Assessment and Monitoring of Astronaut Behavioral Health & Psychological Well-Being Following Long-Duration Exploration Missions

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INTRODUCTION

Space flight occurs in extreme environments characterized by relative isolation, confinement, and crowding, each of which can have a negative impact on the behavioral health and well-being of astronauts. As a result, crew member selection processes are stringent and rigorous. Despite the existence of these processes, behavioral problems and psychological stress can nonetheless emerge among astronauts. As NASA shifts its focus towards long-duration human exploration missions to asteroids and Mars, increased attention has been directed towards understanding the behavioral health needs of those astronauts selected to participate in these missions. As noted by Slack et al.\(^1\), “as space flight missions length, astronauts will spend longer periods away from families and friends” (p. 6). Furthermore, astronauts will spend greater periods of time in confined and dangerous environments and, upon their return to Earth, will have to reintegrate into families and social contexts that will have changed considerably during their absence. As the length of space flight increases, rates of behavioral health problems such as depression, anxiety, and neurocognitive deficits are also expected to increase\(^2\).

Although these problems are unlikely to rise to the level of full clinical disorders, subclinical and milder forms of behavioral health conditions can nonetheless have a negative impact on an astronaut’s health and well-being. Assessment strategies must therefore be sensitive enough to detect subclinical behavioral health problems. To this end, optimal assessment methods will need to depart from traditional psychiatric classification approaches such as the Diagnostic and Statistical Manual of the American Psychiatric Association, currently in its fifth edition\(^3\), and the International Classification of Diseases\(^4\). In contrast to the psychiatric classification approach, NASA should therefore embrace a psychopathological assessment approach that focuses on the measurement of constructs and etiological factors that underlie behavioral health issues of interest. For example, the measurement of certain attentional biases has been shown to be a useful strategy for assessing vulnerability to depression and anxiety and for differentiating between those individuals with and without these conditions. Such an approach aligns with emerging trends in mental health research among agencies and institutions such as National Institute of Mental Health, which has embraced the Research Domain Criteria (RDoC) framework for measuring constructs relevant to the full spectrum of behavioral health issues.

Unfortunately, existing procedures for assessing and monitoring the behavioral health of astronauts following their return from space flight missions do not lend themselves to rigorous research that might lead to greater understanding of post-mission behavioral health in this population. As noted by several SMEs, current practices are generally unstructured and based in large part on the subjective impressions of NASA medical professionals, which in turn hinge on the honest and accurate disclosure of behavioral health problems and concerns by astronauts. Because the astronaut culture is characterized by high demands and a general expectation to minimize or deny behavioral health problems, the information gained during these routine evaluations are not maintained in NASA’s medical research data repository administered by the Lifetime Surveillance of Astronaut Health (LSAH). These data are therefore unavailable to the broader research community, which could limit efforts to understand and describe the incidence of behavioral health concerns and their relation to occupational demands and exposure. NASA’s current methods for assessing and monitoring the long-term, post-mission behavioral health of astronauts is therefore considered to be inadequate by some stakeholders such as current and former astronauts and researchers. In light of the anticipated stressors associated with long-duration space flight and the
increased likelihood of behavioral health problems afterwards, enhanced methods for identifying and tracking behavioral health is clearly needed.

The purpose of the current report is to provide an overview of:

1) likely contributors to astronauts’ post-mission behavioral health,
2) a description of existing and potential future methods for assessing and monitoring astronauts’ behavioral health following their return from long-duration space flight,
3) possible countermeasures to mitigate and offset threats to astronauts’ post-mission behavioral health, and
4) recommended directions for future NASA research to address existing knowledge gaps in behavioral health assessment among astronauts.

METHOD

The information presented in this report was based on information gained from several sources including scientific publications in peer-reviewed journals, presentations at scientific conferences, government reports, and the anecdotal reports of individuals who have been directly or indirectly involved in spaceflight (e.g., astronauts, flight surgeons and behavioral health professionals, analog study participants). A review of the extant literature was conducted and combined with source documents and articles provided by NASA scientists. Studies focused on military and veteran populations, in particular, were prioritized for several reasons. First, military deployments are considered by many within NASA to be reasonable analogs for long-duration exploration space missions because they are characterized by extended separations from family members and social support networks, often times in extreme environments. Second, military personnel reflect a healthy and generally resilient population, similar to astronauts. Third, many astronauts have a history of military service.

A total of 12 semi-structured interviews were conducted with 10 subject matter experts (SMEs):

- SME #1: Former astronaut and engineer with multiple space flights;
- SME #2: Current astronaut with multiple space flights;
- SME #3: Former participant of long-duration analog studies in Antarctica;
- SME #4: NASA crew psychologist (interviewed twice);
- SME #5: NASA crew psychiatrist (interviewed twice);
- SME #6: Retired NASA flight surgeon;
- SME #7: Space scientist;
- SME #8: NASA behavioral health researcher;
- SME #9: Lifetime Surveillance of Astronaut Health scientist;
- SME #10: Lifetime Surveillance of Astronaut Health scientist.

These interviews were conducted to obtain expert input regarding the post-mission experiences of astronauts that might not be available in the extant scientific literature, to contextualize scientific findings, and to provide direction and guidance regarding topics and issues that might otherwise be missed. The specific questions used in these semi-structured interviews can be found in Appendix A. Information from these multiple sources of information were integrated for the present report.
POTENTIAL CONTRIBUTORS TO POST-MISSION BEHAVIORAL HEALTH

ACCELERATION-INDUCED HEAD INJURIES

Because astronauts can experience up to 3 G’s of force during launch, questions about the potential for acceleration-induced head injuries were raised by NASA scientists. Diffuse axonal injury (DAI), in particular, was of concern. DAI entails widespread damage to axons in the white matter of the brain, and is commonly seen following a head injury, especially as a consequence of angular (or rotational) acceleration. One method for assessing and evaluating the extent of DAI is the cumulative strain damage measure (CSDM), which provides a summary metric of the proportion of damaged elements in the cerebrum that exceeds an established level of strain. Rotational injuries are more strongly associated with CSDM scores than linear injuries, suggesting that DAI is less likely to be observed subsequent to linear acceleration of the head.

In contrast to rotational injuries, which are believed to be the consequence of a strain response, linear acceleration-based injuries are proposed to be the consequence of short-term increases in intracranial pressure. Both linear and rotational aspects of injury contribute to the likelihood of concussion, but linear acceleration appears to contribute slightly more to the overall likelihood of sustaining a concussion. Although this might suggest that the linear forces experienced by astronauts during launch could affect the brain in a manner that is consistent with concussion injuries, the average acceleration force experienced during launch (approximately 3 G’s) is far less than the average linear acceleration associated with concussive impacts (i.e., 104 ± 30 G’s) and sub-concussive impacts (i.e., 26 ± 19 G’s) experienced by football players.

As applied to the forces that act upon astronauts during launch, rotational forces are much less likely to occur than linear forces due to the primary linear trajectory of spacecraft during takeoff. Given that brain damage associated with DAI is often the result of mechanical causes that occur at the moment of injury rather than being the result of subsequent factors such as hypoxia, brain swelling, or intracranial pressure, DAI is assessed to be an unlikely contributor to long-term behavioral health issues among astronauts.

HIGH ENERGY RADIATION

Once outside Earth’s magnetosphere, astronauts will be exposed to high levels of radiation. Two forms of radiation in particular may increase risk for long-term adverse health effects among astronauts: chronic low-dose exposure to galactic cosmic rays and short-term exposures to solar energetic particles associated with solar flares and coronal mass ejections. Measurements of radiation levels by the Mars Science Laboratory spacecraft’s Radiation Assessment Detector during its 253-day flight to Mars indicate that astronauts are likely to be exposed to a radiation dose equivalent of 0.66 ± 0.11 sievert during the round-trip transit and 0.32 ± 0.50 sievert while on the Mars surface. Exposure to such radiation in the form of high-energy charged particles (HZEs) can have a negative impact on the central nervous system, which could lead to long-term changes in cognitive and psychological functioning. For example, animal models suggest that exposure to such doses of HZEs can accelerate impairment in cognitive functioning including attention and memory, contribute to deficits in visual discrimination and reaction time, inhibit neuronal growth in the hippocampus, and lead to deficits in the dopaminergic and glutamatergic neurotransmitter systems. Hippocampal neurogenesis, dopamine, and glutamate have each been implicated in a range of psychiatric and behavioral disorders including substance use...
disorders, mood disorders, and other impulse-control problems, as well as resistance to antidepressant medication.

More recent animal research suggests there may be individual differences that moderate the deleterious effects of HZE radiation on subsequent cognitive and neurobehavioral performance, especially in domains associated with impulsive behavioral responding. In a study investigating the effects of HZE radiation exposure on subsequent cognitive performance, Davis et al. found that approximately half of rats exposed to HZE radiation showed declines in cognitive performance and changes in dopamine transporter and receptor activity regardless of the dose of HZE exposure level, suggesting a radiation sensitive group. The other half, by contrast, showed no changes in cognitive performance and neural functioning regardless of HZE exposure level, suggesting a radiation insensitive group. These differences between the radiation-sensitive and radiation-insensitive groups did not emerge until the twenty-first day of observation, suggesting that radiation-induced declines may emerge only gradually over time. Taken together, these findings suggest that radiation exposure may have more pronounced effects on astronauts who are radiation-sensitive, and these effects may not be immediately apparent. Unfortunately, it remains unknown what factors contribute to radiation-sensitivity. Future research should focus on identifying potential genetic and/or biological factors associated with radiation insensitivity, as well as investigating potential therapeutic agents (e.g., medication) that may confer or enhance radiation insensitivity.

There was consensus among SMEs that high energy radiation exposure constituted an important risk factor for the long-term behavioral health of astronauts returning from long-duration space exploration missions. SMEs noted that because our knowledge of HZE radiation exposure effects is based primarily on animal research, however, it remains unknown how HZE radiation exposure might affect human astronauts with respect to long-term psychological and behavioral health. Given the ethical and methodological difficulties of conducting human research focused on the psychological and behavioral health effects of HZE radiation, knowledge in this particular area may remain limited for the foreseeable future.

