Behavioral Health: The Propaedeutic Requirement

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Concern about the behavioral effects of spaceflight can be traced back a half century to the earliest preparatory bioastronautics experiments in the mid-1950s. A central focus of the first primate suborbital flights, as well as the orbital chimpanzee pretest flights of Project Mercury, was the effects of such stressful ventures on the learned performances of these space behavioral health pioneers. The hiatus in spaceflight behavioral health experimental investments that followed these early initiatives began with the advent of the 'human astronaut' era of the mid-1960s, and has dominated the last several decades. Contemporary concerns in this regard have most recently been articulated by a turn-of-the-century Committee of the Institute of Medicine, National Academy of Sciences, providing a visionary view of space medicine during travel beyond Earth orbit. This 2-yr study focused on those most complex behavioral health interactions involving humans in extreme, isolated, and confined microsocieties—areas that have not received the necessary level of attention. The evident behavioral health issues raised by the prospect of long-duration exploratory missions beyond Earth orbit, including performance and general living conditions, recovery and support systems, and the screening, selection, and training of candidate participants are reviewed and discussed.

Keywords: behavioral health, long-duration spaceflight missions, confined microsocieties, beyond Earth orbit, extreme isolated environments, learned performance.

THE BEHAVIORAL effects of space travel were among the primary concerns of the earliest preparatory bioastronautics spaceflight experiments during the late 1950s and early 1960s. The Russian Sputnik II experiment with the dog Laika in November 1957, for example, provided the first telemetered activity data on a living organism in the space environment, though failure of the life support system made it impossible for the animal to survive more than the first few days of the extended 5-mo orbital expedition (19). In the following year (1958), however, the first two behaviorally trained primates, Able and Baker, were launched in the nose cone of a rocket (**Fig. 1**) on an American bioastronautics spaceflight experiment. This suborbital flight was undertaken on the initiative of Dr. Wernher von Braun, Director of the Army Ballistic Missile Agency in Huntsville, AL, in collaboration with behavioral scientists at the Neuropsychiatry Laboratories of the Walter Reed Army Institute of Research in Washington, DC (11). Not only did the two rhesus monkeys endure launch in their insulated restraining couches (**Fig. 2**) and meet the pretraining performance requirements established before experiencing the 300+ mile trajectory at speeds in excess of several thousand mph, but they survived reentry as well with minimal compromise of either their behavioral or physiological integrity (**Fig. 3**).

This early focus on the behavioral effects of spaceflight was perhaps most evident in the 1961 animal pretest flights for Project Mercury with the chimpanzees Ham and Enoch*. The planning for these flights coincided with the establishment of the National Aeronautics and Space Administration (NASA) in the late 1950s and was initiated in the course of meetings with Department of Defense representatives at Langley Field, VA. Operational responsibility for these animal pretest flights was assigned to the military services since NASA had few resources available for such an undertaking at this early stage of its existence. At these early planning meetings, both the Air Force, represented by General Donald Flickenger, and the Navy, represented by Captain Ashton Graybiel, were quite receptive to participating in this obviously futuristic initiative. Their enthusiasm more than compensated for the Army's somewhat reluctant assignment of a military behavioral biologist from the Walter Reed Medical Center to attend the Langley Field gathering. It was, however, agreed that performance measurements would be an essential part of these test flights since there was then—and still is—no better indicator of an organism's physiological integrity and behavioral capabilities. With strong input from the White House, it was decided that the experimental animal of choice would be the chimpanzee (**Fig. 4**) because of its close phylogenetic relationship—not to mention its physical resemblance—to the human successors waiting to take over. Since neither the Air Force general nor the Navy captain knew much about the behavioral training and management of such experimental animals, the task of preparing the chimpanzees for the planned flights fell to the Army, though the Air Force agreed to provide the specialized chimp training facility at Holloman Air Force Base in New Mexico. The soon-to-be-famous 'space chimps,' Ham and Enoch, spent the better part of a year with scientists from the Walter Reed Army Institute of Research along with behavioral science professionals from the Air Force, learning a lever manipulation performance required to match a range of geometric symbols to sample presentations in order to obtain highly valued banana chip rewards. The animals were trained to perform this task on a work panel

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* (cf., Life Magazine, February 10, 1961.)

Fig. 1. Rocket nose cone used for Abel and Baker flights. Personal collection of the author.

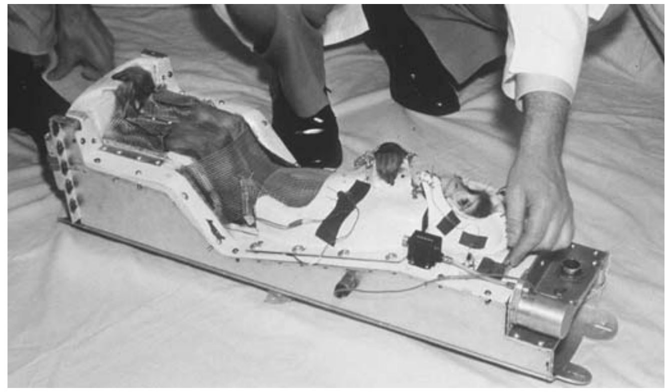

Fig. 2. Insulated restraining couch used in Abel and Baker flights. Personal collection of the author.

mounted within an insulated couch (**Fig. 5**) secured for flight inside a Mercury space capsule on a Saturn launch vehicle. These two chimpanzees returned safely to the deck of a recovery ship (after their ocean 'splash-down') and were to make history by being the first American primates to provide the required experimental pretests for Project Mercury. It was from the subsequent pioneering human suborbital and Earth-orbiting spaceflights however, that Alan Shepard and John Glenn returned as heroes to 'ticker-tape parade' welcomes. And when the 'First Space Chimp' Ham died in the 1980s after surviving for two decades following what was at the time considered a dangerous and potentially lethal mission, his obituary in the New York Times provided ample testimony to the long and productive retirement he had enjoyed after his perilous 1961 adventure!

