Long-Duration Space Exploration and Emotional Health: Recommendations for Conceptualizing and Evaluating Risk

Candice A. Alfano

Joanne Bower

Jennifer Cowie

Simon Lau

Department of Psychology, University of Houston

Richard J. Simpson

Department of Health and Human Performance, University of Houston

This paper was supported by a research grant from the National Aeronautics and Space Administration (NASA; # NNX15AC13G) awarded to C. Alfano and R. Simpson. Address all correspondence to Candice A. Alfano, 126 Heyne Building, Department of Psychology, University of Houston, Houston, TX, USA, 77204; caalfano@uh.edu.

Abstract

Spaceflight to Mars will by far exceed the duration of any previous mission. Although behavioral health risks are routinely highlighted among the most serious threats to crew safety, understanding of specific emotional responses most likely to occur and interfere with mission success has lagged in comparison to other risk domains. Even within the domain of behavioral health, emotional constructs remain to be 'unpacked' to the same extent as other factors such as attention and fatigue. The current paper provides a review of previous studies that have examined emotional responses in isolated, confined, extreme environments (ICE) toward informing a needed research agenda. We include research conducted during space flight, long-duration space simulation analogs, and polar environments and utilize a widely-accepted and studied model of emotion and emotion regulation by Gross [6] to conceptualize specific findings. Lastly, we propose four specific directions for future research: (1) use of a guiding theoretical framework for evaluating emotion responses in ICE environments; (2) leveraging multi-method approaches to improve the reliability of subjective reports of emotional health; (3) a priori selection of precise emotional constructs to guide measure selection; and (4) focusing on positive in addition to negative emotion in order to provide a more complete understanding of individual risk and resilience.

Keywords: spaceflight; extreme environments; emotion; regulation; coping; behavioral health

1.0 Introduction

Exploration of Mars has been an explicit goal of the National Aeronautics and Space Administration (NASA) for decades. A Mars mission will by far exceed the duration of any previous mission, including the recent 340-day journey of American astronaut Scott Kelly, and the world record 437-day mission of former Russian cosmonaut, Valeri Polyakov. The approximate 34 million miles that separate Mars and Earth is not the only challenge for a Mars mission. Prolonged exposure to high levels of radiation, low levels of gravity, isolation and confinement, sensory deprivation, altered light/dark cycles, heavy workloads mixed with periods of monotony, and delayed communications with ground crew are among a long list of extreme stressors that threaten the safety and success of a Mars crew [1,2].

Along with a host of potential physical and technological risks, maladaptive psychological reactions greatly threaten the success of a future Mars mission. The range of extreme stressors that a Mars crew will face provides fertile ground for psychological problems to emerge. Crew selection methods and effective countermeasures can serve to reduce such risk, but even the most competent, highly-skilled humans are susceptible to adaptation problems in unpredictable, extreme environments. In fact, psychological risks are considered among the most serious threats posed to crew members during space exploration [3] with psychologists and psychiatrists cautioning against these dangers since the inception of the U.S. space program [4]. Apt example comes from the “Strike in Space” that occurred in December, 1973, when a Skylab space station crew voluntarily cut off communication with Houston Mission Control. Numerous events and factors contributed to the crew’s decision, but most prominent among them were feelings of frustration and anger [5]. It is seemingly paradoxical then, that previous research has paid far less attention to potential psychological reactions during a future Mars mission than other risk factors.

The overarching goal of this paper is to review current knowledge regarding emotional health during long-duration space exploration (LDSE) utilizing a theoretical framework of emotion. We focus on 'emotional health' for two reasons. First, although emotions represent only one aspect of psychological health, far greater effort has been directed at evaluating and understanding the cognitive and behavioral alterations that occur in space [3]. As a result, emotional constructs remain to be 'unpacked' to the same extent as other psychological factors such as attention, reaction speed, and fatigue. Second, despite a dearth of empirical data, it is widely believed that maladaptive emotional responses pose as great if not greater risk for LDSE as other aspects of psychological health [3].

Our review is organized by four main objectives. First, we provide a brief historical perspective in understanding some of the challenges for assessing emotion during space flight. We then propose a new direction for future research in this area guided by precise definitions of emotional constructs, a focus on positive along with negative emotion, and a well-supported theoretical model of emotion regulation [6,7]. This is followed by an integrative summary of available research conducted during space flight and in analog isolated, confined, extreme (ICE) environments including extended-duration space simulation studies and polar environments. In line with a focus on emotional health, we include studies where emotional constructs have specifically been examined, including coping behaviors. In a final section, we integrate our literature review with our theoretical model in providing several specific recommendations for future research.

1.1 Psychological Risk in Space: A Brief History

Astronauts' have inspired awe from the media and public since the first U.S. solo (Mercury), two-person (Gemini), and three-person (Apollo) sub-orbital and orbital missions. Wide-spread perception that these individuals simply had "the right stuff" [8] was confirmed by the absence of any critical psychological incidents or performance deficits during these brief, early missions. Consequently, extensive psychological testing was replaced with a more simplistic focus on exclusionary criteria which included any pre-existing psychiatric disorders [4]. Interest in psychological factors was renewed however in the mid-1990s as a result of several overlapping developments. In 1994, flight surgeon and psychiatrist, Patricia Santy, published the controversial book, *"Choosing the Right Stuff: The Psychological Selection of Astronauts and Cosmonauts"* in which she highlighted major gaps in NASA's evaluation processes and research program with regard to mental health. Phase one of the Shuttle/Mir Program, a collaborative effort between the Russians and U.S. also began that year. These longer duration missions provided new, anecdotal evidence of significant individual and interpersonal problems in space [9,10].

In 2001, the National Academy of Sciences published a commissioned, comprehensive report titled, "*Safe Passage: Astronaut Care for Exploration Missions"* [11]. Along with exposure to radiation and bone loss, the report named 'behavioral health' among the most significant risks for crew members during a Mars mission. Behavioral health is a broad, all-encompassing term that recognizes behaviors, cognition, aspects of performance, and emotional responses to emerge as a result of interactions between personal and environmental characteristics. Although the terms 'behavioral health' and 'mental health' are sometimes uses interchangeably,[1] the former is much broader. It also more successfully avoids the stigma that continues to accompany the topic of mental health specifically.

Today, NASA and other agencies favor the term behavioral health in place of mental or emotional health. On the one hand, assessment of a wide range of changes and symptoms aligns with many of the unique aspects of LDSE including multiple phases and transitions and atmospheric changes. On the other hand however, broad-based assessment approaches are unlikely to provide an understanding of precise indicators of risk for more serious problems. Assessment of nonspecific, emotion-laden constructs such as ‘stress reactions’, ‘emotional instability’ and ‘asthenia’ found in prior studies underscores this point. In fact, one previous review identified 20 different definitions and 58 distinct symptoms associated with asthenia [12]. Clearly, the ability to predict and, ultimately, counter emotional health risk during LDSE necessitates greater sensitivity and specificity.

1.2 Shifting Focus to Emotional Health

To date, identification of emotional health in space and other ICE environments has primarily relied on broad measures of mood and/or affect – terms that are commonly, though incorrectly, used interchangeably [13]. *Affect* is a superordinate construct, typically examined across two general dimensions (negative and positive affect) that tend to be negatively correlated. Affect can also be high or low in terms of arousal level (e.g., one’s positive affect can

---

[1]Notably, as of the writing of this article, entering the term ‘behavioral health’ in Wikipedia’s search field automatically directs the user to a the definition for ‘mental health’.

be of high or low-level arousal). Individuals experience affect constantly, although its nature and intensity varies over time.

By comparison, *moods* are more global, longer-lasting, and linked to innate differences in personality [14,15]. Moods are generally considered either positive or negative and subsume all subjective feelings states, which means non-emotional feelings can contribute to one's mood (e.g., feeling tired can contribute to a negative mood). A negative mood that persists for a prolonged period of time is the basis of several clinical disorders, including depression and dysthymia.

Concordant with the need to both forecast and counter risk for LDSE, we argue for a more specific focus still, on emotion. *Emotions* differ from affect and mood in critical ways. First, emotions are rapid, multi-faceted responses to specific (internal or external) stimuli/events that allow the individual to meet the demands of their environment [16]. Emotions can be felt briefly or linger over time, and serve specific functions in various types of situations and contexts (e.g., feelings of disgust when smelling spoiled food). Emotional reactions also involve subjective, behavioral, and physiologic components, and can therefore be measured using multiple forms of assessment.

Evaluation of emotion is also better suited to understanding aspects of resilience in addition to risk. Although space travel has been found to exert salutogenic effects (i.e., positive experiences that support well-being) including feelings of accomplishment, wonderment, and awe [17–21], evidence is primarily limited to unstructured individual descriptions. Furthermore, many of the stressors present during space flight, such as sleep loss and altered light/dark cycles, have been found to adversely affect positive emotions to the same or even greater extent as negative emotions. For example, both partial and total sleep deprivation has been shown to be most detrimental for positive emotions [e.g., 22–24]. Concurrent assessment of positive and negative emotional responses would therefore provide a more comprehensive understanding of both risk and resilience.