**DAILY HASSLES**

Daily hassles are irritating, frustrating, and distressing demands that characterize daily life and typically include nontraumatic annoyances or inconveniences such as losing objects, financial concerns, family problems, and technical problems. Because daily hassles often persist over time, they are commonly experienced as chronic stressors, which may explain why they have generally shown stronger relationships with negative psychological and physical health outcomes than major life stressors or traumatic experiences. These daily hassles can impact psychological health and well-being in both the short-term and the long-term.

The long-term impact of daily hassles on behavioral health is perhaps best demonstrated by studies conducted with deployed military personnel. Among military personnel, daily hassles are among the most commonly-reported stressors while deployed. For instance, over one-third of service members deployed to Iraq and Afghanistan endorse boring or repetitive work as their leading complaints and stressors. Concerns about extended separations from family members while deployed is another commonly-reported issue that is positively correlated with posttraumatic stress, depression, and somatic symptom severity within the first few months of service members’ return home. The relationship of daily hassles with depression and posttraumatic stress
symptoms persists for at least 12 months postdeployment and shows a stronger relationship with mental health symptoms than exposure to traumatic events such as combat\textsuperscript{37}, suggesting that daily hassles can confer long-term vulnerability for behavioral health problems. Similar findings have been reported in international military samples. For example, a longitudinal study of Danish military personnel found that daily hassles while deployed were more strongly associated with the later emergence of PTSD symptoms than combat exposure\textsuperscript{38}.

Military research further suggests that the relationship of daily hassles with postdeployment mental health symptoms can be magnified by perceived danger while deployed\textsuperscript{39}. Unpublished research findings by the National Center for Veterans Studies supports this perspective. In a sample of U.S. Air Force rescue personnel, perceived threat while deployed was significantly correlated with postdeployment emotional distress, and accounted for approximately 50\% of the correlation between stressor exposure and behavioral health symptoms. The long-term negative impact of daily hassles may therefore be pronounced if astronauts experience a crisis, catastrophe, or other contingency that fosters a sense of danger or threat to their safety.

Similar to findings in military studies, astronauts have generally reported daily hassles such as a lack of privacy, lack of meaningful work, lack of control over environmental factors (e.g., temperature, lighting), confinement, and limited communication with family members and social support networks as their most commonly-reported stressors during space flight\textsuperscript{40}. SMEs generally concurred with these findings, and specifically identified conflicts between astronauts and Earth-based “management” as a likely source of frustration. Astronauts and analog study participants generally shared the perspective that “management” did not always listen to their concerns or input. Crew members also felt they were discouraged from expressing their concerns or complaints about ground support personnel, and in some cases felt they were being admonished or otherwise disciplined when they voiced their complaints after returning to Earth, which fostered hostility, resentment, and job dissatisfaction.

These “minor” or benign stressors are likely to play a more central and pronounced role on the emergence and maintenance of post-mission behavioral health symptoms than major stressors and potential traumas. The relative strength of “minor” stressors relative to “major” stressors on long-term behavioral health is likely explained by their relative persistence combined with the individual’s subjective appraisal of these stressors. Routine daily events become hassles when they are perceived as relatively unimportant as well as highly controllable. Such events do not ordinarily warrant a high level of attention, but when they persist over time without resolution, they require greater amounts of attention and time than is subjectively perceived to be necessary (e.g., “I shouldn’t have to deal with this”). Over time, chronic exposure to relatively low-level stress can degrade psychological resources and increase vulnerability to more severe behavioral health issues like depression, anxiety, and substance use. Supporting this potential relationship is a recent study showing that occupational stress and burnout are strongly correlated with depression in special duty military personnel\textsuperscript{41}.

The culture gap that exists between astronauts and ground-based command crew therefore has the potential to serve as a source of vulnerability for the long-term behavioral health of astronauts. SMEs noted that the time delay that will occur in communication between Earth and Mars (up to 22 minutes) could force a change in this dynamic, as astronauts will need to be granted a much higher level of autonomy and control than is currently provided by NASA. Astronauts on exploration missions are therefore expected to have greater control over the mission and day-to-day
operations, a contextual factor that could potentially serve as a protective factor for behavioral health. One potential threat to this protective factor, however, is the loss of autonomy and control that might occur as the astronauts approach Earth on their return flight, during which the communication time delay will reduce. Under these circumstances, there may be a desire among ground-based command crew to assume greater control and responsibility for mission-related decisions. This transition could be met with considerable resistance by astronauts, however, which could result in stress, frustration, and anger that could affect post-mission behavioral health. Additional research focused on the effects of transitioning across different levels of responsibility are needed to better understand how this could impact post-mission behavioral health among astronauts.

TRAUMA EXPOSURE

A concern raised by several SMEs was the risk for trauma exposure that could occur during an exploration mission. Trauma is defined as exposure to actual or threatened death and/or serious physical injury, and can occur via direct exposure and/or witnessing of the event, or indirect exposure by learning that a significant other was exposed to a trauma\(^3\). The probability of a traumatic event occurring during an exploration mission was estimated by SMEs to be higher than current and past space flight missions due in large part to the longer duration of an exploration mission, which would provide a greater amount of time during which a traumatic event could occur. Within the context of exploration missions, trauma exposure could occur subsequent to unanticipated stressors or tragedies such as accidents or mishaps, severe injury or illness of crew members, and/or the death of a crew member. Trauma could also occur for astronauts who learn about the injury, illness, or death of family members or friends back on Earth, but are unable to adequately respond or assist. The general consensus among SMEs was that this latter form of trauma was more likely than injury, illness, or death of an astronaut.

Longitudinal studies conducted among military personnel have identified several distinct trajectories of PTSD symptoms following service members’ return from deployment\(^38\),\(^42\). The most prominent finding from these studies is that the vast majority of military personnel (>80%) are highly resilient in that they do not report PTSD symptoms before or after their deployments. This resilience tends to persist for several years postdeployment. Other subgroups (~10-15%) of military personnel show moderate to high symptom severity immediately after returning from deployment, of which approximately half show marked improvement over time and the other half continue to experience symptoms over time. These two subgroups are the most likely to be identified by standard screening and assessment methods, and are often referred for intervention and treatment as a result. Finally, a much smaller proportion of military personnel (<5%) display a “delayed-onset” trajectory of symptoms in that they report minimal symptoms soon after their return from deployment but gradually show symptom worsening over time. This latter subgroup is of greatest concern as they typically remain undetected for many months or years. Furthermore, when symptoms and problems do emerge, they are often attributed to other more proximal life events, thereby resulting in misdiagnosis and/or mismatched treatments. Anecdotal reports from military veterans and professionals who have worked with these populations suggest that early symptom minimization due to social pressures and stigma may explain in part the delayed-onset trajectory among elite military professions. These observations are judged to be relevant and applicable to astronauts.
Military research further suggests that those personnel who display worsening PTSD symptoms over time are more likely to be female and to have a history of early life trauma. Following return from deployment, worsening of PTSD is most strongly associated with daily hassles. Research among UK military personnel indicates that persistent postdeployment PTSD symptom severity is also associated with older age, higher educational qualifications, recent discharge from the military, multiple physical symptoms, and limited social support. Several of these risk factors are relevant to astronauts on exploration missions (i.e., daily hassles during and after the mission, higher education level, social support).

Of particular concern to long-duration exploration missions is the limited range of options available to astronauts to confront or handle stressful and traumatic events. For example, astronauts who become ill or sustain an injury will be unable to return to Earth early for treatment. Similarly, astronauts who learn about the injury, illness, or death of a family member or friend will be unable to return to Earth. An astronaut’s death within-flight may be experienced as especially traumatic, especially if the death occurred subsequent to an injury or accident. Research among military veterans, for instance, has found that feelings of inadequacy over the inability to prevent the death of a peer are strongly correlated with incidence of suicide attempts and severity of posttraumatic stress disorder many years after the trauma. Survivor guilt is another common contributor to persistent PTSD symptomatology and functional impairment that may be relevant to astronauts on exploration missions. The impact of these stressors is likely to be compounded by communication limitations with Earth, which will likely serve as a barrier to social support, a well-established protective factor against posttraumatic stress disorder (PTSD). Limited communications with Earth could serve as a barrier to receive the information needed to quickly and effectively resolve a crisis (e.g., providing emergency care to an injured crew member) as well as to provide information or support to help others resolve a crisis (e.g., assisting a family member or friend in need). This could contribute to a sense of powerlessness and failure, which can lead to long-term behavioral health problems.

In light of the limitations of Earth-based sources of support, support derived from fellow astronauts will therefore play an important role for mitigating post-mission behavioral health concerns. This is supported by a considerable body of military research showing that PTSD symptom severity and emotional well-being following the return from deployment is positively affected by strong peer bonding and cooperation, also known as unit cohesion. Team cohesiveness during exploration missions is therefore likely to mitigate post-mission behavioral health issues.

There was disagreement among SMEs about the probable impact of stressful and traumatic events on long-term behavioral health, however. Although the majority of SMEs agreed that trauma exposure could impact the behavioral health of astronauts, SMEs who were current or past crew members generally felt that astronauts received sufficient training to effectively cope with a range of traumatic events. In contrast, SMEs who were medical personnel generally felt that trauma was among the most likely sources of long-term behavioral health problems and therefore should be monitored nonetheless. As noted by SME #6, “because of the newness of everything related to [an exploration] mission, there might be some form of a ‘posttraumatic stress’ reaction,” although this reaction may not meet the threshold for a full-scale diagnosis of PTSD. Monitoring for subthreshold trauma-related symptoms is therefore implicated. Screening and assessment methods must therefore be sufficiently sensitive to detect mild or subclinical symptoms.
The divergence in perspectives among these two subgroups of SMEs mirrors a pattern often observed in the military, especially in with special duty military professions (e.g., special operations forces, pilots) who, similar to astronauts, demonstrate above-average levels of physical and psychological resilience that is presumed to reduce their risk for psychological morbidity. Supporting this perspective is research showing somewhat lower rates of behavioral health problems such as posttraumatic stress disorder (PTSD) among elite military units as compared to conventional forces. Thus, although rates of trauma- and stressor-related behavioral health conditions are uncommon among elite and high-performance professions such as astronauts, given the considerable long-term impact of trauma on physical and behavioral health, trauma-related symptoms should nonetheless be monitored post-mission.

