: General configuration of shuttle General Purpose Work Station (GPWS) flown in Spacelab 1985.
Item 127: Human factors and space station design.
Item 371: Design of spacecraft with human factors input.
Item 484: Habitability in space vehicles 1965.
Item 496: Engineering psychology of space flight.

Search B:

Item 44: "Space station designs and operations that could affect crew performance include: interior architecture, crew support, crew activities, and IVA/EVE interface."
Item 52: Features of space station design
Items 190-93: Design, architect., and human factors of colonization.
Item 308: 1972 design of spacecraft IN RUSSIAN

## B. Organizational Variables Affecting Performance

### 1. Training

Search A:

Item 51: Description of Russian trainers and simulators.
*Item 183: 1971 Training program for long duration space station simulation test.
Item 210: 1971 Navigation training for Apollo flights.
*Item 245: Soviet book on astronaut training, performance, impressions, etc.
Item 258: Psychophysiological training to prepare cosmonauts for space, translated Russian.
Item 260: 1969 Soviet cosmonaut training.
Item 266: Use of high temperature as a functional diagnostic tool during Soviet training.
Item 276: Vestibular training program to increase tolerance for Coriolis effects.
Item 286: Selection and training of US and USSR astronauts.
Item 457: Physical training to counter stresses of microgravity.
Item 492: Training and simulator requirements for space flight 1964.
Item 535: Selection and training for space flight 1963.
Item 564: Spacecrew training review 1961.

Search B:

Item 153: Stress and psychological training and performance in USSR cosmonauts.
Item 233: Russian 1975 discussion of Cosmonaut prep - "The importance of psychological preparation, especially during longer flights, is stressed."

Item 251: USSR experiments designed for training of astronauts in weightless and referenceless space are described.

Search C:

Item 63: Spacelab D1 effects on training discussed. IN GERMAN
Item 101: Small part of 1977 larger report.
Item 148: Training under microgravity conditions.

## 2. Astronaut Selection

Search A:

Item 27: Review of astronaut selection history.
Item 75: Personality of ideal astronauts.
Item 286: Selection and training of US and USSR astronauts.
Item 486: Physical and psychological tests used in USSR for selection and training IN POLISH.
Items 526 & 544: Selection criteria for astronauts IN ITALIAN.
Item 535: Selection and training for space flight 1963.
Item 552: Astronaut selection criteria 1962.

Search B:

Item 40: astronaut scientist selection
Item 60: Russian cosmonaut selection historical background
Item 72: Astronaut and crew selection
Item 94: Some selection issues are covered
*Item 95: Astronaut selection.
Item 98: French battery of tests used to select their astronauts.
Item 99: Personality tests did not predict problems in isolation.
Item 151: Selection and training of shuttle payload specialists and future SS personnel.
Item 159: Like 151 but different authors?
Item 172: Selection and training of USSR cosmonauts based in part on "response to weightlessness" IN RUSSIAN
Item 176: Airline and payload specialist crew selection IN GERMAN
Item 185: Test for determining stability of judgements for psychoneurologists who monitor flight crew members.
Item 257: Selection based on social compatibility.
*Item 269: Cosmonaut selection based on responses to space flight factors including confinement, orientation, microgravity, decrease in afferent nerve pulses, danger, and separation from earth. USSR translation
Item 306: 1972 selection and training of crew IN RUSSIAN

Search C:

Item 101: Small part of 1977 larger report.

### 3. Preadaptation to Weightlessness

Search B:

Item 201: One of numerous articles that talks about parachuting.
Items 161-170: Hypnosis as simulation - one of many articles
*Item 235A: Translated Russian account of training/prep for microgravity.

Search C:

Item 25: Describes apparatus and data at JSC.

## C. Water Immersion and Other Techniques for Simulating Microgravity

Search A:

Item 29: Bed rest as simulated microgravity.
Item 89: Not appropriate for studying muscular metabolism and performance capacity in sub-maximum exercise.
*Item 119: Using tilt table at -30 deg to simulate blood distribution of microgravity - then looked at spatial position illusions - similar to those in horizontal positions.
Item 123: Use of head up or down (5 deg) bedrest and head out of water immersion were investigated as simulation of microgravity.
Item 130: 1977 look at the technique in German report.
Item 145: Description of Marshal SFC Neutral Buoyancy Simulator.
Item 197: 1970 Describes effect of immersion on motor functions IN RUSSIAN
Item 201: 1971 Simulation of microgravity (teterboard and cargo transfer examples).
*Item 229: Circadian circulatory rhythms in microgravity or bedrest.
Item 244: Underwater habitats for research on space.
Item 275: Unidirectional change in oxygen balance after bed confinement and isolation chamber.
Item 369: High fidelity underwater simulation of microgravity.
Item 374: Gravity effects on blood distribution - relates astronauts to bed rest patients.
Item 449: Human motor performance in water simulation of microgravity.