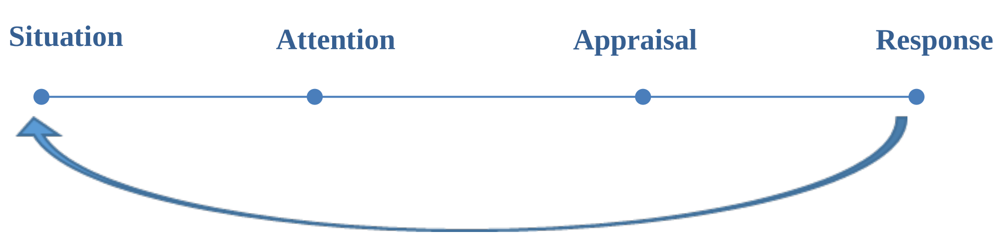
From a risk assessment standpoint, it is also true that the experience of affect, mood, and emotions might ultimately be less indicative of risk than the degree to which they can be effectively regulated. Example of this comes from research in trauma-exposed individuals who subsequently develop post-traumatic stress disorder (PTSD). While elevations in negative emotions such as fear, sadness, and guilt are typical in the days and weeks following a traumatic event, attempting to regulate these emotions through the use of ineffective strategies increases the probability of developing PTSD. In particular, avoidance of trauma-related cues paradoxically serves to increase emotional reactivity and maintain distress over time [e.g., 25–27]. Even in non-clinical populations, those who cannot effectively regulate their emotional responses to meet the demands of their environment experience longer and more severe emotional distress [28]. Regulatory strategies are therefore viewed as both risk factors for, and protective against, psychopathology.

Broadly, *emotion regulation* refers to the heterogeneous set of actions that influence what emotions we have, when we have them, and how often [6]. Emotion regulation is sometimes conflated with coping, but these constructs, while overlapping, are not interchangeable. Both are associated with active attempts to modify emotional responses, but two key differences distinguish coping from emotion regulation. *Coping* is predominantly focused on managing negative emotions while emotion regulation includes attempts to change the intensity and/or duration of both positive and negative emotions. Secondly, coping emphasizes management of one's emotional responses over prolonged periods (e.g., winter-over season) whereas emotion regulation focuses on modifying specific emotions elicited by a proximal stimulus or event [29]. Similar to distinctions between mood, affect and emotion, we believe an explicit focus on emotion regulation to be a critical direction for future research.

1.3 A Framework for Conceptualizing Emotional Health

Gross's [6,7] *Modal Model of Emotion* represents one of the most widely-accepted and well-studied models of emotion. According to the model, emotions involve person-situation transactions that give rise to a set of coordinated, yet flexible multi-system of responses. Figure 1 depicts a *situation – attention – appraisal – response* sequence at the core of this model [30]. The sequence is initiated by a situation, either internal or external, that is personally relevant to the individual. External situations relate to aspects of one's physical or social environment whereas internal situations represent private, personal experiences (e.g., feeling physically ill, thinking one has failed at a task). The individual attends to these situations in various ways (e.g., visually, cognitively) which results in a subjective appraisal (e.g., positive or negative) that is reflective of one's personal goals. Appraisals give rise to subjective feelings, behavioral actions, and physiological reactions (i.e., a coordinated set of responses). Emotional responses can in turn influence and modify aspects of the original situation (depicted by an arrow in Figure 1).

Figure 1. Modal Model of Emotion. From *Gross & Thompson, 2007*.



Principally, emotional responses are adaptive in that they allow the individual to manage situational demands (e.g., the emotion of fear increases blood flow to the extremities to facilitate escape from threat). Emotional responses can also be maladaptive however, either in terms of their intensity (the response is too large or small given the situation), duration (the emotion lasts too long or not long enough), frequency (experiencing an emotion too often or too seldom), and/or type (the emotion experienced is inappropriate for the specific situation) [29].

Once generated, there are a multitude of ways one might attempt to regulate (i.e., modify) his/her emotions. Gross [6,7] describes five stages along an unfolding timeline of emotional response at which emotion regulation strategies might occur (see Figure 2). The first four stages of the model (i.e., situation selection, situation modification, attentional deployment, and cognitive change) are described as *antecedent-focused* strategies. They are employed prior to the full generation of an emotional response and therefore before any changes in behavior or physiologic arousal are typically observable.

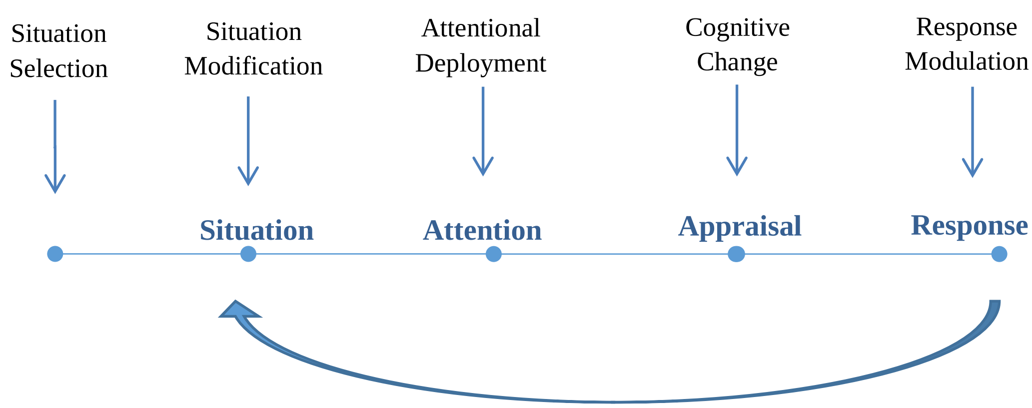
Situation selection occurs when an individual creates, seeks out, or avoids a situation that results in a desired or undesired emotional state. For example, one might engage in exercise or read an old letter from a family member in order to create a positive emotional experience, or purposefully avoid a crew member who routinely elicits frustration.

Situation modification refers to attempts to modify or change aspects of an external situation already encountered in order alter its emotional impact (e.g., using humor in a tense situation; displaying certain facial expressions to communicate annoyance and a desire to be left alone). Both situation selection and modification alter the emotion generation process at its earliest point.

Attentional deployment refers to the way an individual directs their attention in relation to an emotion-eliciting situation/event. A commonly studied attentional strategy in emotion regulation research is *distraction*. Attention can be altered either externally (e.g., looking away from a sad image) or internally (e.g., thinking about a positive memory) and disrupt the emotion generation process by altering which aspects of a situation are most salient.

Cognitive change involves regulatory strategies that alter the meaning of an emotion eliciting-situation/event. *Reappraisal* is one commonly used strategy and includes the modification of one's thought-processes about a situation/event (e.g., "He is just irritable because he did not sleep well") or internal feelings (e.g., "I am acting defensively because I feel embarrassed"). Adaptive use of cognitive change strategies typically includes appraisals that are less negative or more positive.

Figure 2. Process Model of Emotion Regulation. From *Gross & Thompson, 2007.*



The final stage is *response modulation* and includes strategies that are employed after an emotional response has already been fully generated (i.e., they are *response-focused).* Examples of response modulation are vast but can be thought of broadly as either adaptive (e.g., exercise, deep breathing) or maladaptive (e.g., verbal aggression, alcohol use). One such strategy is *suppression*, which includes attempts to hide any visible signs of emotion (e.g., giggling, crying).

Attempts to alter an emotional response once it has already been elicited generally necessitate greater effort than those occurring earlier in the process.

2.0 Methods of the Current Review

The electronic databases MEDLINE, PubMed, Academic Search Complete, Inter-university Consortium for Political and Social Research, Journal Storage, PsycARTICLES, Psychology & Behavioral Sciences Collection, PsychINFO, Google Scholar, and the Johnson Technical Reports Server were searched for relevant empirical papers, official reports, and book chapters. The following search terms were used: *psychology*, *psychiatry*, *mental health*, *neurobehavior*, *mood*, *affect*, *emotion*, *stress*, *reactivity*, *coping*, *adaptation*, *depression*, *anxiety*, and *psychopathology*, which were cross-referenced with the terms, *space*, *isolated environment*, *confined environment*, *extreme environment*, *long duration mission*, *long duration isolation*, *Mars*, *Mars105*, *Mars520*, *Mars500*, *space simulation*, *space analog*, *polar expedition*, *winter-over*, *Artic*, *Antarctic*, *International Space Station*, *Shuttle mission*, and *Mir Space Station.* Given the current paper's focus on emotional health during LDSE, we included only those papers, chapters, and reports that specifically examined at least one emotion-based outcome (e.g., mood, anxiety) during space flight, polar expeditions/winter-over studies, or extended duration (i.e., > 100 days) space simulation environments. Reference lists of appropriate papers were also examined for other relevant empirical studies and/or official reports not identified using the search terms above.

Based on these criteria, a total of 76 publications were identified for inclusion in the current review. Notably however, the methodologies, populations included, and overall scientific rigor of these publications varied considerably, from well-controlled analog studies, to multinational crews on board the International Space Station (ISS), to small polar exploration teams, to retrospective designs utilizing non-validated assessment instruments. Since meaningful quantitative analysis of these data was not possible, our review is broken down by qualitative description of findings within specific ICE settings. A summary of findings addressing changes in emotional states during exposure to isolated, confined and extreme environments can be found in Table 1.

<Insert Table 1 here>

3.0 Emotional Responses in Isolated, Confined, Extreme (ICE) Environments

3.1 Human Space Flight Studies

Evidence of emotional responses during space flight primarily comes from a few studies using identical or overlapping samples [19,31–34]. Participants included flight crews from four to seven month Shuttle/Mir and International Space Station (ISS) missions. Shuttle/Mir crews were comprised of two Russians and one American (three-person crews) and included a total of five American astronauts and eight Russian cosmonauts [31]. ISS participants came from two- to three-person crews that included eight American and nine Russian crew members [19,33]. More recently, using data collected between 2003 and 2016, American astronauts and Russian cosmonauts who were members of two, three and six-person crews onboard the ISS were studied [21].

Shuttle/Mir and ISS crews were assessed via weekly administration of the *Profile of Mood States* [POMS; 35] beginning four weeks prior to missions and weekly throughout missions. In addition to a total mood disturbance score, the POMS yields six mood dimensions including tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia and confusion-bewilderment. Additionally, among two to six-person crews onboard the ISS, content of 20 astronauts' personal journals was examined for emotional responses [21]. Entries were analyzed for content and assigned to one of 24 primary topical categories, such as adjustment, work, outside communications, and group interactions. Entries were also coded as positive, negative, or neutral in tone.