**SOCIAL SUPPORT**

Although social support has been operationalized in different ways across studies, a generally accepted definition is “the presence of others, or the resources provided by them, prior to, during, and following a stressful event.” This definition suggests several dimensions by which the positive effects of social support might operate:

- **Belonging** entails the perception that one “fits in” with others as well as the availability of companions to engage in shared activities. For example, having access to family members or friends who are willing to go to dinner together or participate in recreational activities together.
- **Tangible support** entails the receipt of material support to assist with the resolution or prevention of problems. For example, having access to family members or friends who are willing to provide transportation to a medical appointment or provide financial support when money is tight.
- **Appraisal support** entails the receipt of emotional support for self-evaluation purposes. For example, having access to family members or friends who are willing to provide constructive feedback or emotional support during a stressful time.
- **Esteem support** entails the perception that one is valued by and important to others. For example, having access to family members or friends who express confidence in one’s abilities.

Each of these dimensions of social support have shown positive effects on behavioral health, but they may confer benefits in different ways. With respect to suicide risk among military personnel who have deployed, for example, esteem support is directly associated with decreased suicide risk whereas tangible support weakens the effect of emotional distress on suicide risk. A greater sense of belonging appears to offset the effects of trauma on suicide risk, however, especially among older military personnel. In terms of depression and PTSD symptoms, belonging appears to have a beneficial effect on depression but not PTSD. The positive impact of social support on behavioral health may therefore be much more complex than initially assumed.

The complexity of the relationships among different dimensions of social support and different aspects of behavioral health warrants further research, as a more nuanced understanding of these relationships could lead to the development of more focused countermeasures.

There was considerable agreement among SMEs that the strength of social support, especially family relationships, across all stages of an exploration mission would have an important
influence on post-mission behavioral health. As noted by SME #4, “[Family] connectivity is much more important than duration of the mission.” The impact of social support on long-term behavioral health has considerable scientific support. Military research in particular has supported the protective effect of social support on postdeployment behavioral health. For instance, postdeployment support from family members and friends has been shown to be negatively correlated with PTSD symptom severity\textsuperscript{39}. Similar benefits of peer-based support on psychological symptom severity and overall well-being have been found\textsuperscript{41,46,47}. By contrast, concerns about how extended separations will negatively impact one’s family are associated with worse behavioral health outcomes, especially for men\textsuperscript{39}.

In light of the anticipated challenges of communication between astronauts and Earth-bound sources of social support, considerable concern was expressed by SMEs that traditional methods for maintaining connectivity with family members and friends will be inadequate. As noted by one subject matter expert, research from analog conditions that can provide information about different communication parameters (e.g., sporadic versus regular email, video messages versus text-based messages, batched versus unbatched communication) is needed.

\textbf{POST-MISSION ROLE TRANSITIONS}

There was consensus among SMEs that role transitions for astronauts and their families would be a likely source of post-mission stress. Reintegration problems and role confusion after return to Earth was uniformly viewed as an anticipated and natural consequence of extended separation from social support networks and society in general. The reintegration process is expected to begin well before the astronauts’ return to Earth, akin to the process used in analog winter deployments to Antarctica. As noted by SME #5, although this advance preparation is helpful, it is inherently unable to fully prepare individuals for the “little things” that are often taken for granted in day-to-day life, such as using money, having to wait in lines, and making routine decisions about daily activities (e.g., meals, daily scheduling, where to sleep). SME #5 further added that the transition from a highly-regimented schedule to “the constant change that occurs in actual life” can be very challenging. The post-mission bureaucratic requirements (e.g., paperwork) can be especially frustrating and stressful. This initial “culture shock” is expected to last several days to several weeks after return.

Relative to current and past space flight missions, reintegration issues were uniformly expected by SMEs to be magnified following a long-duration mission due to the longer period of time during which daily routines can be reorganized by astronauts and their family members. With respect to the reintegration process, SMEs generally agreed that there would likely be different reintegration trajectories for astronauts who were unmarried or unpartnered, astronauts who were married without children, and astronauts who were married with children. There was a general sense among SMEs that astronauts who were partnered or married would experience greater role transition challenges than astronauts who were unpartnered due to the need to renegotiate responsibilities and living space. SMEs cautioned, however, against the potential tendency to emphasize the needs of partnered astronauts at the expense of unpartnered or single astronauts, who will face unique challenges and have unique needs. The development of support programs and countermeasures to facilitate reintegration may therefore need to differ based on the relationship status of individual astronauts.
Regardless of their relationship status, post-mission role transitions are expected to be a source of stress for all astronauts and to impact a wide range of relationships. The relational turbulence model provides a template for understanding relationship dynamics during periods of transition, and posits that individuals experience relationship upheaval during times of transition because changes in relationship circumstances give rise to uncertainty\textsuperscript{55}. Although this model is often studied within the context of married couples, the model is nonetheless generalizable to other relationships as well (e.g., family, peer, coworker). Relational turbulence refers to the propensity to be cognitively, emotionally, and behaviorally reactive in interpersonal situations that would not elicit these same reactions under typical circumstances\textsuperscript{56} whereas relational uncertainty refers to the degree of confidence that an individual has regarding their perceived involvement in a relationship. According to this model, relational uncertainty increases in salience during transitions because these periods are often marked by changes in usual relational patterns and habits. An individual’s relational distress during times of transition is not just related to their own uncertainty, however; relational distress is also impacted by the perception that the other member of the relationship is making it more difficult to accomplish daily routines\textsuperscript{55}. Greater relational uncertainty among the partner further increases one’s own relational distress\textsuperscript{55}, indicating that role transitions are transactional in nature.

Further supporting the transactional and dyadic nature of relational stress during periods of transition are findings from studies conducted among military families during the postdeployment reintegration process. Among military families in which one partner recently returned from a deployment, depression symptom severity among service members was associated with greater relationship uncertainty within both the service member and their partner, as well as perceived partner interference in achieving one’s goals\textsuperscript{57}. A spouse’s emotional distress and perceptions of a service member’s deployment are also correlated with service member’s behavioral health. Service members whose spouses report more severe depression and anxiety symptoms tend to report more severe symptoms themselves\textsuperscript{58}. Military research further suggests that a spouse’s perceptions about the astronaut’s experiences during the mission may also influence post-mission behavioral health. For example, service members report more severe behavioral health symptoms after returning from deployment when their spouses underestimate the demands and tasks they experienced while deployed\textsuperscript{55}. Taken together, these findings suggest that countermeasures for stress related to role transitions among returning astronauts and their families (and/or peer groups) would need to include interventions and strategies targeting both members of the relationship as opposed to targeting only the astronaut. By extension, there may be benefit in monitoring the behavioral health and well-being of family members in addition to astronauts. This strategy may be met with resistance by the astronaut community, however.

Astronaut families are likely to go through several phases of separation and reintegration following an exploration mission, similar to military families who are reintegrating after an extended deployment. In a longitudinal qualitative study of 34 military families, Faber et al.\textsuperscript{59} found that during the deployment itself, family members frequently reported “ambiguous absence,” which is characterized by the feeling that the service member was psychologically present but physically absent. As the end of the deployment approached, family members and service members frequently reported looking forward to returning to their predeployment lives (e.g., “We just want things to be how they used to be”), although this expectation was often unable to be met. In light of this situation, military family support programs often focus on the concept of establishing a “new normal” as opposed to “getting back to (predeployment) normal.” In contrast to the “ambiguous absence” experienced while deployed, during the early phases of
postdeployment reintegration, family members often reported an “ambiguous presence” of the service member, which entails the feeling that the service member was physically present but psychologically absent. A similar process may occur for astronaut families, especially if the astronaut struggles to establish a sense of meaning in life post-mission, an issue that was identified by several SMEs as a potential threat to post-mission behavioral health (the issue of post-mission meaning in life will be discussed in greater depth below).

Across military studies, the most common struggles for the transitioning military family tend to revolve around changes in roles and responsibilities, communication patterns, and identity:

- **Difficulty resuming prior roles and responsibilities.** Family members felt uncomfortable asking the service member to resume certain roles whereas service members felt uncomfortable asking to resume roles that had been redistributed to others. This often created confusion and tension within the family. A similar process could occur within astronaut families following a multi-year separation.

- **Changes in communication patterns and expectations.** Family members and service members were more closed in communication. This tended to occur more for spouse/partner relationships than for parent/child relationships. Closed communication often contributed to relationship distress, and was most pronounced in relatively newer marriages. The risk of communication problems is expected to be greater following long-duration space exploration missions due to communication delays that will require asymmetric, “batched” communication patterns that could reinforce closed communication styles.

- **Identity transition.** Many service members struggled to transition from military to civilian life. This conflict tended to resolve within the first four weeks of transition. Along these same lines, several SMEs noted that astronauts should remain very involved with NASA after their return to Earth. This will ensure they remain connected to their “in-group” and mitigate the potential for astronauts to “fall through the cracks.”

Military research suggests that in most cases, family distress often reduced when the service member returns to work, as this seems to contribute to the reestablishment and stabilization of family roles. In contrast, service members who experience occupational problems and other life stressors in general experience heightened distress and reintegration problems that endure for much longer. SMEs generally agreed that work-related tasks and expectations were likely to be a source of stress for astronauts. To this end, several SMEs noted that providing meaningful and stimulating work tasks could facilitate reintegration, offset potential behavioral health declines, and mitigate the risk of identity transition.

**MEANING IN LIFE**

Meaning in life has been defined by Steger et al. as “the sense made of, and significance felt regarding, the nature of one’s being and existence” (p. 81). Empirical evidence indicates that meaning in life is comprised of at least two separate dimensions: the presence of meaning in life and the search for meaning in life. Presence of meaning in life entails the subjective experience that one currently possesses or understands one’s purpose in life, whereas the search for meaning in life entails the active pursuit of this purpose. Research indicates that the presence of meaning in life is positively correlated with life satisfaction, hope, and positive mood states, and is negatively
correlated with neuroticism, depression, posttraumatic stress, and negative mood states.\textsuperscript{61-64} Search for meaning in life, in contrast, has been found to be unrelated to life satisfaction and positive mood states, but is positively correlated with negative mood states, depression, and posttraumatic stress.\textsuperscript{61,64} which may suggest that the active pursuit of a personal meaning in life is conceptually similar to a subjective sense of meaninglessness.

