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Review article

Psychosocial issues in isolated and confined extreme environments

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ABSTRACT

PALINKAS, L.A., and P. SUEDFELD. Psychosocial Issues in Isolated and Confined Extreme Environments. NEUROSCI BIOBEHAV REV (1) XXX-XXX, 2020. Psychosocial elements of behavior and performance will significantly impact the outcomes of long duration missions in space, ranging from individual and team decrements to positive benefits associated with successful adaptation. This paper reviews our current understanding of the individual, interpersonal and organizational issues related to living and working in isolated and confined extreme (ICE) environments. Individual issues include changes in emotions and cognitive performance; seasonal syndromes linked to changes in the physical environment; and positive effects of adapting to ICE environments. Interpersonal issues include processes of crew cohesion, tension and conflict; interpersonal relations and social support; the impact of group diversity and leadership styles on small group dynamics; and crew-mission control interactions. Organizational issues include the influence of organizational culture and mission duration on individual and group performance, crew autonomy, and managerial requirements for long duration missions. Improved screening and selection, leadership, coping and interpersonal skills training, and organizational change are key elements to optimizing adjustment to the environment and preventing decrements during and after long duration missions.

1. Introduction

Although adaptation to changing environments has been as a fundamental part of the human experience, systematic research on the psychosocial issues relating to prolonged isolation and confinement in such environments is more recent, beginning with investigations conducted more than 50 years ago during polar expeditions in the Arctic and Antarctic, observations of astronauts during crewed missions in space, and studies of teams in environments that were considered or designed to mimic long-term missions in space. Findings from such studies challenged long-held views that dismissed the importance of psychosocial issues in space within organizations that considered psychology and psychiatry to be “soft” (Harrison, 1986), believed in “the right stuff” of astronauts (Wolfe, 1979; Santy, 1994), and whose actual space experience was with relatively short duration space flights where the occurrence and severity of psychosocial problems was viewed as minimal at worst (Committee on Space Biology and Medicine, 1998; Helmreich, 1983).

However, awareness of such issues began in the 1960s and early 1970s (Kubis and McLaughlin, 1967; Sells, 1966; Space Sciences Board, 1972) and increased with the accumulating anecdotal evidence of the individual and interpersonal problems that occurred during long-duration Russian/Soviet missions (Lebedev, 1988; Oberg, 1981) beginning in the 1970s, the Shuttle-Mir Space Program (SMSP) (Burrough, 1998; Linenger, 2000) in the 1990s, and with the need to plan for longer duration missions in the U.S. space program in the 1980s featuring larger and more diverse crews (Conners et al., 1985; Space Science Board, 1987). Studies of individuals and crews in space followed, as well as of people in environments considered to be analogous to spaceflight, such as submarines, polar stations, and purpose-built simulated space capsules, and in other isolated and confined extreme (ICE) environments (Gunderson, 1974; Harrison et al., 1991; Kanas et al., 2009; Palinkas and Suedfeld, 2008; Sandal et al., 1995). The emphasis was on factors that could impar mood or cognition: prolonged depression, episodes of anxiety, social withdrawal, interpersonal tension and hostility, poor leadership, miscommunication and human error. Such reports precipitated a re-examination of the ability of astronauts possessing the “Right Stuff” to live and work, alone or in groups, in an ICE environment for prolonged periods of time.

A latecomer among the concerns of researchers working on ICE

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issues is positive psychology (Snyder and Lopez, 2001; Suedfeld, 2002). The problems faced by people who have spent time in analogue environments, and by astronauts themselves, have been widely publicized. Because the difficulty of living in such places is intuitively daunting, and because some problems may be lethal to the crew and disastrous to the mission, engineers and scientists concentrated on identifying those and devising ways to prevent, ameliorate, or solve them.

What was – and is – often overlooked is the puzzle that so many people want to experience ICEs, perform their tasks well, and enjoy being there. They report a range of desired changes in motivation, values, optimism, interpersonal relations, and personal strengths. Just as most polar explorers were eager to participate in repeated expeditions, so most astronauts are eager to fly into space more than once (Suedfeld, 2002, 2012). The study of bonding with the ICE environment, and the positive changes that accompany and follow the experience, are the topics of a growing body of research literature (e.g., Steel, 2000).

There exist numerous reviews that illustrate the breadth of psychosocial issues relating to long-term exposure to ICE environments (Bell et al., 2015, 2019; Christensen and Talbot, 1986; Connors and Harrison, 1985; Golden et al., 2018; Gunderson, 1974; Harrison et al., 1991; Kanas et al., 2009; Nicholas, 1987; Palinkas, 1990, 1991, 2001; Palinkas et al., 2011; Palinkas and Suedfeld, 2008; Sandal et al., 2006; Suedfeld and Steel, 2000). In contrast, the objective of this article is to examine in depth three hierarchical domains of behavior: the individual, the interpersonal, and the organizational.

Although they are often grouped together as ICE environments, there are important distinctions between polar expeditions, submarines and underwater habitats, space simulations, and actual spaceflight, making it somewhat challenging to draw inferences about psychosocial issues from one setting to another. These environments differ with respect to the characteristics of the physical environment (the cold temperatures and altered light/dark cycles of high latitudes versus radiation and microgravity of space or regulated temperature in a 1 g environment in a space simulation chamber), the duration of exposure to isolation, confinement and an extreme physical environment (ranging from a few weeks to one or more years), and the degree of isolation (ranging from limited to daily contact with family, friends and outsiders) and from 3 to 6 member space crews or polar expeditions to 150 submarine crewmembers).

Moreover, all of these characteristics are under constant examination and change. Advances in transportation and communications technology, expansion of habitable volumes, and protection against physical hazards have made many of these environments safer and less isolated and confining over time. Thus, what may have been an issue in the past for a particular environment may not necessarily be an issue today. For these reasons, there has been ongoing research evaluating the psychological fidelity of the Antarctic-space analogue (Suedfeld, 2018).

2. Individual issues

2.1. Stress and coping

There is little doubt that for many individuals, the prospects of living and working in an environment that is both isolated and confining for prolonged periods can be quite stressful. Crews of long-term space missions must endure separation from family and friends, limitations on communication with Earth caused by distortion of audio and visual signals, and the inability to detect nonverbal cues important to communication and interaction. As missions extend further from earth, crews may encounter delays in communication; a mission to Mars, for example, could result in delays lasting up to 20 min to and from Earth. Space vehicles and many other ICEs offer little in the way of privacy and personal space. Territoriality is likely to become more important in such a setting. Social monotony is likely to occur in response to the constant interaction with the same group of fellow crewmembers. Advances in technology may do little to alter the perceived risk of living in an environment characterized by microgravity, exposure to high doses of radiation, collisions with micrometeorites and supply vehicles, fires, and other environmental hazards. For those living in other ICE environments, stress may occur due to physical fatigue and exhaustion, physical hazards, hot or cold conditions, altered cycles of light and dark, low humidity and high altitudes, resulting physiological responses such as light-related disruption of circadian rhythms, altitude-related cardiopulmonary symptoms, and cold-related changes in peripheral circulation, hypothermia and frostbite, immune suppression, and hormone dysregulation (Palinkas and Suedfeld, 2008).

However, the extent to which those who volunteer for missions in such environments experience stress, remains controversial. On the one hand, anecdotal reports of previous space flights and studies conducted in space simulations and polar research stations have sometimes reported symptoms of depression, insomnia, irritability or anger, anxiety, fatigue, and decrements in cognitive performance (Arendt, 2012; Barabasz et al., 1983; Bishop et al., 2010; Chouker et al., 2001; Christensen and Talbot, 1986; De La Torre et al., 2012; Eddy et al., 1998; Gemignani et al., 2014; Grigoriev and Federov, 1996; Gunderson, 1974; Ishizaki et al., 2002; Kanas, 1985; Kass and Kass, 1999; Mallis and DeRoshia, 2005; Manzey and Lorenz, 1998; Nicolas and Weiss, 2009; Palinkas, 1991; Palinkas and Houseal, 2000; Reed et al., 2001; Stampi, 1994; Suedfeld and Steel, 2000). Although there have been anecdotal reports of astronauts experiencing cognitive changes described as "space fog" or "space stupids" (Kanas et al., 2001a,b), operationally significant declines in cognitive performance have not been reported from the more controlled empirical studies available, thus far (Strangman et al., 2014). However, studies in space analogues have found such decrements to be linked to sleep deprivation (Nasrini et al., 2020). The NASA twins study reported some post-mission cognitive decline in the astronaut who spent one year aboard the International Space Station (Garrett-Bakelman et al., 2019). A study by Palinkas et al. (2004a) reported that 5.2 % of a cohort of men and women with no prior history of mental health problems who spent an austral winter in the Antarctic over a four-year period met the criteria for a DSM-IV disorder. Even larger percentages of Antarctic winter-over personnel experience symptoms of sleep disorders, depression, irritability and impaired concentration and memory (Palinkas, 1992). While some symptoms may be viewed as minor in most other environments, their significance to the health and well-being of these individuals can become magnified by the conditions of isolation and confinement (Palinkas, 1992).