3.1.1 Negative Emotional Responses. Studies conducted by Kanas and colleagues [31–33] found no significant changes in negative mood among crew members during Shuttle/Mir or ISS missions compared to pre-mission ratings, including no evidence of a third quarter effect (i.e., when extreme emotional reactions may be most likely to occur). In contrast, Stuster's [21] analysis of journal entries among ISS crewmembers identified the greatest proportion of negative content and tone during the 3rd quarter of spaceflight. Specifically, entries in 17 out of 20 journals analyzed provided evidence of a third quarter effect. Meanwhile, other studies have reported greater negative emotion during the initial stage (i.e., the first month) of space flight as compared to during the mission [36]. Thus, across available studies, there is evidence for no change in negative emotional responses during space flight, evidence of increased negative emotional responses during the initial phase of space flight, and evidence for increased negative emotional responses during the third quarter of missions (i.e., a third quarter effect).

The reason for such divergent findings among ISS and Shuttle/Mir crews is unclear, but several potential explanations exist. Most obviously, structured questionnaires and open-format journal entries yield very different information whereby the latter is likely to better capture an individual's unique emotional state at any given point in time. Second, Mir but not ISS crew members reported greater workloads during mission compared to baseline which may have influenced responses on a mood questionnaire. Third, Mir crews experienced staggered arrivals at the space station (compared to ISS crews that arrived and disembarked together) which could produce less team cohesion and greater team conflict.

It may also be noteworthy that Mir crews were comprised of two Russian cosmonauts and one American astronaut, whereas ISS crews were more culturally variable. Boyd and colleagues [37] indeed found cultural differences in emotional responses where fatigue predicted symptoms of depression among Russian cosmonauts and anxiety was a stronger predictor of depressive symptoms in American astronauts.

3.1.2 Positive Emotional Responses. Space flight has been shown to exert salutogenic effects including feelings of accomplishment, confidence, wonderment, and awe [17–21]. ISS crew members have reported joy and amazement at viewing the Earth from space and experiencing weightlessness [19,21]. Still, systematic data examining salutogenic effects (which likely include positive emotions) are rare. In one study where positive moods were assessed via the vigor-activity subscale of the POMS, no significant changes were found during either Shuttle/Mir or ISS missions [32].

Ihle, Ritsher and Kanas [38] created the *Positive Effects of Being in Space* (PEBS) questionnaire to assess salutogenic effects, though this measure assesses cognitive and behavioral responses rather than emotions per se. In a sample of 39 astronauts and cosmonauts, all reported salutogenic effects using the PEBS measure. Notably, of the eight PEBS subscales (Perceptions of Earth, Perceptions of Space, New Possibilities, Appreciation of Life, Personal Strength, Changes in Daily Life, Relating to Others, and Spiritual Change) endorsements on the Perceptions of Earth scale primarily accounted for these results. This finding may be noteworthy for LDSE crews since Earth will not always be visible during a Mars mission (i.e., earth-out-of-view phenomenon).

3.1.3 Coping. A few studies have retrospectively examined coping responses during and after spaceflight via thematic content analysis [39,40]. A modified version of the *Brief COPE Inventory* [41] has also been used, which assesses various forms of coping, including problem-focused coping (e.g., active coping, planning), emotion-focused coping (e.g., seeking social support, acceptance), and other, less useful coping responses (e.g., behavioral disengagement and denial). Both investigations found problem-focused coping strategies to be used more often than emotion-focused strategies during space flight.

Differences in pre, during, and post-mission coping were also examined. Confrontation and escape/avoidance coping were reported less commonly during mission compared to pre and post-mission, whereas use of denial peaked during missions and was less frequent pre and post-mission [39]. Utilizing Gross's Process Model of Emotion Regulation, denial coping might be conceptualized in one of two ways: as a function of internal *attentional deployment* away from an emotion-eliciting situation, or as a *cognitive change* strategy whereby the gravity of an emotion eliciting-situation is deemed less important/serious than it actually is. Either way, denial would represent an antecedent-focused emotion regulatory strategy requiring less effort than *response modulation*.

Anecdotal reports indicate that crew members sometimes attempt to manage their negative emotions by displacing them on ground crew or supervisors [e.g. ,42]. *Emotional displacement* refers to efforts to cope with negative emotions by directing them toward members of an 'out-group'. Kanas and colleagues [31–33] provide potential empirical support for the use of displacement via inverse relationships between crew member mood disturbance scores on the POMS and perceived support from supervisors. Within an emotion regulation framework, displacement might be viewed to reflect a form of *attentional deployment* or *response* *modulation*; the former being an antecedent-focused strategy that would require less effort than the latter (i.e., a response-focused strategy).

3.2 Extended-Duration Space Simulation Studies

Since space simulation studies include replication of the physical environment, mission duration, and/or contextual conditions of space flight (e.g., delayed communications with mission control), they afford a high degree of control and flexibility. Most research has come from the *Mars500 Project*, the longest and most comprehensive space simulation study to date. Two extended-duration Mars 500 missions have been conducted; a 105-day mission with four Russian and two European crewmembers, and a 520-day mission with three Russian, two European, and one Chinese crewmember.

3.2.1 Negative Emotional Responses. The POMS was used to assess mood states before and after the 105-day mission, with no significant changes found [43]. Another study found decreases in depression, anger, and aggression during the last five weeks of the same mission using the POMS [44]. Potential changes in affect have also been examined using the *Positive and Negative Affect Schedule* [PANAS; 45], a 20-item self-report scale assessing positive and negative affective dimensions. No significant changes in negative affect were found [46]. Examination of depressive symptoms using the *Beck Depression Inventory* [BDI; 47] similarly failed to reveal changes across the 105-day mission [46].

Similar findings have been reported among the 520-day Mar 500 mission crew [46,48,49]. Negative mood (based on the POMS) remained low and stable across the mission [48,49]. Other investigators have similarly found low levels of depression using the *Patient*

Health Questionnaire [50] and anxiety using the *Overall Anxiety Severity and Impairment Scale* [51].

Remarkably, while BDI scores were lower in comparison to population norms, Basner and colleagues [48] reported a significant increase in BDI scores during the second half of the 520-day mission among one crew member. It is also notable that this crew member evidenced the lowest social desirability score (i.e., a form of bias wherein a participant answers questions in a manner more likely to be viewed favorably by others) among crew members on a pre-mission self-report measure.

In a novel investigation of emotional responses conducted during the 520-day mission, Wang and colleagues [49] utilized 295 images from the *International Affective Pictures* System [IAPS; 52], a normative set of color images used world-wide for the assessment of emotion. Images include a range of pleasant, unpleasant, and neutral stimuli rated on two dimensions; valence (i.e., the image's intrinsic attractiveness or aversiveness) and arousal/intensity (i.e., the extent to which the image elicits an emotional reaction). Whereas ratings for pleasant and neutral pictures remained stable, negative images were rated less negatively over time such that ratings for positive and negative images did not differ meaningfully at the end of the mission. The authors interpreted this result to reflect a withdrawal from negative stimuli due to increasing psychological stress over the course of the mission. This explanation is plausible yet inconsistent with stable POMS scores found across the mission [48,49].

In an earlier 135-day simulation misson where the POMS was administered weekly to three crewmembers, overall mood disturbance was significantly higher in the first half of the mission whereas anger and aggression significantly increased during the second half of the mission [53].

3.2.2 Positive Emotional Responses. Findings for positive emotional responses in the 105-day Mars mission are more limited and considerably mixed. Positive mood (based on the POMS vigor-activity subscale) did not change during misson in one study [43] whereas positive affect (based on the PANAS) declined progressively in another [46]. Still another study found crewmember mood to improve overall during the final five weeks of the mission [44], a period that corresponded with both greater autonomy and communication delays with ground control. However, cultural differnces in outcomes were apparent whereby European crewmembers reported increases in negative mood and Russians crewmembers' mood remained the same or improved slightly during the final weeks of the mission.

Schneider and colleagues [54] used a 'moodmeter' to assess psychological well-being during the 105-day mission, finding improvements across time in terms of variables such as mood, calmness, and relaxation. Some of these changes appear to have occurred in associated with periods of increased physical activity.

POMS vigor-activity scores were found to decrease in the second quarter of the Mars-520 mission [48]. However, use of an alternative measure of emotional responses produced different results [55]. On a list of various emotional items rated monthly, positive emotions were rated as more common, intense, and stable than negative emotions.[2] Among the specific items endorsed, optimism, trust, joy, and love were most common.

3.2.3 Coping. Nicolas and colleagues [46] assessed coping responses in the Mars-105 isolation facility with the Brief COPE Inventory, grouping coping strategies into two

---

[2] Positive affect was stable with the exception of two isolated incidents reportedly associated with sharp but brief declines in positive affect. Further description of these incidents was not provided.

dimensions; task-oriented and disengagement-oriented. Overall use of these strategies did not change during the mission, though use of disengagement coping was linked with greater depressive symptoms. Together with a general decrease in positive affect (via the PANAS) across the mission, the authors interpreted these findings to reflect a*"….progressive reduction of emotional regulation"* (pg. 56).

Baseline and follow-up assessment of proactive and resilient coping were collected among five of the six crew members in the Mars-520 mission [56] with differential patterns observed. Resilient coping increased in two crewmembers but remained stable others. Increases in proactive coping were reported by three crewmembers, a slight decrease was reported by another crewmember, and no change in yet another. Such variation surely reflects normative individual differences.

