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Psychophysiology in Microgravity and the Role of Exercise

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Introduction

The Space Transportation-Shuttle (STS) Program has greatly expanded our capabilities in space by allowing for missions to be flown more frequently, less expensively, and to encompass a greater range of goals than ever before. However, the scope of the United State's role and involvement in space is currently at the edge of a new and exciting era. The National Aeronautics and Space Administration (NASA) has plans for placing an orbiting space station (Space Station Freedom) into operation before the year 2000 [18]. Space Station Freedom promises to redefine the extent of our involvement in space even further than the STS program.

Space Station crewmembers will be expected to spend extended periods of time (~30 to 180 days) in space exposed to an extremely diverse and adverse environment (e.g., the major adversity being the chronic microgravity condition) [18]. Consequently, the detrimental effects of exposure to the microgravity environment is of primary importance to the biomedical community responsible for the health and well-being of the crewmembers.

Space flight and microgravity exposure presents a unique set of stressors for the crewmember; weightlessness, danger, isolation/confinement, irregular work-rest cycles, separation from family/friends, and mission/ground crew interrelationships [7]. A great deal is beginning to be known about the physiological changes associated with microgravity exposure, however, limited objective psychological findings exist. Examination of this latter area will become of critical concern as NASA prepares to place crewmembers on the longer space missions that will be required on Space Station Freedom [5]. Psychological factors, such as interpersonal relations will become increasingly important issues, especially as crews become more heterogeneous in the way of experience, professional background, and assigned duties.

In an attempt to minimize the detrimental physiological effects of prolonged space flight and microgravity exposure, the United States and Russian space agencies have taken steps to implement various countermeasure programs. One of the principle countermeasures used by both nations is exercise during space flight. The purpose of this paper is to present a brief overview of the major research findings examining the psychophysiological changes associated with microgravity exposure, and to address the potential role of exercise as a countermeasure in affecting these psychophysiological changes.

Psychophysiology is concerned with the mind/body interaction. It can be viewed as a general systems approach to human behavior that integrates findings from different disciplines [4, 9, 11, 18]. In discussing the psychophysiology of microgravity exposure, several important factors complicate and hinder attempts to address the nature and scope of this issue. These include:

- <u>Sample size</u>. To date only 250 astronauts/cosmonauts have flown in space.

- Extensive use of countermeasures. Prophylactic and therapeutic use of countermeasures has undoubtedly masked some of the direct effects attributable to microgravity.

- Limited research focus. Until recently, biomedical research has focused on physiological rather than psychology.

- Limited accessibility to data. Most of the space missions involving prolonged exposure to microgravity have been conducted by Russia. Therefore, findings have been available to United States scientists on a limited basis.

- Limited capabilities for scientific observation. Biomedical observations have been restricted by the operational constraints imposed on most space missions, and also by the time spent in space.

After reviewing the literature it becomes apparent that Russia is the leader in the area of psychological assessment and evaluation of crews during space flight. This is for two basic reasons: (l) it has been a major point of the Russian's to include a professional "Psychological Support Group" as an essential component of their mission control unit, and (2) the Russian's have allowed behavioral scientists to take an active, integrated role in the research focus of their missions [5, 20]. Furthermore, Russia has logged a much greater number of sustained man-hours in space than the United States (see Table 1). This has allowed Russia to study the psycho-physiological effects of prolonged exposure to microgravity and space flight extensively [16]. As noted however, access to this substantial data base that Russia has amassed on human function during prolonged manned space flight has been limited. Hopefully, with the changing political climate, more of the Russian information will become available and be incorporated into the United States scientific community.

Table 1. *U.S. and Russian Space Program Summary*

U.S. Program	Days in Space	Russian Program	Days in Space
Mercury	≤1	Vostok	≤2
Gemini	4-8	Voskhod	1-2
Apollo	6-13	Soyuz	1-185
Skylab	28-84	Salyut	16-237
Apollo-Soyuz	9		
STS	2-7		

Psychological Findings

There is little objective psychological data on the effects of prolonged microgravity exposure. However, the limited reports available suggest that the psychological consequences of exposure to space flight and the microgravity environment can be classified into affective, behavioral, and cognitive responses. Although presented separately, these responses are closely related and in most cases not independent of each other.