2.2. Seasonal syndromes

Changes in the physical environment have been shown to produce changes in the psychosocial issues confronting crews in high latitude settings. Polar explorers in both the Antarctic and Arctic have long noted the occurrence of seasonal variations in these symptoms among expedition members (Mocellin and Suedfeld, 1991). For instance, American winter-over expeditioners between 1963 and 1974 experienced a significant increase in symptoms from early to late winter (Palinkas et al., 2000b). A study of Indian Antarctic expeditioners reported significant increases in sleep disturbances in June (the austral mid-winter), and significant declines in rapport with fellow crewmembers in September and satisfaction with work and life situations in December and January (Bhargava et al., 2000). Similar patterns of seasonal variation in mood and somatic complaints was reported in Japanese Antarctic expeditioners (Ikegawa et al., 1998). When seasonal changes exist, they also characterize three distinct "syndromes" or clusters of behaviors experienced by polar expeditioners.

2.2.1. Winter-over syndrome

The Winter-Over Syndrome is a cluster of symptoms of sleep disturbance, impaired cognition, negative affect, and interpersonal tension and conflict experienced by polar expeditioners in the Antarctic (Strange and Youngman, 1971) The symptoms may also represent a form of hibernation that occurs over a long period of isolation and confinement in which coping strategies, sleep quality, and positive mood are influenced by environmental conditions to a smaller or larger degree during midwinter (Sandal et al., 2018). A study of two winter-over expeditions at Concordia Station in Antarctica found that when the conditions are harshest, resources were more depleted and participants reported less coping and positive affect (Sandal et al., 2018). However, many of the behavioral symptoms associated with the Winter-Over Syndrome also appear in other ICE settings that lack changes in seasons. In the Mars 500 study, for instance, investigators reported a progressive sedentariness or psychological "torpor" with time in mission, reflected in increased sleep time and decreased performance (Basner et al., 2013). Another Mars 500 study reported reduced need for stimulation around the third quarter (Sandal and Bye, 2015). However, other analogue studies have reported longer and more frequent wake periods at the mission midpoint, along with a decrease in positive affect and an increase in neurobehavioral disorders (e.g., increased memory lapses and errors, anger and depression) during total sleep deprivation (Landon et al., 2018).

2.2.2. *Polar T3 syndrome*

A second, circannual pattern observed in polar research station crews is an alteration of mood and cognition related to thyroid function. Known as the Polar T3 Syndrome, this condition was observed in a cohort of 12 American men and women at McMurdo Station in Antarctica (Do et al., 2004; Reed et al., 2001; Palinkas et al., 2001), 9 members of an Indian Antarctic expedition (Sawhney et al., 1995), a cohort of 10 crewmembers of China's Great Wall Station in Antarctica (Xu et al., 2003), and a cohort of 16 crewmembers of China's Zhongshan Station in Antarctica (Chen et al., 2016a), but not in a cohort of at South Pole Station (Palinkas et al., 2007a). In each instance, the alteration of thyroid function in polar expeditioners was significantly correlated with performance on cognitive tests and mood. These alterations share many of the same characteristics of subclinical hypothyroidism (SCH), including elevated thyrotropin-stimulating hormone (TSH) levels and/or enhanced TSH response to thyrotropin-releasing hormone (TRH) stimulation (Do et al., 2004; Reed et al., 1986, 1990; Xu et al., 2003). Furthermore, reductions in cognitive performance and increases in negative affect have been shown to be effectively treated through the administration of low dosages of thyroid supplements (Reed et al., 2001; Palinkas et al., 2007b). The cognitive and affective symptoms characteristic of the Polar T3 Syndrome are believed to represent a state of relative CNS hypothyroidism accompanied by systemic euthyroidism (Palinkas et al., 2001; Reed et al., 2001), which is a physiological adaptation to prolonged exposure to cold and darkness (Do et al., 2004).

2.2.3. *Subsyndromal seasonal affective disorder*

Extreme variations in patterns of daylight and darkness in high latitude environments have also been linked to a third pattern of seasonal changes in polar analogue studies. A study of 70 male and female expeditioners at three American stations in Antarctica in 1991 revealed a significant increase in the prevalence of Subsyndromal Seasonal Affective Disorder (S-SAD) from late austral summer to mid-winter (Palinkas et al., 1996). A study of 17 Chinese male expeditioners who spent the winter at Zhongshan Station in Antarctica found a similar increase in the prevalence of S-SAD to be associated with significant delays in the acrophase of 6-sulphatoxymelatonin rhythm, sleep onset and offset, and mid-sleep time were relative to departure values (Chen et al., 2016b). The behavioral symptoms associated with this seasonal syndrome has been attributed to a disruption of circulating melatonin concentrations, a major transducer of photoperiod information for the timing of multiple circadian and circannual physiologic rhythms (Lewy et al., 1985), including rhythms of energetic arousal, mood and cognitive performance (Magnusson and Partonen, 2005; Melrose, 2015).

2.3. *Positive effects of adapting to ICE environments*

While several studies have documented stress and mental health problems in ICE environments, many studies have found no such adverse psychosocial impacts. For instance, studies of polar expeditions have reported no increases anxiety, (Mocellin et al., 1991; Corneliussen et al., 2017; Weiss et al., 2000) or decrements in cognitive performance during a year in isolation (Barkaszi et al., 2016; Corneliussen et al., 2017). Studies of crews at the Mars Desert Research Station (MDRS) (Rai et al., 2012) and the MARS 105-day simulation (Gemignani et al., 2014) found no declines in cognitive performance despite increased fatigue and sleepiness. Several studies conducted in space analogue settings have reported declines in stress symptoms and levels over time (Nicolas and Gushin, 2015; Leon et al., 2002). Even when such symptoms have been observed to increase, they do not always pose a threat to the health and well-being of crew or to the success of the mission (Leon et al., 1989).

While the extent of negative impacts of ICE environments on behavior and performance continues to be debated, there is substantial evidence that long-term exposure to such environments may lead to significant increases in positive outcomes such as self-direction, self-confidence, courage and caring for others (Gushin et al., 1998; Kanas et al., 2006; Suedfeld et al., 2012a,b). For instance, a study of winter personnel at four Australian stations reported significantly more positive experiences than negative ones (Wood et al., 2000). The responses of astronauts on measures of post-flight personality changes show general increases in various aspects of positive psychological development (Ihle et al., 2006; Suedfeld et al., 2012a,b). Studies documenting such increases suggest one of four possibilities: 1) isolated and confined extreme environments are not significantly more stressful than other environments (Suedfeld and Steel, 2000); 2) highly motivated, self-selected individuals who volunteer for such long-term missions are capable of maintaining high levels of performance in such environments over long periods of time (Palinkas et al., 1995); 3) some highly motivated individuals do better than others (Palinkas et al., 2000a); and 4) such environments generate positive forms of response and adaptation that are beneficial and health-promoting (Antonovsky, 1987).

Studies of polar expeditioners uncovered three particular sources of evidence suggesting that many individuals exhibit improvements in performance and well-being during extended periods of isolation and confinement in extreme environments. The first source of evidence was obtained from an examination of mood disturbances during early and late winter among the 657 men who overwintered between 1963 and 1974. Symptoms of the winter-over syndrome (depression, irritability, insomnia, cognitive impairment) were inversely associated with the altitude, latitude, and mean annual temperature of the stations where individuals spent the austral winter. However, complaints of disturbed sleep were positively associated with the severity of the station physical environment in early winter, but not in late winter, suggesting adaptation to the characteristics of the physical environment, thereby minimizing the impact of this environment on their sleep patterns. On the other hand, other negative experiences (feeling blue, lonely, annoyed or irritated, critical of others, uneasy or worried, nervous or tense, and unable to concentrate) were *inversely* associated with severity of the station physical environment at both early and late winter. In other words, the more severe the physical environment, the fewer mood disturbances that were not sleep-related (Palinkas, 1991; Palinkas et al., 2000a).

A second piece of evidence suggesting positive adaptation to the characteristics of the physical environment is derived from a comparison of the seasonally-related depressive symptoms experienced among personnel who over-wintered at McMurdo and South Pole Stations in 1991. Although we noted earlier that S-SAD is positively associated with station latitude, mean Hamilton Depression Rating Scale (HDRS) scores and seasonally-related depressive symptom (SAD-SIGH) scores of personnel at McMurdo in 1991 were significantly higher than the respective scores of personnel at South Pole the same year (Palinkas et al., 1996).

Third, despite the potential degradation to health and performance associated with more severe forms of the winter-over syndrome, the Antarctic winter-over experience does not appear to have any adverse long-term effects. In fact, exposure to such stress may actually confer some long-term health benefits. Using medical and service history records as well as screening data obtained from volunteers to the Operation Deep Freeze Program between 1963 and 1974, the subsequent first hospital admissions of 328 enlisted Navy men who actually wintered-over at six small Antarctic research stations were compared with those of a control group of 2,396 Navy winter-over volunteers who were assigned elsewhere because of the limited number of available winter-over assignments (Palinkas, 1986). All of these individuals were evaluated by screening teams, each consisting of a clinical psychologist and psychiatrist, and found to be medically and psychologically qualified for winter-over duty. The study found that the winter-over personnel experienced 20 % fewer total first hospital admissions subsequent to their return from Antarctica than the control group during the same period. The winterover group also displayed significantly fewer first admissions for neoplasms (73 % fewer admissions); endocrine, nutritional, and metabolic diseases (60 % fewer admissions); diseases of the musculoskeletal system (44 % fewer admissions); and nonsignificant declines in admissions for mental disorders (36 % fewer admissions) and accidental injuries (27 % fewer admissions) (Palinkas, 1986).