Individual differences were also apparent in emotional expression among the six Mars-520 crewmembers [55]. Three participants reported expressing their emotions as they felt them, two tried not to show their emotions, and one expressed emotions less than they were felt. An observed trend in all participants was that positive emotions were more easily and commonly expressed compared to negative emotions.

3.3 Polar Expeditions and Winter-over Studies

Research conducted among Arctic and Antarctic crews has been conducted at research stations and among expedition teams. It is important to note from outset that personnel, environmental conditions, and stressors differ considerably across studies, as do the assessment methodologies used. At polar research stations, crews typically range in size from 15 to 1000 and deploy for up to 12 months [57–59]. Periods of isolation (i.e., winter-over) last from six to nine months [59–61]. Polar expedition teams are smaller (e.g., as few as two crew members), but face greater risk than crews at polar research stations, including blizzards, frozen patches, and channels of water. Accordingly, polar expeditions tend to be much briefer than polar research station deployments, with durations ranging from 56-185 days [62–66].

3.3.1 Negative Emotional Responses. As compared to space flight and extended-duration simulation studies, examination of emotional responses in polar environments is more extensive. In one study where diagnostic interviews were conducted among 313 winter-over personnel interviewed at the end of the season, the reported incidence of mood disorders was 5.2% [67].

Research using the PANAS has commonly found negative affect to decrease during expeditions and lower overall endorsement of negative compared to positive affective items [62,63]. Expeditioners have been found to report lower negative affective scores than published normative values [65].

3.3.1.1 Anxiety. Using the *State-Trait Anxiety Inventory* [STAI; 68], Mocellin and colleagues [69] examined trait (i.e., a disposition toward feeling anxious) and state (i.e., anxiety induced temporarily by a situation) anxiety levels in isolated and non-isolated polar stations. Levels of both types of anxiety were similarly low among personnel at both stations, with no changes in state anxiety observed across the winter season. Similar to findings for negative affect, winter-over personnel tend to score lower on general measures of anxiety than control groups [e.g., 60].

Other anxiety-based findings create a more complicated picture. Isolated cases of evacuation from Antarctica due to extreme anxiety (and depression) have been reported [e.g., 66] but few details are provided in most cases. In a more systematic study including crews from several polar stations, small but significant increases in scores on the tension-anxiety subscale of the POMS were found over the course of the winter season [58]. Palinkas and Houseal [58] also identified curvilinear changes in tension-anxiety characterized by decreases during the winter months and increases in springtime. Still, overall variation in scores remained within a restricted and normative range.

3.3.1.2 Depressive Symptoms. A majority of studies provide evidence for increases in depressive symptoms in polar environments. Using diagnostic interviews, Palinkas and colleagues [67] found mood disorders to account for more than 30% of all clinical diagnoses. Among winter-over personnel in another study, 62% reported experiencing feelings of sadness and depression, and 48% reported feelings of irritability and hostility at some point during the winter season [67]. Strange and Youngman [70] similarly reported that 85% of winter-over personnel disclosed periods of feeling depressed during debriefing interviews. Evidence of increased irritability and anger, which are often symptomatic of clinical levels of depression, was found in 65% of this sample as well.

In a more comprehensive study, Decamps and Rosnet [71] utilized a 59-item observational grid completed by a physician to examine changes in various symptoms during winter-over. Consistent with results from several other studies [72–74], a 3rd quarter effect was identified, whereby thymic symptoms (e.g., pessimistic feelings, sadness, feeling blue, brooding about unpleasant things, lack of self-confidence, low self-esteem) increased steadily from mid-season until the end of winter.

Regarding the temporal sequence of depressive symptoms, Palinkas and Browner [57] also found a significant increase in depressive symptoms toward the end of the winter-over season compared to baseline using the *Health and Daily Living Form* [HDLF; 75]. Of the 91 crew members in this study, approximately 5% exceeded the clinical threshold for depressive symptoms at the end of the winter-over season.

A few studies have failed to find evidence of elevations in depressive symptoms. For example, Palinkas and Houseal [58] found scores on the depression-dejection subscale of the POMS to decline over the winter season in one of three polar stations where data were collected. The sample size at this station was relatively small however, and no changes in depression-dejection scores were observed at the other stations.

In a more comprehensive study of depressive symptoms, results were largely dependent upon the specific measure examined [76]. Among a range of measures assessing depressive symptoms, including a modified *Center for Epidemiologic Studies Depression Scale* [CES-D; 77] and the *Subjective Health Complaints Inventory* [SHC; 78], the CES-D indicated no change in depressive symptoms during winter-over while the SHC showed symptoms to increase.

3.3.2 Positive Emotional Responses. Systematic investigation of positive emotion in polar environments is far more limited compared to negative emotion, but general moods among polar crews have been (subjectively) described as positive [e.g., 69]. Studies using the PANAS have also produced evidence of generally positive affect [63]. In this self-secting group, specific experiences emerging from exposure to polar environments are indeed likely to engender positive experiences, including appreciation of the environment, successfully coping with extreme conditions, and camaraderie [62,79].

By comparison, findings are mixed with regard to the stability and time-course of positive emotional responses. For example, in a small sample of expeditioners on a 7-week trek, positive affect (assessed with the PANAS) was stable and declined only during the final week of the mission [80]. In a much larger sample however, Grant and colleagues [76] found PANAS positive affect scores to decrease during winter-over.

Using the POMS, multiple studies have found vigor-activity scores to be most adversely affected in polar environments [61,64]. In one study, decline in vigor-activity scores was most evident during the springtime (e.g., toward the end of the season) [58]. Still, considerable variation was found across the research stations included in this study.

3.3.3 Coping. Measures used to assess coping in polar samples range considerably, including the *COPE Inventory* [e.g., 81,82], the *Ways of Coping Scale* [WOC; 83] [e.g. ,64,84], and modified versions of these measures [63,65,85]. Likewise, the timing and frequency of assessments differs from baseline and follow-up assessments only [e.g., 57,81,84,85], to various regular intervals during missions [e.g., 59,63,81,85].

Many of the coping strategies used by expedition and winter-over crew members have been considered ‘adaptive’ [64,65,81,82,86,87]. For example, frequent seeking of social support (pre-expedition), use of problem-focused coping, positive reappraisals, and humor (during missions) have been identified by Leon and colleagues [64,65,85]. Barbarito and colleagues [81] found problem-solving to be most commonly-used during winter-over; a pattern that remained relatively stable throughout the mission. However, in the absence of simultaneous emotional assessment, it is not possible to determine the effectiveness of these strategies.

Less adaptive methods of coping have also been identified. Barbarito and colleagues [81] found increased use of denial, behavioral disengagement, and restraint coping (i.e., waiting until an appropriate time to deal with the problem) among nine wintering-over expeditioners. Increases in avoidance and emotional discharge (i.e., verbal and behavioral expression of unpleasant emotions and indirect efforts to reduce tension) have also been found from baseline and follow-up approximately 1 year later after winter-over [57]. Decreases in social support seeking and problem-focused coping have also been reported during winter-over [84].

A few studies have examined relationships between coping and emotional responses. Venting, behavioral disengagement, and suppression of competing activities – all considered negative coping styles – have been associated with increased stress [82]. Avoidance and emotional discharge have been linked with greater depressive symptoms [57], and emotion-focused coping increased the probability of being rated as 'poorly adapted' to the polar environment by station commanders [76].

Coping may also be governed to some degree by specific stressors encountered. For example, Kahn and Leon [63] found physical stressors to most commonly elicit goal-focused coping, interpersonal stressors to elicit sharing of emotions with team members, and psychological stressors to relate to all types of coping strategies.

4.0 Overall Summary of Research

Across research studies conducted during spaceflight, in simulation settings, and in polar environments, self-reported negative emotions are generally found to be low. Notably, most studies have examined total scores from broad-based measures of various emotion-related constructs such as affect or mood (e.g., the POMS or PANAS). However, when more specific emotional constructs are examined, the picture becomes more nuanced. As one example, Basner and colleagues [48] detected a significant increase in depressive symptoms in one simulation study crew member using a well-validated measure of depression. This same crew member also had the lowest score on a measure of social desirability, suggesting that reports of negative emotion need to be considered in conjunction with potential response bias. Further, studies utilizing novel measures of emotion (e.g., negative IAPS images), while generally limited, have found changes in emotional responses not detected via self-report questionnaires [49]. Overall, these findings suggest that broad-based assessment approaches do not provide adequate detection or understanding of discrete symptoms that signal risk for more serious emotional health problems during LDSE.

Methodological limitations also have relevance for the detection of a ‘third quarter effect’. Reference is made to this phenomenon throughout the literature, which theorizes the negative psychological effects of prolonged exposure to ICE environments to be most pronounced during the third quarter of a mission. Empirically however, evidence for a third quarter effect is primarily limited to anecdotal reports and broad-based assessments of various domains of psychological functioning. As such, the presence of increased levels of emotional distress during this specific period, or any other for that matter, remains to be confirmed.

Findings regarding positive emotions in ICE environments are more limited overall and yield more mixed results. Across studies, positive emotions have been shown to decrease, increase, and remain stable across time. Much of the variation observed appears to hinge on the specific measure used and construct assessed. The POMS has frequently been used, even though this questionnaire contains only one subscale assessing positive mood and includes items that are not emotion-specific (e.g., energetic, alert). The PANAS has been used as well, with evidence for both stability and decline of positive affect over time. The PANAS positive subscale does capture several positive emotions, but items notably include high arousal (e.g., enthusiastic, determined, strong) rather than low arousal (e.g., relaxed, calm, content) positive affects states, which is likely to be particularly limiting for assessment in ICE environments.