Over the several decades following John Glenn's historic Earth orbiting flight in the early 1960s, there was a dearth of in-flight experiments on the behavioral effects of space environments. It is perhaps not surprising that there was little enthusiasm on the part of the early astronauts selected predominantly from a military test pilot population to expose themselves to anything that appeared even remotely like further testing of performances for which they felt they had long since proven qualified and for which special incentives had been provided. In all fairness however, it must be recognized that the range of biomedical and behavioral challenges that accompanied the increasing frequency and duration of space missions and human habitation in the space environment over this period were met with remarkable success, often under adverse circumstances. There were no documented behavioral health problems sufficient in magnitude to compromise mission objectives involving the 1969 Apollo Moon landings, the 1973 launch of the Skylab orbiting laboratory, the 1981 Shuttle Earth/orbit/Earth round trip, the 1984 untethered spacewalk, and the recurrent Shuttle/Space Station docking exchanges throughout the 1990s. Indeed, there was apparently little or no urgency in the need to address the host of in-flight behavioral research questions that would remain unanswered during this busy and demonstrably successful spaceflight era.

Behavioral Health in Space Environments

The so-called 'human behavior element' however, continues to be the most complex component of the plans and designs for more extended long-duration space exploration missions beyond Earth orbit. And though the opportunities for in-flight behavioral experiments were limited or virtually nonexistent from the 1970s through the 1990s, ground-based studies in basic laboratory, simulation, and analogue settings continued to provide a focus for at least some pertinent group interaction investigations. An extensive literature on the functioning of small groups, for example, has been generated over the past several decades in both experimental laboratory settings (9,10,23,27,55,56) and analogue environments (28,31,33,69,72,89–91,94). In addition, there have been at least a few publications in the 1990s addressing some of the behavioral health issues that will doubtless require more focused experimental attention in the forthcoming era of spaceflights beyond Earth orbit. Psychological support issues were addressed by Kanas (37) and spaceflight performance studies were reviewed by Manzey and Lorenz (51). In addition, Brady, Kelly, and Hienz (13) have reported on the stability and precision of performance during spaceflight.

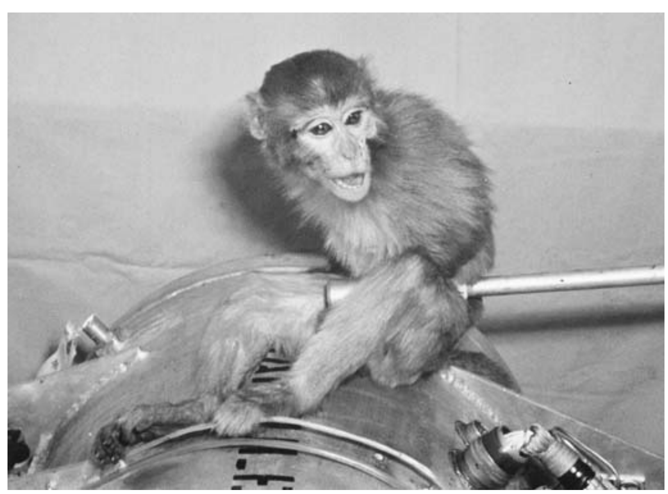

Fig. 3. Postflight photograph of Abel. Personal collection of the author.

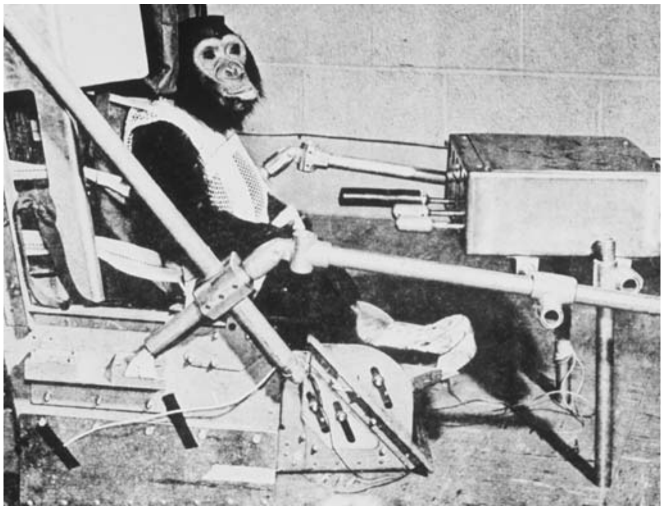

Fig. 4. Chimpanzee training device for animal pretest flights of Project Mercury. Personal collection of the author.

Clearly, the imperatives of behavioral health and performance effectiveness will require a quantum increase in research and development attention if we are to meet the major challenges presented by planned missions beyond Earth orbit that will necessarily require significant increases in the distance traveled and the time spent in space environments (4). Of primary concern, for example, must be the organization of work and living conditions in considering the essential operational requirements for such bold endeavors. Critical features of these planning arrangements must also focus on the Earth-bound support and recovery systems involved and the important role of screening, selection, and training of the candidate participants. The initial organization of such expeditionary ventures will doubtless be characteristically authoritarian because of the limits on provisioning as well as the uncertainties and hazards involved. The original "senders" of the expedition will program the activity, pay explicit fees, and demand absolute control. As the distance traveled and the time spent in space habitats increases however, the needs and aspirations of those "sent" will become progressively more influential than those of the "senders."

