NASA is planning long-duration space exploration (LDSE) missions, with an expected manned mission to Mars in the early 2030s. This follows NASA’s broad strategic objective to “expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration.” Manned space missions entail unusual conditions to which astronauts must adapt, including isolation from family and friends, confinement in cramped spaces, and having to live and work in extreme environmental conditions. There is constant danger of serious injury or death should critical life support equipment fail or essential supplies run out. Demands will be even greater for astronauts on LDSE missions. Longer distances from Earth and delays in communication will increase the sense of isolation. Crews will have to function more autonomously, without assistance from NASA’s Mission Control. Space vehicles on LDSE missions will afford smaller living areas for astronauts, since more space is needed for fuel and supplies. Exposure to environmental extremes will be greater and for longer periods.

Considering this, it is important that astronauts on LDSE missions be able to adapt effectively to the range of isolated, confined, and extreme (ICE) conditions they encounter. It is well known that people differ in how quickly they adapt to spaceflight and other extreme conditions. However, the reasons for these differences are not clear. By better understanding the factors that influence individual adaptability, organizations like NASA can design more effective training and selection programs, as well as risk mitigation strategies. To that end, the present paper provides a systematic review of the available literature on human adaptation to isolated, confined, and extreme environments.

**INTRODUCTION:** Future deep space missions will expose astronauts to more intense stressors than previously encountered. Isolation will be greater and more prolonged, living and work areas more confined, and communications and resupply channels to Earth longer and less reliable. Astronauts will need to function more autonomously, with less guidance and support from Earth. Thus, it is important to select and train astronauts who can adapt and function effectively under extreme and variable conditions. In order to identify factors linked to individual adaptability, we conducted a systematic review of the literature on cognitive and behavioral adaptation to isolated, confined, and extreme (ICE) environments.

**METHODS:** We searched PubMed, Embase, Web of Science, and PsychINFO databases for studies addressing individual adaptability to ICE environments. Studies were rated for quality and fidelity to long-duration space missions and key results extracted.

**RESULTS:** There were 73 studies that met all inclusion criteria. Adaptability attributes for ICE environments include intelligence, emotional stability, self-control, openness, achievement facets of conscientiousness, optimism, mastery, introversion, task-oriented coping, past experience, low need for social support, and adequate sleep.

**DISCUSSION:** This review identifies individual factors linked to adaptability under ICE conditions. Further studies are needed to verify causal directions and determine the relative importance of these factors.

**KEYWORDS:** adaptability, individual differences, space, ICE environments.
extreme environmental conditions of the type future astronauts will encounter.

Recent years have seen a dramatic increase in the number of studies examining human adaptability, most often in the context of work performance in organizations. This interest was prompted by the recognition that rapid technological change in the modern era makes it essential for workers and organizations to adjust quickly to new methods and systems for getting things done.31 The movement away from manufacturing to knowledge-based services also means that people are more often working in teams that are diverse in terms of expertise and cultural background, again placing a premium on worker adaptability.33

The concept of adaptability has been broadly applied at many levels, from individual cells28 to teams, organizations, and whole societies.50,130 Regardless of the unit of analysis, adaptability involves changing or adjusting in response to changing conditions. A reasonable definition is: “the capacity to make appropriate responses to changed or changing situations; the ability to modify or adjust one's behavior in meeting different circumstances or different people.”120 (p. 17) A recent report by the Defense Science Board40 goes further, defining adaptability as “…the ability and willingness to anticipate the need for change, to prepare for that change, and to implement changes in a timely and effective manner in response to the surrounding environment”40 (p. 3).

This literature on adaptation remains quite diffuse, in part due to different ideas about what adaptability is. Studies of adaptive groups and organizations are largely conceptual in nature, relying mainly on case studies.4,125 Research on adaptability at the individual and team level is more rigorous, using experimental, observational, and correlational methods to examine adaptability in the face of changing work or task conditions. Individual level factors found to be associated with adaptive performance outcomes include intelligence or cognitive ability,16 emotional stability,57 achievement or mastery orientation,35 and conscientiousness.114 Also linked to adaptability at work are openness,57,118 optimism,122 hardness,13,11 and tolerance for ambiguity.28 While these studies provide useful clues as to what factors may influence adaptability in space conditions, they are limited in that adaptability is examined under routine work conditions. Adaptability to ICE environments will likely call for different or additional personal qualities. The present study summarizes and synthesizes available evidence regarding factors associated with individual adaptability under isolated, confined, and extreme environmental conditions.