Affective

Anecdotal information from space missions of the United States and Russia indicates that the affective states of crewmembers become dramatically altered in space. Specifically, increased levels of anxiety, boredom, irritability, hostility, and anger have been reported in astronauts and cosmonauts [18]. These affective states seem to be linked to mission length, as their frequency and intensity increases during longer intervals in space [16, 20].

These affective changes can and have presented potential compromises to the successful outcome of missions. This is illustrated especially by the incidences of elevated levels of hostility and anger that have been frequently reported in prolonged space missions [1, 7, 20]. On several Russian missions, cosmonauts note in their diaries that interpersonal hostility begins to develop about 30 days into the mission and grows continually worse. This has lead to withdrawal from one another and a minimizing of interaction. The increasing hostility, however, has not been experienced amongst crewmembers alone. Hostility has also developed between space crews and ground-control crews. A frequently cited episode occurred on Skylab 4 where mission scientists and ground control disagreed on work schedules. This led to increased tensions between the groups which resulted in a work slow-down in space. Considerable measures were taken in order to bring about an agreeable adjustment in schedules so mission operations could continue (an open, frank "bull session" between the crew and ground control occurred) [2, 7]. Furthermore, on several of the extended Russian missions (>100 days), the cosmonauts have even reported feeling relieved when communications with ground control were interrupted and even desired at times to disrupt communications themselves [2, 7].

Behavioral

Many of the behavioral changes found coincide with the altered affective states noted above. Those commonly reported lethargy and fatigue, decreased motivation, and inappropriate psychosocial interaction [1, 2, 7, 14]. Additionally, psychosomatic symptoms and sleep disturbances have occurred in some crewmembers [18]. These last two changes are of particular interest.

There is the now famous psychosomatic incident involving Russian cosmonaut Valeri Ryumin during the 175-day Soyuz 32 mission. Ryumin was constantly afraid during the first half of the mission that he would get a toothache while in space. During the latter part of the mission, while asleep, he dreamed he had a toothache. When he awoke his tooth actually did hurt [1]. Similar complaints and incidents have been noted on other missions [1, 18, 20].

Historically, sleep disturbances have been a common complaint on most space missions [6, 16]. Throughout the Gemini, Apollo, Skylab, and STS programs, crewmembers have reported difficulty in establishing appropriate sleep/wake cycles. Some of this disruption may have been due to mission operations, comfort limitations, design problems, and physiological accommodations to microgravity. However, Russian reports would also suggest psychological factors play a role. The frequency of cosmonaut's reporting sleep problems is greatest during early and late phases of a mission, when crew anxiety levels are likely heightened due to the demanding events at hand [18, 20]. Currently, there is no evidence that these sleep changes significantly impair performance [18]. However, one-g based sleep deprivation studies have substantially shown reductions in psychological and physiological performance as chronic fatigue develops [3, 18].

Cognitive

Perception seems to be affected on a transient basis with microgravity exposure. Illusory sensations have been noted upon experiencing weightlessness, such as overturning or inversion of the body and movement of objects in the visual field [2]. The genesis of such sensations is not fully understood. Possible explanations for the origin of these phenomena lie in vestibular system dysfunctions, space sickness, or psychological manifestations. Whether it is any one of these possibilities or several acting in a synergistic fashion remains to be determined.

An interesting event occasionally reported by crewmembers has been labeled *time compression* [2, 18]. The phenomenon involves an altered sense of time and is manifested in a perceived slippage between performance and scheduled time-lines [2]. It probably evolves from excessive mental work-load, information overload, and cognitive processing involving inferences, judgment and decision-making [2, 13, 18].

These cognitive disruptions, while slight in nature, increase the mental effort demanded of an individual performing a task in space. The accumulative effect of this increased demand could have negative consequences during extended space flight.

Physiological Findings

There are numerous physiological changes associated with exposure to microgravity and space flight, which are summarized in Table 2 [21]. Many of these physiological changes warrant significant discussion; however, within the scope of the present paper only those changes of primary interest to psychophysiology will be addressed.

Table 2.