While not all individuals obtain such an experience, these results demonstrate that prolonged exposure to an ICE environment does not necessarily produce pathogenic consequences. On the contrary, there may be significant psychological benefits or flow experiences from such environments. Perhaps the most valid conclusions that can be drawn are (a) that positive and negative psychological effects of living in an ICE can coexist, (b) that many of the effects are time-limited, and (c) that the prevalence of one or the other kind is the result of a complex and dynamic interplay between environmental, social, and personal characteristics (Suedfeld, 2005).

3. Interpersonal issues

3.1. Interpersonal tension, conflict and cohesion

As with individual issues, interpersonal issues may become increasingly important in the training and performance evaluation of astronaut personnel (Bell et al., 2015, 2019; Christensen and Talbot, 1986; Conners et al., 1985; Golden et al., 2018; Kanas, 1987; Kanas et al., 2009; Landon et al., 2018; Nicholas, 1987). Anecdotal evidence collected from astronaut personnel in the U.S. and Soviet/Russian space programs as well as studies of small groups in other isolated environments suggest that prolonged isolation and confinement often leads to increased social tension. Of course, such tension is not rare among work groups in other environments, but ICE conditions are likely to exacerbate it. This tension is reflected occasionally in open antagonism directed either towards fellow crew members or Mission Control, or more commonly through social withdrawal and isolation and, ultimately, to decreased cohesiveness. Occasional periods of solitude, privacy, and absence from distracting stimulation are desired by and important to many people. ICE participants should be taught not to regard this need, in themselves or crewmates, as signs of rejection, hostility, or maladaptation and to respect them as much as possible.

Reports and records from extended space missions conducted during the early years of the Soviet space program described decreased crew cohesiveness over time (Christensen and Talbot, 1986; Conners et al., 1985; Kanas, 1985). Russian cosmonaut Valentine Lebedev, who spent 211 days aboard the Mir Space Station in 1982, estimated that 30 percent of the time spent in space involved crew conflict (Lebedev, 1988). One study showed that cosmonauts' motive to have warm, friendly relations was high prior to spaceflight, but dropped steadily from then on and continuing after their return to Earth (Suedfeld et al., 2018). The problem was salient in studies of small (sometimes, just two-person) groups in small capsules such as Mir. The difficulty of avoiding interaction with crewmates who are temporarily or permanently disliked is most likely a factor, tension increasing the more one has to work cooperatively or to socialize with such a person. Social withdrawal may be a useful coping device in such cases (Suedfeld and Steel, 2000).

Increased social conflict and decreased crew cohesiveness have also been reported in studies of prolonged isolation of small groups in analogue environments (Gunderson, 1974; Gushin et al., 2001; Kanas et al., 2001a,b; Natani and Shurley, 1974; Nicolas, 2009; Nicolas and Weiss, 2009; Nicolas et al., 2016; Palinkas, 1992; Palinkas and Suedfeld, 2008; Sandal et al., 2011; Stuster et al., 2000, 2000; Taylor, 1987; Wood et al., 1999). For instance, significant declines in group cohesiveness at and social support were observed in a multinational crew spending a year in the Antarctic (Nicolas et al., 2016). The occupational dimensions of implementation/preparedness decreased significantly, and counterproductive activity increased significantly for the group as a whole, while cultural differences were observed in psychological demands and decisional latitude.

Increased conflict and decreased cohesion among teams in ICE environments are often represented in two distinct phenomena. The first is the formation of distinct subgroups or cliques. The emergence of "bitter factionalism" among crewmembers, was the most difficult challenge of a two-year simulation conducted in Biosphere 2 (Alling et al., 2002; Nelson et al., 2015). Space analogue studies have reported that subgroups can form around nationality (Rivolier et al., 1991; Sandal, 2004), gender (Walford et al., 1996) and values (Sandal et al., 2011; Vinokhodova et al., 2012). Although subgrouping is not always problematic (Kraft et al., 2002), there is consistent evidence from analogue environments that subgrouping can occur and that subgroup formation may result in conflicts that threaten mission success and crewmember well-being (Bell et al., 2015).

The second phenomenon observed in all of these settings has been the ostracism or social isolation of individuals perceived to be deviant by other crew members (Miller et al., 1971; Palinkas, 1992). Scapegoating has been reported during Antarctic expeditions (Rivolier et al., 1991) as well as in chamber-isolation space simulations (Gushin et al., 1998). Deviant behaviors of individual crewmembers can also contribute to interpersonal tensions and overt conflict as illustrated by the instance of inappropriate advances made by a male crewmember towards a female crewmember during a space simulation that led to growing hatred for the man among other crewmembers. The altercation prompted some group members to close and seal a hatch separating them from the man, along with other group members (Gushin et al., 2001).

Even in the absence of overt conflict, team performance can decline with prolonged stays in ICE environments. A study of 4 crews, each containing 4 members, who were confined for 30 days in NASA's HERA habitat found increases in behavioral team performance (cognitive and psychomotor tasks) and decreases in conceptual team performance (creativity and intellective tasks) over time (Larson et al., 2019). Studies by Palinkas et al. (2004b, 2004c) of multinational crews at Antarctic research stations found that the percentage and number of fellow crew members sought for interaction declined across the duration of the mission (i.e., from March to October). Simple disagreements between individual members of polar expeditions can adversely impact crew relations (Corneliussen et al., 2017).

However, not all isolated crews have experienced such conflict. Stuster's (2010) analysis of diary entries among crewmembers aboard the International Space Station found that the number of entries addressing interpersonal conflicts increased slightly across the four quarters of a mission; however, entries concerning how well the crew get along show a similar pattern and, in terms of absolute number, clearly outperform the "conflict entries". Group cohesiveness was found to be high among participants in three Sealab missions in 1964 and 1965 (Radloff and Helmreich, 1968) and the Tektite missions in 1969–1970

(Miller et al., 1971). Two of three studies of 4-person crews in McDonnell Douglas space cabin simulators, lasting 30-d and 60-d in duration, found no significant level of interpersonal conflict among crew members, although a tendency to displace irritation and anger to outside observers was reported in each study (Dunlap, 1965; McDonnell Douglas, 1968). In the third and longest duration (90-day) study, crew morale began to suffer two-thirds of the way through the mission, resulting in decreased cohesiveness and increased hostility (Jackson et al., 1972). Studies of Antarctic winter-over crews have found that group cohesion varies from one year to the next (Palinkas, 1992). A systematic review of analogue research conducted by Bell et al. (2019) found that team members of longer missions generally spend less social time together than shorter missions and that consistent team efficiency over time was more typical than decreased team efficiency over time.

The social dynamics of small groups in isolated and confined environments is characterized by three stages (Palinkas, 1992). The first stage is characterized by open interaction and identification of common interests between and among crewmembers. The process of social comparison establishes the basis for social interaction. However, this same process leads to the identification of areas of differences and dislikes. In the second stage, subgroups begin to form as individuals organize on the basis of common sociodemographic characteristics, occupational demands, leisure interests, political and ideological allegiances, and so on. In some instances, these subgroups become exclusive in membership, leading to the formation of cliques that may result in less efficient completion of interdependent tasks (Vinokhodova et al., 2012). As noted above, conflict between subgroups can generate stress within the entire group (Gushin et al., 2001). In the third stage, the entire group begins to coalesce around a social core with an attendant social identity. However, this core may emerge at the expense of certain individuals who cannot or refuse to adhere to group norms and standards of behavior. These individuals become ostracized and isolated from the group itself. Thus, at each stage, the group may lean toward tension and conflict or toward cooperation and cohesion.

In turn, the extent to which the social dynamics of a crew are characterized by tension, conflict or cohesion can influence both the structure of a crew and the behavior and performance of its individual members. Use of multidimensional scaling of data collected from pile sorts of crewmember categorization of the structure of the winter-over crews at the South Pole during a three-year period revealed three distinct patterns: 1) a clique structure in which crew members identified three distinct subgroups, based on areas of the station each subgroup usually spent most of their leisure time; 2) a core-periphery structure in which most crewmembers strongly identified themselves as members of the same group (the core), and two small groups of individuals who maintained close ties with the core but were somewhat more independent (semiperiphery) or more independent in their social interactions (periphery); and 3) a clique-core/periphery hybrid in which a relatively unified group contained identifiable subgroups. The crew characterized by a clique structure exhibited significantly higher levels of tension-anxiety, depression and anger than the crew characterized by the core-periphery structure throughout the entire winter. The mood scores of the crew characterized by the hybrid structure fell between those of the other two crews. The three crews also differed significantly with respect to the amount of support given to fellow crewmembers over the course of the winter (Palinkas et al., 2000b).