**METHODS**

A systematic review was conducted in accord with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist85 and the Institute of Medicine standards.67 Further guidance was drawn from Harris et al.61 Studies of humans in space are limited and difficulties inherent in conducting research in extreme environments mean there are few (if any) randomized controlled trials in this domain. Thus, our strategy sought to include studies conducted with various methods in a variety of environments analogous to that of space travel. While the space analog environment is not well defined in the literature, it includes environments and situations that share elements of social isolation, confined, or restricted space and movement, persistent danger, and austere, harsh living conditions.34,72

English language articles published in peer-reviewed journals during any year from 1900 to March 2016 were considered for inclusion. Four databases were searched: PubMed, Embase, Web of Science, and PsychINFO. Search terms were:

- Group 1: adaptability/adaptation/adapt/adaptive/adaptable;
- Group 2: performance/health/morale/well-being/adjustment/ psychosocial/coping;

Published studies were eligible for inclusion if they A) took place in space or an analog ICE environment or simulation, or reported retrospectively on ICE experiences; B) addressed factors that influence individual adaptability to the ICE environment; C) included some psychosocial behavioral or cognitive outcome measure of adaptability (e.g., performance, health, well-being, adjustment); and D) used human subjects. Sleep and fatigue studies were considered if they addressed individual differences in cognitive and behavioral adaptability outcomes. ICE environments include space or space simulations, polar regions, submarine and underwater scenarios, prisoner of war (POW) conditions, or military operations. If all other criteria were met, we also included studies of adaptability in shift workers, hospital patients, tunnel workers, and cave explorers.

Studies were excluded if they A) did not occur in space or an analog environment, or report retrospectively on such a study; B) did not attempt to address factors influencing adaptability or effects of adaptability on relevant behavioral or cognitive outcomes; C) considered only team or group level adaptability; D) were reviews without new data, or E) used animal subjects. Studies dealing only with musculoskeletal, cardiovascular, vision, and hearing systems, and balance and posture assessments were also excluded.

Selected studies were assessed for fidelity/similarity to LDSE missions using an adapted version of the Palinkas et al.101 scheme. Total fidelity score represents the sum across four categories, as displayed in Table I. Two adjustments were made to
we based this on studies showing there is a significant difference in behavioral effects between missions of 6 mo or less and longer missions. Summary scores on this revised fidelity index had a theoretical range of 4–14. Two independent raters scored each study, with an initial agreement of 89.58%. Disagreements were resolved by discussion. Final fidelity ratings ranged from 5–12. There were 26 studies rated as High (9–12), 34 as Medium (7–8), and 13 as Low fidelity (5–6).

Studies were also rated for quality using criteria adapted from Buckman et al., Smith et al., and the Cochrane Handbook for Systematic Reviews. Study designs were classified as A) experimental or quasi-experimental; B) controlled observation (cohort, cross-sectional, case-control); or C) observation without control (qualitative-descriptive), as described by Mann. Higher quality ratings were assigned to experimental and quasi-experimental studies, and lower ratings to observation without control studies. Studies were also rated on sample size and representativeness, use of control group(s), measurement strategies, statistical procedures, and whether IRB approval was obtained. Additional details on quality ratings are given in Table II. Each study was assessed by two independent raters, with 98% agreement. Where raters differed, articles were re-examined and a final rating agreed. Studies with a total score of 10–13 were considered High quality (40 studies); a score of 7–9 of Medium quality (27 studies); and 4–6 of Low quality (6 studies). Note that, in this rating scheme, qualitative studies may receive lower ratings despite being methodologically sound.

RESULTS AND DISCUSSION

Of 73 studies meeting the inclusion criteria, 19 used experimental designs, 47 were controlled observation, and 7 were observational without controls, or qualitative studies. None of the included studies occurred in space; 11 involved space simulations; 55 were in an analog setting (e.g., polar studies), and 7 incorporated some aspect of an analog environment, such as shift work or sleep deprivation. There were 37 studies which addressed both antecedents and outcomes of adaptability, while 24 focused just on antecedents, and 12 examined adaptability outcomes only. Table III (not included here) summarizes the parameters.