A few studies have examined use of coping strategies and adaptation during spaceflight and in polar environments, finding that problem-focused coping is reportedly used more often than other strategies including emotion focused coping [e.g., 39,64,65,85]. However, the extent to which retrospective self-reports match actual in-situation behaviors remains to be established. Moreover, in order to determine the true effectiveness of any coping strategy, concurrent assessment of emotional responses must take place. As an example, the coping strategy of denial can be useful in minimizing acute levels of distress, but can lead to greater distress over time if a problem becomes more serious. Thus, without corresponding information about emotional changes, it would not be possible to fully determine whether denial is an effective coping strategy. Different situations also require different responses in order to produce a positive outcome. Accordingly, rather than coping or adaptation, we argue for a broader focus on emotion regulation which includes the ways in which individuals modulate positive in addition to negative emotions in various types of situations.

5.0 Recommendations for Future Research

1) The complexities of evaluating emotional health during LDSE necessitate the use of a guiding theoretical framework. As is evident from the current review, existing evidence for emotion responses in space and other ICE environments is limited overall, but particularly with regard to conceptualization. Thus, a critical direction for future research includes a more refined focus on discrete emotional responses and constructs. Gross's Modal Model of Emotion provides a relevant guiding framework for such efforts. A focus on emotion generation, for example, permits understanding not only of specific emotions that are problematic but of the ways which individuals perceive and evaluate information/events which in turn gives rise to their emotional responses. Multiple modalities are available for assessing individual points in the emotion generation process including self-report questionnaires, eye tracking technologies, computerized performance tasks, and measures of interpretation information recall. Emotional responses, including their intensity, duration, and/or frequency, can in turn be understood more meaningfully.

Gross's model also emphasizes the multitude of ways an emotional response can be regulated. Although the model highlights five specific stages at which regulatory strategies might be employed, the use of other strategies is certainly possible and should be considered. We further propose distinctions between emotion regulation strategies and aspects of the emotion generation process itself to be vital for evaluating and maintaining emotional health during LDSE. Indeed, negative emotional responses might ultimately pose less threat for a Mars mission than the degree to which they can be effectively modulated by the individual.

We also acknowledge that assessment of emotion regulation is not without its challenges. A number of validated self-report instruments are available, such as the *Emotion Regulation Scale* [88] and the *Difficulties in Emotion Regulation Scale* [89], but individuals differ considerably in terms of their emotional awareness and understanding. The experience of an emotion is also quite easily confounded with its regulation, and subjective reports may not align with actual behavior, particularly in extreme environments. For these reasons, our second recommendation includes integrating observational and/or physiologic assessments with self-reports.

2) Multi-method approaches can improve the reliability of subjective reports of emotional health. Self-report questionnaires are easy to use, uncomplicated to analyze, and can be administered across multiple participants and time points. Unstructured reports such as daily diaries provide another option for capturing subjective emotional responses and may be less subject to social desirability bias. However, missing data, superficial responses, and a lack of comparability across participants are major challenges of this approach. Self-report questionnaires also have limitations, including restricted response formats that may in turn limit a measure's sensitivity and predictive validity.

Visual analog scales (VAS) represent a useful hybrid of subjective assessment approaches. Unlike questionnaires that include a narrow range of response option (e.g., from 0 to 3), VAS permit continuous reports of subjective experience by allowing respondents to mark a line (either on paper or electronically, using a movable slider) that is anchored only by opposing constructs or statements at each end (e.g., no anxiety → extreme anxiety). Because individual marks on a VAS have no interpretable meaning, this format provides a more desirable method of assessment in populations where social desirability is a concern. Moreover, unlike open-format journals or diaries, specific constructs and variables of interest can be assessed directly.

All subjective measures nonetheless depend on an individual's ability to accurately reflect upon and understand his/her own internal states. This point is central to the measurement of emotional health because selection of an effective self-regulatory strategy is directly influenced by one's ability to correctly identify an emotion as something that should be regulated [7]. By necessity, astronauts are a highly motivated and self-aware group, but they face a wealth of other factors that promote reticence in disclosing emotional health information, including job responsibilities, preservation of crew cohesion, and maintaining flight status. In the context of LDSE, these issues raise essential questions about the ability of self-report measures to adequately capture signs and symptoms of emotional risk.

Because emotions are rooted in underlying neurobiological and physiological processes, various objective tools and approaches can also be used to evaluate emotional health. Biofeedback, content analysis of speech patterns, computerized facial analysis software, infrared thermography, and video analysis of behavior have recently been used to study aspects of behavioral health in ICE environments [e.g., 90–92]. As one example, biofeedback is a process that enables individuals to learn how to recognize and alter their physiological activity through real-time monitoring of brainwave activity, heart rate, respiration, muscle activity, skin conductance, etc. In a novel study by Vinokhodova and colleagues [92], biofeedback was used to evaluate dynamics among and compatibility of crew members during the 105-day Mars 500 mission.

A word of caution is also warranted here. Although we emphasize the value of multi-method approaches, objective measures should not be viewed as superior to subjective reports. The fact remains that individuals vary greatly in their experience, expression, and tolerance of emotional responses to stressful situations/events. An emotion that is felt as too intense or distressing for one crew member might be experienced as highly tolerable and manageable for another; information that objective measures may be unable to provide. Accordingly, it is the combination of different assessment approaches that is valuable rather than relying on any one individual measure.

3) Precise emotional constructs need to be delineated to guide valid measure selection. Mood, affect, and emotion represented overlapping constructs, but they are not interchangeable. These distinctions are particularly salient as they relate to LDSE given the need to efficiently and accurately evaluate risk. Previous studies conducted in ICE environments have seldom considered precise constructs of interest a priori, resulting in inappropriate measure selection and interpretation of findings. The POMS and PANAS, for example, are commonly used but in the absence of a clear basis for their selection. In addition to distinctions between mood states and dimensions of affect, the POMS and PANAS can be administered using different temporal instructions [45] but information regarding the administration of these measures is rarely reported.

The use of shortened and/or modified versions of previously-validated questionnaires is also common. Such measures may lessen the assessment burden for crew members and reduce the number of data points to be aggregated, but the drawbacks of modifying a valid instrument in the absence of establishing it's psychometric properties might outweigh any benefits. Even minor modifications to an established measure can undermine its reliability and, in turn, any inferences drawn.

Building on the previous point, many of the self-report questionnaires used in ICE environments were not designed to be administered in the ways they are commonly used. For example, daily or even weekly administration of the same set of questions inflates systematic error. Practice effects, resulting from awareness of specific items and/or boredom, decrease reliability by artificially inflating the relationship between measurement points. Even in the absence of practice effects, the auto-regressive nature of repeated measurements is seldom considered. Thus, attention should be directed to how assessment schedules directly impact the constructs being assessed.

4) A focus on positive in addition to negative emotion can provide a more complete understanding of individual risk and resilience. Understanding of emotional health in space and other ICE environments has primarily been concerned with detecting negative emotional responses. Positive responses (sometimes referred to as salutogenic effects) including feelings of accomplishment, vitality, and awe are nonetheless common [18,20]. We propose the significance of studying positive emotions for LDSE to be three-fold. First, better understanding of the presence and absence of positive emotions would provide a more complete understanding of risk. Many of the stressors present during a Mars mission, including sleep loss [e.g., 23,24] and altered light/dark cycles [e.g., 93,94] have been shown to exert more dramatic influence on positive rather than negative emotions. Furthermore, reductions in positive emotion have been shown to be a unique risk factor for psychological distress, even after controlling for the presence of negative emotions [95].

Second, prospective assessment of positive emotion is better suited to reveal insights into processes of resilience and effective emotion regulation than purely negatively-focused approaches. It is clear from the broader research literature that positive emotions generally help buffer against stress [96]. Certain coping strategies, such as problem-focused coping and positive appraisals of stressful events are associated with greater positive affect and serve to predict longer-term psychological health [97]. The experience of positive emotion has also been shown to facilitate successful implementation of emotion regulation strategies [e.g., 98].

Third, a joint focus on positive as well as negative emotions might serve to both increase intra-individual variability of responses and improve the validity of self-reports. We have highlighted some specific challenges and factors that motivate denial and/or minimization of negative emotions during LDSE. Assessment approaches that balance negative with positive-valanced items conceivably provide greater protection against socially-desirable response patterns and thus increase the likelihood of capturing signs and symptoms of risk.

6.0 Limitations and Conclusion

Despite the comprehensive nature of the current report, some limitations should be acknowledged. The scientific rigor of the studies included in our review varied dramatically, some with more serious methodological flaws than others. Further, a host of cognitive symptoms and behavioral deficits not considered in the current report can reflect potent markers of emotional distress. However, because far less is known about the emotional responses that pose risk for LDSE, we focused on emotional constructs specifically. Ultimately, we hope that the theoretical model referenced, conceptual distinctions, and recommendations presented here will serve to stimulate a new direction of emotion-focused research in the years leading up to a successful Mars mission.

References

[1] R.A. Kerr, Radiation Will Make Astronauts’ Trip to Mars Even Riskier, Science. 340 (2013) 1031. doi:10.1126/science.340.6136.1031.

[2] V.K. Parihar, B. Allen, K.K. Tran, T.G. Macaraeg, E.M. Chu, S.F. Kwok, N.N. Chmielewski, B.M. Craver, J.E. Baulch, M.M. Acharya, F.A. Cucinotta, C.L. Limoli, What happens to your brain on the way to Mars, Science Advances. 1 (2015). doi:10.1126/sciadv.1400256.

[3] K. Slack, T.J. Williams, J.S. Schneiderman, A.M. Whitmire, J.J. Picano, Evidence Report: Risk of adverse cognitive or behavioral conditions and psychiatric disorders, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, TX, 2016.

[4] D.A. Vakock, Psychology of space exploration: Contemporary research in historical perspective, Government Printing Office, Washington, DC, 2011.

[5] Hitt, D. Garriott, O.K. & Kerwin, J. (2008). *Homesteading Space: The Skylab Story*. University of Nebraska Press.