It is this change in the dynamic relationship between the "senders" and the "sent," known to develop even in the course of limited duration missions, that creates the recognized tension between Earth-bound control and spaceflight operators. Under such conditions, the sequelae of long-duration expeditionary missions can be expected to involve emergent autonomous changes that are the fountainhead for the evolution of social structure and governmental policy manifest in empire, colony, and sovereign states. This process has filled history books with a major portion of human activity, suffering, and bloodshed throughout time. Understanding the factors that influence and control the dynamics of social organization and the processes involved must provide a major focus for space-related behavioral health research and development.

Long-Duration Expeditionary Missions Beyond Earth Orbit

General Living Conditions

Hundreds of humans have now participated in missions that required the occupancy of spaceflight vehicles or orbiting space stations for periods of several months up to a year or more under generally adverse environmental and behavioral health conditions (4). Living space is confined, food is restricted in quality and diversity, there is a lack of privacy, and facilities for personal hygiene are limited. The quality of the environment provided by artificial life-support systems, compounded by high noise levels and unpleasant odors, is hardly comparable to that on Earth. Weightlessness requires motor and perceptual readjustments under conditions in which disorientation and motion sickness are common, at least during the initial exposure to the space environment (61). Social interactions are limited and sexual activity is constrained. Only distant and remote communication with family and friends is possible. Workloads can be demanding and stressful, with the ever-present danger of a major life-threatening system failure. And all of these constraints and restrictions occur under conditions that make no provision for escape during exploratory expeditions beyond Earth orbit (4).

These conditions create an overarching need for en-

Fig. 5. Insulated flight couch and work panel for animal pretest flights of Project Mercury. Personal collection of the author.

hancement of the evidence base on the organization of general living conditions and the performance requirements for small groups of humans in isolated and confined microsocieties over extended time intervals in space environments (9,11). The objectives of this knowledge-seeking endeavor would be specification of the conditions under which effective individual and group work performances can be generated and maintained within the context of productive and harmonious living arrangements that satisfy human needs: clean air and water; adequate food supply; waste management and recycling; adequate lighting; clean clothing; repair-shop facilities and communication capabilities; medical care; sleep/rest; privacy; exercise; social/sexual interactions; leisure/recreation; housekeeping/maintenance; education/training; remote contact; and useful work. Extensive ground-based and spaceflight mission research will be required to generate the knowledge base essential to adequately provide for these necessary but far from sufficient life support and general living conditions (4).

Engineering and technological interactions: These interactions will of necessity be required to support systematic studies involving specific subsets of these essential elements, particularly those for life support. Over the past decade for example, study groups have been determining "space maximum allowable concentrations" of potentially toxic chemicals in the air and water supply of spaceflight vehicles and habitats (59,60). The interdependent nutritional (e.g., 45,87) and food supply system (e.g., 35) challenges of long-duration space missions have also received research and development attention. Clearly, food is not only a key habitability issue but also a biomedical concern and a critical feature of engineering and systems design. Considering the duration of missions beyond Earth orbit, a bioregenerative life-support system (e.g., crop growth) would be more cost-effective than the physical-chemical regenerative systems (e.g., freeze-dried storage) now in use. But bioregenerative systems require growing and processing in situ crops, treatment of food wastes, and preparation of daily meals, all within severe constraints for which space-compatible technologies have yet to be developed. Under the circumstances, the evident behavioral health and habitability challenge is the development of a bioregenerative cuisine of nutritious and appealing meals that make up a predominantly plant-based diet with a range of choices acceptable to a historically omnivorous population (4).

Biomedical and behavioral interactions: These interactions will be unavoidably involved in the essential requirements for general living conditions as they impact human performance effectiveness in the technologically rich spaceflight environment (4). The effects of changes in circadian rhythms and sleep patterns on behavioral health and performance, for example, continue to receive attention in both ground-based simulation studies (e.g., 20,42,79,95) and experiments in the course of actual space missions (17,57). A strictly scheduled wake-sleep cycle, with dim light levels comparable to those currently provided on space shuttle missions, is sufficient to maintain entrainment of the human circadian pacemaker to the 24-h day for most, but not all, study participants. Circadian misalignment results in disturbed sleep, impaired performance alertness, waking-day melatonin secretion, and reduced nocturnal growth hormone secretion. The results of these studies suggest that during long-term missions beyond Earth orbit, stronger synchronizers such as brighter or appropriately colored lights will be necessary to entrain the longer-than-24-h intrinsic circadian period of all humans to the 24-h day, and to other day lengths such as the 24.65-h solar day of Mars. Even with appropriate circadian alignment however, spaceflight experience suggests the more likely emergence of restricted sleep patterns in the 4 to 6 $h \cdot d^{-1}$ average range, and with that, the risk of developing cumulative homeostatic pressure across consecutive days of inadequate sleep during long-term missions beyond Earth orbit. Thus, one objective of ongoing simulation studies is to determine the extent to which the duration of sleep per 24 h and the use of combined 'anchor' plus 'nap' sleep opportunities each day can prevent or attenuate the development of cumulative fatigue and performance deficits related to sleep deprivation (4).