Table I. System for Rating Fidelity of Reviewed Studies to Long-Duration Space Missions.

<table>
<thead>
<tr>
<th>FIDELITY CATEGORY</th>
<th>SCORING</th>
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<tbody>
<tr>
<td>A. Similarity to spaceflight</td>
<td>4: Spaceflight</td>
</tr>
<tr>
<td>B. Similarity of study participants to long-duration expedition astronauts</td>
<td>(Intentionally blank)</td>
</tr>
<tr>
<td>C. Similarity with respect to duration of mission</td>
<td>4: Greater than 12 mo</td>
</tr>
<tr>
<td>D. Similarity to crew size</td>
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</table>

Overall fidelity: High: 9–12 (26 studies); Medium: 7–8 (34 studies); Low: 5–7 (13 studies).

Table II. Criteria and Method for Rating the Quality of Reviewed Studies.

<table>
<thead>
<tr>
<th>RATING CRITERIA</th>
<th>SCORING</th>
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<tr>
<td>TYPE OF STUDY</td>
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</tr>
<tr>
<td>SELECTION METHOD</td>
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</tr>
<tr>
<td>Prospective</td>
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</tr>
<tr>
<td>Appropriate control group</td>
<td>1: Yes</td>
</tr>
<tr>
<td>Multiple assessment methods</td>
<td>1: Yes</td>
</tr>
<tr>
<td>Sample size</td>
<td>2: N &gt; 100</td>
</tr>
<tr>
<td>Adjusted for potential confounders</td>
<td>1: Yes</td>
</tr>
<tr>
<td>Appropriate statistical tests used</td>
<td>1: Yes</td>
</tr>
<tr>
<td>Conclusions justified by results</td>
<td>1: Yes</td>
</tr>
<tr>
<td>Ethics or IRB approval</td>
<td>1: Yes</td>
</tr>
<tr>
<td>Overall Quality</td>
<td>High: 10–13 (40 studies)</td>
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essential elements and findings for reviewed studies and is available at: http://dx.doi.org/10.13140/RG.2.2.29380.94083.

Intelligence. Three studies identified general intelligence as a predictor of adaptability. Colodro et al. found that intelligence and reasoning ability predict positive adaptation in a rigorous military diving course. Deppe also found intellectual ability is an important factor in adaptability for diver trainees in South Africa. Likewise, Pulakos et al. reported general intelligence predicts supervisor ratings of adaptability in military personnel across multiple job specialties. In all cases, the contribution of general intelligence was in addition to other factors such as personality.

Several studies examined cognitive performance not as a predictor of adaptability, but as an outcome variable that may reflect individual differences in adaptability to demanding conditions. Abraini et al. found hypoxia-induced cognitive decrements in a simulated mountain climb and attributed observed individual differences to past experience and upbringing in high or low altitude settings. Cowings et al. identified declines in cognitive performance resulting from sleep deprivation, motion sickness, and hypergravity conditions, with marked individual differences in extent of decline. A field study by Defayolle et al. found substantial individual differences in cognitive performance over time during a 71-d Antarctic stay. The authors attribute these differences to variations in individual motivation. The research reviewed thus confirms that intellectual ability has a positive influence on adaptability in ICE environments, and that under stress some individuals show greater cognitive performance declines than others. This accords with findings from the general literature linking cognitive abilities to adaptability.

Emotional stability. Several studies identified emotional stability/instability as a factor influencing adaptability in ICE, which likewise corresponds with findings in the wider literature. Emotional stability predicts adaptability for Colodro et al., Deppe, Fiedler et al., Lachar et al., and Nicolas et al. Likewise, Palinkas found that emotional stability (low neuroticism) predicted adaptability for scientists on an Arctic expedition. Wright et al. found poorly adapted Arctic workers were higher in psychopathology indicators (MMPI), or low in emotional stability. Weybrew et al. reported that submariners who failed to adapt and were disqualified from duty were higher in depression, anxiety, and interpersonal problems compared with those who adapted well. In a simulated mountain climb study, subjects with higher levels of state anxiety showed greater sensitivity to environmental changes and increased altitude sickness. In a 35-d bed-rest study, Dolenc et al. likewise found higher levels of anxiety associated with poor adaptation in terms of mental performance. Emotional stability is thus an important factor in individual adaptability under ICE conditions.