Search B:

Item 107: Use of hypnosis to induce weightlessness (IN RUSSIAN)

Search C:

Item 32: "The physical properties of water limits the validity of the simulation to movements with very extremely low speed."

Item 186: 1967 report that is the same as 1969 Human Factors article.

Search D:

*Item 16: Bibliography of water immersion techniques for simulating microgravity.

### D. Possible paradigms, Tasks, Test Beds for Future Phases

B.

Item 22: Telerobotic system.

Search C:

Item 3: Robot operation.
Item 4: Space suit operation.
Item 37: Space suit automated gloves (Stanford).
Item 38: OMV operation.
Items 80 & 81: Human Factors requirements for teleoperators.
Item 107: EVA system effectiveness.
Item 108: Mundane tasks tested on KC135.

### E. Related Bibliographies

Search A:

Item 259: (and numerous other items throughout) "Space Biology and Medicine" multiple volume set dealing with physiology of space.
Items 271 267 and others: Series of volumes in Compendium of Human Responses to Aerospace Environment.
Item 335 and others: Aerospace Medicine and Biology - A continuing bibliography with indexes.
Item 365 and others: Human Ecology in Space Flight. Vol 1-x
Item 463: Bibliography of Russian research in space 1965.

Search B:

Item 7: Trends in Poland for Space Psychology 1981-86
*Item 8: 1988 overview of USSR performance measures including attention.

Items 11 & 12: 1986 summary of USSR knowledge - IN RUSSIAN

Search C:

Item 12: (AEROSPACE - already have)
Item 18: Bionics 1970-89 - small section on simulation of bio effects of space flight possibly relevant.
Items 20 & 21: 1989 - try to borrow - only small parts are relevant.
Item 61: Index of issues 1-4 of USSR Space Life Sciences Digest.
Item 111: Space Biology and Med. Vol 3 (1975).
Item 140: Aerospace med and biology a continuing bibliography (old: 1972).
Items 145 & 146: Aerospace, medicine and biology 1972.
Item 160: 1970 summary of USSR papers in psychophysiology and engineering psychology in space.
Item 173: 1964-68 summary of Naval Aeromedical Institute research.
Item 177: Early USSR effects of microgravity : Space Biology & Medicine Vol 2, 1968.
Item 184: USSR USA work : Space bio and med Vol 1, 1967.
Item 185: Human Ecology in Space Flight Vol 2, 1964.
Item 207: 1964 AMD review of what was known
Item 211: 1961-62 Human Engineering Bibliography.

### F. Interesting and Relevant Information

Search A:

Item 71: Discussion of lack of behavioral science in NASA programs.
Item 73: Log of space flights including crew identities - possibly valuable.
Item 79: Possibly interesting German article on gravity receptors in animals.
Item 102: Interesting discussion of space plane concept being side tripped by capsule program because of Sputnik in 1958.
Item 108: Idea of computer simulation/modeling movements in microgravity.
Item 203: Evolution of the space suit to 1971.
Item 208: Effects of microgravity on otorhinolaryngological organs during 18-day Soyuz 9 flight IN RUSSIAN (NOTE: VOICE CHANGES - possibly automaticity - also, if voice changes in certain direction, then attribution could affect interpretation of mood)
Item 321: Effects of artificial atmosphere on speech (See 208 above).
Item 565: Effects of time lag during remote control at large distances.

Search B:

Item 15: Mars flight will include training, cross training and sharpening skills.

Search C:

Item 3: Constraints due to "safety concerns and an anticipated increase in acceleration levels due to manipulator motion." They used KC135 to test human/robot interaction in microgravity.

Item 29: Discussion of "graviperception is an active physiological process" in loxodes and paramecium.

Item 83: Carnegie-Mellon looked at telerobotics for space and concludes ". . . found not to be satisfactory due to communication time delays and bandwidth limitations, and human costs and performance limits."

Item 106: Stanford development of an EMG biotelemetry system for man and animals.