3.2. Interpersonal relations and social support

Although these results point to a clear association between crew dynamics and patterns of interaction and individual behavior and performance, they also reveal a paradox. On the one hand, social support is important to members of groups in ICE settings. Support from crewmembers has repeatedly been the most frequently mentioned coping strategy among both Western and Russian space crew members (Suedfeld et al., 2009). This was reflected in the significant inverse associations between satisfaction with support and concurrent and prospective measures of depressive symptoms (Palinkas and Browner, 1995). However, personnel who spent the austral winter at the South Pole between 1992 and 1994 revealed a significant decline in the extent to which individuals asked other crewmembers for advice or provided advice to others (Palinkas et al., 2000a). Another study of 217 participants across five stations during an 8-month winter-over mission in Antarctica reported that the percentage of fellow crewmembers sought out for interaction was significantly associated with an individual's level of tension–anxiety, depression, and confusion, while frequency of advice seeking from fellow crewmembers was also positively associated with levels of tension–anxiety (Palinkas et al., 2004b). A similar study of 77 men and women during an 8-month winter-over at the South Pole found that frequency of advice seeking at baseline was positively associated with tension–anxiety, depression, and anger during early winter, and tension– anxiety and depression during late winter (Palinkas et al., 2004a). Leon (1991) found that the use of social support as a coping mechanism was negatively associated with well-being and positively associated with stress reactions and negative emotions among crewmembers in the North Pole and Bering Bridge expeditions. Sandal et al. (2003) found a positive association between social support seeking and stress from social factors such as lack of privacy, interpersonal tension, and crowding.

The question, therefore, is whether seeking support leads to negative emotions because such support is not forthcoming from fellow crewmembers, or whether negative emotions precipitate seeking of support from these same crewmembers. A previous study of the 1989 winter-over crew of McMurdo (Palinkas and Johnson, 1990) revealed that station members who scored low on measures of emotional stability and supervisor/clinician evaluations of individual performance were not socially isolated. This finding was in contrast to the numerous studies that have documented an association between depression and a decrease in size of social networks and amount of received social support (Cohen and Wills, 1985; Lin et al., 1990). The lack of an association may be interpreted as evidence of the tolerance of depressive symptoms on the one hand (Cravalho, 1996), and the limited use of other crewmembers to cope with stress on the other hand, largely because these crewmembers are facing the same stressors (Palinkas, 1992). On the other hand, a content analysis of the records of 72 astronauts and cosmonauts found that by far the most frequently invoked coping mechanism was seeking social support – to the surprise of the researchers, who expected active, planful problem-solving to dominate in such a highly trained, technologically sophisticated group (Suedfeld et al., 2009). Thus, individuals may request support but not receive it, leading to negative emotions and stress from social relationships (Golden et al., 2018). Hence, an important distinction must be made between social dynamics as a stressor and social support as a mediator of the stress-performance relationship. Behavior and performance in ICE environments is social from the standpoint that impaired social interaction may be responsible for decrements, but that individuals adapt to such environments by refraining from a reliance upon their fellow crewmembers for support.

3.3. Predictors of conflict and cohesion

Inevitably, evidence of both conflict and cohesion appears in small groups in isolated and confined extreme environments. However, the extent to which a group experiences one or the other depends on a number of factors, including the style of leadership exercised by the commander (Johnson et al., 2003), social, cultural and personality characteristics of crew members (Kraft et al., 2002; Sandal et al., 2011), the extent of individual adaptation to ICE environments (Palinkas, 1992), and size and structure of occupational subgroups (Doll and Gunderson, 1971; Gunderson, 1968). In some instances, heterogeneity in personality characteristics is preferred to homogeneity. In space simulation and polar environments, for example, crewmates who are both high on psychological dominance do not work well together

(Altman and Haythorn, 1965; Haythorn et al., 1966; Kanas, 1985; Nelson, 1964b), whereas people who are compatible and sensitive to each other in a complementary manner do much better. In the ISEMSI 90 spaceflight simulation, antagonism between three dominant crewmembers resulted in the eventual isolation of one of these three (Sandal et al., 1995).

On the other hand, there are instances where homogeneity is to be preferred to heterogeneity. Differences in attitudes were associated with poor group cohesion in the HUBES and ECOPSY simulation studies (Gushin et al., 1998). Polar expedition teams with similar personalities and approach to dealing with expedition stressors exhibited better coping and less conflict (Leon and Sandal, 2003). Research conducted in the Antarctic and in space analogues provides evidence of the adverse impact of a lack of social compatibility on morale and performance (Connors and Harrison, 1985). Studies conducted by Gunderson and colleagues of American polar expeditioners found social compatibility to be significantly associated with supervisory ratings and peer nominations and whether or not the Antarctic adventurers had a "good year" or a "bad year" (Gunderson, 1963, 1968; Gunderson and Mahan, 1966; Gunderson and Nelson, 1963, 1965, 1966; Nelson, 1965). Differences in hobbies and recreational activities, and rural versus urban backgrounds were found to be predictive of less social compatibility in Antarctic winter-over crews (Gunderson and Ryman, 1967). In the Mars 500 simulation study, two crewmembers who had the highest ratings of stress and physical exhaustion accounted for 85 % of the perceived conflicts (Basner et al., 2014). Drawing from need compatibility theory, Altman and Haythorn and their colleagues found that members of isolated and confined groups in space simulation studies who were incompatible showed increased stress, withdrawal, and territorial behaviors (Altman and Haythorn, 1965, 1967a, 1967b; Altman and Taylor, 1973; Haythorn, 1968, 1970, 1973; Haythorn and Altman, 1967; Haythorn et al., 1966, 1972). Social compatibility has also been found to be associated with crew morale and performance in studies of Russian cosmonauts (Leonov and Lebedev, 1975). However, there are several different predictors of social compatibility in ICE settings that may not necessarily correspond with predictors of social compatibility in the general population. Socially adept introverts with little need for affection from others are viewed as more socially compatible than socially inept extraverts with high needs for affection or interaction in polar expeditions (Palinkas et al., 2000a).

Differences in age among crewmembers have been found to increase as well as decrease group cohesion. Age heterogeneity has been associated with social compatibility in some studies of polar expeditioners, especially during the winter months when crews are isolated and confined, (e.g., Cusak, 2010; Nelson, 1964a), but not in other studies (e.g., Gunderson and Ryman, 1967). Average age has also been inversely associated with depression and anxiety in the short term and with hostility in the long term (Palinkas et al., 1989). Overall, these results suggest that a mature, less age-diverse crew may have fewer problems (Bell et al., 2015).

The presence of both men and women on long-term space missions may also contribute to tension and conflict. There have been instances of overt and implicit sexual stereotyping, both in space and in Earth analogues (Goel et al., 2014; Lebedev, 1988; Leon, 2005; Leon et al., 1994; Rosnet et al., 2004), particularly in the early years of mixed gender crews in space. While it is not unusual for such behavior to take place in the general population, it often takes on added significance in isolated and confined environments, resulting in misunderstandings and increased tension between men and women who must live and work together for a long time with little opportunity to establish and maintain a personal space or social distance that is necessary for social harmony and individual identity. As noted earlier, lack of clear boundaries in social and sexual relations can adversely impact the entire crew (Sandal, 2000; Gushin et al., 2001). This problem is exacerbated when not merely different, but clashing, cultural norms result in situations where, e.g., one person or group perceives sexual harassment or violence while others see acceptable, customary interactions (Lapierre et al., 2009). Other studies have found that the inclusion of women in ICE environments helped to reduce crew tension (Sandal et al., 1995) and improve group dynamics (Leon et al., 1994; Rosnet et al., 2004). Hence, the evidence supporting the risks or benefits of gender diversity in space or space analogues remains inconclusive.

Differences in occupation and career orientation among crew members may also lead to increased interpersonal tension and conflict. Shared interests between scientists and engineers were associated with social compatibility and performance in Tektite II simulation (Helmreich, 1973; Watters and Miller, 1971). Studies conducted in polar environments have identified tensions between individuals or groups of individuals representing different occupations or possessing different career objectives (Gunderson and Ryman, 1967; Leon et al., 2011b; Nicolas et al., 2016; Palinkas, 1992; Sandal et al., 1996; Suedfeld, 2010; Weiss et al., 2007). In some cases, conflicts develop between such individuals or groups that have compromised mission goals (Harrison et al., 1991). In space, pilots and engineers and scientific payload specialists or “guests” with no operational responsibilities may likewise differ in their perception of mission objectives and the importance of specific tasks. Tensions also can occur when some crew members value their roles as being more important than those of other crew members (Committee on Space Biology and Medicine, 1998).

Finally, national, cultural and language differences may lead to miscommunication, misunderstanding, embarrassment, irritation, tension, and ineffective responses to danger, all of which can negatively impact on the success of the mission (Leon et al., 2011b; Nicolas et al., 2016; Sandal, 2004). Reports from early long-duration Russian space missions involving people from other nations have highlighted conflicts among crew members based on differences in language competency and culturally-determined expectations, values, attitudes, and patterns of behavior (Bluth, 1981, 1984; Chaikin, 1985; Oberg, 1981; Lebedev, 1988). Both Antarctic and space participants have reported that an outsider among a crew of otherwise monocultural participants often feels ignored, devalued, or mistrusted (McCormick et al., 1985; Suedfeld et al., 2012a,b). An individual who had a different primary language than the rest of the crew reported feeling isolated and pressure to confirm to the majority during a Mars simulation study in the high Arctic (Bishop et al., 2010). Language problems and different attitudes toward gender relations were believed to be associated with increased tension among crewmembers participating in the SFINCSS’99 space simulation (Sandal, 2004) and members of a Soviet-American polar expedition (Leon et al., 1994).