Mental health. A number of studies in our review include mental health measures as outcome indicators of poor adaptability. For example, Bartone et al. reported that depression and anxiety complaints rise with increasing stress related to isolation, boredom, and powerlessness on a military deployment. Dolan and Adler also found increases in depression related to deployment stress, an effect moderated by hardiness. Hancock reported more depression among poor adapters to a stressful military academy environment. Molassiotis et al. reported increased depression and anxiety among poorly adapted hospital isolation patients.

Control. Several studies identified control as an important predictor of adaptability in ICE. This is also in line with findings from the broad literature on adaptability. Kinnunen et al. found Finnish military recruits high in control adapted better to demanding situations. Molassiotis et al. maintained control was associated with better adaptability. Self-control also contributes to adaptability, according to Overdale et al. and Shved et al. An intriguing experimental study by
Souza et al. indicates that individual differences in control at the physiological level also have an impact on adaptability. They found higher levels of vagal control were linked to better adaptation and faster recovery from acute stress episodes. The vagus nerve is involved with parasympathetic control of the heart and other organ systems and plays a critical role in counterbalancing sympathetic arousal associated with stress. These authors also report that stronger vagal system control is associated with trait resilience. This suggests that psychological factors associated with adaptability may have underlying biological and physiological parallels.

**Openness.** Openness is frequently reported as a personality factor influencing adaptability.\(^ {57,114,118}\) This is confirmed in our review of ICE studies. In a study of British Antarctica winter-over workers, Grant et al.\(^ {55}\) found that openness to experience predicted high adaptability as rated by supervisors. Pulakos et al.\(^ {105}\) report similar findings, with openness predicting greater adaptability as rated by supervisors, particularly in intercultural and interpersonal adaptability. Gibbons et al.\(^ {51}\) reported that “keeping an open mind” had an influence on positive adaptation among military medical personnel deployed to Iraq or Afghanistan. Two of the reviewed studies point to openness in communications as an important aspect of adaptability. Blakely et al.\(^ {18}\) report that positive personal outlook contributes to adaptability. Positive attitude was also found by Agazio\(^ {3}\) to be related to adaptation. Only one study in our review explicitly addressed optimism, finding it to be a strong predictor of rated adaptability in British Antarctica winter-over workers.\(^ {55}\) Other studies using different terminology may be addressing the same underlying construct. For example, Blakely et al.\(^ {18}\) report that positive personal outlook contributes to adaptability. Positive attitude was also found by Agazio\(^ {3}\) to be related to adaptation. Some studies focused on positivity as a coping strategy employed more frequently by highly adaptive individuals. Jennings et al.\(^ {68}\) found veterans’ positive appraisals of military service and combat exposure were related to positive adaptation 10 yr later. Johnsen et al.\(^ {69}\) reported successful adaptation on an Arctic ski march was linked to positive daily coping as well as self-appraisals of performance. Similarly, positive appraisals of stressful situations and thinking positive thoughts were identified as adaptive coping strategies by Kjærgaard et al.\(^ {74}\) in their study of Danish Arctic dogsled patrol teams. Wagstaff et al.\(^ {121}\) likewise found that positive reappraisal is an adaptive coping strategy in personnel engaged in a 43-d Antarctic traverse.

**Extraversion/introversion.** A number of studies in the general literature link the Big Five factor of extraversion to adaptability.\(^ {54}\) However, only one study in the present review finds a positive role for extraversion in ICE. Hermann et al.\(^ {62}\) found that subjects who adapted poorly to a navy military academy environment (early attrition) were also low on the extraversion component of joining and following. In contrast, three studies in this review found introversion is associated with better adaptability. Bolmont et al.\(^ {20}\) showed that adaptability in a simulated mountain climb was linked to introversion; and Rosnet et al.\(^ {107}\) reported introversion and low assertiveness contributed to positive adaptation in Antarctic winter-over crews. The study by Wood et al.\(^ {127}\) reported positive adaptability in an Antarctic traverse was associated with “keeping thoughts private,” an aspect of internality. It thus appears that in ICE environments, some degree of introversion is desirable and contributes to adaptability. This may be especially important for long-duration missions, where opportunities for extensive social interaction are limited and greater self-reliance is necessary.