## Appendix B: Astronaut Questionnaire

# NASA ASTRONAUT QUESTIONNAIRE

## PERFORMANCE DEGRADATION IN MICROGRAVITY

July 1991

Part of NASA Grant No. NAG9-487
Southwest Research Institute

### Background

The purpose of this questionnaire is to increase our knowledge about the effects of space flight on human performance. There is evidence from a variety of sources, including published papers and anecdotal self-reports, of incidents in which individuals in microgravity environments have experienced some decline in their ability to conduct tasks or in their confidence that they are performing at a high level. Your input is valuable in our attempt to determine if a problem exists and, if so, what countermeasures can be taken. When answering the following questions, it is important that, unless instructed otherwise, you limit your answers to reflect your memory of your first space flight. It is also important that you provide answers that reflect your experience, not those you might have read or heard about from other crew members. Please do not put your name on this document to insure that you remain anonymous. You will be asked to provide some demographic information (below), but this information will be used only in the statistical analysis and will not be used to identify you as an individual. The data collected in this questionnaire will be used only by an outside researcher to help identify areas where problems might exist and where improvements might be made.

We thank you for your cooperation.

Astronaut Tracking Number: __________

Age:

26-30 31-35 36-40 41-45 46-50 51-55 56-60

Sex: M F

Number of space flights: 1 2 more than 2

Number of hours exposed to microgravity: ___

**Sensation and Perception**

In this section, you are asked to report any changes you might have experienced in terms of how quickly and accurately you sensed stimuli (sensation) and how quickly and accurately you perceived what the stimuli were (perception). Please answer the following questions by circling the alternative that best represents your answer.

I. Vision

1. When looking at objects located within 20 feet, I would rate my ability to detect visual forms:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ____________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ____________________

____________________

2. When looking at objects located within 20 feet, I would rate my ability to discriminate different visual forms:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

3. When looking at objects located within 20 feet, I would rate my ability to detect and discriminate colors:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

4. When visually scanning a scene within 20 feet (e.g., trying to locate a specific gauge in the middle of a complex panel), I would rate my ability to quickly and accurately locate a specific object or feature:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

5. When visually tracking a moving object located within 20 feet, I would rate my ability to easily and accurately track that object:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ____________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ____________________________________

________________________________________________________________

## II. Hearing

1. I would rate my ability to detect sounds:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

2. I would rate my ability to discriminate different sounds:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

**Touch**

1. I would rate my sense of touch:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

**Taste**

1. I would rate my sense of taste:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

________________________________________

**Vestibular**

1. I would rate my sense of balance:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________

____________________________________________________________

2. I would rate my ability to orient myself to my surroundings:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

Please provide any comments you have on your general ability to sense and perceive in space or on the information in the above questions: ______________________________

______________________________

______________________________

**Time Perception**

1. I would rate my sense of time perception:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much poorer than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much better than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

ALSO:

___ I tended to <u>underestimate</u> the amount of time that had passed.
___ I tended to <u>overestimate</u> the amount of time that had passed.
___ There was no systematic direction to my errors in estimating time.

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

**Psychophysiological**

In this section, you are asked to report any changes you experienced with respect to how you physically or mentally felt.

1. I would rate my feelings of nausea and upset stomach:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

2. I would rate my frequency and intensity of headaches:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________

________________________________

3. I would rate my frequency and intensity of dizziness:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________

________________________________________________

4. I would rate my frequency and intensity of anxiety feelings (e.g., butterflies):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

5. I would rate my frequency and intensity heart irregularities (e.g., unusually fast or slow rates or unusual rhythms):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

____________________________________________________________

6. I would rate my feelings of being confused:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________________

__________________________________________________________

7. I would rate my feelings of self confidence in ability to perform my job:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

8. I would rate my general motivation level:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

______________________________________________________________

## Cognitive Performance

In this section, please report any changes in your ability, or your perception of your ability to perform cognitive tasks. A cognitive task is one that primarily involves thinking (rather than physical actions). Examples of cognitive tasks are solving problems, forming strategies, remembering information, making plans, using logic, using mental imagery, doing mathematical operations in your head, etc.

1. I would rate my ability to remember information:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) __________________________________

____________________________________________________________

2. I would rate my ability to learn new information:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

____________________________________________________________

3. I would rate my ability to remember and utilize information required for a special mission-specific operation (e.g., remember a series of coded data and use the procedure for entering the data):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

____________________________________________________________

4. I would rate my ability to perform general flight tasks (e.g., remembering or logically reconstructing the routine procedure to prepare for descent):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

5. I would rate my ability to remember and use simple everyday information (e.g., doing math in my head, recalling names of people and places, answering questions from other crew members, etc.):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

________________________________________

6. I would rate my ability to perform procedural mental tasks (e.g., mathematics, logic, etc.):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________

________________________________________________

7. I would rate my ability to perform spatial tasks (e.g., form a mental picture of what the robotic arm looks like from the other side):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ____________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________________

____________________________________________________________

8. I would rate my ability to perform verbal tasks (e.g., constructing reports or explanations for fellow crew member):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ____________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ____________________

____________________

9. In general, I would rate my confidence that I could successfully complete cognitive tasks:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

## Behavioral or Motor Tasks

In this section, you are asked to report any changes in your ability to perform behavioral or motor tasks. A motor task is one that primarily involves physical movements. Examples include walking, driving a vehicle, using tools to repair equipment, operating machinery, playing a musical instrument, etc.