On the other hand, the tensions experienced by crewmembers of the MARS-105 simulation were more strongly associated with differences in value orientations and on assessments of the surrounding social environment than with differences in cultural background. (Vinokhodova et al., 2012). A recent study with veteran cosmonauts found that they recognized cultural differences between Russian and foreign (mostly American) crewmates, but this recognition was accompanied by a stereotyped positive evaluation of the latter group (Vinokhodova et al., 2017). Cultural differences may be buffered by the fact that, as members of a common profession, and in the ISS era undergoing language and technical training together, astronauts of different nations share a body of knowledge, set of expectations, and common skills which contribute to the “microculture” of the space crew (Connors and Harrison, 1985). Such microcultures emerge as crews make explicit the values and norms of behavior, often at the expense of deviant members who are ostracized for failing to adhere to such norms (Palinkas, 1992). Inherent in such microcultures is the shared experience and excitement of space flight that significantly contributes to enhancing communication between and among crewmembers (Kelly and Kanas, 1992). However, as crews become larger and include individuals with a diverse set of backgrounds, skills, and responsibilities, the development of such a microculture may become more problematic (Committee on Space Biology and Medicine, 1998) and may also contribute to conflicts with Mission Control (Landon et al., 2018).

3.4. Leadership

Poor or ineffective leadership can lead to task disruptions and decreased morale (Nelson, 1964a; Sandal et al., 1995; Suedfeld, 2010). During short-term space flights, the identified leader is the mission commander, the lines of authority are clear, and activities are task-oriented. On long-term missions, however, periods of unstructured time and the stress of isolation and confinement call for supportive leadership. The ideal commander of such a mission should possess both task-oriented and supportive-oriented leadership traits (Committee on Space Biology and Medicine, 1998). In the 135-day Mir simulator study, crew cohesion was significantly associated with high crewmember evaluations of the leader's task-oriented, instrumental characteristics, and his supportive, expressive qualities (Kanas et al., 1996). Supportive but not over-controlling leadership was also found to be correlated with crew cohesiveness, expressiveness, and involvement in a lunar space station analogue in China (Wang and Wu, 2015). One study of 18 ISS expeditions, assessing 18 mission commanders and 35 flight engineers, found that commanders in general emphasized group maintenance (i.e., morale, cohesiveness) while crew focused on task performance. Another interesting difference was that the commanders sought social support from their crewmembers and their space agency, while the engineers tended to rely on their family and friends on Earth (Brcic and Suedfeld, 2008).

However, the mission commander may be unable or unwilling to provide social or emotional support to his or her fellow crewmembers, either because he or she lacks the capacity for exercising supportive leadership, or because such leadership would be inappropriate under the circumstances. In the event that such leadership is exercised informally by some other member of the crew, lines of authority may alter, and the mission commander may experience status leveling (Committee on Space Biology and Medicine, 1998).

The one fixed constant of leadership during long-term missions in any ICE environment is that it must be flexible. For example, studies of polar expeditions have found task leadership to be more important during the initial stages (e.g., establishing camp), while supportive leadership becomes more important during the latter phases of an expedition (Gunderson and Nelson, 1963; Nelson, 1964a). During emergencies, it is essential that the leader be decisive and directive. In other instances, shared decision making may be more appropriate, as in the case of the Salyut 6 mission, where a younger commander shared decision making with an older crewmate who possessed the specific skills needed to accomplish the primary mission goals (Committee on Space Biology and Medicine, 1998).

A review of studies of air crews, polar research stations, submarines and undersea habitats, and mountaineering expeditions by Nicholas and Penwell (1995) identified several different leadership styles and traits believed to be relevant to long-term space missions. These traits fall within four specific domains: personal traits, task management style, interpersonal style, and group maintenance style. Their review found that successful leaders of long-term missions are achievement oriented, possess a personal and a professional stake in mission outcome, exhibit confidence, competence and experience; and maintain a positive, optimistic outlook. The leader solicits subordinates' advice or judgement when necessary and appropriate, delegates responsibility but does not interfere with work, exercises a flexible leadership style (e.g., takes command in crisis, allows subordinates to exercise leadership at other times), participates with subordinates in routine work, emphasizes discipline, adopts a generally democratic leadership style, and clearly communicates with subordinates' plans, roles and responsibilities. The leader is also sensitive to subordinates' personal problems and well-being, initiates frequent personal contact with subordinates, openly shows pride in subordinates, and gives frequent recognition and compliments to subordinates. Finally, the leader works to reduce clique rivalries and maintain group harmony, appears nonaligned and impartial in making decisions, and works to resolve subgroup conflicts (Nicholas and Penwell, 1995).

3.5. Ground-crew interactions

Tension involving a confined group of people may be displaced to outsiders who are monitoring or controlling their activities, since it is easier to express anger and anxiety toward more remote individuals rather than toward people with whom one must frequently interact. Such displacement has been reported during both Russian and American space missions (Cooper, 1976; Lebedev, 1988), in the Antarctic (Palinkas, 1992), and during previous ground-based simulation studies (Kanas et al., 1996; Sandal et al., 1995; Nelson et al., 2015; Wang and Wu, 2015). Space simulation studies have reported decreases in the scope and content of communications from crews to outside personnel over time (Bell et al., 2019; Gushin et al., 1997, 2012). Overt hostility on the part of astronaut personnel toward excessive, unreasonable, or unclear demands placed upon them by ground control personnel has led to expressions of hostility and conflict in the past (Burrough, 1998; Douglas, 1991; Lebedev, 1988). For their part, ground control personnel have complained of the failure of astronauts to adhere to schedules or follow directions, leading to increased risk of accidents and mission failure (Kanas et al., 2011). More often, degradation in ground-crew interactions has led to instances of miscommunication. Both astronaut and ground crew personnel have experienced difficulties in understanding messages sent (Committee on Space Biology and Medicine, 2000). Tensions between space crews in flight and mission control personnel may also be exacerbated by delays in communication between the two groups, delays that will increase as missions extend further into space to Mars and beyond (Caldwell, 2000; Landon et al., 2018; Palinkas et al., 2016).

On the other hand, these apparent degradations in ground-crew interactions may actually have an adaptive function (Kanas, 1987; Committee on Space Biology and Medicine, 1998). Several studies of crews aboard nuclear submarines, other undersea submersibles, and land-based space simulators found decreased group cohesiveness and social interaction and increased interpersonal conflict and/displacement of anger to outside observers over time (Haythorn, 1970; Nelson et al., 2015). In a study of psychological confinement and behavioral changes during the Mars 500 simulation at the IDMP in Moscow, crewmember conflicts with mission control were reported five times more often than conflicts among crewmembers (Basner et al., 2014). Because they are remote from the crew in a physical sense, ground control personnel may serve as an outlet for crew aggression and irritability that may be the result of factors external to ground-crew relations. The direction of anger and hostility towards external authorities and individuals may also serve to unite astronaut crews, thereby facilitating cooperation and enhancing performance.

4. Organizational issues

4.1. Organizational cultures and spaceflight operations

The third major component of the psychosocial system likely to influence the behavior and performance of multinational space crews is the organizations represented by their individual members. As noted above, individual and group differences in values, motives for participating in long duration missions, expectations, and the meanings attached to one's own behavior and the behavior of others may have a significant impact on interpersonal relations and group dynamics. However, these individuals are also members of larger organizations represented in multinational space programs. Each of the major space agencies likely to participate in such ventures (NASA, RSA, ESA, CSA, JAXA) represent differences in experience with crewed space flight, which may account for differences in expectations and operational procedures during long-duration missions (Ritsher, 2005). NASA and RSA, for instance, have been involved in human space flight for a longer period of time than the other space agencies. Russian cosmonauts were reported to evidence higher autonomy, initiative, and industriousness than Western astronauts (Suedfeld and Brcic, 2011). Furthermore, NASA and RSA are characterized by a number of operational features that reflect differences in their respective organizational cultures. These include differences in ground-crew interactions (e.g., Russian personnel have been reported to be more confrontational than the Americans in their ground-crew interactions); duration of ground-crew communications (e.g., American ground control personnel remain in contact with space crews for longer periods of time); the NASA emphasis on overtraining for missions versus the RSA emphasis on “on-the-job” training; and structure of rewards and restraints (e.g., Russian practice of rewarding cosmonauts for doing extra work with extra pay while also docking the pay of cosmonauts who fail to perform prescribed tasks). These differences have been reported by astronaut and cosmonaut personnel as exerting a significant influence on crew dynamics (Burrough, 1998; Linenger, 2000). A study of aircrews and surgical teams from 26 nations on five continents showed highly significant national, organizational and professional differences regarding appropriate relationships between leaders and followers, in group versus individual orientation, and in values regarding adherence to rules and procedures. A negative component of professional cultures was characterized by a sense of personal invulnerability regarding the effects of stress and fatigue on performance. This misperception of personal invulnerability has operational implications for spaceflight such as failures in teamwork and increased probability of error (Helmreich and Merritt, 1998; Helmreich, 2000). The commercialization of space and exploration is likely to introduce even greater diversity in spaceflight operations, crew composition, and organizational structure (Golden et al., 2018).