Living environment interactions: These interactions have long provided a focus for behavioral health concerns related to privacy, leisure, and recreational activities under spaceflight conditions involving multi-person crews in orbital flights of more than a few days duration (24,36,40). The interaction between the structural/physical design and the personal/social organization of space environments is likely to be most critical in leisure and recreational pursuits as well as those activities related to personal hygiene, exercise, housekeeping, and maintenance. Historically, human spaceflight experiences reflect a predominantly empirical, and generally successful, approach to these matters. The research and development requirement however, for evidence-based coordination between design engineering, habitability considerations, and behavioral health imperatives assumes ever-increasing importance with extended mission durations. Under such 'closed-loop' conditions for example, all waste products (including human excretions, expired gases, fluids, etc.) must be repeatedly recycled. The unique behavioral health factors involved in the toleration and acceptance of such environmental constraints must be investigated and determined. The extent to which behavioral self-management techniques (5,7,16) can be expected to provide effective coping procedures for a range of such intrapersonal challenges will depend on the development and testing of individualized self-monitoring and assessment methodologies of demonstrated validity and reliability (4).

Group interactions: These represent core issues of the highest priority in the spaceflight performance and general living conditions domain. The obvious challenge is the development of an evidence-based approach to the management of harmonious and productive small multinational groups living and working together in isolated, confined, and hazardous space habitat environments (4). Despite an extensive literature in the area, the available knowledge base continues to be deficient in several respects as it pertains to long-duration missions beyond Earth orbit. Findings from group studies conducted in one setting are often not applicable to groups functioning under other environmental conditions, and empirical results are of such limited scope that they lack generalizability and practical use.

Viewed from the perspective of groups as small social systems operating in multifactor 'behavior settings' comprised of specific physical situations involving people, the spaceflight experiences over the past five decades have been demonstrably successful (4). Mission objectives have been completed at a quality level and the behavioral interactions among individual flight crewmembers have enhanced (or at least, have not compromised) the viability of the group as a performing unit. Importantly, spaceflight crewmembers have accomplished mission objectives without seriously compromising their own individual behavioral or biomedical well-being. Against this background of generally effective group performance in the course of missions of up to a year or more in duration, major challenges remain with regard to the promotion of performance effectiveness, group solidarity, and personal well-being in the course of long-duration spaceflight missions beyond Earth orbit. The enhancement of this essential knowledge base must begin by identifying those features of small social systems that foster the effectiveness of groups functioning semi-autonomously over extended periods of time (29,30).

In the first instance, there is need for evidence-based information on the appropriate partitioning of authority between ground-based mission managers and flight crew in accomplishing clear, unambiguous, and engaging objectives that orient and motivate group members toward overall organizational goals (77,82). The key question to be answered is how legitimate authority can be constructive and empowering while insistently setting directions without dictating procedural details (4). How can the needs of the space travelers for substantial latitude in developing, executing, monitoring, and managing their own performance strategies be best accommodated within the overall direction required? How can relations within the space traveling group as well as between the space travelers and the ground-based authorities regarding inevitable disputes be managed in real time?

The second critical challenge in fostering performance effectiveness is to create a well-composed group engaged in well-structured tasks (21,28,62). Collective work productivity, in the context of harmonious living conditions, requires the right people, correctly configured (i.e., personal and skill characteristics that 'fit' the task and the setting) and properly trained. Despite extensive experience related to personnel screening, selection, placement, and training, there is a serious lack of knowledge regarding group composition and preparation relevant to the requirements of long-duration space missions beyond Earth orbit. There is also a need for research on the development, over time, of semi-autonomous task-oriented groups. And to complement the available data on relevant individual tasks, enhancement of the knowledge base on how to structure group tasks that promote motivated and effective performances is also essential (4).

A third requirement for effective group functioning is a supportive physical and organizational context (66,89). The first order of business here is the architectural and human factors considerations that determine the extent to which individuals and groups can live and work together comfortably and productively. The essential organizational factors to be considered must include the performance consequences (i.e., reward system) for the group, the communication/information system (i.e., data access and technical assistance for on-line decisions), and material resources (i.e., for task execution). The evidence regarding the potency and essential nature of these factors is clear and compelling, but the existing knowledge base on the most effective delivery system for ensuring their availability to semi-autonomous remotely located groups is in need of considerable enhancement. Seemingly mundane contextual factors represent powerful determinants of group performance effectiveness and individual behavioral integrity. There is, however, little or no evidence-based information on how their operational delivery and organizational configuration can provide optimal group support (4).

A fourth important factor in understanding and managing the performance effectiveness of small operational social systems is the requirement for competent leadership (4). The history of leadership research indicates clearly that an investigative initiative must be structured to generate information that is more evidence-based, trustworthy, and usable than that presently available (54,55). What is required is an approach that identifies the leadership functions essential to insure group performance effectiveness and then examines how and by whom these functions are best carried out. There is an evident need for research on how various leadership functions and responsibilities should be partitioned among group and individual participants on long-duration space missions beyond Earth orbit since such ambitious and hazardous undertakings will doubtless involve many different leadership roles (65).