Some scholars have suggested the Big Five personality factors are too broad to be useful predictors, and that a better approach would consider the component facets of these broad domains.\(^ {64}\) This may be the case here with extraversion-introversion. Facets of extraversion that reflect assertiveness and dominance appear to be detrimental to adaptability in ICE environments, while facets of warmth and sociability seem valuable, especially in team-based missions. Future research should examine the facets of extraversion, not just the broad domain. It may also be worth exploring the value of attaining a mix of more introverted and extraverted types in comprising space exploration crews.

**Achievement (mastery).** There is evidence in the broad literature that achievement or mastery orientation is related to better adaptability.\(^ {15,35,103}\) Our review confirms this also holds in ICE environments. In one study by Hanchon,\(^ {59}\) mastery orientation was related to adaptability in military academy students. Sandal et al.\(^ {109}\) also found mastery was related to adaptability in Norwegian submariners engaged in 2–6 wk missions. And Pulakos\(^ {105}\) found achievement motivation predicts supervisor ratings of adaptability among military personnel.

However, there also is evidence that achievement or mastery orientation can sometimes have negative effects on adaptability. Hanchon\(^ {59}\) found positive effects only when mastery was associated with self-esteem, confidence in one’s abilities, and low anxiety. The effects of achievement orientation on adaptability were negative when paired with poor self-esteem, self-doubt and anxiety over failure. Described as “non-adaptive perfectionists,” these individuals showed a high mastery orientation, yet poor adaptability. Similar to the Type A personality, they have a strong drive to succeed, but are at the same time persistently anxious about failure. It thus appears the influence of mastery or achievement orientation on adaptability can vary greatly depending upon other qualities of the individual. In support of this, Sandal\(^ {108}\) found that achievement motivation together with interpersonal sensitivity were associated with better adaptation to isolated and confined environments. This underscores the need for future research to consider the possible combined influence of multiple variables on adaptability, rather than examining them separately.

**Conscientiousness.** Although multiple studies in the broad literature identify conscientiousness as an important influence on adaptability, our review found little support for this under ICE conditions. The one ICE study examining conscientiousness found that low scores were associated with better adaptation to low oxygen conditions in a simulated mountain climb.\(^ {20}\) This aligns with other studies showing that in ICE environments,
conscientiousness is either unrelated to, or negatively related to, adaptability. One possible explanation is that low conscientiousness may indicate mental flexibility, which would be helpful in adapting to ICE conditions. However, two studies did find adaptability to extreme environments was associated with task orientation and focus on work activities, suggesting that some level of conscientiousness is still important. A recent study of 10 Danish military personnel deployed to Greenland, while not addressing adaptability directly, did find higher levels of conscientiousness in this group compared to the general population.

To understand these contradictory findings, one may have to examine the component facets of conscientiousness. In studies of organizational workers, Griffin and Hesketh found only the achievement facets of conscientiousness (achievement striving, competence, self-discipline) predicted adaptability. The dependability facets (order, dutifulness, deliberation) were either unrelated or negatively related to adaptability. It may be that the dependability facets reflect rigidity and preference for the familiar, which could serve to inhibit adaptive responses in the face of changing environments. Thus, in studying the effects of conscientiousness on adaptability in ICE environments, it is important to look at the component facets, not just the broad domain. This is reinforced by findings of studies that examined mastery and achievement orientation. Adaptability in ICE environments is enhanced when achievement orientation is balanced with team orientation and sensitivity, and individual aspirations are subordinated to group goals.

**Hardiness.** Multiple studies in the broad literature link hardiness to good health and performance under stress and better adaptability. We identified 10 studies linking hardiness to individual differences in adaptability under demanding environmental conditions. A study of Gulf War veterans found those high in hardiness adapted better to combat stress, showing fewer posttraumatic stress disorder and somatic symptoms than low hardiness soldiers. Hardiness also predicted adaptability in Army Special Forces candidates undergoing a rigorous selection course, with high hardy candidates more likely to graduate. Carston et al. found New Zealand military personnel high in hardiness made more positive threat appraisals, saw stressful situations as challenging rather than threatening, and displayed more positive affect and task-oriented coping behaviors. In a longitudinal study of U.S. military academy cadets, hardiness scores as freshmen predicted adaptability as Army officers 7 yr later. A more recent study found that soldiers returning from Afghanistan who were low in hardiness showed more stress-related alcohol problems, indicating poor adaptation.