Military research suggests that meaning in life may decrease during the reintegration period following a deployment, especially among those reporting high levels of operational stressors.\textsuperscript{65} In this study, the negative relationship between deployment stressors and the presence of meaning in life was especially pronounced among male personnel, suggesting a possible vulnerability for loss of meaning among men. Following return from deployment, a stronger sense of meaning in life is significantly associated with decreased emotional distress and suicide ideation among military personnel\textsuperscript{63,64} and is associated with better daily functioning across multiple domains including occupational performance, family life, social relationships, and life satisfaction.\textsuperscript{64} Research has further suggested that a strong sense of meaning in life among military personnel mediates the relationship of social support with life functioning,\textsuperscript{64} which suggests that the positive impact of social support during life transitions may be due to the strong sense of purpose that an individual feels when surrounded by a strong support network.

The positive effects of meaning in life postdeployment converge with research supporting the deleterious effects of daily hassles on service members’ long-term behavioral health.\textsuperscript{37,39} Although daily hassles are relatively minor annoyances and stressors, they nonetheless have a disproportionate influence on behavioral health because they are often experienced as trivial, meaningless, and/or a “waste of time.” Consistent with this perspective, research conducted among astronauts has identified a lack of meaningful work as one of the most commonly-reported daily hassles.\textsuperscript{40}

There was consensus among SMEs that a sense of purpose and meaning will play an important role in post-mission behavioral health. Prior research indicates that increases in transcendence (e.g., inner harmony, unity with nature, justice, and wisdom) and enjoyment (e.g., positive emotions, life enjoyment) following space flight are common, especially among male astronauts.\textsuperscript{66,67} Because of the social and scientific magnitude of a long-duration exploration space mission, long-duration exploration missions are expected to be a peak experience for those astronauts who complete them, especially those assigned to the first few exploration missions. Exploration missions are therefore likely to be a source of personal growth for astronauts. SMEs cautioned, however, that there also exists a risk for post-mission life on Earth could to be experienced as a “let down” or “mundane,” which could increase the risk for behavioral health problems. Another potential threat to astronauts’ sense of meaning in life that was reported by several SMEs related to the cultural differences that exist between astronauts and ground crew. SMEs with space flight or analog research study experience voiced the concern that their input and experiences were often ignored or dismissed by “management” when returning from a mission. This perspective was echoed by SMEs who have served in support roles for astronauts. The perceived lack of receptivity to crew members’ input and suggestions was seen as a risk to astronaut morale and well-being, primarily because there was a general desire by astronauts to contribute their firsthand knowledge in ways that might improve mission success in the future, thereby providing crew members with a sense of purpose and meaning.
PUBLIC EXPOSURE AND CELEBRITY STATUS

Given the unique nature of long-duration exploration missions, SMEs noted that astronauts returning from exploration missions are very likely to experience much higher than usual levels of fame and public recognition. The first astronauts to return from Mars, in particular, are expected to be seen as “heroes” by the general public and are likely to receive close public scrutiny that may lead to considerable pressure to maintain very high expectations of performance and conduct, which can foster elevated levels of stress. In addition, the public relations schedule for returning astronauts is expected to be “very demanding” and “grueling.” According to several SMEs, public relations events and travel generally do not include astronauts’ family members and social support system. A busy public relations schedule could therefore result in extended separations from family members and sources of social support, which could disrupt the reintegration process. Allowing astronauts to be accompanied by family members and/or friends during public relations travel could help to offset the stress associated with this expected post-mission activity.

Unfortunately, no studies could be identified that have scientifically examined the impact of fame and celebrity status on behavioral health and psychological well-being. NASA should therefore consider researching the social and psychological process of celebrity status transition, as well as the factors and dimensions of celebrity status (e.g., frequency and type of public appearances, amount and type of media coverage) that might influence behavioral health. Such research might include qualitative and quantitative studies of the experiences of public figures and celebrities. In addition, examination and consideration policies and strategies related to maintaining and protecting astronaut privacy may be warranted, especially with regards to social media and widespread access of cameras and video recording devices by members of the public. Repatriation procedures and policies from other government agencies (e.g., Department of Defense, Central Intelligence Agency, Federal Bureau of Investigations) may serve as a useful guide or foundation for managing public exposure and social reintegration of astronauts following their return to Earth.

SUMMARY

Previous research conducted with astronaut and military samples, the latter of which is believed to be a good analog for the astronaut community, suggest the most likely contributors to long-term behavioral health and well-being among astronauts will be relatively minor, day-to-day stressors and annoyances experienced both during and after exploration missions. Animal research further suggests that exposure to high-energy radiation during space flight is likely to influence neural structure, which could lead to declines in neurocognitive, psychological, and behavioral functioning. SMEs largely agreed that these two factors were the primary threats to post-mission behavioral health. Individual differences are expected to moderate these vulnerabilities, which highlights the importance of crew member selections. Future research should focus on the relative contributions of and interactions among individual differences, within-mission stressors, and post-mission stressors on behavioral health and well-being over time.
CURRENT METHODS FOR BEHAVIORAL HEALTH ASSESSMENT AND MONITORING OF ASTRONAUTS

Existing methods for assessing and monitoring astronauts’ behavioral health are primarily based on regularly-scheduled evaluations with NASA psychiatrists and psychologists. According to SME #4 and SME #5, an annual behavioral health exam is completed concurrent with the annual physical health exam when an astronaut is not assigned to a flight. This annual behavioral health exam is a relatively new addition to the annual comprehensive flight health exam for active astronauts, having been implemented in 2008. During this exam, astronauts meet separately with a psychiatrist for a 30-minute semi-structured interview that reviews the astronaut’s current career status, professional training and workload, sleep, social and family relationships, and goals for the coming year (see Appendix B). SME #5 noted that this interview serves as an occupational health assessment more so than a psychiatric diagnostic interview. Once an astronaut is assigned to a mission, they follow a protocol of behavioral health evaluations, completed with NASA behavioral health professionals, that entails more frequent assessment and monitoring of behavioral health status.

After being assigned to a flight or mission, preflight behavioral health evaluations are scheduled at 12, 6, and 1 month preflight. These evaluations are conducted by NASA psychiatrists and psychologists, and are designed to assess the astronaut’s mental status and psychological health. In addition to these behavioral health evaluations, astronauts are also administered the WinSCAT, a computerized neurocognitive assessment tool described in greater details below, at 11, 9, 7, 5, and 3 months preflight. The purpose of these WinSCAT administrations is to assess and monitor neurocognitive health and performance.

During flight, astronauts participate in a 15-30 minute private conference with a NASA psychiatrist and psychologist every two weeks. This conference follows a semi-structured format and focuses on sleep, workload, fatigue, relationships with other crew members, family issues, mood, cognition, and operational support issues (e.g., access to recreational activities). The astronaut’s affect and general appearance are also assessed during these conferences as an objective indicator of behavioral health. These regularly-scheduled conferences are supplemented by emails and private phone conversations between astronauts and behavioral health professionals on an as-needed basis. According to SME #4, these latter communications often cover a wide range of topics and are designed to enable open and immediate communication with behavioral health professionals.

Within the first three days of return from a mission, astronauts participate in a semi-structured psychiatric interview that is combined with an operational assessment interview. Clinical assessments are subsequently performed at 14, 30, and 60 days postflight, and are intended as a “status check” during the astronaut’s reintegration. A WinSCAT assessment is also conducted 30 days postflight.

All behavioral health data gained from the annual, preflight, inflight and postflight behavioral health assessments (including neurocognitive assessments) are entered and maintained in NASA’s electronic medical record. Access to these data is restricted to NASA behavioral health professionals and is not fed into the Lifetime Surveillance of Astronaut Health (LSAH) Repository, with the exception of WinSCAT data, which are available to qualified researchers. The LSAH is an occupational health surveillance program designed to screen and monitor astronauts for work-
related injury or disease. The LSAH program examines the incidence and course of short-term and long-term morbidity and mortality of astronauts, and quantifies the potential health risks of spaceflight and other occupational exposures encountered by astronauts. Medical data for this research program are extracted from NASA medical records and maintained in the LSAH Repository. In order to obtain WinSCAT data, researchers must submit a request to LSAH, who then contacts BHP to request the data. LSAH and BHP then work together to determine the appropriateness of data release. Other behavioral health data are not available through LSAH, however, due to high levels of concern regarding the sensitivity of this information. For example, astronauts’ medical records can be reviewed by LSAH epidemiologists, who can ask follow-up questions of the medical providers and suggest changes to the documentation. If a similar process were used for behavioral health records, many suspect that astronauts would be much less likely to honestly disclose their symptoms, problems, and concerns to behavioral health staff.

According to SME #9 and SME #10, a significant limitation of NASA’s electronic medical record is that there are limited ways to control access to various portions of the electronic medical record. Behavioral health notes are partitioned from the rest of the electronic medical record for privacy reasons and can only be accessed by behavioral health clinicians or EMR administrators. Access to behavioral health notes is also restricted for LSAH epidemiologists. Because of this restricted access, astronauts are more willing to honestly disclose problems and concerns to behavioral health clinicians. The LSAH therefore has very limited access to behavioral health information and is unable to query for behavioral health data for research purposes.

SME #9 and SME #10 indicated there are two general exceptions to the separation between medical and behavioral health records, however: medication prescriptions and WinSCAT scores. If an astronaut has been prescribed a psychotropic medication, the name and dose of that medication is available to non-behavioral health professionals and to the LSAH, although the specific reason for the medication remains protected. WinSCAT data are managed by the BHP team, and requests for these data are tightly controlled and undergo rigorous scrutiny prior to release. For instance, WinSCAT scores can only be released to psychologists with appropriate training in test administration and interpretation. Because of the separation of behavioral health records from other medical records, as well as the high level of concern about protecting astronauts’ behavioral health data, research on post-mission behavioral health is extremely limited and lags considerably behind research focused on other areas of astronaut health (e.g., inflight behavioral health).