Considerations for Paired Transport Vehicles Beyond Earth Orbit

Virtually all aspects of onboard behavioral health and group performance effectiveness are most likely to be enhanced by designs that use pairs of transport vehicles for long-range space missions beyond Earth orbit. In addition to the motivational effects of the friendly competition generated under such conditions, the reassuring presence of an accompanying mission support group would confirm the availability of an augmented resource base. To the extent that interactions between flight groups could be established and maintained—including intermittent rendezvous during the extended outbound voyage—general living conditions would be clearly enriched, and potentially disruptive within-group issues attenuated. Cost/benefit analyses would take into consideration the modest incremental engineering and human systems requirements—support, training, and recovery—of an undertaking that represents a major funding investment for the dispatch of even a single manned space transport vehicle beyond Earth orbit (4).

Such a paired transport vehicle approach also acknowledges the difficulties associated with predicting the performance of necessarily complex adaptive systems involving spacecraft, space travel groups, and Earth-based support components over intervals as long as several years. Under such conditions, optimizing the likelihood of mission success has been considered to require an operational focus on the establishment of a few simple behavioral rules with the voyagers and their leaders learning their way through the problems encountered during the journey on the basis of common objectives (safe, successful missions) and powerful motivational (survival) resources (48,97). It is nonetheless clear that the promotion of performance effectiveness as well as social and ecological stability for small groups involved in long-duration space missions beyond Earth orbit will require evidenced-based technological developments grounded at the most fundamental scientific level. Within the context of such an enhanced database, an investigative focus will be required on potentially disruptive group influences that adversely affect harmonious and productive performance interactions. Among the more obvious candidates are cultural differences characterizing multinational groups, professional/technical disciplinary differences, distribution of authority issues, and gender-based sexual interactions. In the latter case, careful consideration must be given to living arrangements accommodating this particularly complex challenge to group cohesiveness (4). Few human element issues require as important a behavioral health vision as that confronting the design of multiyear missions beyond Earth orbit for healthy individuals in the prime of sexually active lives.

Support and Recovery Systems

Experiences over the past several decades in spaceflight and analogue settings indicate clearly the importance of a behavioral health role in supporting both participants and ground control personnel during and on return from extended space missions. Monitoring both individual and group interactions has long been recognized as a potentially informative component of such exploratory and/or expeditionary endeavors, but the methods and procedures for such oversight have seldom been adequate to the task. Certainly, the behavioral health contribution to the planning and implementation of such support and intervention systems will need to be increased. As the time/distance dimension separating space travelers from their ground base increases, enhancement of behavioral health support systems becomes an increasingly important requirement. Under such conditions, there is obvious need for the development and refinement not only of individual and group performance monitoring and assessment technologies, but also of evidence-based behavioral interventions and effective countermeasures. Of at least equal importance is the role of behavioral health professionals in planning and implementing the reentry, recovery, and follow-up evaluation of travelers returning from long-duration spaceflight missions (4).

The key element in spaceflight support systems is mission control. There is probably no other area of space operations that has served as well, and as long, as the essential institutional memory of such bold ventures. Over the past five decades, mission control functions, prominently concerned with the monitoring of every aspect of every mission from the ballistic flights of monkeys Able and Baker to the current International Space Station (ISS) endeavor, have dominated virtually all spaceflight activities. It must be recognized that the remarkable record of safety and success that has characterized spaceflight is due in large part to this dominant mission control influence. The magnitude of this investment in support functions can be gauged by even casual observation of the number of dedicated individuals at computer stations during the continuous monitoring of every spaceflight mission. Perhaps the most striking contrasts are those which characterize the so-called manned missions where Earth-based mission control on-duty personnel can outnumber the in-flight crew and passengers by more than 100 to 1 (4).

From a behavioral health perspective, the communication functions of the in-flight support systems are of the utmost importance. Aside from routine operational interactions, frequent communications with medical support personnel are available, along with less frequent opportunities for interacting with sources of emotional support (e.g., family, behavioral health personnel, flight surgeons, others). There are indications that ongoing monitoring of at least the voice communications may have some operational value for assessing the behavioral status of in-flight crewmembers (37). A Crew Status and Support Tracker (CSST) questionnaire, completed in flight on a weekly basis by U.S. astronauts on the Russian Mir space station, has also been used for individual assessment (e.g., mood, morale, privacy, physical status, social interactions, and other behavioral indicators). The validity and reliability of this assessment procedure, however, is yet to be determined (4).

Other features of the current support system appear to focus on behavioral health. For example, favorite foods and surprise presents are dispatched with periodic supply vehicle flights. Two-way communications with Earth-based family and friends are intermittently enhanced via combined audio/video. Computer-based family picture albums of spouses, children, friends, and co-workers are enthusiastically endorsed by spaceflight participants. E-mail and ham radio capabilities are also available, along with private conferences with the behavioral health and performance staff. Recreational software, audiotapes, and videocassettes are provided for leisure (4).

Over the past decade, debriefing protocols have been developed focusing on the well being of the individual and on her/his reintegration with family and friends. Debriefing also identifies and helps to address any residual difficulties that may have developed within and between crewmembers, mission control, and/or family, friends, and co-workers (34). Currently, however, constrained access to debriefing data limits the extent to which these procedures can be adequately evaluated (4).

Earth-based and space mission interactions: These interactions clearly provide the foundation for the most important support system exchange between ground mission control and spaceflight operations. Despite, or perhaps even because of the critical role played by this interface, disagreements between the senders and those sent have a long history under a wide variety of circumstances (67). Although anecdotal reports of such disagreeable exchanges between ground and flight crews have been most likely during relatively long-duration missions, the impact of such friction between the senders and those sent in both space and analogue environments has been described in a publication by Nicholas (64).