1. I would rate my ability to remember how to perform behavioral tasks:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ____________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ____________________________________

______________________________________________________________

2. I would rate my ability to learn new behavioral tasks:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) __________________________________

__________________________________________________________

3. I would rate my ability to perform specially trained mission-specific operations (e.g., physically assemble a special piece of equipment):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

4. I would rate my ability to perform general flight tasks (e.g., conducting routine maintenance procedures):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

5. I would rate ability to move around in my environment:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________________

________________________________________

6. I would rate ability to perform simple everyday tasks such as writing, using tools, entering data on a keyboard, etc. (other than moving around):

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ________________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ________________________________

________________________________________

7. In general, I would rate my confidence that I could successfully complete behavioral and motor tasks:

a) During the first 8 hours after ascent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

b) During the last 8 hours before descent on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

c) During the first 8 hours after landing on my first mission:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Much less than in the week prior to takeoff | | | Equal to that in the week prior to takeoff | | | Much greater than in the week prior to takeoff |

d) If you answered "4" to all of the above questions, go to "e" below. If not, do you have an explanation for the changes you experienced:

___ No
___ Yes (explain) ______________________________

e) If you have flown more than one mission, were your experiences in later missions:

___ Same as above
___ Different (explain how) ______________________________

______________________________

## General

1. What, if anything, was a "surprise" to you during your first mission?

________________________________________

________________________________________

2. Do you recall any specific instances where you felt less than fully confident about your performance:

__ No

__ Yes (describe) ______________________________

________________________________________

3. Did you notice any particular categories of tasks during which you felt less than fully confident about your performance:

__ No

__ Yes (describe) ______________________________

________________________________________

4. Please rate your evaluation of the effectiveness of your training program to prepare you for your first space mission in each of the following areas:

a) Training for special, mission-specific tasks:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Poor | | | | | | Excellent |

b) Training for general spaceflight tasks:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Poor | | | | | | Excellent |

c) Training for routine, everyday tasks:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Poor | | | | | | Excellent |

5. Do you have any suggestions about what could be done to improve crew performance?

______________________________________________________________________

______________________________________________________________________

6. Are there any changes in the training program that would enhance crew performance (e.g., reductions, additions, or elaborations)?

__ No

__ Yes (describe) ______________________________________________________

______________________________________________________________________

7. Do you think you would have benefitted from on-site (in-space) training, rehearsal, or opportunity to practice some tasks?

__ No

__ Yes (describe) ______________________________________________________

______________________________________________________________________

8. In the future, as the length of missions increases, do you think that the crews would benefit from on-site (in-space) training, rehearsal, or opportunities to practice some tasks?

__ No

__ Yes (describe) ______________________________________________________

______________________________________________________________________

9. Do you think that as the amount of time increases between task-training and task-performance during the mission that one's ability to perform the task significantly degrades to the point that NASA should be concerned:

for cognitive (thinking) tasks?

__ No __ Yes

for motor (doing) tasks?

__ No __ Yes

10. If you were provided an opportunity to refresh your training for a specific task during the mission, do you think that it would have a beneficial effect on your ability to successfully perform that task?

__ No __ Yes

11. There are several methods that could be used to provide refresher training during the mission. Rate the potential benefit of the following methods:

A. Watching a videotape of someone performing the task:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Significantly degrade performance | | | No effect on performance | | | Significantly improve performance |

B. Reviewing your own notes, sketches, etc. on how to perform the task:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Significantly degrade performance | | | No effect on performance | | | Significantly improve performance |

C. Practicing the task "hands-on":

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Significantly degrade performance | | | No effect on performance | | | Significantly improve performance |

D. Mentally practicing the task:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Significantly degrade performance | | | No effect on performance | | | Significantly improve performance |

E. Reviewing some computer-based training:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Significantly degrade performance | | | No effect on performance | | | Significantly improve performance |

F. Reviewing a training manual:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Significantly degrade performance | | | No effect on performance | | | Significantly improve performance |