[6] J.J. Gross, The emerging field of emotion regulation: An integrative review, Review of General Psychology. 2 (1998) 271–299. doi:10.1037/1089-2680.2.3.271.

[7] J.J. Gross, Emotion Regulation: Current Status and Future Prospects, Psychological Inquiry. 26 (2015) 1–26. doi:10.1080/1047840X.2014.940781.

[8] P.A. Santy, Choosing the right stuff: The psychological selection of astronauts and cosmonauts, Praeger Publishers/Greenwood Publishing Group, Westport, CT, 1994.

[9] B. Burrough, Dragonfly: NASA and the crisis aboard Mir, Harper Collins, New York, NY, 1998.

[10] J.M. Linenger, Off the planet: Surviving five perilous months aboard the space station Mir, McGraw Hill, New York, NY, 2000.

[11] J.R. Ball, C.H. Evans Jr, (Eds.), Safe Passage: Astronaut Care for Exploration Missions, National Academies Press, Washington, DC, 2001.

[12] L. Sandoval, A.P. Costigan, M. Orr, R. Ainslie, Asthenia: Cultural differences can affect how space agencies treat it, Paper Presented at the 64th International Astronautical Congress, 2013. 2012.

[13] C.D. Batson, L.L. Shaw, K.C. Oleson, Differentiating affect, mood, and emotion: Toward functionally based conceptual distinctions, in: M.S. Clark (Ed), Review of Personality and Social Psychology, Vol. 13: Emotion, Sage Publications, Newbury Park, CA, 1992, pp. 294–326.

[14] J.A. Russell, L.F. Barrett, Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant., Journal of Personality and Social Psychology. 76 (1999) 805–819. doi:10.1037/0022-3514.76.5.805.

[15] D. Watson, J. Vaidya, D. Watson, J. Vaidya, Mood Measurement: Current Status and Future Directions, Handbook of Psychology. 3 (2003) 349–375. doi:10.1002/0471264385.wei0214.

[16] P.J. Lang, M.M. Bradley, Emotion and the motivational brain, Biological Psychology. 84 (2010) 437–450. doi:10.1016/j.biopsycho.2009.10.007.

[17] N. Kanas, Psychological, psychiatric, and interpersonal aspects of long-duration space missions, Journal of Spacecraft and Rockets. 27 (1990) 457–463. doi:10.2514/3.26165.

[18] G.D. Steel, Whole lot of parts: stress in extreme environments., Aviation, Space, and Environmental Medicine. 76 (2005) B67-73.

[19] J. Stuster, Behavioral issues associated with long-duration space expeditions: Review and analysis of astronaut journals, Experiment 01-E104: Final Report, NASA/TM-2016-216130, National Aeronautics and Space Administration, Johnson Space Center, Houston, TX, 2010.

[20] D.B. Yaden, J. Iwry, K.J. Slack, J.C. Eichstaedt, Y. Zhao, G.E. Vaillant, A.B. Newberg, The overview effect: Awe and self-transcendent experience in space flight., Psychology of Consciousness: Theory, Research, and Practice. 3 (2016) 1–11. doi:10.1037/cns0000086.

[21] J. Stuster, Behavioral issues associated with long duration space expeditions: Review and analysis of astronaut journals, Experiment 01-E104: Phase 2 Final Report, NASA/TM-2016-218603, National Aeronautics and Space Administration, Johnson Space Center, Houston, TX, 2016.

[22] P.H. Finan, P.J. Quartana, M.T. Smith, The Effects of Sleep Continuity Disruption on Positive Mood and Sleep Architecture in Healthy Adults, Sleep. 38 (2015) 1735–42. doi:10.5665/sleep.5154.

[23] J.J. Pilcher, C. Callan, J.L. Posey, Sleep deprivation affects reactivity to positive but not negative stimuli, Journal of Psychosomatic Research. 79 (2015) 657–662. doi:10.1016/j.jpsychores.2015.05.003.

[24] L.S. Talbot, E.L. McGlinchey, K.A. Kaplan, R.E. Dahl, A.G. Harvey, Sleep deprivation in adolescents and adults: Changes in affect., Emotion. 10 (2010) 831–841. doi:10.1037/a0020138.

[25] M.T. Boden, M.O. Bonn-Miller, T.B. Kashdan, J. Alvarez, J.J. Gross, The interactive effects of emotional clarity and cognitive reappraisal in Posttraumatic Stress Disorder, Journal of Anxiety Disorders. 26 (2012) 233–238. doi:10.1016/j.janxdis.2011.11.007.

[26] N.C. Feeny, E.B. Foa, Cognitive vulnerability to PTSD, in: L.B. Allow, J.H. Riskind (Eds.), Cognitive Vulnerability to Emotional Disorders, Lawrence Erlbaum Associates, Mahweh, NJ, 2005: pp. 285–301.

[27] B.P. Marx, D.M. Sloan, Peritraumatic dissociation and experiential avoidance as predictors of posttraumatic stress symptomatology, Behaviour Research and Therapy. 43 (2005) 569–583. doi:10.1016/j.brat.2004.04.004.

[28] A. Aldao, S. Nolen-Hoeksema, S. Schweizer, Emotion-regulation strategies across psychopathology: A meta-analytic review, Clinical Psychology Review. 30 (2010) 217–237. doi:10.1016/j.cpr.2009.11.004.

[29] J.J. Gross, Emotion regulation: Conceptual and empirical foundations, in: J.J. Gross (Ed.), Handbook of Emotion Regulation, 2nd ed., Guilford Press, New York, NY, 2014, pp. 3–20.

[30] J.J. Gross, R.A. Thompson, Emotion regulation: Conceptual foundations, in: J.J. Gross (Ed.), Handbook of Emotion Regulation, Guilford Press, New York, NY, 2007, pp. 3–24.

[31] N. Kanas, V. Salnitskiy, E.M. Grund, D.S. Weiss, V. Gushin, O. Kozerenko, A. Sled, C.R. Marmar, Human interactions in space: Results from Shuttle/Mir, Acta Astronautica. 49 (2001) 243–260. doi:10.1016/S0094-5765(01)00103-5.

[32] N.A. Kanas, V.P. Salnitskiy, J.B. Ritsher, V.I. Gushin, D.S. Weiss, S.A. Saylor, O.P. Kozerenko, C.R. Marmar, Human interactions in space: ISS vs. Shuttle/Mir, Acta Astronautica. 59 (2006) 413–419. doi:10.1016/j.actaastro.2006.02.007.

[33] N.A. Kanas, V.P. Salnitskiy, J.B. Ritsher, V.I. Gushin, D.S. Weiss, S.A. Saylor, O.P. Kozerenko, C.R. Marmar, Psychosocial interactions during ISS missions, Acta Astronautica. 60 (2007) 329–335. doi:10.1016/j.actaastro.2006.09.001.

[34] J.B. Ritsher, N.A. Kanas, E.C. Ihle, S.A. Saylor, Psychological adaptation and salutogenesis in space: Lessons from a series of studies, Acta Astronautica. 60 (2007) 336–340. doi:10.1016/j.actaastro.2006.09.002.

[35] D. McNair, M. Lorr, L. Droppleman, Manual: Profile of Mood States, Educational and Industrial Testing Service, San Diego, CA, 1971.

[36] V.I. Gushin, Problems of psychological control in prolonged spaceflight., Earth Space Review. 4 (1995) 28–31.

[37] J.E. Boyd, N. Kanas, V.I. Gushin, Stephanie Saylor, Cultural differences in patterns of mood states on board the International Space Station, Acta Astronautica. 61 (2007) 668–671. doi:10.1016/j.actaastro.2006.12.002.

[38] E.C. Ihle, J.B. Ritsher, N. Kanas, Positive Psychological Outcomes of Spaceflight: An Empirical Study, Aviation, Space, and Environmental Medicine. 77 (2006) 93–101.

[39] P. Suedfeld, J. Brcic, K. Legkaia, Coping with the problems of space flight: Reports from astronauts and cosmonauts, Acta Astronautica. 65 (2009) 312–324. doi:10.1016/j.actaastro.2009.02.009.

[40] P. Suedfeld, J. Brcic, P.J. Johnson, V. Gushin, Coping strategies during and after spaceflight: Data from retired cosmonauts, Acta Astronautica. 110 (2015) 43–49. doi:10.1016/j.actaastro.2014.12.011.

[41] C.S. Carver, You want to measure coping but your protocol's too long: Consider the brief cope, International Journal of Behavioral Medicine. 4 (1997) 92–100. doi:10.1207/s15327558ijbm0401_6.

[42] N. Kanas, W.E. Fedderson, Behavioral, psychiatric, and sociological problems of long-duration space missions, NASA-TM-X-58067, National Aeronautics and Space

Administration, Johnson Space Center, Houston, TX,1971.

[43] A. Gemignani, A. Piarulli, D. Menicucci, M. Laurino, G. Rota, F. Mastorci, V. Gushin, O. Shevchenko, E. Garbella, A. Pingitore, L. Sebastiani, M. Bergamasco, A. L'Abbate, P. Allegrini, R. Bedini, How stressful are 105 days of isolation? Sleep EEG patterns and tonic cortisol in healthy volunteers simulating manned flight to Mars, International Journal of Psychophysiology. 93 (2014) 211–219. doi:10.1016/j.ijpsycho.2014.04.008.

[44] N. Kanas, M. Harris, T. Neylan, J. Boyd, D.S. Weiss, C. Cook, S. Saylor, High versus low crewmember autonomy during a 105-day Mars simulation mission, Acta Astronautica. 69 (2011) 240–244. doi:10.1016/j.actaastro.2011.04.014.