4.2. Duration of exposure to ICE

The organizational challenge of mission planning must also take into consideration the variation in performance requirements imposed on the crew by the duration of the mission itself. Prior to deployments on the ISS for periods of 3 months to 1 year in duration, evidence from the U.S. space program was of limited use in determining optimal periods of mission duration because the majority of crewed missions had been of two weeks or shorter in length (Committee on Space Biology and Medicine, 1998). Consequently, the experience of long-duration Soviet/Russian crewed missions in general and the Mir missions lasting 3–14 months in particular was relied upon extensively for planning mission duration and crew psychosocial support aboard the ISS. Despite the general consensus that long-duration missions represent a qualitatively different experience in terms of behavior and performance from missions of short duration, it is unclear whether mission duration is a significant predictor of performance and behavior. For instance, several studies of small groups in isolated undersea research labs and space simulation studies have reported significant increases in symptoms of depression, anxiety, and group hostility over time (Haythorn, 1970). A study by Stuster et al. (2000) reported less negativity in the diary entries of French polar expeditioners on short duration missions than those on long duration missions. These results have supported the hypothesis that ICE environments influence human behavior in a linear dose-response manner, such that the longer the exposure, the more significant the decrements.

Other studies have been used to support the hypothesis that decrements in performance under these environmental conditions occur in stages (Sandal et al., 1996). Bechtel and Berning (1990) described the “Third Quarter Phenomenon” in which performance is likely to decline during the third quarter of a mission in an isolated and confined environment regardless of the total duration of the mission itself. Evidence of such a phenomenon has been observed in the Antarctic (Palinkas et al., 2000b; Sandal, 2000; Stuster et al., 2000), space simulation analogues (Sandal and Bye, 2015; Wang et al., 2014), and in space (Liu et al., 2016). However, other studies have found no evidence of the Third-Quarter Phenomenon (Basner et al., 2014; Kanas, 2004; Khandelwal et al., 2017; Miller et al., 1971; Nicolas and Gushin, 2015; Palinkas et al., 1995; Wang and Wu, 2015). A determination of whether and when a decline in performance occurs is important for task scheduling, implementation of countermeasures, and rotation of crews.

4.3. Crew autonomy

Another important feature of the organization of spaceflights and operations in other ICE environments is the extent to which crews living and working in such environments can exercise autonomy from mission administration and control. Future space exploration missions will require a change in the current model of interaction, procedural functioning, and communication between crewmembers and ground control. As spaceflights begin to extend beyond Earth to asteroids and Mars, delays in communication to and from Earth may impact the quality of communications and team coordination in such a way as to require the crew to work semi-autonomously in order to maximize health and performance during deep space exploration missions (Caldwell, 2000, 2005).

Communication delays have been found to adversely impact task efficiency, communication quality, crew-mission control interactions, and situational awareness in simulated space tasks and in analogue space environments on Earth (Fischer and Mosier, 2014; Love and Reagan, 2013). A study of 3 astronauts on the ISS and 18 mission support personnel examined the performance of tasks of varying degrees of novelty and complexity with and without communication delays (50-second one-way) during a mission lasting 166 days found crew well-being and communication quality were significantly reduced in communication delay tasks compared to control (Kintz et al., 2016). Communication delays were also significantly associated with increased stress/frustration. Qualitative data suggest communication delays impacted operational outcomes (i.e. task efficiency), teamwork processes (i.e. team/task coordination) and mood (i.e. stress/frustration), particularly when tasks involved high task-related communication demands, either because of poor communication strategies or low crew autonomy. These studies suggest space crews will need to be more autonomous from mission control during long-duration space missions (Kanas et al., 2010; Palinkas et al., 2016; Wu and Hera, 2019).

One way to reduce the tensions of both communication delay and flight-ground conflict is to endow the crew aloft with more autonomy. Decentralized authority for decision-making would reduce the feelings of intrusion from the outside, the resentment that the people making the decisions are far away and perhaps not fully appreciative of all relevant factors (or of the crew’s attempts to solve the problem), as well as making the time lag less critical. It would also lead to crew members feeling more respected, perhaps particularly important when the crew consists of highly competent and intelligent individuals, such as astronauts. Embarrassing and mission-impacting events such as the widely mischaracterized “mutiny” of the overworked and over-programmed crew of Skylab 4 (Douglas, 1991) could be avoided. At this point, research on the possible effects of such a change is in its infancy (e.g., Kanas et al., 2012), So far, two caveats are obvious: (a) the deeper into space humanity goes, the more the crews’ decisions will have to become autonomous (Wu and Hera, 2019); and (b) making this development operational will require attention to subtle issues such as crew compatibility (Sandal et al., 2011). Crews that can exercise high levels of autonomy in ICE environments exhibit higher levels of positive mood and self-direction (Bell et al., 2015; Kanas et al., 2010, 2011; Roma et al., 2011). Kanas et al. (2011) manipulated crew autonomy levels in a simulated Mars mission over the course of 105 days in a crew of six men in a Mars mission simulator in Moscow. They found that crewmember mood and self-direction was greater under conditions of high autonomy, but mission control reported greater levels of anxiety and confusion.

4.4. Task scheduling and monitoring

One of the important management functions of the organizations involved in long-duration missions is the scheduling and monitoring of tasks performed in flight. Identifying the optimum amount of work that can and should be performed during long-duration missions is important for a number of reasons. Studies conducted by Stuster (2010, 2016) of diaries collected for astronauts aboard the ISS found that work was the most frequent diary entry topic of 24 topics identified. Frequent topic subgroups related to work included complaints about insufficient time allocated for tasks and frustration concerning work and reactions to tedious and repetitive tasks. Evidence from previous spaceflights has pointed to the potentially adverse impacts of scheduling too many tasks within the time available (Cooper, 1976). These impacts have included conflicts between astronauts and ground control personnel, refusal to perform assigned tasks, fatigue, sleep deprivation, a decline in cognitive performance, and increase in negative affect (Committee on Space Biology and Medicine, 1998), and is one of the flashpoints of the movement to increase crew autonomy (e.g., Douglas, 1991). Evidence from long-duration space missions and analogue environments suggests that a lack of sufficient amounts of meaningful and productive tasks can result in boredom, producing many of the same symptoms associated with overwork as described above, a problem that will likely become more salient as missions expand from multi-month expeditions to the ISS to multi-year explorations of Mars Committee on Space Biology and Medicine, 1998). Alert organizations and leaders, and crew members themselves, can devise ways to deal with the problem (Johnson and Suedfeld, 1996; Stuster, 1996). Individual and group performance may also be affected when disparities in workload occur among crew members such that some are given too much to do and others are not given enough to do during a long-duration mission (Burrough, 1998).

5. Improving human adaptation to ICE environments

5.1. Screening and selection

To minimize the risk of poor psychosocial adaptation, decrements in task performance and the need to treat and possibly evacuate individuals with psychiatric disorders resulting from long term-exposure to these stressors, all national space agencies and most national Antarctic research programs have adopted some form of psychological screening and selection. These procedures vary from one country to the next. Some Antarctic programs screen both summer and winter-over personnel, while other programs limit their screening to winter-over candidates. Some programs rely upon formal clinical evaluations and use of standardized psychometric tests, while others place their reliance on time-tested methods of personal interviews with program administrators, former expeditioners and station managers. In each of these instances, however, screening procedures are intended to accomplish two objectives. The first objective is to "select-out" or disqualify any candidate with a history of psychiatric disorder, current psychiatric symptoms, or other characteristics that place him or her at risk for a psychiatric disorder during his or her stay on the ice. The second objective is to "select-in" or identify and select candidates with characteristics that predict for optimum performance in ICE environments (Committee on Space Biology and Medicine, 1998; Santy, 1994).

Psychological screening and selection of astronaut personnel began with the psychological testing of cosmonaut candidates in the Russian (Soviet space programs, a practice that increased with the advent of multicrew and long duration missions (Garshnek, 1989). Psychological assessment methods included interviews, evaluations of biographical data, performance tests, and projective techniques (Manzey et al., 1995). Particular emphasis was given to analyses of psychophysiological reactions and individual stress-resistance, assessed by reactions to specific stressors such as parachute jumps and short-term weightlessness during parabolic flights (Garshnek, 1989; Gazenko, 1980). Research conducted with American astronauts identified a number of characteristics that predict for astronaut effectiveness. Based on the work of Spence and Helmreich (1978), (Chidester et al., 1991) grouped personality traits of astronauts into three clusters, labeled the "Right Stuff," the "Wrong Stuff," and "No Stuff." Individuals characterized as having the "Right Stuff" exhibit high levels of positive instrumentality (a cluster of attributes reflecting goal-orientation and independence), positive expressivity (a cluster of attributes reflecting interpersonal warmth and sensitivity), mastery (a preference for challenging tasks and striving for excellence), and work (a desire to work hard and do a good job), and by low levels of negative instrumentality (negative characteristics reflecting arrogance, hostility, and interpersonal invulnerability) and verbal aggressiveness (complaining, nagging, fussy). Individuals characterized as having the "Wrong Stuff" exhibit high levels of competitiveness (preference for tasks with clear winners and losers and a desire to outperform others), negative instrumentality, and impatience/irritability, and low levels of positive expressivity Individuals characterized as having "No Stuff" exhibit low levels of positive instrumentality, positive expressivity, mastery, work, and competitiveness, and high levels of negative communion (self-subordinating, subservient, or unassertive) and verbal aggressiveness. These traits have been found to be significant predictors of performance among astronauts (McFadden et al., 1994; Rose et al., 1994), aircrews (Chidester et al., 1991), simulation study participants (Sandal, 1998), polar expeditioners (Gunderson, 1974b; Rivolier et al., 1983; Sandal et al., 2000; Taylor, 1987; Xue and Zhang, 1980; Corneliussen et al., 2017), and submariners (Sandal et al., 1999).