Dolan and Adler reported similar findings for U.S. military personnel deployed to Kosovo. They found hardiness moderated the effects of deployment stress on depression, an indicator of poor adaptation. Eid et al. examined adaptability of navy personnel in a disabled submarine simulation. Here, hardness predicted adaptability, as indexed by fewer PTSD and general health symptoms. Hardiness also predicted adaptability in Norwegian border patrol rangers on an Arctic ski march. Those who successfully completed the course were significantly higher in hardiness than those who failed. The hardness facet of commitment was the strongest predictor of success. Hardiness commitment includes the sense of purpose, meaning, engagement in work and life, and striving for personal competence. Britt, Adler, and Bartone found that high hardiness soldiers deployed to Bosnia were more likely to view their work as meaningful, while others saw the work as boring. Hardiness thus appears to be a valuable quality for future astronauts who must adapt to a work environment that is demanding, but sometimes repetitive and dull.

Hardiness also predicted shift work tolerance in a large sample (N = 150S) of nurses working rotating shift schedules. Nurses high in hardiness showed greater adaptability, fewer sleep problems, and lower depression and anxiety. Another study by Schneider et al. found that among West Point female cadets, those who adapted more effectively to the stressful environment also showed a suppression of the normal menstrual cycle, as well as higher total hardiness and commitment scores.

Hardiness control entails the generalized belief that one has the skills and resources to get things done, a concept closely related to self-efficacy. Factor analytic studies suggest that hardiness and self-efficacy may belong to the same latent construct. Indeed, some studies have found that self-efficacy is linked to adaptability in workers. In an ICE study, Eid et al. found submariners who were high in hardiness, including the sense of control, challenge, and commitment, adapted more effectively in a simulated accident at sea. Hardiness challenge involves cognitive flexibility, the tendency to see change and variety as interesting and valuable, providing opportunities to learn and grow. Challenge also incorporates an attitude of openness to varied experience in life. According to hardiness theory, the facets of commitment, control, and challenge operate synergistically to form a general life perspective or world view which guides perception and behavior across the whole of experience. Hardiness thus represents a higher-order construct that incorporates several personality dimensions related to adaptability.

**Coping strategies.** A number of studies point to the importance of different coping strategies for positive adaptability. In their study of new Norwegian military personnel, Johnsen et al. found that positive adaptation to the changed environment was related to task-focused and emotion-focused coping, while avoidant coping was linked to poor adaptation. Looking at long-term isolated hospital patients, Gordon reported that successful adaptation to the isolation environment required an attitude of cooperation with the staff, and a willingness to relinquish some control. In their study of scientists deployed to Antarctica, McCormick et al. noted wide individual differences in coping strategies employed. Positive adaptation was demonstrated by those who exercised greater control over emotions.

In the MARS 105-d simulation study, task-oriented coping was associated with positive adaptation, while withdrawal or disengagement coping was linked to depression and poor adaptation. Similarly, Trapp et al. found social withdrawal was a nonadaptive coping strategy in a simulated mountain climb,
while “trivialization” or making light of things was associated with better adaptability to physical and psychosocial stress. These studies are in agreement in showing that avoidant or withdrawal coping strategies are associated with poor adaptation in ICE environments, while task-focused coping is associated with positive adaptation. Also, findings from several studies indicate that maintaining control over one’s emotions is important for positive adaptation in ICE conditions.

**Past experience.** Several studies in the present review identified past experience as important in building adaptability. In a qualitative study of successful mountain climbers, past experience was an important resource, allowing them to adapt to the hardships and challenges encountered during the climb. In their study of military personnel in various jobs, Pulakos et al. found past experience contributed to adaptability, controlling for intelligence and personality variables. Weybrew et al. likewise found adaptability in submariners was due in part to past experience. In Chinese military recruits, positive family background and parental relationships were related to more effective adaptation to the demanding basic training environment.

Background factors can also have negative effects, weakening or reducing adaptability. Dimoulas et al. found that in military women undergoing a highly stressful survival course, poor adaptability was associated with past history of exposure to traumatic events. Similarly, Lachar et al. found poor adaptation in military trainees was linked to past history of drug abuse and emotional instability. In a study of U.S. Vietnam POWs, Nice et al. found those with longer periods of captivity had greater difficulties readapting to married life. Overall then, this review finds good support for the importance of past experience in influencing adaptability under ICE conditions.