Facial puffiness	Vestibular difficulties
Altered posture	Decreased body mass
Decreased bone density	Decreased blood volume
Decreased red cell mass	Decreased plasma volume
Orthostatic intolerance	Cardiac deconditioning
Decreased leg volume	Variable reflex times
Decreased urinary ADH	Decreased plasma osmolarity
Increased angiotensin I	Increased cortisol
Increased urinary aldosterone	Increased growth hormone
Increased catecholamines	Increased serum enzymes
Decreased submaximal exercise capacity	
Decreased strength of different muscle groups	

Neuroendocrine - Metabolite

Throughout both the United States' and the Russian space programs, biochemical markers of stress have been assessed in crewmembers. Elevations in urinary catecholamines and cortisol as well as plasma ACTH, growth hormone, cortisol, catecholamines, and aldosterone have all been reported [8]. Additionally, elevations in select serum enzymes (creatine phosphokinase, lactic acid dehydrogenase, and gammaglutamyl transpeptidase), also indicative of stress responses, have occurred. The changes in these stress markers has been extremely variable and the data have been compromised by technical difficulties and/or mission constraints. Additionally, it is known that a general population exhibits a great deal of interindividual variation in the biochemical responses to stress and the astronauts-cosmonauts are no exceptions [18].

The most consistent and significant elevations in these neuroendocrine hormones and enzymes have typically occurred before and after flights while in-flight values have been relatively stable [8, 18]. The time course of the changes would seem to correspond to heightened levels of anxiety reported by crewmembers at these critical points in missions. These findings also suggests that some degree of stress accommodation may be occurring during the missions (i.e., in flight).

Cardiovascular

Typically, in one-g experimentation, the monitoring of cardiovascular vital signs provides useful information concerning the psychophysiological status of an individual [3]. It is questionable whether this may be the case in space as many factors induce cardiovascular changes which compromise the interpretation of the data (e.g., gravitational changes). Historically, there have been consistent findings of elevations in resting heart rates, and in some incidences blood pressure, observed before, during, and after missions [6, 15, 16]. Other than anticipatory rises pre- and postflight, however, these changes do not seem to be reflecting vigorous stress responses. Furthermore, in-flight changes, if any, are likely due to the cardiovascular adjustments accompanying exposure to the weightless environment (e.g., cephalic fluid shift) [15, 16].

Circadian Disruptions

The psychophysiological aspects of the circadian cycle are of particular importance to space flight. As noted earlier, sleep disturbances are frequently reported during space flight. This alteration of the sleep/wakefulness cycle can disrupt many physiological systems which are rhythmic in nature (e.g., endocrine) [13, 18]. Evidence indicates circadian disruptions can lead to a *desynchronization* of the body's biological clock and play a role in the development of some of the affective and behavioral problems discussed earlier (e.g., mood shifts, lethargy, or fatigue) [2, 13, 18]. Our understanding of the underlying mechanisms of circadian rhythms is still quite limited, but environmental cues seem to play an important role in the process. In space, environmental cues are extremely limited, therefore the level of desynchronization becomes exacerbated. Mission length may also play a factor in the extent of desynchronization. Several cosmonauts from the extended Soyuz missions (>175 days) report a greater number of sleep disruptions during the latter half of their extended missions [20].

The Role of Exercise

Traditionally, the role of exercise as a countermeasure in space has been entirely physiological in nature, however, an alternative role may exist. That is, the use of exercise as a psychological countermeasure to challenge the negative psychophysiological changes associated with space flight and microgravity exposure.

Physiological Countermeasure

It is well established that during prolonged space flight, significant detrimental changes in certain physiological functions of the human body take place [16, 21]. In particular, biomedical research indicates that muscle atrophy, cardiovascular deconditioning, and bone demineralization have occurred in Russian and American crewmembers [15, 16, 21]. These changes appear to be the physiological consequences of exposing the body to microgravity and a reduction in the typical level of Earth-bound activity. The extent of these detrimental adaptations seems to be a function of space-flight duration.