Astronauts have the option to designate whether or not their medical data can be used for research studies, and must consent to including their data for each individual research protocol that is submitted to the LSAH. According to SME #9 and SME #10, a similar process should be implemented for any behavioral health research that might be conducted in the future. There was a general consensus among the subject matter experts that the current culture of the astronaut corps would be opposed to the use of behavioral health data for research purposes, although SME #9 and SME #10 noted that in the past there was a very high level of resistance to using general health and medical data for research purposes. A culture shift has gradually occurred over the course of many years, however, concurrent with a general shift in astronauts’ perceptions of flight medicine. In the past, flight medicine was often seen as a program designed to “screen out” astronauts with various health and medical conditions, but it is now seen an occupational health or “maintaining your job” program. The culture shift within the astronaut corps is also attributed in part to an increased level of trust with the LSAH program, which has been careful to maintain astronauts’ confidentiality and
protect their privacy. The level of trust among the astronaut corps, flight medicine, and LSAH program has therefore created a sufficient level of comfort that medical data are now routinely used for research. Trust among astronauts and behavioral health clinicians has strengthened considerably over the years as well, a positive shift that has been attributed in part to the successful preservation of astronauts’ privacy specific to behavioral health information.

SME #9 and SME #10 additionally noted that resistance to the use of medical data tends to be much less among former astronauts no longer in the active astronaut corps, as this group “has nothing to lose.” In contrast to active astronauts, former astronauts are much more likely to encourage the LSAH program to use their data more often. The willingness to use their medical data tends to increase over time, as such research is often seen as a way to “give back” or help current and future astronauts.

A robust research program focused on post-mission behavioral health would therefore be most likely to succeed via the collection of relevant data that are specific to predetermined research questions, similar to how many behavioral health studies are designed and implemented. Data generated during the course of such studies would be maintained separate from the electronic medical records, thereby creating clear distinction between research and medical data. Under these conditions, astronauts may be more willing to participate in behavioral health research studies. Because research based on information contained within astronauts’ medical records are likely to provide unique information of value to NASA, such research should be pursued as well, although this particular course would likely be more challenging due to the privacy concerns noted above. Because information contained in behavioral health notes is obtained within the context of close, trusting relationships, the sensitivity of these data are much greater. Such research will therefore require a collaborative effort among astronauts, behavioral health professionals, and the LSAH program, and will likely take several years (or longer) to develop. Procedures for facilitating this line of research should therefore be implemented in the very near future in preparation for long-duration exploration missions. The importance of approaching this particular line of research with caution cannot be emphasized enough, however, as the protection of astronauts and their family members must be preserved, along with the professional relationships between NASA behavioral health clinicians and the astronaut corps. The cost associated with a disruption in these relationships could result in the loss of free exchange of information between astronauts and behavioral health clinicians, which could pose a threat to mission effectiveness and safety.
POTENTIAL FUTURE APPROACHES FOR ASSESSING AND MONITORING POST-MISSION BEHAVIORAL HEALTH

Based on the potential contributors to post-mission behavioral health among astronauts summarized in the previous section, the behavioral health issues that are judged to be in greatest need for tracking and monitoring include depression, anxiety, posttraumatic stress disorder, and neurocognitive deficits. Case studies and anecdotal reports of past astronauts who have struggled with one or more of these issues indicate that marital problems and substance use also warrant attention. Marital problems may serve as an early indicator of other behavioral health problems, whereas substance misuse (alcohol misuse in particular) may serve as a maladaptive strategy by which astronauts attempt to manage or cope with mood and/or neurocognitive disturbances. With the exception of posttraumatic stress disorder, there was consensus among SMEs that these behavioral health issues warranted the greatest amount of attention because they were deemed to be the most probable conditions to emerge following an exploration mission.

In contrast to full-blown psychiatric disorders and conditions, subclinical levels of behavioral health conditions are much more likely to emerge among astronauts following their return from exploration missions. In order to be maximally useful, assessment methods should therefore be sensitive to relatively mild or low levels of the constructs they are measuring. This characteristic is especially key for the early detection of emerging behavioral health problems, which could in turn lead to early intervention that could prevent the development of a severe clinical disorder.

SELF-REPORT METHODS

A voluminous number of self-report measures exist for assessing various dimensions of behavioral health and psychological well-being. Because of their ease and convenience of administration, and the minimal amounts of technical experience or training required for use, self-report questionnaires and surveys are among the most widely-used methods for assessing psychological and behavioral constructs. Self-report questionnaires have therefore been extensively researched and validated as tools for tracking behavioral health and psychological well-being across diverse populations. In light of recent methodological advances in psychometrics and testing theory (e.g., item response theory, factor analysis, Mokken analysis), many self-report measures have been subjected to rigorous empirical evaluation that have led to refinements in construct measurement and enhanced reliability. Another advantage of self-report methods is the minimal costs associated with ongoing maintenance (or upgrading) of equipment. Specifically, when new versions of a test or assessment tool are published, users typically do not need to purchase expensive equipment to replace obsolete versions. Instead, users merely need to purchase a new supply of surveys (in the case of paper administration) and/or an updated license (in the case of web-based or computer administration).

Although there are many benefits to using self-report assessment methods, arguably the largest setback or limitation of this approach is related to face validity, which lends vulnerability to biased responding. Response bias is often assumed to be associated with intentional symptom exaggeration for secondary gain (i.e., “faking bad” or malingering), but in high-performance and elite populations characterized by high mental health stigma, a much greater concern is the underreporting or minimization of psychological symptoms and behavioral problems (i.e., “faking good”). SMEs uniformly agreed that the underreporting of psychological symptoms and
behavioral problems is a limitation of self-report methods for long-term behavioral health monitoring of astronauts. Some SMEs felt that the use of self-report methods could reinforce the general principle of self-monitoring and were therefore in favor of their use in addition to other assessment and monitoring methods. However, **sole reliance on self-report methods was generally discouraged.**

**STARTLE REFLEX TASKS**

The startle reflex entails involuntary psychophysiological responses to a sudden and intense sensory stimulus, whether auditory or visual in nature. The amplitude of the startle reflex is influenced by the emotional content of the material presented, with pleasant stimuli being associated with reduced startle reflex amplitude whereas unpleasant stimuli are associated with increased startle reflex amplitude. At a neural level, animal studies indicate that the increased startle reflex amplitudes associated with fearful stimuli are influenced by the amygdala whereas the reduced start reflex amplitudes associated with pleasant stimuli are influenced by the nucleus accumbens.

Because startle reflex tasks assess involuntary psychophysiological responses, concerns regarding motivated responding are reduced, although it is important to note that research focused on intentionally deceptive responding has not yet been conducted with startle reflex tasks.

Specific to anxiety disorders, numerous studies support increased startle reflex during situations that signal safety, but not during situations that explicitly signal danger. Startle reflex during safe conditions versus danger conditions has also been found to predict the later onset of anxiety disorders. This pattern of findings is consistent with the general perspective that a hallmark characteristic of anxiety is the presence of worry, anxiety, and fear that is contextually inappropriate and/or excessive. In other words, in situations that are actually dangerous or threatening, a pronounced startle reflex is appropriate and adaptive, but in situations that are not dangerous or threatening, a pronounced startle reflex is unnecessary and therefore excessive. The startle reflex task might therefore be most useful as an indicator of anxiety when conducted within the context of a safe and nonthreatening environment.

Relative to anxiety disorders, startle reflex tests may be less useful as a predictor of future unipolar depressive disorders, although some research suggests that depression may have a unique response “signature” that could potentially be used to assess for a lack of positive emotions, consistent with anhedonia. For example, depressed patients rate pleasant stimuli as less pleasant and unpleasant stimuli as less unpleasant than nondepressed controls, which may suggest a form of emotional “numbness” or attenuated reactivity in response to emotionally-salient stimuli. Anxiety, by contrast, is associated with no differences in ratings of pleasant stimuli, although individuals with high anxiety tend to rate unpleasant stimuli as more unpleasant than individuals with low anxiety, a finding that suggests heightened sensitivity to negative emotional stimuli. The potential utility of startle reflex tasks for assessing and monitoring depressive symptoms is further suggested by findings indicating that nondepressed patients show a dose-effect relationship of startle reflex with emotional stimuli. Specifically, for nondepressed patients the lowest amplitude startle reflex is for pleasant stimuli and the highest amplitude startle reflex is for unpleasant stimuli. Depressed patients, however, show comparable startle reflex amplitudes for pleasant and unpleasant stimuli, perhaps because pleasant stimuli serve as an aversive condition for depressed individuals. This pattern is especially pronounced for those patients with higher levels of depressed mood and anhedonia, suggesting relative startle reflex amplitudes may be especially...
useful as an indicator of more severe mood disturbance. Shifts in the relative magnitudes of startle reflex amplitudes over time might therefore serve as an early indicator for the emergence of depression.

One potential limitation of the startle reflex task relates to possible decreased performance among individuals with comorbid depression and anxiety. Because depression attenuates the startle reflex, patients with comorbid anxiety and depressive disorder show reduced startle reflex as compared to patients with anxiety disorder only. Individuals with comorbid anxiety and depression may therefore fail to show the pronounced startle reflex in response to unpleasant cues that is characteristic of anxiety disorders. Because the utility of startle reflex tests may be reduced for individuals experiencing both anxiety and depression, this particular assessment method may need to be complemented by other methods that are more robust under conditions of comorbidity.

ATTENTIONAL BIAS TASKS

Attentional bias is the tendency for perceptual processes to be influenced by internal cognitive-affective states. For example, individuals experiencing depressive mood states tend to pay attention to and notice negative environmental stimuli associated with sadness and/or the absence of positive emotional states (e.g., words such as “sad” and “failure”; images of frowning or crying faces). Similarly, individuals prone to misuse or abuse substances tend to pay attention to alcohol- and/or drug-related cues in their environment (e.g., bottles of liquor; pill bottles). Advances in the assessment of attentional bias have led to more objective methods for measuring psychological and behavioral phenomena including mood and anxiety states, substance abuse, and even suicidal behavior. Because attentional bias involves the selective allocation of cognitive resources towards specific features or dimensions of the individual’s environment, attentional bias tasks could prove useful for assessing and detecting subclinical or premorbid behavioral health conditions. Several attentional bias tasks have been developed and used for the purposes of understanding the cognitive-affective processes that underlie psychopathology, including the emotional Stroop task, the dot-probe task, and the implicit association task. Each method differs with respect to the specific task to be performed by the respondent, but the outcome of interest for all of these tests is response latency (i.e., reaction time). Additional research is needed to determine which of these various attentional bias tasks might be most useful for assessing and monitoring various indicators of post-mission behavioral health among astronauts.