[45] D. Watson, L.A. Clark, A. Tellegen, Development and validation of brief measures of positive and negative affect: The PANAS scales, Journal of Personality and Social Psychology. 54 (1988) 1063–1070. doi:10.1037/0022-3514.54.6.1063.

[46] M. Nicolas, G.M. Sandal, K. Weiss, A. Yusupova, Mars-105 study: Time-courses and relationships between coping, defense mechanisms, emotions and depression, Journal of Environmental Psychology. 35 (2013) 52–58. doi:10.1016/j.jenvp.2013.05.001.

[47] A.T. Beck, R.A. Steer, G.K. Brown, Manual for the Beck Depression Inventory-II, The Psychological Corporation, San Antonio, TX, 1996.

[48] M. Basner, D.F. Dinges, D.J. Mollicone, I. Savelev, A.J. Ecker, A. Di Antonio, C.W. Jones, E.C. Hyder, K. Kan, B. V. Morukov, J.P. Sutton, Psychological and Behavioral Changes during Confinement in a 520-Day Simulated Interplanetary Mission to Mars, PLoS ONE. 9 (2014) 1–10. doi:10.1371/journal.pone.0093298.

[49] Y. Wang, X. Jing, K. Lv, B. Wu, Y. Bai, Y. Luo, S. Chen, Y. Li, During the Long Way to Mars: Effects of 520 Days of Confinement (Mars500) on the Assessment of Affective

Stimuli and Stage Alteration in Mood and Plasma Hormone Levels, PLoS ONE. 9 (2014) 1–9. doi:10.1371/journal.pone.0087087.

[50] K. Kroenke, R.L. Spitzer, J.B.W. Williams, The PHQ-9, Journal of General Internal Medicine. 16 (2001) 606–613. doi:10.1046/j.1525-1497.2001.016009606.x.

[51] S.B. Norman, S. Hami Cissell, A.J. Means-Christensen, M.B. Stein, Development and validation of an Overall Anxiety Severity And Impairment Scale (OASIS), Depression and Anxiety. 23 (2006) 245–249. doi:10.1002/da.20182.

[52] P.J. Lang, M.M. Bradley, B.N. Cuthbert, International affective picture system (IAPS): Affective ratings of pictures and instructional manual, Technical Report A-8, 2008.

[53] N. Kanas, D.S. Weiss, C.R. Marmar, Crewmember interactions during a MIR space station simulation., Aviation, Space, and Environmental Medicine. 67 (1996) 969–975. http://psycnet.apa.org/psycinfo/1996-06913-005 (accessed April 19, 2017).

[54] S. Schneider, V. Brümmer, H. Carnahan, J. Kleinert, M.F. Piacentini, R. Meeusen, H.K. Strüder, Exercise as a countermeasure to psycho-physiological deconditioning during long-term confinement, Behavioural Brain Research. 211 (2010) 208–214. doi:10.1016/j.bbr.2010.03.034.

[55] I. Šolcová, A. Lačev, I. Šolcová, Study of individual and group affective processes in the crew of a simulated mission to Mars: Positive affectivity as a valuable indicator of changes in the crew affectivity, Acta Astronautica. 100 (2014) 57–67. doi:10.1016/j.actaastro.2014.03.016.

[56] I. Šolcová, A.G. Vinokhodova, Locus of control, stress resistance, and personal growth of participants in the Mars-500 experiment, Human Physiology. 41 (2015) 761–766. doi:10.1134/S0362119715070221.

[57] L.A. Palinkas, D. Browner, Effects of Prolongea Isolation in Extreme Environments on Stress, Coping, and Depression, Journal of Applied Social Psychology. 25 (1995) 557–576. doi:10.1111/j.15591816.1995.tb01599.x.

[58] L.A. Palinkas, M. Houseal, Stages of change in mood and behavior during a winter in Antarctica, Environment and Behavior. 32 (2000) 128–141. doi:10.1177/00139160021972469.

[59] L.A. Palinkas, J.C. Johnson, J.S. Boster, Social support and depressed mood in isolated and confined environments, Acta Astronautica. 54 (2004) 639–647. doi:10.1016/S0094-5765(03)00236-4.

[60] J.N. Butcher, M. Ryan, Personality stability and adjustment to an extreme environment, Journal of Applied Psychology. 59 (1974) 107–109. doi:10.1037/h0035793.

[61] X. Chengli, Z. Guangjin, X. Quanfu, Z. Shandong, D. Guoyuan, X. Yanzhen, L.A. Palinkas, Effect of the Antarctic environment on hormone levels and mood of Chinese expeditioners, International Journal of Circumpolar Health. 62 (2003) 255–267.

[62] M.M. Atlis, G.R. Leon, G.M. Sandal, M.G. Infante, decision processes and interactions during a two-woman traverse of Antarctica, Environment and Behavior. 36 (2004) 402–423. doi:10.1177/0013916503262217.

[63] P.M. Kahn, G.R. Leon, Group climate and individual functioning in an all-women Antarctic expedition team, Environment and Behavior. 26 (1994) 669–697. doi:10.1177/0013916594265004.

[64] G.R. Leon, C. McNally, Y.S. Ben-Porath, Personality characteristics, mood, and coping patterns in a successful North Pole expedition team, Journal of Research in Personality. 23 (1989) 162–179.

[65] G.R. Leon, R. Kanfer, R.G. Hoffman, L. Dupre, Interrelationships of personality and coping in a challenging extreme situation, Journal of Research in Personality. 25 (1991) 357–371. doi:10.1016/0092-6566(91)90027-N.

[66] I.A. McCormick, A.J.W. Taylor, J. Rivolier, G. Cazes, A Psychometric Study of Stress and Coping during the International Biomedical Expedition to the Antarctic (IBEA), Journal of Human Stress. 11 (1985) 150–156. doi:10.1080/0097840X.1985.9936752.

[67] L.A. Palinkas, F. Glogower, M. Dembert, K. Hansen, R. Smullen, Incidence of psychiatric disorders after extended residence in Antarctica, International Journal of Circumpolar Health. 63 (2004) 157–168.

[68] C.D. Spielberger, R.L. Gorsuch, R. Lushene, P.R. Vagg, G.A. Jacobs, Manual for the State-Trait Anxiety Inventory, Consulting Psychologists Press, Palo Alto, CA, 1983.

[69] J.S. Mocellin, P. Suedfeld, J.P. Bernadelz, M.E. Barbarito, Levels of anxiety in polar environments, Journal of Environmental Psychology. 11 (1991) 265–275. doi:10.1016/S0272-4944(05)80187-2.

[70] R.E. Strange, S.A. Youngman, Emotional aspects of wintering over, Antarctic Journal of the United States. 6 (1971) 255–257.

[71] G. Decamps, E. Rosnet, A Longitudinal Assessment of Psychological Adaptation During a Winter-Over in Antarctica, Environment and Behavior. 37 (2005) 418–435. doi:10.1177/0013916504272561.

[72] G.M. Sandal, Coping in Antarctica: Is it possible to generalize results across settings?, Aviation, Space, and Environmental Medicine. 71 (2000) A37–A43.

[73] G.D. Steel, Polar Moods: Third-Quarter Phenomena in the Antarctic, Environment and Behavior. 33 (2001) 126–133. doi:10.1177/00139160121972909.

[74] J. Stuster, C. Bachelard, P. Suedfeld, The relative importance of behavioral issues during long-duration ICE missions, Aviation, Space, and Environmental Medicine. 71 (2000) A17–A25.

[75] A.G. Billings, R.C. Cronkite, R.H. Moos, Social-environmental factors in unipolar depression: Comparisons of depressed patients and nondepressed controls, Journal of Abnormal Psychology. 92 (1983) 119–133. doi:10.1037/0021-843X.92.2.119.

[76] I. Grant, H.R. Eriksen, P. Marquis, I.J. Orre, L.A. Palinkas, P. Suedfeld, E. Svensen, H. Ursin, Psychological Selection of Antarctic Personnel: The “SOAP” Instrument, Aviation, Space, and Environmental Medicine. 78 (2007) 793–800.

[77] L.S. Radloff, The CES-D Scale: A Self-Report Depression Scale for Research in the General Population, Applied Psychological Measurement. 1 (1977) 385–401. doi:10.1177/014662167700100306.

[78] H.R. Eriksen, C. Ihlebaek, H. Ursin, A scoring system for subjective health complaints (SHC), Scandinavian Journal of Public Health. 27 (1999) 63–72. doi:10.1177/14034948990270010401.

[79] A. Antonovsky, Health, stress, and coping, Jossey-Bass Publishers, San Francisco, CA, 1979.

[80] G.R. Leon, N. List, G. Magor, Personal Experiences and Team Effectiveness During a Commemorative Trek in the High Arctic, Environment & Behavior. 36 (2004) 386–401. doi:10.1177/0013916503262215.

[81] M. Barbarito, S. Baldanza, A. Peri, Evolution of the coping strategies in an isolated group in an Antarctic base, Polar Record. 37 (2001) 111–201. doi:10.1017/S0032247400026930.

[82] S.L. Bishop, R. Kobrick, M. Battler, K. Binsted, FMARS 2007: Stress and coping in an

arctic Mars simulation, Acta Astronautica. 66 (2010) 1353–1367. doi:10.1016/j.actaastro.2009.11.008.

[83] S. Folkman, R.S. Lazarun, Manual for the ways of coping scale, Consulting Psychology Press, Palo Alto, CA, 1988.

[84] A. Peri, C. Scarlata, M. Barbarito, Preliminary Studies on the Psychological Adjustment in the Italian Antarctic Summer Campaigns, Environment and Behavior. 32 (2000) 72–83. doi:10.1177/00139160021972432.

[85] G.R. Leon, M.M. Atlis, D.S. Ones, G. Magor, A 1-year, three-couple expedition as a crew analog for a Mars mission., Environment and Behavior. 34 (2002) 672–700. doi:10.1177/0013916502034005006.