Among the most important core functions of the ground-based support delivery system is the maintenance of communication exchange capabilities between the space travelers and Earthbound family, friends, and co-workers. While these clearly supportive interactions are both essential and heartily endorsed by all concerned, there remain a host of unanswered questions regarding the nature of such exchanges (37,68). The extent to which such activities must be enhanced and/or modified to provide essential behavioral health support for long-duration spaceflight missions remains to be determined as part of an essential behavioral research agenda in both analogue and space environments. An evidence-based approach to the design of an effective behavioral health support delivery system for long-duration spaceflight missions beyond Earth orbit is clearly needed (4).

Monitoring behavioral health and performance: This type of monitoring has continued to provide an important focus for the development and testing of environmental and biomedical technologies for spaceflight support system applications (58,74,84,96). The validity and reliability of such monitoring techniques however, has continued to present special problems that are not easily managed even in face-to-face settings, much less at the distances that separate Earth-bound support systems from space travelers on a mission. A range of in-flight performance evaluation issues remain to be addressed if adequate assessments of long-term spaceflight effects on behavioral health and human performance are to be provided. In bridging this gap, early developments in the analysis of verbal interactions, both vocal and nonvocal, have shown promise of providing effective approaches (4).

Over the past several decades, computerized methods for evaluating verbal communications have been refined as potential early warning indicators of more general performance changes. One diagnostic technique (26) has been refined to reflect affective changes on a series of rating scales (e.g., anxiety, hostility, depression). The method employs computerized scoring of speech transcriptions, and is currently under evaluation for validity and reliability. In addition, direct voice analysis methods have already been used in spaceflight applications (37). Continued refinements in computer technology will doubtless enhance voice change discriminations that are indicative of disruptive interactions that may have potentially adverse effects on performance (49,73,92).

The feasibility of assessing the stability and precision of individual crewmember performance with computerized test batteries has now been demonstrated in the course of several Space Shuttle missions (13,57). For example, self-report rating scales, timing, learning, memory, and psychomotor components have been included in brief performance batteries scheduled recurrently during spaceflight missions. The demonstrated stability and maintained sensitivity of the indicated measures over extended time intervals confirmed their effectiveness in detecting even small magnitude behavioral changes—changes that occurred below the threshold of spaceflight duty performance decrements that would require countermeasure intervention. The continued development of such technological approaches to the assessment of behavioral integrity and countermeasure efficacy evaluation is essential not only to ensure the success of extended spaceflight missions, but to enhance safety and the quality of life in many applied settings (41). The outcome measures for these spaceflight studies were stored in the on-board computers for postflight analysis. Further real-time evaluations will require on-line down-link capabilities in studies conducted during longer-duration spaceflight missions (4).

Psychophysiological monitoring adds a potentially important dimension to the evaluation of behavioral status in space travelers. Bioengineering initiatives will be required to develop more portable, noninvasive, and natural on-body instrumentation (e.g., nanotechnology) to record and down-link psychophysiological measures for the assessment of affective changes and cognitive dysfunction of relevance to performance integrity (14). Among the more obvious candidates for such psychophysiological monitoring would be heart rate variability, EKG waveform, pulse volume, facial muscle action, blink rate and magnitude, ear canal and skin surface temperatures, as well as multiple electrode EEG measures (4).

While monitoring technologies have focused on individual performance and behavioral health, there is also a need for methods and procedures to evaluate group interaction patterns under spaceflight conditions. Standardized systems for monitoring and evaluating the interactions between the members of small groups using audio/video down-link capabilities that are adaptable for space-dwelling groups are available. One such psychometrically robust instrument, "Systematic Multiple Level Observation of Groups" (SYMLOG), adapts easily to gender and culture and has demonstrated validity and reliability in both military and expeditionary operations (2,3).

The interactive monitoring of long-duration spaceflight missions will depend critically on communication modalities and verbal interaction. The availability of automated interactive simulation technologies makes possible an experimental approach to determining the most effective mix of communication modalities (12). Technological research is also needed to address constraints likely to be associated with the expected transmission time delays in the course of long-duration expeditionary missions beyond Earth orbit (estimated to be in the range of 40–50 min).

Countermeasure development and implementation: The development and implementation of countermeasures have long provided a focus for applied life sciences research activities in support of human spaceflight initiatives. Until recently however, investigative attention has been devoted mainly to protecting against and/or counteracting the effects of weightlessness and radiation on core biomedical systems and functions—cardiovascular, neurovestibular, immunological, bone, and muscle, as well as sleep and physiological well-being. With the establishment of the National Space Biomedical Research Institute (NSBRI) in the late 1990s however, the countermeasure development and implementation agenda has undergone substantial expansion and formalization to now include a range of innovative, investigative behavioral health activities focused on neurobehavioral and psychosocial issues and concerns. Of primary interest is the need to address the risks of human performance failure due to neurobehavioral dysfunction and/or poor psychosocial adaptation during long-duration spaceflight missions beyond Earth orbit. The objective of the research investments in these critical areas is to provide preventive and operational countermeasures to insure the maintenance of behavioral health and the facilitation of optimal individual and group performance during prolonged space travel and extended occupancy of space habitats (4).