With respect to anxiety, research indicates that individuals with generalized anxiety disorder tend to show attentional bias towards threat-related stimuli. For instance, individuals with this condition show greater bias towards threat words as compared to neutral control words. Furthermore, individuals who predominantly worry about physical health show a bias towards physical threat words whereas those who predominantly worry about social situations show a bias towards social threat words. Other research suggests the attentional bias observed in generalized anxiety disorder may also be associated with depression-related constructs and stimuli.

Research on attentional bias tasks with depression has been less consistent than research with anxiety-related disorders, although results appear to be more robust when using self-relevant stimuli. For example, attentional bias towards negative self-descriptive target words selected by the participant (as opposed to words selected by the researcher) is apparent only if these stimuli are primed by negative self-descriptive phrases that activate negative self-schemas among depressed
individuals. Research further suggests that stimuli need to be presented for relatively long periods of time (1000-1500 ms) to elicit the bias in depressed individuals.\textsuperscript{85,86} Attentional bias in depression may therefore be limited to negative, self-relevant linguistic stimuli that are presented for relatively long periods of time.\textsuperscript{87} These criteria may facilitate elaborative processing that makes it difficult to disengage from negative self-descriptive language, consistent with the notion of rumination.

Research among nonclinical samples using pictures portraying neutral, happy, or threatening faces indicate that individuals with high trait anxiety show bias towards threatening facial expressions whereas dysphoria is associated with the tendency to avoid happy faces.\textsuperscript{88} Bradley, Mogg, and Millar\textsuperscript{89} similarly found that dysphoria was associated with reduced attentiveness to happy faces but no attentional bias in either direction for sad faces. Subsequent research in clinical samples has indicated that depressed individuals have an attentional bias for sad faces.\textsuperscript{90} Taken together, these results may suggest that reduced attentiveness to happy faces can serve as an early marker of subclinical or future depression, whereas increased attentiveness for sad faces could serve as a marker for current depression. Similar differences between nonclinical and clinical samples have been noted using other attentional bias tasks such as the Affective Go/No-Go Task. Using this measure, Erickson et al.\textsuperscript{91} reported that depressed patients made more omission errors when responding to happy words as compared to sad words, whereas nondepressed controls showed the reverse pattern.

Attentional bias tasks have also demonstrated incremental predictive validity relative to more traditional assessment methods for other behavioral outcomes of interest such as marital satisfaction, substance use, and suicide. For example, a four-year study of 135 married couples found that conscious attitudes about one’s spouse did not predict marital satisfaction over time but implicit (unconscious) attitudes did.\textsuperscript{92} Using the dot-probe task, attentional bias towards substance-related cues was similarly found to be a better predictor of future substance abuse than psychiatric diagnosis and a history of substance abuse treatment.\textsuperscript{93} Emotional Stroop and implicit association tasks utilizing suicide- and death-related stimuli have also proven to be better predictors of future suicide attempts than psychiatric disorder, suicide ideation, and other clinical variables.\textsuperscript{94,95}

Although the implicit association paradigm provides a useful assessment approach for assessing and monitoring a wide range of behavioral health conditions that are likely to be experienced by astronauts following long-duration exploration missions, one limitation to this method is that separate tasks are required for separate conditions of interest. In other words, the implicit association’s tasks for depression, substance abuse, marital satisfaction, and suicide implicit have been developed and tested separately. Using implicit association tasks to assess the full range of behavioral health constructs of interest could therefore by time intensive and tedious, which would lead to astronaut frustration. A useful direction for future research might therefore be the development and evaluation of a “combined” implicit association task that can measure multiple domains in a single, time-efficient test.

VOICE FREQUENCY ANALYSIS

A relatively new approach for assessing mood disturbance and anxiety entails the analysis of various qualities of speech and voice patterns. Individuals with depression, for instance, tend to have lowered speech intensity, increased monotonicity, reduced articulation rate, greater speech pause duration, and decreased fundamental frequency change rate and frequency.\textsuperscript{96-98} Although
research to date using voice-based mental health classification approaches show promise, they have largely suffered from small sample sizes, however. For instance, Scherer et al.\(^{98}\) used voice quality as an indicator of depression and PTSD in a sample of 43 subjects, Ozdas et al.\(^{99}\) attempted to use voice quality as an indicator of depression and near-term suicide risk based on the speech of 30 participants (10 suicidal, 10 depressed, and 10 control), and Moore et al.\(^{100}\) used voice data from 33 participants to classify depression.

As compared to studies focused on depression, the use of voice-based classification methods for posttraumatic stress disorder is only now emerging. Preliminary research by Scherer et al.\(^{98}\) demonstrated the ability to accurately diagnosis PTSD in 75% of cases, although more recent work by Xu et al. using machine learning methodology suggests accuracy rates up to 95%.\(^{101}\) It is possible that the accuracy of these methods with PTSD are related to the type of interview questions or audio/video stimuli used. For instance, some researchers have found that positive and neutral questions allowed for better disambiguation of PTSD group from control group than negative interview questions\(^{98}\). However, others have found that the stronger and more negative the elicited emotional response is from the patient, the better the discriminative power becomes.\(^{102}\) Because it is well-known that the confidence level for the performance of a machine learning algorithm increases with sample size\(^{102}\), larger samples are needed to refine and more definitively test the accuracy of such systems, which hold considerable promise for their ease of use and high potential for transportability via smart phone apps and internet-based interfaces.

**NEUROCOGNITIVE ASSESSMENT**

The long-term neurocognitive health of astronauts following return from exploration missions is one of NASA’s greatest concerns and was a leading issue raised by SMEs due in large part to the expectation for astronauts to be exposed to high-energy radiation for extended periods of time, which has been shown in animal models to contribute to a range of cognitive deficits\(^{15-22,25,104}\). Because astronauts will be monitored for many years post-mission, neurocognitive assessment tools that can be repeatedly administered with minimal practice effects will be necessary. **Computerized neurocognitive tests, many of which have been designed with a large number of equivalent item and test versions, therefore hold considerable promise relative to human-administered neurocognitive tests.** Several other benefits of computerized assessment have been identified including efficiency of administration, improved assessment of time-related tasks, reduced assessment time through adaptive testing protocols, cost efficiency, ease of administration across cultures and languages, and improved ability to develop and automatic decision-making algorithms\(^{105}\).

Based on research examining the effects of high energy radiation on neural structure and neurocognitive performance, tests should assess, at a minimum, the following domains due to their sensitivity to high energy radiation exposure:

- memory and attention (assessed across both visual and auditory domains);
- visual discrimination;
- reaction time; and
- behavioral impulsivity.
Several of these domains (i.e., memory and attention, visual discrimination, reaction time) are assessed by the WinSCAT, a computerized neurocognitive test currently in operational use by NASA\textsuperscript{106}. The WinSCAT is comprised of several subtests derived from the Automated Neuropsychological Assessment Metric (ANAM) developed by the Department of Defense for use with military personnel. The ANAM has been used widely with military personnel as a brief method for assessing and tracking neurocognitive performance subsequent to head injuries. Research with the ANAM has supported its validity as compared to other well-established tests of neurocognitive performance, test-retest reliability, ability to detect a recent concussion, and ability to track change in neurocognitive performance over time\textsuperscript{107-110}.

The benefit of tests like the WinSCAT and ANAM is that they assess reaction time in addition to other relevant neurocognitive domains, but as noted by Schneiderman et al.\textsuperscript{111}, the overall range of cognitive domains assessed by these tests is somewhat limited. **Newer neurocognitive tests that can efficiently assess a wider range of cognitive domains would therefore be beneficial, especially if these newer tests could also accurately assess domains relevant to mood, anxiety, and other forms of psychopathology.**

Other computerized neurocognitive tests that have demonstrated good validity and reliability are commercially available (e.g., the ImPACT)\textsuperscript{112-114}. These tests measure many of the same cognitive domains as the WinSCAT and the ANAM and have been implemented in athletic settings. Because these commercially-available tests are similar to the WinSCAT and ANAM, and no research yet exists supporting their superiority in terms of assessing neurocognitive functioning and detecting associated disorders and conditions\textsuperscript{113}, they may be less cost-effective as a method for assessing post-mission neurocognitive performance.

**SUMMARY**

Self-monitoring of behavioral health and well-being is an expectation of crew members. Self-report methods for assessing post-mission behavioral health were generally perceived as beneficial since they facilitate and reinforce this expectation. Overall, however, post-mission behavioral health assessment and monitoring should not rely solely upon self-report methods due to their considerable vulnerability to motivated responding. Within the astronaut community, underreporting and denial of symptoms and behavioral health problems are especially likely. Self-report methods are therefore judged to be insufficient for behavioral health assessment and monitoring following long-duration spaceflight. To circumvent this problem, objective assessment methods should be implemented, whether in conjunction with or in the place of self-report methods. Although several objective methods exist for assessing common behavioral health problems such as mood, anxiety, substance abuse, relationship functioning, posttraumatic stress, cognitive performance, and even suicide risk, research has not yet been conducted that compares the relative performance and efficiency of these methods in isolation or in combination. Future research should focus on determining the most effective combination of measures that balances predictive validity and efficiency.

From an implementation perspective, assessment methods should also be engaging and/or fun, as monotonous and “boring” tasks could reduce performance and potentially the validity of results. Future research should therefore include studies designed to determine how assessment methods can be reliably and validly administered in formats that increase engagement and interest (e.g., game format).
POTENTIAL COUNTERMEASURES FOR PROMOTING AND MAINTAINING POST-MISSION BEHAVIORAL HEALTH

PHYSICAL HEALTH

Physical fatigue and health complaints were reported by all SMEs as the most salient features of post-mission reintegration. The impact of weightlessness on muscle strength and volume is now well-known, with evidence supporting a dose-effect relationship in which longer duration weightlessness is associated with greater atrophic declines in muscle strength. Although the astronauts interviewed for this project indicated they knew about these effects prior to their missions, the subjective experience of physical exhaustion and fatigue upon return to Earth nonetheless presented a greater challenge than what they were expecting. Crew support personnel further indicated that the physical toll of spaceflight is often a salient issue impacting reintegration post-mission, and can often have a larger impact on astronauts than is often expected. Post-mission physical fatigue and exhaustion are not limited to low-gravity or zero-gravity missions, however; these issues are also reported by analog study participants during and after long-duration ICE missions in Antarctica, suggesting that post-mission physical fatigue is likely influenced by psychological and environmental demands as well as the physical demands of long-duration missions.