Both the United States and Russia, in an attempt to minimize these detrimental adaptations to space, have implemented in-flight exercise programs. The extent and nature of the exercise programs have varied tremendously from nation to nation as well as within space programs. To date, the work by biomedical scientists suggests that the use of exercise as a physiological countermeasure seems most promising [16]. However, this research is still in its infancy and many questions remain unresolved. To address this issue, NASA has established the Exercise Countermeasures Project (ECP) working group. The ECP has been given the following charge: ...implementing a preventive health care program for flight crews that will: (1) offset the physiological and operational effects of adaptation to microgravity; (2) ensure effective functional return to Earth; and (3) increase the rate of postflight readaptation.

Over the next few years the ECP working group will attempt to fulfill these objectives, and should therefore provide valuable information to the scientific community as to the effectiveness of exercise as a physiological countermeasure.

Psychological Countermeasure

The use of exercise as a psychological countermeasure has been examined in several one-g studies, but apparently not so in space. The Earth-bound studies suggest that vigorous exercise is associated with positive, beneficial psychological changes to participants. Both affective and behavioral changes have been reported [4, 10, 11, 12, 17].

Specifically, an increased sensation of well-being and positive mood shift occurs after acute bouts of exercise and the effects seem to persist for 2 to 5 hours (10). These subjective states have been objectively quantified with psychophysiological data. For example, Profile of Mood States (POMS) scores show reduced levels of state anxiety and depression following exercise. Concomitantly, lowered heart rates, blood pressure, and catecholamines have been observed [10, 11, 17]. Exposure to chronic exercise (i.e., training programs) has produced similar effects. Participants in such training programs have persistent reductions in state anxiety and depression, as well as increases in self-esteem [10]. Also, it is well established that exercise training produces accommodations in the neuroendocrine system result in reduced physiological *stress responses* (e.g., catecholamine, heart rate, blood pressure responses) to external challenges [4, 17].

Potentially, these positive psychological effects of exercise have important implications for space flight. Exercise could become an additional *tool* for the behavioral scientist to use in working with crewmembers. Specifically, exercise could be used as one mechanism for inducing positive affective states in crewmembers, and/or play a role in behavioral coping strategies during the prolonged space missions [19]. This potential is based upon the assumption that the positive psychological effects of exercise found in a one-g environment are applicable to microgravity, since no space based research exist. The validity of such an assumption is uncertain, but warrants the attention of the scientific community and presents a unique opportunity for future research.

Recommendations, Future Concerns, and Conclusions

As NASA enters this new and exciting era of space exploration, it is vital that a firm commitment to continued physiological research exist. However, it is equally important that an expanded role be given to the psychological research community. The United States has lagged far behind Russia in this area. The first steps in this direction seem to have been taken with the establishment of the Biobehavioral Research Group at the NASA Johnson Space Center. In light of the information that is becoming available, it seems only logical that NASA's future studies examining man's capacity and ability in space, should be of a more integrated nature and take on a psychophysiological approach.

In the focus of exercise as a countermeasure to microgravity exposure, some key issues that need to be addressed in the future are: (1) does exercise in space induce the same positive psychological changes as found in one-g studies; (2) what type or mode of exercise will be the most effective in producing positive psychophysiological responses in space; and (3) what is the optimal exercise prescription in space? This last issue is especially important as an inappropriate exercise prescription can lead to an undertrained or overtrained states in the crewmember. Undertraining is associated with physical deconditioning (e.g., decreased cardiovascular and muscular function) which could led to an augmentation of the detrimental physiological effects of microgravity exposure. Conversely, overtraining induces some severe psychological and physiological changes (see Table 3) which could tremendously exacerbate the psychophysiological perturbations of microgravity exposure [4].

Table 3. *Psychophysiological Changes Found in Overtrained Individuals*

Apathy	Muscle soreness
Lethargy	Sleep loss
Appetite loss	Mood changes
Weight loss	Increased depressing
Lymphadenopathy	Increased anxiety
Gastrointestinal disturbances	Increased fatigue

Regardless, both conditions (under and overtraining) are inappropriate training stimulus and are representative of extremes which should be avoided.

In conclusion, some of the existing research suggests exercise may be an effective countermeasure for dealing with some of the psychophysiological responses to space flight and microgravity exposure. Many questions, however, remain to be answered, as well as identified, which presents exciting new avenues of research for biomedical scientists to pursue in the future.

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Footnote

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