In addition to the long-standing dependence on personnel screening, selection, and training approaches as countermeasure development and implementation at the most fundamental level, a range of documented as well as potential 'on-mission' problem areas remain to be addressed. Interventions which function to optimize communications within space dwelling groups and between such groups and Earth-based support units (including systems management, technical/personal advisers, family, and friends) under unforeseen conditions that involve decision making and problem solving provide an important focus for enhanced research attention. Behavioral treatment technologies are also being addressed to provide neurobehavioral and psychosocial support when stressful environmental circumstances and group conflict situations create the inevitable need for therapeutic countermeasures. Intervention strategies for enhancing environmental habitability involving relaxation, privacy, and leisure activity as well as motivational conditions affecting work performances are also in need of research, development, and implementation. And in those hopefully rare instances that involve severe affective reactions and/or serious psychiatric disorders, extensive investigation and skillful professional implementation of neuropsychopharmacological interventions are needed (4).

Perhaps the most imposing investigative aspect of countermeasure research and development is the continuing need not only for an evaluation of the effectiveness of such critical interventions in attenuating the specific problem areas addressed but also for an assessment of the generalized, non-specific effects on other aspects of the behavioral health environment, both Earth-based and in space.

Recovery and debriefing: Debriefing of returning space travelers has focused principally on a biomedical follow-up that continues as long as contact can be maintained with the individuals involved. Enhancement and formalization of the procedures involved are necessary in order to develop a more comprehensive data collection and management system. It is essential that these initiatives incorporate a range of behavioral factors to insure the availability of a rich source of space habitability debriefing data as well as post-mission recovery experiences for research analysis. Systematic evaluation of the validity, reliability, and effectiveness of such debriefing and follow-up procedures will facilitate the development and implementation of interventions that support required readjustments for returning space travelers as well as reintegration with family, friends, and Earth-bound living conditions. The availability of such a valid and reliable longitudinal database will doubtless prove an invaluable asset in the essential research and development required to improve intra- and interpersonal support and countermeasure interventions in the course of ongoing spaceflight missions (4).

Postflight debriefings and longitudinal behavioral health monitoring also provide the opportunity to evaluate the long-term effectiveness of preflight training and in-flight behavioral interventions. Additionally, they allow the collection of data on behavioral, social, and cultural issues that may not have been obvious during the pre- and in-flight phases of the expedition. The relative importance and long-term impact of individual and group factors and the availability of individual and group support can also be assessed during a prolonged period of follow-up.

The "work of return" following long-duration missions should include astronaut participation in a structured recovery program with both physiological and behavioral components. Reintegration challenges include redefinition of roles and relationships with the mission sponsor, family, and the community at large. These processes will be impacted by behavioral, cultural, and organizational factors as well as the ability of the senders and those sent to realign their interactive expectations. Investigative analysis of the recovery process must be an essential part of the behavioral health research agenda in order to inform the design and implementation of support and recovery systems for future generations of space explorers.

Screening, Selection, and Training

Procedures for screening, selection, and training of flight personnel have a long and distinguished history among industrial nations with advanced military defense and air transport capabilities. Over the past five decades, spaceflight programs have enjoyed ready access to the resources of the nation's military, including access to standardized and well-validated methodologies for screening, selection, and training. Beginning as early as the Project Mercury initiatives of the 1960s, a remarkable record of accomplishment has characterized a space program that owes its success in no small measure to the effectiveness of these discriminating procedures. Moreover, similar programmatic approaches to screening, selection, and training have been adopted by a range of international spaceflight partners (4) including Russia, Germany, France, and Japan (83) (and more recently China).

Screening and selection: The procedures for screening and selection have continued to provide a central focus for a space program that has grown and prospered over the past half century. Well over 1000 candidates for space travel assignments have been interviewed and tested, with some 350 or more of those surviving this initial screening having participated in flight missions. The extent to which these initial interview and test results have been systematically collated and analyzed for consideration by the actual Astronaut Selection Board remains unclear (4). Regardless of such likely shortcomings, the extant process has made important contributions to the successful accomplishment of mission objectives in that missions have remained free of serious behavioral disorders among participants for at least relatively short-term spaceflight journeys of up to a year or more. The existing knowledge base is enhanced to some extent by the analogue and simulation studies that have been undertaken in polar regions. In a study of some 600 American men spending an austral winter in Antarctica, for example, pretest and intake interview information was found useful in accounting, at least in part, for the variance in individual performance measures (70). In addition, recent initiatives under the auspices of NASA have involved the exposure of small groups of astronaut trainees to extreme polar environments for relatively brief stay-over intervals. With notable recent exceptions however (e.g., 94), there is little evidence in such settings of systematic data collection and analysis relevant to the behavioral challenges of extended-duration spaceflight. However, these analogues/simulations do provide an opportunity to pretest and refine instruments and procedures that can be used to select individuals and to select for effective group interactions and performance (4).

There are a range of newly emerging approaches to the study of intellectual aptitudes and personal characteristics to be explored for their predictive value in assessing levels of behavioral functioning in candidates for spaceflight. Specific constellations of measured 'fluid intelligence' aptitudes—analytic, creative, and practical—have been shown to make solving new problems easier without recourse to a crystallized knowledge base or previously developed problem-solving skills (88). Other behavioral measures of functional significance have been shown to predict pilot performances related to processing speed and working memory (32,80) as well as multiple task attention, breaking set, visual reasoning, and rotation skills (38). These advances in behavioral assessment are relevant to the enhancement of screening and selection for spaceflight due to the results of studies under both simulated and actual spaceflight that show the potential for performance degradation as a result of fatigue and a range of other factors (52).