Because physical and emotional health are highly interrelated, post-mission behavioral health programs should include physical exercise programs. As applied to behavioral health, physical exercise is negatively associated with depression, anxiety, and sensitivity stress, but is positively associated with psychological well-being. In alignment with these research findings, SMEs uniformly agreed that physical activity is an important part of post-mission reintegration. NASA currently implements a post-mission physical rehabilitation program that was generally perceived by SMEs as positive and critical for reintegration. The consensus was that this program should be maintained for astronauts returning from long-duration exploration missions, although it might be necessary to expand or adapt the program for long-duration missions.

FAMILY CONNECTEDNESS & SOCIAL SUPPORT

There was consensus among SMEs that strong connections with family members and other sources of social support were critical for post-mission reintegration and long-term behavioral health. SME #2 noted that having someone to help manage the day-to-day responsibilities of life (e.g., car problems, dealing with home repairs) is critical, especially for unmarried or unpartnered crew members. This sentiment was echoed by SME #3, who noted that the biggest challenges following their deployments was becoming reacquainted with the minor routines of society that are often taken for granted, such as making decisions about what to wear and what to eat, and how to use money. These observations align with anecdotal reports of military personnel returning from deployments, who describe struggling with the “little things” more so than major stressors. The tangible dimension of social support, which entails the receipt of material support to assist with the resolution or prevention of problems (see discussion in a previous section of this report), may therefore be especially important soon after the return to Earth.

Preparing family members and astronauts for this transition may be a useful countermeasure for easing post-mission transitions. Access to supportive services for family members and service members have been found to be among the most frequently-reported and
useful coping strategies for military families postdeployment. Transitioning family members who can talk to other transitioning family members cope more effectively with reintegration, as do transitioning service members who can talk to other transitioning service members. Creating mechanisms by which astronauts and their families can remain in contact with each other during the months immediately following the return to Earth may therefore have a positive impact on reintegration and long-term behavioral health.

Given the unique nature of long-duration exploration missions, multiple SMEs noted that astronauts returning from exploration missions are very likely to experience much higher than usual levels of fame and public recognition. According to SMEs, public relations events and travel generally do not include astronauts’ family members and social support system. Because a busy public relations schedule could disrupt the reintegration process, allowing astronauts to be accompanied by family members and/or friends during public relations travel could help to offset the stress associated with this expected post-mission activity. In addition, NASA should implement strategies for helping astronauts to maintain as much privacy as desired during reintegration.

POST-MISSION TRANSITION CENTER

One strategy for easing reintegration is the implementation of a formal transition and reintegration program for astronauts, similar to the Deployment Transition Center (DTC) model implemented by the U.S. Air Force in 2009. The DTC was established “…to provide critical reintegration and decompression time to meet the needs of Airmen” by providing knowledge and skills to facilitate decompression and reintegration to their home station, workplace, and families. The DTC is a two-day program that implements educational discussions on a range of topics including stressors experienced while deployed and strategies for transitioning back home. The program is facilitated primarily by senior peers with relevant military and deployment experiences, and is supported (but not led) by behavioral health professionals. By positioning peers as the primary facilitators, the program gains credibility to participating service members and increases the likelihood that participants will share their experiences openly and honestly. Preliminary data collected by the Air Force suggests that over 80% of military personnel rate the DTC as worthwhile. In terms of effectiveness, this same report indicates that DTC participants report less severe PTSD symptoms, fewer serious conflicts with others, and less alcohol use during postdeployment health screening as compared to military personnel who do not participate in the DTC.

An important characteristic of the DTC that is believed to contribute to its efficacy is its physical location at Ramstein Air Base, Germany. The decision to place the DTC at this location was influenced by several criteria that could serve as a foundation for establishing a similar program for astronauts:

- **Proximity to existing airflow routes.** The transition site should be placed close enough to existing travel routes to minimize costs while preserving the “natural flow” during transition. Sites should also have sufficient support services available to facilitate the transition home.
- **Safety.** The transition site should be placed in a location that can sufficiently protect the safety and security of crew members. This includes the ability to control public access to crew members.
• **Seclusion.** The transition site should be located in a sufficiently secluded location to provide safety and security while also reinforcing the notion that the mission is not considered complete until the program has been completed.

• **Site setup.** The transition site should have sufficient resources to support the operational needs of the program (e.g., computers, internet access, projectors, classrooms, etc.).

• **Quality of life.** In addition to room and board, the transition site should provide sufficient amenities to ensure a high quality of life for crew members. These amenities include computer and internet access, phones, laundry facilities, fitness facilities, and recreational facilities.

• **Recreation.** The transition site should provide easy access to recreational activities.

Currently, the Air Force does not allow family members to participate in DTC programming or to visit with service members in order to allow redeploying service members the opportunity to use the DTC as a “stepping stone” in the transition process. *It remains unknown if a similar transition program for spouses and family members would lead to even better outcomes; this may be an area for future research.*

**MEANINGFUL WORK & ACTIVITIES**

Because an exploration mission is likely to be perceived as a peak experience in life, returning astronauts may struggle to find meaning or enjoyment in life upon their return to Earth. As several SMEs noted, astronauts may struggle with questions about what they should do with their lives upon return because typical and usual goals may be perceived as mundane or unrewarding. Activities and tasks that provide a personal sense of meaning to each individual astronaut will therefore be critical.

Because meaning in life is a subjective experience defined by the individual[^61^], countermeasures designed to enhance astronauts’ meaning in life will need to be flexible and “customized” to each individual crew member; universal or standardized activities that are mandated for all crew members are unlikely to be effective. For example, a few SMEs suggested that purpose and meaning in life could by fostered by giving astronauts a more central role in the scientific projects that will be conducted during the exploration. SMEs noted that crew members’ roles in scientific studies are typically limited to being research subjects and/or study technicians. Including astronauts as co-investigators who contribute to study design, data analysis and interpretation, and presentation and/or authoring of results may increase crew member buy-in and provide a sense of ownership of the mission. SMEs also suggested quickly moving crew members into leadership roles to help plan future missions, which would create an opportunity for returning astronauts to directly use their knowledge and experience to help other crew members as well as to influence NASA’s decision-making and overall mission.

**ATTENTIONAL BIAS MODIFICATION TASKS**

Attentional bias modification tasks are based on the same principles and procedures used to measure cognitive-affective vulnerabilities to behavioral health issues, and may potentially be used as countermeasures and interventions to prevent or reduce psychological distress and/or behavioral problems. For example, previously-depressed individuals who undergo an attentional bias modification task using images of positive faces report significantly reduced depression symptom...
severity one month later; the same effect was not seen for word-based stimuli, however. A recent meta-analysis of 12 randomized controlled trials supported an overall positive effect of attentional bias modification tasks for the reduction of anxiety across a range of samples and stressors, of which one was moving to a foreign country, which may be a useful analog for astronauts returning from long-duration space exploration missions. Subsequent meta-analytic work has suggested that attentional bias modification tasks may be relatively more effective for reducing anxiety than depression, with larger effects being observed among individuals who participate in multiple training sessions as compared to those who participate in only one training session, and larger effects being observed when assessed after exposure to a stressor. Preliminary evidence further suggests that attentional bias modification tasks reduce attentional bias to alcohol-related cues and may reduce alcohol-related risk factors such as craving and subjective control over drinking, and contributes to decreased rates of relapse among individuals with alcohol dependency.

The mechanisms by which attentional bias modification tasks reduce psychopathology are unclear, although research has implicated changes to the lateral prefrontal cortex following the procedure. It also remains unclear if attentional bias modification tests can be used to “inoculate” nonclinical individuals against the subsequent development of behavioral health issues such as depression, anxiety, and substance abuse. This may be an important future direction for NASA research, as attentional bias modification tasks administered during the final stages of a long-duration exploration mission (e.g., during the return trip) may be a useful strategy for preventing the emergence of post-mission behavioral health issues among astronauts returning from long-duration exploration missions. Although some studies suggest that attentional bias modification tasks completed in an individual’s home can lead to reductions in behavioral health vulnerabilities similar to those seen in laboratory settings, other studies suggest that attentional bias modification tasks delivered over the internet do not yield the same positive results. Additional research to adapt and modify the task for effective use in non-laboratory settings, whether during or post-mission, would therefore be an important future direction for NASA.

**SUMMARY**

Countermeasures for potential threats to astronauts’ behavioral health should include a range of institutional and individual-level strategies. Because of expected variability in the needs and preferences of crew members, customization of strategies to the unique needs of each astronaut will be important. To maximize efficacy, countermeasures should target multiple domains including physical health, psychological and cognitive functioning, occupational satisfaction, and family and social relationships. Future research should seek to identify individual differences in the relative efficacy of various countermeasures.
OPERATIONAL RECOMMENDATIONS

Based on the results of this literature review and series of SME interviews, several operational recommendations are provided. These operational areas are assessed to be most relevant to post-mission behavioral health, and are expected to have the greatest positive impact.

AREA 1: CREW MEMBER AUTONOMY

A commonly-reported source of tension among astronauts and ground-based command crew surrounds the balance of operational decision-making during missions. There is consensus among all stakeholders that astronauts will need to exercise a much higher level of control over operational decisions during long-duration exploration missions relative to current spaceflight missions due to the extended time delay that exists between Earth and Mars. There is a general sense that the high level of autonomy will be welcomed by crew members, but there is also a concern that increased tension and stress might occur as astronauts lose autonomy during their approach towards Earth, during which the communication time delay with ground control will shorten. In addition to conducting analog studies focused on understanding the issues related to communication time delays of varying lengths, NASA should also seek to understand the issues related to the impact of autonomy and control on mission performance. The change process itself (i.e., shift from high to low autonomy) that is expected to correlate with change in time delay should receive particular emphasis. Such research could inform “best practices” for negotiating astronauts’ return to Earth, which could in turn mitigate tension and conflict that could adversely impact post-mission behavioral health.