[86] G.R. Leon, Individual and group process characteristics of polar expedition teams, Environment and Behavior. 23 (1991) 723–748. doi:10.1177/0013916591236005.

[87] G. Yang, Q. Ye, C. Tang, Adaptation and coping strategies in Chinese Antarctic expeditioners' winter-over life, Advanced Polar Science. 22 (2011) 111–117. http://journal.polar.org.cn/EN/column/column79.shtml.

[88] J.J. Gross, O.P. John, Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being, Journal of Personality and Social Psychology. 85 (2003) 348–362. doi:10.1037/0022-3514.85.2.348.

[89] K.L. Gratz, L. Roemer, Multidimensional assessment of emotion regulation and dysregulation: Development, factor structure, and initial validation of the Difficulties in Emotion Regulation Scale, Journal of Psychopathology and Behavioral Assessment. 26 (2004) 41–54. doi:10.1023/B:JOBA.0000007455.08539.94.

[90] D.M. Shved, V.I. Gushchin, A.G. Vinokhodova, I.A. Nichiporuk, G.I. Vasil'eva,

Psychophysiological adaptation and communication behavior of human operator during 105-day isolation, Aviakosmicheskaia I Ekologicheskaia Meditsina = Aerospace and Environmental Medicine. 45 (2011) 34–39.

[91] C. Tafforin, A. Vinokhodova, A. Chekalina, V. Gushin, Correlation of etho-social and psycho-social data from “Mars-500” interplanetary simulation, Acta Astronautica. 111 (2015) 19–28. doi:10.1016/j.actaastro.2015.02.005.

[92] A.G. Vinokhodova, V.I. Gushchin, K.N. Eskov, M.M. Khananashvili, Psychological selection and optimization of interpersonal relationships in an experiment with 105-days isolation, Human Physiology. 38 (2012) 677–682. doi:10.1134/S0362119712070262.

[93] T.A. LeGates, C.M. Altimus, H. Wang, H.-K. Lee, S. Yang, H. Zhao, A. Kirkwood, E.T. Weber, S. Hattar, Aberrant light directly impairs mood and learning through melanopsin-expressing neurons., Nature. 491 (2012) 594–598. doi:10.1038/nature11673.

[94] K.M. Stephenson, C.M. Schroder, G. Bertschy, P. Bourgin, Complex interaction of circadian and non-circadian effects of light on mood: Shedding new light on an old story, Sleep Medicine Reviews. 16 (2012) 445–454. doi:10.1016/j.smrv.2011.09.002.

[95] A.M. Wood, Tarrier, Positive Clinical Psychology: A new vision and strategy for integrated research and practice, Clinical Psychology Review. 30 (2010) 819–829. doi:10.1016/j.cpr.2010.06.003.

[96] S. Folkman, J.T. Moskowitz, Positive affect and the other side of coping, American Psychologist. 55 (2000) 647–654. doi:10.1037/0003-066X.55.6.647.

[97] G. Affleck, H. Tennen, Construing Benefits from Adversity: Adaptotional Significance and Disposltional Underpinnings, Journal of Personality. 64 (1996) 899–922. doi:10.1111/j.1467-6494.1996.tb00948.x.

[98] M.M. Tugade, B.L. Fredrickson, Resilient Individuals Use Positive Emotions to Bounce Back From Negative Emotional Experiences., Journal of Personality and Social Psychology. 86 (2004) 320–333. doi:10.1037/0022-3514.86.2.320.

TABLE 1: Evidence for Changes in Emotional States in Isolated, Confined and Extreme Environments

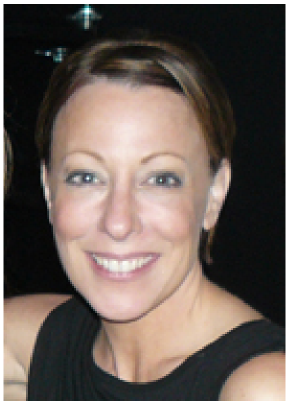
Article	Emotion Measures	Changes in Negative Emotion	Changes in Positive Emotion	Comment
Spaceflight				
Kanas et al., 2001a	Profile of Mood States	NC	NC	
Kanas et al., 2001b	Profile of Mood States	NC	NC	
Kanas et al., 2006	Profile of Mood States	NC	NC	
Kanas et al., 2007	Profile of Mood States	NC	NC	
Ritsher, Kanas, Ihle, Saylor, 2007	Profile of Mood States	NC/-	NC	Reanalysis of previously reported data; comparison of within mission to pre-mission scores
Stuster, 2016	Diary entry analysis	+/-	+/-	
Space Simulation: 105-day				
Gemignani et al., 2014	Profile of Mood States	NC	NC	
Kanas et al., 2011	Profile of Mood States	+/-	+	Cultural differences in NA were observed between American and European crew members.
Nicolas, Sandal, Weiss, & Yusupova, 2013	Beck Depression Inventory-II, Positive and Negative Affect Schedule	+	-	
Kanas et al., 2010	Profile of Mood States	+/-	+	
Schneider et al., 2010	Mood Meter	+/-	+/-	Authors note that mood both decreased and increased, but mood decreased during first half of mission.
Space Simulation: MARS 500				
Solcova & Solcova, 2014	Mood Adjective Checklist (UWIST)	-	+	
Antarctic Winterover				
Palinkas et al., 2004a	Profile of Mood States	+/-/NC	X	

Palinkas & Houseal, 2000	Profile of Mood States	+/-/NC	-/NC	
Palinkas et al., 2004b	Structured Clinical Interview Guide for Hamilton Depression Rating Scale, Seasonal Affective Disorders version	+	X	Based on post-winterover diagnoses, however different measures were used at pre- and post- winterover
Decamps & Rosnet, 2005	59-item observational grid	+/-	X	
Palinkas & Browner, 1995	Depression items from Health and Daily Living Form (HDLF)	+	X	Unclear whether depressive symptom changes based on the HDLF or another index of 18 symptoms described in methods.
Grant et al., 2007	Center for Epidemiologic Studies Depression Scale;	NC	X	
	Subjective Health Complaints;	+	X	
	Positive and Negative Affect Schedule	-	-	
Chengli et al., 2003	Profile of Mood States	NC	-	
Polar Expeditions				
Atlis et al., 1994	Positive and Negative Affect Schedule	+/-	+/-	Both positive and negative affect fluctuated across the expedition, though positive affect was generally higher than negative affect.
Kahn & Leon, 2000	Hopkins Symptom Checklist; Stress Arousal Checklist	NC/+	X	One person was evacuated for severe anxiety but other participants showed no change from pre-deployment to Antarctic
McCormick et al., 1985	Hopkins Symptom Checklist; Stress Arousal Checklist	NC	NC	Antarctic measures compared to pre-deployment phase for same people

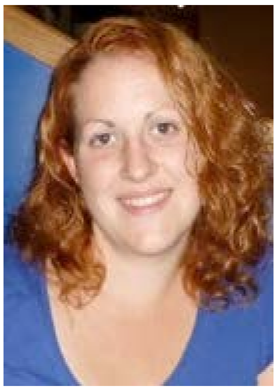
Leon et al., 2004	Positive and Negative Affect Schedule	NC/+	NC/-	Positive affect was stable for 6 weeks before declining in the final week of the expedition (week 7) Negative affect was more variable but increased for all participants during the final week.
Leon et al., 1989	Profile of Mood States	+/-	+/-	

Note: Only studies assessing changes in emotional states during ICE periods are included in table.
+ increase; - decrease; NC No change; X not measured

Vitae



Dr. Candice Alfano is Professor of Psychology, a licensed clinical psychologist, and Director of the Sleep and Anxiety Center of Houston (SACH) at the University of Houston. Dr. Alfano's research program integrates several overlapping fields of study including the role of sleep-wake processes in the pathogenesis of psychopathology, especially anxiety disorders, and the development of evidence-based interventions for children and adolescents. Her research has been funded by the National Institutes of Health (NIH), the Department of Defense (DoD), and the National Aeronautics and Space Administration (NASA).



Dr. Joanne Bower is a Postdoctoral Fellow working within the Sleep and Anxiety Center of Houston at the University of Houston. She received her Ph.D. from the University of Reading, England, in 2016 and has subsequently been coordinating a NASA-funded study investigating psychological risk and resilience in isolated, confined and extreme environments. Her research interests include the bidirectional influence between sleep, emotions and emotion regulation, particularly in response to positive emotions. She has co-authored several papers within this area.

Jennifer Cowie is a doctoral student in the University of Houston clinical psychology doctoral program. She is currently completing her pre-doctoral internship at Texas Children's Hospital, Houston. Jennifer's research interests broadly include examining the factors contributing to the development of internalizing disorders in children and adolescents, particularly those affecting the course and treatment of anxiety and compulsive disorders. She graduated with a B.A. in Psychology from Smith College in 2009.

Simon Lau is currently a graduate student in the Sleep and Anxiety Center of Houston and served as projector coordinator for the Military Families Project. He previously served in the U.S. Army supporting multiple theater of operations, where he earned numerous awards, including the Bronze Star Medal and multiple commendations for leadership. Honorably discharged from the Army in 2010, Simon graduated from the University of Houston with a BA in Psychology in 2013. Simon hopes to use his experiences from his military career to improve military research on post-traumatic stress disorders, anxiety, depression, and fear.

Dr. Richard Simpson is Associate Professor at the University of Arizona, in the Department of Nutritional Sciences, Department of Pediatrics and Department of Immunobiology. His research interests include the effects of exercise and stress on the immune system, particularly in aging, cancer, and spaceflight. His research has been funded by the National Aeronautics and Space Administration (NASA) and National Space Biomedical Research Institute.