Past experience can contribute to adaptive expertise, or the capacity to transfer knowledge gained in other domains to a novel situation. This is thought to be primarily a learned ability that grows when individuals have broad experience in different contexts and with varied types of problems. On the other hand, negative past experiences can sometimes impede later ability to adapt to extreme or difficult conditions, as found by Dimoulas et al. and Weybrew et al. More research is needed to clarify under what conditions negative past experiences can have a strengthening or weakening effect on adaptability.

**Sex differences.** Sex-based differences are generally regarded as group level differences, not individual differences per se. Nevertheless, we included sex differences here since they may help to explain observed individual differences in adaptability. Our review of ICE studies showed mixed results regarding sex differences. In a study of 140 British winter-over workers in Antarctica, women received significantly higher supervisor ratings on adaptability than did men in the same environment. On the other hand, female nurses showed greater difficulty adapting to shift work than their male counterparts. More research is needed to understand how and under what conditions women and men may differ in their adaptability for LDSE missions.

**Social support.** While social support also is not generally considered an individual difference variable, it merits consideration as a contextual factor that may influence individual adaptability. It is possible that individuals differ in their ability to develop and make use of social support networks. Research shows social support can facilitate adaptation in a variety of circumstances, for example, in workers adapting to organizational change and college graduates adapting to new careers. Support from peers is also known to contribute to adaptability in the workplace.

Multiple studies conducted in ICE environments found social support has a positive impact on adaptation. For U.S. military personnel returning from deployment to Somalia, social support in the homecoming was related to better adaptation and fewer PTSD symptoms. In a study of experienced mountain climbers, Burke found support from other climbers facilitated adaptation. Gibbons et al. report that social support from peers was important for adaptation in military medical personnel deployed to war zones. Goldman et al. reported similar results for National Guard troops. Here, unit level social support during and after deployment was associated with better adaptation and fewer stress-related symptoms. In a study of New Zealand military recruits in a rigorous training program, Overdale et al. identified social support from instructors as a positive influence on adaptation and performance. This review thus finds good evidence for the value of social support as a contextual factor facilitating positive adaptation in ICE environments.

A somewhat contradictory finding emerged in three reviewed studies. Examining scientists on an Arctic exploration mission, Palinkas found positive adaptation linked to low use of social support. Similar results appeared in a larger study of Antarctic winter-over personnel, where better adaptation (low anxiety, tension, and depression) was associated with less seeking of social support. Sandal et al. likewise found better adaptation was linked to low levels of social support seeking in submariners. This corresponds with results showing that self-control and the ability to focus on tasks is important for adaptability under stressful conditions.

Together, these findings suggest that for people operating in ICE environments, it is beneficial to have social support available from one’s crewmates on the mission, as well as those back home. But the most well-adapted individuals apparently do not need or seek out social support as much as others. This coincides with results showing that some degree of introversion, privacy, and emotional restraint is adaptive for those on long-duration ICE missions. It also corresponds with what is known regarding hardiness and social support. Persons high in hardiness appear to be more selective in their use of social support resources to facilitate positive coping with stressful conditions.

**Sleep and circadian disruptions.** Long-duration space missions will entail continuous operations, requiring astronauts to work in shifts and at times sleep deprived. Recent studies have reported substantial individual differences in how people perform under various conditions of sleep deprivation and...
circadian shifting. However, the reasons for these differences are not well understood. The present ICE review identified several studies showing individual differences in adaptability to sleep disruptions. In their MARS 500-d study, Basner et al. found that sleep quality and vigilance degraded for all subjects over the course of a 520-d simulation, but more so for some than others. Bonn et al. also observed substantial individual differences in sleep problems and fatigue in a controlled study of high altitude mountain climbers. Hughes et al. found that U.S. Iraq and Afghanistan veterans low in resilience also showed more sleep problems postdeployment.