Findings with respect to the role played by motivational factors, however, have led to less than completely consistent conclusions regarding successfully performing candidates for analogue, simulation, and actual spaceflight studies (71,81,94). But there are a number of promising new developments in the rapidly advancing fields of neuroscience and molecular genetics that hold considerable long-range potential for the assessment and evaluation of future space travelers. Neuroimaging procedures involving functional brain scans, for example, are continuing to advance knowledge of the relationship between behavioral interactions on the one hand, and well specified neural systems and regional structures on the other (1,15,18,43). It is important that the screening and selection procedures for space dwellers involved in long-term missions beyond Earth orbit be capable of validly and reliably identifying effective group interaction skills and competencies. Essential developments in this regard will depend on the availability of an expanded knowledge base on the requirements for harmonious and productive group functioning in unique space environments (4).

Training: Procedures for training both spaceflight candidates and ground support personnel are well recognized to be notoriously time-consuming, thorough, and highly technical. For the most part, they have been demonstrably effective in guaranteeing the successful accomplishment of well-defined mission objectives. To a considerable extent, the successful application of these training procedures is attributable to the involvement of well-educated, very experienced, and highly motivated selectees in exceptionally good health with well-above-average intellectual capabilities. Moreover, the focus of spaceflight training objectives to date has been the mastery of skills required to operate advanced spaceflight technology in the course of relatively brief missions (4). Generally, these flight assignments have not exceeded a few weeks, although in selected instances several months may have been involved. On such brief assignments, with skillful and highly trained crewmembers, individual behavioral health issues have been of minor concern. Until recently, group training appears to have been introduced into the flight preparation process only after a mission has been scheduled and a flight crew designated. Considerable lead-time (often a year or more) is usually involved in group training, and the ensuing team training process may involve not only the designated crew and supernumerary back-ups, but also ground support personnel and monitors. Like individual training, group training also appears to focus on the operational aspects of the mission objectives, with little programmed attention to group functioning, per se. The long-duration space traveler will confront a range of intra- and interpersonal challenges however, the nature of which cannot be accurately determined at present. Therefore, substantive features of training must be based on continuously accumulating experiences in actual spaceflight environments and analogue settings with specially designed algorithm software packaging technologies (50,63). Personalized individual training approaches must also incorporate and evaluate countermeasures based on behavioral procedures that can be adapted for computerized administration for self-assessment and supportive interventions (5–7,16,47,75,78,93). Training approaches can build on experience gained in simulated operational exercises, which have long since proven their effectiveness, as can recent developments in Distributed Interactive Simulation (25,76) using multiperson computer-generated workstation networks in realistic environments. This method or its successors can provide for the objective recording and evaluation of interpersonal interactions within and between small training groups and related ground-based monitoring and support systems under conditions that simulate extended-duration spaceflight operations (4).

Training for long-duration spaceflight missions must involve an integrated approach that includes ground-based monitoring and support groups specifically selected for participation in such operations. Appropriate assessment tools and countermeasure development will be required to meet the challenges presented by emergencies and technical assistance requirements under conditions that involve multinational cultural and language complexities, mixed gender, and command structure constraints (34,39).

Strategic Research Considerations

The conceptual and methodological challenges associated with designing, establishing, and maintaining functional systems that promote performance effectiveness as well as social and ecological stability for small groups involved in long-term spaceflight missions beyond Earth orbit will require an approach grounded at the most fundamental scientific level (4). Evidence-based technological developments can be facilitated by research methodologies that incorporate analogue settings and simulations of space-related environmental conditions involving behavioral interactions over extended periods of time. The approach would be explicitly experimental, dictated by both scientific and pragmatic considerations that closely approximate procedures of established effectiveness in other areas of natural science (8,46). Without such an experimentally derived database, the over-generality of ecological systems proposals and recommendations for space occupancy designs (e.g., 53,85,86) would render them incapable of ensuring the successful establishment of functional and enduring space habitats (4).

The relevance of such an experimentally derived knowledge base to the success of future space ventures depends in large part on the precision with which required performances can be specified and on how effectively they can be produced and maintained in individuals and groups. Despite the abundance of extensively reviewed small group experiments over the past several decades (54,55), the development and application of a technology for the analysis of behavioral interactions among and between groups and group members remains an early stage "work-in-progress" (9–11). With the advent of computer-based communication technologies (22), small group interactions and decision-making can now be automated in the context of distributed performance sites. An empirical research base must be established, however, to evaluate the effectiveness (73) and test the assumptions that underlie these technological developments (22,44).

Distributed communication interactions within and between space-dwelling and Earth-bound groups will be an inherent feature of long-duration spaceflight missions beyond Earth orbit (4). The availability of automated group interaction technologies not only opens the door to enhanced precision of performance measurement but also provides for a research approach to determining the correct mix of group interaction/communication modalities that maximize efficiency without overcomplicating the design of the system. Research applications of such computerized distributed interactive simulation systems can provide for the specification, with nearly exact precision, of the stream of psychosocial cues and consequences within a small group interaction. Under such conditions, systematic investigation can determine which of the many potential modes of communication and verbal interaction are most effective in advancing group stability and efficiency.

Within the context of both analogue and simulation settings, a strong case can be made for an action research strategy to address the operational performance and general living condition challenges associated with long-duration spaceflight missions beyond Earth orbit (4). Such an action research approach will require the integration of research investigative and organizational management activities in an attempt to establish and pretest effective small group social systems under operational conditions that provide for a controlled experimental analysis. In this way, major applied research questions of direct relevance to enhancing the knowledge base required for spaceflight beyond Earth orbit can be pursued without sacrificing methodological rigor using the participant volunteers of primary interest (4).

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