In analogue settings, emphasis has been placed on the importance of high emotional stability, social compatibility, and task ability as predictors of successful adaptation to ICE environments (Gunderson, 1974). Palinkas et al. (1995) found that high emotional stability (reflected in low levels of neuroticism) predicted adaptability for scientists on an Arctic expedition. Wright et al. (1967) found that poorly adapted Arctic workers had lower emotional stability (reflected in higher MMPI psychopathology scores). Weybrew and Noddin (1979) reported that submariners who failed to adapt and were disqualified from duty were higher in depression and interpersonal problems compared to those who adapted well.

Palinkas et al. (2011) conducted a systematic review of predictors of optimal behavior and performance in ICE environments. Psychosocial characteristics identified in the studies reviewed included social-demographic characteristics, personality characteristics, clinical evaluations, coping skills, and other characteristics of individuals, as well as characteristics of groups and their leaders. Measures of performance were grouped into five categories, task ability, emotional stability, social compatibility, leadership, and overall performance. Further, a coding system was developed to prioritize variables based on the fidelity of the study design to long-duration missions in space. A fidelity score was calculated for each study based on similarity to spaceflight, study participants to long-duration expedition astronauts, mission duration and crew size. Characteristics were then placed into three groups for each type of performance predicted: 1) the three most important predictors; 2) other important predictors that were based on three or more studies reporting statistically significant associations; and 3) less important predictors that were based on one or two studies reporting statistically significant associations. A comparison of predictors of by performance outcomes is provided in Table 1.

Personality characteristics and coping skills were found to be among the most predictive of adaptation in general and the five specific forms of adaptation identified in the systematic review. Specific personality characteristics that have been shown to predict for high adaptability include openness to experience (Grant et al., 2007), optimism (Grant et al., 2007), positive appraisal or reappraisal (Kjaergaard et al., 2015; Wagstaff and Weston, 2014), introversion (Bolmont et al., 2001; Rosnet et al., 2000), internality (Wood et al., 1999), and low conscientiousness (Bolmont et al., 2001).

Table 1
Prioritization of predictors by performance category.

Prioritization	Performance Measure				
Level	Task ability	Emotional stability	Social compatibility	Leadership	Overall
I. Top 3	Global personality traits Crew homogeneity/ heterogeneity Interpersonal needs and skills	Age, maturity, experience and skills Interpersonal needs and skills Global personality traits	Crew homogeneity/ heterogeneity Global personality traits Interpersonal needs and skills	Leadership style Global personality traits High motivation	High motivation Global personality traits Interpersonal needs and skills
II. Other Important	Age, maturity, experience and skills Group cohesion	Civilian status Clinical characteristics Mood High motivation Group cohesion High self-efficacy Cultural background	Age, maturity, experience and skills Group cohesion High motivation Cultural background	Leadership skills Interpersonal needs and skills High self-efficacy Age, maturity, experience and skills	Age, maturity, experience and skills High self-efficacy Clinical characteristics Mood Leadership skills Coping characteristics
III. Less Important	High self-efficacy High motivation High alertness Low hostility against the self Large groups High positive affectivity Number of previous expeditions High religiosity Unmarried Male gender Military/civilian status Urban residence.	Crew homogeneity/ heterogeneity Male gender Military service Urban residence High alertness High need for orderliness High conscientiousness High satisfaction with social support Low use of acceptance as a coping strategy Number of previous expeditions Enjoyment and sense of awe of the environment High/low interest in hobbies and leisure activities Low religiosity Large/small crew sizes Participative/supportive leadership style	Clinical characteristics Coping characteristics Enjoyment and awe of the environment Low interest in hobbies and leisure activities High religiosity Low work-related stress Low hostility against the self High alertness Large crews High positive affectivity Rural residence Military service Male gender Unmarried Participative/supportive leadership style Leader's ability to adapt style to context	High alertness High expressed control Married.	Cognition High/low interest in hobbies and leisure activities Military/civilian status Female gender Low family socioeconomic status Married/ unmarried Rural residence High openness to experience High religiosity Leaders' use of recognition and reward

Source: Palinkas et al., 2011.

With respect to coping styles and strategies, the Mars 105-day simulation study found task-oriented coping to be associated with positive adaptation, while withdrawal or disengagement coping was associated with depression and poor adaptation (Nicolas and Gushin, 2015; Nicolas et al., 2013). Trapp et al. (2014) also found social withdrawal as a coping strategy to be associated with poor adaptation in a mountain climbing simulation. However, studies of Antarctic winter-over crews (Palinkas et al., 2004a, 1995) and submariners (Sandal et al., 2003) have reported successful adaptation to be associated with less use of or need for social support. Sandal et al. (2018) concluded that the "hibernation" observed during the third quarter of Antarctic isolation and confinement is itself a form of adaptive coping with extreme environmental conditions. Studies of participants in polar crossing teams indicate considerable flexibility in use of coping strategies (Leon et al., 1991, 2011a; Suedfeld et al., 2017).

Demographic characteristics have also been associated with adaptability in analogue ICE settings including age, maturity, skills and experience (Biersner and La Rocco, 1987; Gunderson and Arthur, 1966; Gunderson and Nelson, 1965; Ikegawa et al., 1998; McGuire and Tolchin, 1961; Palinkas et al., 2000b; Sarris, 2006; Taylor and McCormick, 1985; Weybrew and Noddin, 1979). Some studies have also reported that women adapt better to such environments than men (Bishop et al., 2005; Grant et al., 2007), despite reporting concerns for the welfare of a teammate as a significant stressor (Leon, 2005), while other studies have found men experience fewer mental health problems (Palinkas et al., 2004c) and greater social compatibility (Schmidt et al., 2005) in ICE settings. Crewmembers from countries with a more individualistic cultural orientation seek fewer interactions and less advice and display lower levels of perceived support from leadership than did those from more collectivist-oriented countries (Kanas et al., 2001a,b; Palinkas et al., 2004b).

A person-environment fit model of behavior suggests that the ability of personality traits such as instrumentality and expressivity or coping styles and strategies to predict performance is mediated by the characteristics of the environment itself. In this instance, personality traits that predict behavior and performance pre-flight may be of little value in predicting behavior and performance in-flight because the characteristics of the environment in which the behavior occurs is so dramatically different. For instance, a study of 119 men and women who spent the 1989 austral winter in Antarctica found that while several features of personality characteristics, coping methods and resources, and social resources were associated with concurrent measures of depressive symptoms, pre-deployment levels of depressive symptoms was the only significant independent predictor of late winter depressive symptoms (Palinkas and Browner, 1995). A prospective study of the 657 men who overwintered at 8 different stations in Antarctica between 1963 and 1974 found the need for order was inversely associated with emotional stability and leadership, while the need for achievement was inversely associated with social compatibility (Palinkas et al., 2000b). A desire for efficiency in friends was inversely associated with emotional stability. High levels of motivation were inversely associated with evaluations of leadership, and a desire for affection from others was inversely associated with task ability, emotional stability, social compatibility, and overall performance. Several studies have noted an increased use of avoidance as a coping strategy (Bishop et al., 2006; Palinkas and Browner, 1995). For instance, a year-long study of Italian Antarctic expeditioners found an increase in multiple forms of avoidance responses, including behavioral disengagement (e.g., reducing efforts for dealing with problem or giving up), restraint coping (i.e., waiting until the appropriate situation to handle a problem), and denial (e.g., not acknowledging the existence of an important situation or problem) (Barbarito et al., 2001).

These results suggest that baseline measures of personality, stress and coping are weak prospective predictors of behavior and performance during the winter because such performance is influenced more by the conditions of isolation and confinement than by stable traits of individuals (Carver and Scheier, 1994; Holahan and Moos, 1987). These conditions include the stressors (e.g., isolation, confinement), and the limited availability of resources necessary to cope with these stressors (Palinkas, 1992; Palinkas et al., 2000a).

Although NASA has traditionally accorded more attention to selecting astronauts on the basis of their ability to perform as individuals, selection of astronauts on the basis of their ability to work as part of a team is another important consideration (Landon et al., 2018; Vanhove et al., 2015). One review of studies focused on team dynamics identified five variables that are important to consider when composing teams for long-duration exploration missions: cultural and gender differences; personality; abilities, expertise and background; team size; and network factors such as compatibility, communication, and trust (Bell et al., 2015). A job analysis performed by a group of NASA astronauts who had participated in ISS missions and subject matter experts identified competencies enhancing team functioning, such as the ability to live in small groups, judgment, motivation, and adaptability, as highly important to the success of Mars-like missions (Barrett et al., 2015). High levels of dominance as a personality trait exhibited by individual team members were found to be associated with group tensions in Antarctic field expeditions (Wood et al., 1999). Kanas (1990) noted that groups containing dominant and/or aggressive individuals tend to experience higher conflict because such domineering personalities are intrusive and demanding of crew members who are already taxed from the ICE conditions (Golden et al., 2018).

The systematic review of predictors of optimal behavior and performance by Palinkas et al. (2011) found that crews whose members express a strong group identity and affiliation and whose members share similarities with respect to social and personality characteristics and cultural background perform better than crews that do not share these traits.