In a study of shift work nurses, Admi et al. found more sleep problems in night shift compared to day shift workers, and some night shift workers showed better adaptation than others, as indicated by morning headaches and fatigue. Natvik et al. observed similar results among Norwegian nurses, with those high in hardiness showing better adaptability (less anxiety, depression, insomnia, and sleepiness). Age also appears to play a role in how well people adjust to circadian shifts. Moliner et al. report that younger men adapted better than older ones to a 6-h phase advance simulated jet lag. More recently, in a study of NASA ground operators forced to adjust to a Mars day-night schedule, some operators adapted better than others. Adaptation to the longer Mars daily cycle was facilitated by exposure to short wavelength (blue) light. Our review thus confirms that in ICE environments, individuals vary in terms of how they are affected by sleep and circadian disruptions. The underlying reasons for these differences remain unclear and merit additional research.

Physical and biological factors. Several studies point to physical and biological factors as important for understanding individual differences in adaptability to ICE environments. In many cases, these appear to overlap with psychosocial factors or consequences. In a simulated mountain climb, Bolmont et al. found poor adaptation to low oxygen conditions was linked to cognitive deficits and increased tension, hostility, and confusion. Another study found that among military personnel on a tropical training mission, eating fresh food rather than combat rations was associated with improved nutritional status and immune system function, and less fatigue. Harris et al. examined British Antarctic winter-over workers, and found that those rated as extremely well-adapted by their supervisors showed higher activation levels, increased salivary cortisol on awakening, fewer sleep problems, and less depression than those rated as poorly adapted. In a study of over 15,000 military personnel, those in worse physical condition showed poor adaptation over the first 6 mo of service, with higher rates of sickness, mental disorders, and early discharge. Studying members of a Japanese high-altitude Antarctica expedition, Otani et al. found individual differences in the incidence of mountain sickness, headaches, and fatigue, with some evidence that increases in the proinflammatory cytokine IL-6 were linked to poorer adaptation.

In a MARS 500-d long-duration space simulation study, Wang et al. reported that positive mood was associated with increases in norepinephrine and 5-hydroxy tryptamine (5-HT) over time. The authors suggest this shows the important role of the serotonin system in mediating the stress response. In another MARS 500 study, Schneider et al. found endurance exercising (running, biking) was linked to positive adaptation in terms of enhanced cognitive performance, whereas strength exercising was not. Endurance exercising thus may carry psychological benefits as well as physical ones.

General adaptability. Several studies noted that physical, psychological, and physiological adaptability tend to co-occur in the same individuals. Kinnunen et al. reported that self-control predicted muscle fitness and physical performance in Finnish military conscripts. Bonn et al. found both cognitive and psychological decrements in response to hypoxia in mountain climbers, with some individuals declining more than others. And Bloomberg et al. reported on a sensorimotor adaptability training program for astronauts in which adaptability gains in one sensorimotor area (e.g., gait stability) appear to generalize to other bodily systems (e.g., visual, vestibular). In considering the widely observed individual differences in cognitive performance following sleep deprivation, Durmer and Dinges suggest there is a trait-like, possibly genetically based differential vulnerability to the ill effects of environmental challenges. Later, Goel and Dinges identified several genetic markers associated with increased vulnerability or resistance to the ill effects of sleep loss. Studies have also found neurological, cognitive, and genetic correlates of sensorimotor adaptability in various space analog environments. Together these results are suggestive of a general adaptability factor that encompasses multiple physical-biological and psychological systems. Future research should investigate this intriguing possibility.

Limitations. It is important to note some limitations to this review. Studies varied widely in terms of design, methods, populations studied, and fidelity to the space environment. This makes it difficult to attach relative importance to any of the factors related to adaptability. Also, most studies were cross-sectional, reporting associations between adaptability and various other variables. Such studies are useful for identifying potential factors that influence adaptability, as well as possible mediators and health and performance outcomes. But longitudinal studies are needed to verify causal pathways and moderating and mediating factors. Such studies could feasibly be done in space simulation or analog environments.

Future research. Related to this, further research on adaptability to ICE environments should go beyond just examining associations and aim to characterize the underlying processes and interactions involved in adaptive and nonadaptive responding. Research should seek to determine the relative contributions of different variables to individual adaptability. Considering the conceptual similarity of many variables associated with adaptability (e.g., achievement orientation, conscientiousness), it is likely that a shorter set of unique adaptability predictors could be identified. This would permit better focused and more effective programs for selecting, developing, and sustaining highly adaptable astronauts.
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* Indicates study included in this systematic review.


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