AREA 2: INTEGRATION OF FAMILY MEMBERS INTO PROGRAMMING

Maintaining social support via family connectivity, peer relationships, and medical professionals will be essential for preventing the emergence and worsening of post-mission behavioral health conditions. Following the return to Earth, role transition is likely to be a primary source of stress for astronauts. Family members and other sources of social support beyond spousal relationships (e.g., friends and peers, extended family, coworkers) should therefore be integrated more centrally into programs and strategies aimed at mitigating the emergence of behavioral health issues.

AREA 3: CREW MEMBER PARTICIPATION IN MISSION PLANNING

Given the high level of autonomy expected of crew members, astronauts should be included in all stages of mission planning. Similarly, crew members should take part in the planning and design of scientific projects and research studies, as this is likely to increase buy-in and support for the scientific mission as well as providing meaningful work that could offset or buffer sources of stress.

AREA 4: MANAGEMENT OF POST-MISSION REINTEGRATION

Returning astronauts are likely to acquire celebrity status as international “heroes” among the public, which could create a high level of pressure and stress. The development of a “repatriation” process could be useful for mitigating this stress. NASA should consider consulting with other federal agencies such as the Department of Defense, Central Intelligence Agency, and the Federal Bureau of Investigations to review existing repatriation procedures for facilitating the
reintegration of personnel experiencing isolation and/or confinement. In addition, NASA should consider the implementation of a “transition center” akin to the Deployment Transition Center used by the U.S. Air Force for military personnel returning from Iraq and Afghanistan. Family members should be allowed to take part in post-mission reintegration programs, to include public relations activities and travel.

**AREA 5: DATA MANAGEMENT AND ACCESS**

Due to concerns about privacy and confidentiality, and the legitimate desire to protect the high level of trust that exists between astronauts and behavioral health clinicians, access to behavioral health records is limited to behavioral health clinicians. Research on post-mission behavioral health among active astronauts is therefore limited to studies and protocols that do not entail the access of behavioral health records by external researchers or LSAH epidemiologists. In order to reduce concerns about confidentiality and privacy of behavioral health records, NASA should initially support and implement studies that collect behavioral health data for the sole use of research. Such data would be maintained separate from the medical record, thereby preserving the trust that exists between astronauts and behavioral health clinicians while advancing our understanding and knowledge of such issues. Because information contained in behavioral health and medical records may provide unique information that can answer important questions regarding post-mission behavioral health, any research based on medical record data should begin with data obtained from retired crew members who are no longer in the active astronaut corps, as this group has reportedly indicated fewer concerns about the use of their data to benefit current and future astronauts. Such research would require the consent of retired personnel, and should follow existing NASA procedures governing the use of medical data for research.

**AREA 6: POST-MISSION BEHAVIORAL HEALTH RESEARCH FUNDING**

Although NASA has an active research program focused on crew member behavioral health, this research has largely focused on preflight, inflight, and short-term postflight timeframes. Research focused on the long-term behavioral health of astronauts is deficient. NASA should therefore increase resources and funding to address this critical knowledge and capability gap.

**RECOMMENDATIONS FOR FUTURE RESEARCH**

Overall, research on the behavioral health and well-being of astronauts is limited. Based on the present literature review, however, several gaps in knowledge relevant to the assessment and monitoring of post-mission behavioral health were identified. Identified gaps are listed below along with recommendations for future research projects that could lead to improvements in the assessment of astronaut behavioral health and psychological well-being. Because the astronaut community is very small in number, research to address these research gaps will likely need to be conducted in analog populations that share common characteristics with astronauts, such as military personnel (especially aviators and special duty personnel), pilots, and highly-educated professionals.

Research focused on these knowledge gaps should also be conducted among former astronauts no longer in the active astronaut corps, a subgroup of astronauts who may have fewer concerns about participating in behavioral health research and/or using their behavioral health data for research purposes. Although the LSAH repository has few data specific to behavioral health,
proxy variables (e.g., cortisol, heart rate, medication use) may be available for use instead. Such research may facilitate the culture shift needed to increase astronauts’ willingness to include their behavioral health data in the LSAH repository for future research use.

GAP 1: EFFECTS OF INTENTIONAL DECEPTION ON COMPUTERIZED ASSESSMENT TESTS

Although objective assessment methods such as the startle reflex task, attentional bias task, and voice frequency methods are assumed to be robust against biased responding, there is limited information available regarding the reliability of validity of these methods under conditions of intentional deception. Research focused on the performance of these methods among individuals attempting to minimize or conceal behavioral health problems like depression, anxiety, or substance misuse, in particular, is needed to determine the accuracy and utility of these methods among astronauts.

GAP 2: REDUCING RESPONSE BIAS ON SELF-REPORT METHODS

As noted above, self-report assessment methods are limited by their face validity and vulnerability to motivated responding and intentional deception. Due to their relative convenience and cost effectiveness, however, self-report assessment methods may hold some practical utility for long-term monitoring of behavioral health. Research focused on strategies that can reduce response bias on self-report assessment tools is therefore needed to determine if the accuracy and utility of these methods can be retained despite intentional deception, especially under conditions of faking good.

GAP 3: OPTIMAL COMBINATIONS OF ASSESSMENT METHODS

Existing research on the psychometric properties and diagnostic accuracy of self-report and objective assessment methods has primarily focused on the performance of each instrument when administered in isolation. In contrast, there is limited research focused on how various instruments could be combined to incrementally improve diagnostic accuracy as compared to each instrument individually. Research is needed to determine if diagnostic accuracy, predictive validity, and reliability can be improved by administering multiple assessment instruments.

GAP 4: EFFECTS OF REPEATED ADMINISTRATIONS ON RELIABILITY AND VALIDITY OF ASSESSMENT METHODS

Existing research on the psychometric properties and diagnostic accuracy of self-report and objective assessment methods typically focuses on the performance of each instrument over time following administration at a single time point. Comparatively less research has focused on the incremental performance of assessment methods when administered repeatedly over time. It is possible, for instance, that relative change in scores across repeated administrations could yield improved performance. Research is needed to determine if predictive algorithms based on repeated assessments result in better predictive validity as compared to algorithms based on a single assessment.
GAP 5: INDIVIDUAL DIFFERENCES IN RADIATION SENSITIVITY

Animal research indicates that certain subgroups of rats exposed to high energy radiation show minimal behavioral changes and declines in neurocognitive performance after exposure, suggesting the possibility of individual differences in radiation sensitivity. Additional research designed to identify genetic and biological factors that influence radiation sensitivity could lead to the development of countermeasures (e.g., medication) that could protect astronauts against the deleterious effects of high energy radiation exposure.

GAP 6: MODERATORS OF PROTECTIVE EFFECTS OF SOCIAL SUPPORT

Different dimensions of social support are differentially associated with various behavioral health conditions. Research further suggests that different sources of social support (e.g., family, peers, co-workers) can differentially influence the emergence of behavioral health conditions. Additional research is needed to determine how these different dimensions could moderate the protective effects of social support on the behavioral health and well-being of astronauts.

GAP 7: EFFECTIVENESS OF COUNTERMEASURES

The effectiveness of many behavioral health interventions are based in large part on studies conducted in clinical samples, many of whom have been diagnosed with behavioral health conditions like depression, anxiety, or substance use disorders. The effectiveness of these methods as strategies to prevent the later onset of behavioral health conditions among healthy, high-performance samples remains unclear. Research focused on the long-term effectiveness of various countermeasures to prevent the later emergence of behavioral health conditions among astronauts, both in isolation and in combination, is therefore needed.
APPENDIX A: SEMI-STRUCTURED INTERVIEW QUESTIONS FOR SUBJECT MATTER EXPERT INTERVIEWS

1. Is there a particular process or “trajectory” of readjustment following the return from an extended mission?

2. Are there any aspects of returning from an extended mission that are particularly difficult?

3. Are there any aspects of returning from an extended mission that are particularly easy?

4. Are there aspects of the most-mission return that seem to be unexpected or unanticipated?

5. What is different about returning from long duration missions as compared to short duration missions?

6. What do you see as being some of the most common concerns or problems following the return from an extended mission?

7. Which dimensions of behavioral health do you believe are most critical for long-term tracking among astronauts returning from an extended mission?

8. What are the biggest challenges in tracking and monitoring behavioral health?

9. How would you recommend those challenges be addressed or circumvented?

10. Do you expect that there would be any differences in behavioral health needs among those returning from a mission to Mars?

11. Do you expect that there would be a need to assess and track behavioral health needs differently for those returning from a mission to Mars?

12. Are there any methods for tracking behavioral health that are currently in use that you think should be maintained?

13. Are there any methods currently in use that you think may need to be improved or adjusted for this mission?

14. Are there any particular gaps that you see in the current methods that you think need to be filled?
APPENDIX B: ANNUAL ASTRONAUT BEHAVIORAL HEALTH & PERFORMANCE INTERVIEW

Astronaut: Date and Time: NASA Interviewer:

1. Summary of current NASA career status:

2. Professional training and workload:

3. Sleep and fatigue:

4. Peer and management relationships:

5. Social and family life:

6. Greatest professional and personal challenges:

7. Primary goals for the coming year:

8. Brief MSE & Conclusions:
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Space flight occurs in extreme environments. As a result, crew member selection processes are stringent and rigorous. Despite the existence of these processes, behavioral problems and psychological stress can emerge among astronauts. As NASA shifts its focus towards long-duration human exploration missions to asteroids and Mars, increased attention has been directed towards understanding the behavioral health needs of those astronauts selected to participate in these missions. Furthermore, astronauts will spend greater periods of time in confined and dangerous environments and, upon their return to Earth, will have to reintegrate into families and social contexts that will have changed considerably during their absence. As the length of space flight increases, rates of behavioral health problems such as depression, anxiety, and neurocognitive deficits are also expected to increase. The purpose of the current report is to provide an overview of the likely contributors to astronauts' post-mission behavioral health, a description of existing and potential future methods for assessing and monitoring astronauts' behavioral health following their return from long-duration space flight, possible countermeasures to mitigate and offset threats to astronauts' post-mission behavioral health, and recommended directions for future NASA research to address existing knowledge gaps in behavioral health assessment among astronauts.