5.2. Psychological support and countermeasures

Procedures for psychiatric and psychological screening and selection represent some of the existing and proposed countermeasures designed to reduce the likelihood of psychiatric morbidity and impaired performance during long-term missions. At the pre-flight stage, training in strategies for coping with isolation and confinement at both the individual and interpersonal levels is also considered important. In-flight countermeasures include monitoring of individual behavior, intervening directly or through the flight surgeon when necessary and appropriate, and facilitating crewmember contact with clinical and social support systems. Post-flight countermeasures include debriefing assessments of health and well-being and intervention when necessary and appropriate (Committee on Space Biology and Medicine, 1998).

The Russian space program pioneered in-flight psychological support for long-duration missions, introducing practices such as the arrangement of entertainment, leisure activities and space-ground contacts (Grigoriev et al., 1987; Kanas, 1991); regular ground-based monitoring of the emotional state of each crew member through voice analysis of videotapes, psychophysiological measurement, and regular contacts with psychologists (Manzey et al., 1995); and implementation of protocols for scheduling wake-sleep cycles and workload based on cosmonaut psychophysiological and biorhythmological characteristics (Litsov and Shevrenko, 1985; Manzey et al., 1995). In the American space program, the Human Factors and Behavioral Health Element at Johnson Space Center is responsible for several psychological countermeasures in three specific domains: Behavioral Medicine, Team Risk and Sleep Risk. The Behavioral Medicine Risk area aims to develop self-assessment tools for early detection and treatment that use unobtrusive and objective measures of mood, cognitive function, and other behavioral reactions to living and working in space. The Team Risk area examines team performance and other team-related outcomes, including crew cohesion and communication, to develop tools and technologies that monitor and support teams throughout autonomous operations. The Sleep Risk area focuses on countermeasure development, including lighting protocols, medication recommendations, education, and tools that optimize work-rest schedules (National Aeronautics and Space Administration (NASA, 2019).

Several authors have recommended investigations of whether team interventions might be used to build resilience against performance decrements (Larson et al., 2019). Although some authors have suggested that the team effectiveness literature currently does not provide strong, evidence-based recommendations to identify the impediments and facilitators of ICE team functioning over long-duration missions involving persistent dangers and stressors (Golden et al., 2018), team training can foster a sense of familiarity and cohesion among team members, reducing the potential for subgroup formation and scapegoating (Landon et al., 2018).

Countermeasures that can be deployed during a mission include monitoring behavior and performance in real time, exercise regimens, digital mental health, and team debriefs. Monitoring tools with feedback mechanisms and intelligent support approaches (e.g., adaptive training) need to be developed and scientifically validated to provide data-driven technological support for spaceflight teams. NASA is currently developing several technologies to assist unobtrusive measurement of team factors and other factors that may influence teamwork (e.g., fatigue and physical health). These include sociometric badges that measure the proximity of individuals and whether they are facing each other, as well as vocal intensity (i.e., a marker of emotions and stress); video and facial analysis that can provide information related to team behavioral interactions and psychosocial states; and lexical analysis of speech and text collected from crew journals and communication logs that can indicate stress and psychosocial states both at the individual and team levels (Landon et al., 2018). In addition to evaluating the behavior and performance of individual ICE crewmembers, data-driven methods of monitoring crews can be used to predict potential points of friction between team members and indicate when team processes may be affected (Landon et al., 2018).

Exercise is another potential countermeasure for deterioration of mood and performance during a mission in an ICE setting. In the Mars 500 Study, Schneider et al. (2013) found endurance exercising but not strength exercising to be positively associated with cognitive performance. Abeln et al. (2015) reported a long-term effect of exercise for brain activity and mood in a study conducted at Concordia Station in Antarctica. Regularly active people showed a decrease in brain activity (alpha and beta) in the course of isolation, and steady mood. In contrast, brain activity in inactive people instead increased and then remained at high levels, although this was accompanied by a deterioration of mood. Neither exercise nor isolation was found to have any effect on cognitive performance.

Technological advances in use of virtual reality (VR) and digital mental health have also been proposed as potential countermeasures in ICE environments (Anderson et al., 2016, 2017; Rose et al., 2013). Preliminary research on natural scene VR suggests that it has great potential in improving mood in spaceflight and other ICE settings (Anderson et al., 2017). Self-guided interactive multimedia programs have been developed to train and assist long-duration flyers in the prevention, assessment, and management of psychosocial problems that can arise on extended missions. One such program is the Virtual Space Station (VSS), a suite of interactive computer-delivered psychological training and treatment programs, that was evaluated by Anderson et al. (2016) during the Hawaii Space Exploration Analog and Simulation (HI-SEAS) III expedition. Rose et al. (2013) conducted a randomized controlled trial of a self-guided, multimedia stress management and resilience training program (SMART-OP) with a stressed but healthy sample. The SMART-OP group reported significantly less stress, more perceived control over stress, and rated SMART-OP as significantly more useful than an attention control group that received marketed videos and published material on stress management. A tool for conducting team debriefs has been found to be effective in improving team performance, resilience, and a sense of psychological safety in space mission simulations (Tannenbaum et al., 2016).

Digital mental health, including internet-based programs and smart phone apps., has also demonstrated effectiveness for self-guided treatment of mental health problems, especially in low-resource settings where mental health specialists are unavailable (Anthes, 2016; Anderson and Cuijpers, 2009; Firth et al., 2017; Haidt and Allen, 2020; Naslund et al., 2017; Sandoval et al., 2017; Wilhelm et al., 2020). These platforms can enable astronauts and others in ICE environments to self-monitor and self-manage in a way that face-to-face/paper-based methods of assessment have up until now not allowed (Carter et al., 2005).

6. Conclusions and future directions

More than fifty years of research conducted during spaceflight and in analogue ICE environments has taught us much about the individual, interpersonal, and organizational challenges confronting individuals exposed to such environments for prolonged periods of time. Many of the challenges, such as mental health problems, sleep disorders, cognitive impairment, seasonal syndromes, and small group tension and conflict, are similar to those experienced in non-ICE settings. Other psychosocial issues considered trivial or minor in such settings are amplified and exacerbated in ICE environments with potentially adverse consequences to individual health and well-being, team performance and cohesion, and mission success. However, successful adaptation to ICE environments may also result in positive psychosocial outcomes such as enhanced self-efficacy, courage, compassion and the experience of flow. Advances in methods of screening and selection and the development and implementation of effective countermeasures can help to prevent or mitigate negative psychosocial outcomes and promote or enhance positive outcomes.

Nevertheless, additional research will be needed before crews of astronauts depart for missions to Mars and beyond. Due to lack of data from spaceflight and spaceflight analogue environments, meta-analysis is not a viable option for examining many of the different factors that will be critical to teams on a Mars mission (Landon et al., 2018). This will require not just additional studies in space and analogue ICE environments, but the development of a common set of tools and measures for assessing behavioral outcomes that will enable more rigorous forms of data aggregation and comparison across settings (Committee on Space Biology and Medicine, 1998, 2000).

While much has been learned about characteristics of individuals that predict for their behavior and performance in ICE environments, future research should identify individual-level value compositions that relate to team performance, as well as how these values interact with strategies for managing diverse crews (Bell et al., 2015). Monitoring tools with feedback mechanisms and intelligent support approaches (e.g., adaptive training) will need to be developed and scientifically validated to provide data-driven technological support for spaceflight teams (Landon et al., 2018). Existing digital mental health interventions will need to be adapted and evaluated for use in ICE environments.

Additional research is needed on optimal protocols for coordinating communication and distributing leadership responsibilities between space crews and mission control under conditions of communication delay (Landon et al., 2018). Training-focused countermeasures must be developed to increase task knowledge and facilitate team communication may improve team and task coordination under situations of communication delays, which, in turn, may improve the quality of communications, task efficiency and situational awareness, and decrease stress and frustration (Palinkas et al., 2016). Research to date has supported the use of training measures focused on improving communication skills and adapting communications strategies to mitigate adverse impacts (Fischer et al., 2013). Furthermore, text-based communications and autonomous mission operation tools have also been shown to improve outcomes under situations of communication delays (Frank et al., 2013).

Although the lessons learned from more than 50 years of research on psychosocial issues in ICE environments has prepared us to successfully travel beyond the confines of this planet, they also hold great potential for preparing us to successfully address the challenges we currently face and are likely to face in the future here on earth. One does not have to travel to space or the South Pole or live in a hypobaric chamber to experience isolation, confinement, and extreme environmental conditions. There is growing interest in collaboration between space agencies and organizations caring for people in terrestrial ICEs such as care homes for aged and/or disabled people (Hughson, 2014), and data from each specialty were shown to be relevant and used to generate recommendations for the other (Suedfeld et al., 2016). The COVID-19 pandemic that began in 2019, has already led to a number of articles in the mass media citing ICE research as relevant to the world-wide imposition of quarantine and self-isolation (MacDonald, 2020; Owens, 2020). Because several of the issues raised by spaceflight, polar wintering, and other extreme ICEs, forms of technology and tools designed for use in space have been found to have useful applications here on Earth, it is highly likely that the identification, prevention, mitigation of psychosocial risks, and promotion of benefits will continue to find useful applications for those of us in less extreme environments.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neubiorev.2021.03.032.

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